GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 34

GEOLOGY OF TUGTUTÔQ AND NEIGHBOURING ISLANDS, SOUTH GREENLAND

PART I

BY

B. G. J. UPTON

WITH 21 FIGURES IN THE TEXT
AND 2 PLATES

Reprinted from
Meddelelser om Grønland, Bd. 169, Nr. 8

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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CONTENTS

Abstract.

Tugtutôq is an island lying off the SW. coast of Greenland, separated from the mainland by fjords overlying major lines of faulting. The main island, together with numerous smaller islands and skerries, is largely composed of Precambrian granites formed after the close of the Ketilidian orogeny. At a still later date in the Precambrian alkaline rocks were extensively intruded into the south Greenland region and, of these, a large variety are preserved in the Tugtutôq area. Many of the intrusions take the form of ENE.–WSW. trending dykes running parallel to one of the major faulting directions. Tugtutôq lies along a belt in which these dykes are especially concentrated and provides a rewarding field for their investigation. One of the earliest dykes, some 500 m broad, is composite and consists of narrow gabbroic marginal zones and a broad central component of syenite. The syenite centre changes character along its 20 km outcrop from a nepheline-poor 'augite syenite' to a variety of foyaite. 'Giant-dykes' of troctolitic gabbro, up to 800 m across, were intruded after the solidification of the composite dyke. In certain sectors of the dykes the gabbros display primary layering. These gabbro dykes themselves occasionally show composite character and possess a central zone of quartz syenite or of alkalic gabbo akin to the marginal gabbro of the earlier composite dyke. Small bodies of pyroxenite, related to a larger mass cutting the troctolitic gabbros on the mainland, occur on the main island. Subsequent to these ultramafic intrusions dense swarms of small dykes composed of olivine dolerite, quartz microsyenite, alkali microgranite and hybrid variants were injected through the area. Many of these are also composite. The widespread presence of labradorite anorthosite fragments in the dyke rocks prompts the suggestion that a large body of anorthosite underlies the area. At a late stage in the igneous cycle a ring-complex developed across the main dyke belt and this, in striking contrast to the nearby and roughly contemporaneous Ilímaussaq complex, consists only of saturated syenite and alkali granites. The complex comprises some half-dozen ring-intrusions of related syenites and granites followed by a stock of coarse perthositic syenite. Intrusive activity in the area came to a close with eruption of further dyke swarms and occasional sills.

PREFACE

This paper presents a preliminary account of the geology of a group of islands situated between 46° and 47°W. and 60°30′ and 61°N., a few kilometres west-south-west of the Ilímaussaq nepheline syenite area. The work was conducted as part of the Greenland Geological Survey's current programme of mapping the south-west Greenland coast-line in the Ivigtut-Narssaq-Julianehaab region. The mapping of the Tugtutôq islands was begun in 1957 and completed in the summer field-seasons of 1959 and 1960.

This account deals primarily with the field-relations and chronology of the major rock units rather than with the petrography. The complexity of the 'newer intrusives' was such that these tended to receive a closer study in the limited time available than the more homogeneous older granites in which they occur. Detailed petrological accounts of the intrusive rocks and a discussion of their petrogenesis will be deferred for further publications.

I wish to thank Mr. K. Ellitsgaard Rasmussen, Director of the Greenland Geological Survey, for making available so wide a range of facilities and also Mr. J. Bondam who was largely responsible for the organisation of field-parties in the Narssaq region. Further thanks go to the boat-crews, helicopter pilots, and the several assistants who, at one time or another, accompanied me during the mapping; I am most grateful to the technical and clerical staff attached to the survey and Mineralogical Museum of Copenhagen University for all their helpfulness and cooperation, and to my other colleagues on the survey for stimulating discussion on various aspects of the work.

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Pasadena, California
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INTRODUCTION

The region described below is one of Precambrian crystalline rocks which can be roughly divided into an earlier sequence of granites and granite-gneiss and a later intrusive suite of alkaline rocks. The main granites are known to have crystallised after the close of the Ketilidian orogeny, which affected most of south Greenland. (WEGMANN 1938 and BERTHELSEN 1960). It appears that these granites were formed over a prolonged period and that they probably arose through the recrystallisation of rocks folded and metamorphosed during the orogeny. A recent concordant age-dating (MOORBATH, WEBSTER and MORGAN, 1960) on one of these granites from the vicinity of Julianehaab gives an age of 1590 ± 70 m years and sets an upper time limit to the orogeny. Later in the Precambrian the Ketilidian metamorphic assemblage and the subsequent Julianehaab granites underwent peneplanation and uplift, presenting a land-surface on which a series of continental sandstones and basaltic effusives developed. These are now retained within a restricted graben structure in the region of Narssaq and Igaliko, where they are found unmetamorphosed and resting unconformably upon the crystalline basement rocks (USSING, 1912). The unconformity marks the opening of the Gardar period during which the various intrusions of the south Greenland igneous province were emplaced. The Tugtutôq region is, as a result of block-faulting, elevated with respect to the adjacent Narssaq-Igaliko area and the lower Gardar sediments and volcanics have been lost by erosion. However, the presence of small masses of these rocks preserved within volcanic centres on Tugtutôq (*lit.* Reindeer Island) and elsewhere testifies to their former widespread occurrence.

The intrusive history of the Ivigtut-Narssaq district appears to have been long and complex. Early in the Gardar period, perhaps in rough contemporaneity with the eruption of the (trachy-) basaltic lavas, nepheline syenites were intruded into the region. These include the Grønnedal-Íka foyaitic assemblage, the broad syenite dyke running through the centre of Tugtutôq island and, possibly, the intrusions in the Igaliko district. After these major intrusions there followed a long period in which activity was mainly confined to dyke intrusion, the great majority of the dykes in these mid-Gardar swarms trending ENE.–WSW.

in accordance with the regional stress pattern which had been established in early Gardar times. These dykes are unusually concentrated and diversified in the region of Tugtutôq and some, like the early syenite dyke, acquire a width remarkable enough to justify the term 'giant-dyke' to distinguish them from the more abundant, smaller dykes whose widths generally fall within the range 1–20 m. The giant-dykes, ranging up to 800 m wide, cooled slowly to yield rocks of distinctly plutonic aspect. Nevertheless, in spite of their unusual size, there is no reason to consider that the giant-dykes differ in kind from their smaller associates nor that the mechanics of their intrusion was in any way exceptional.

Whilst certain of the quartz syenite and alkaline granite plutons of the Tugtutôq-Narssaq area were emplaced during this extensive period charactized by dyke formation, the most impressive phase of major intrusion was reserved for the closing stages of the Gardar igneous cycle. The alkaline rocks intruded in this culminating episode appear to have been mainly emplaced by ring-faulting and subsidence. Only three of the late Gardar complexes within the south Greenland igneous province have so far been described in detail (the Ilímaussaq complex by Ussing, 1912, the Kûngnât complex by Upton, 1960 and the Puklen complex by Pulvertaft, 1961), although work is currently in progress on various of the other centres. The present account gives a description of a previously unknown ring-complex of quartz syenite and alkali granite situated across the main belt of mid-Gardar dykes, in the central part of Tugtutôq. (In this account the term 'early Gardar' will be used to include events up to and including the crystallization of the Hviddal syenite, 'mid-Gardar' for the succeding time period up until the emplacement of the central ring-complex and 'late Gardar' for the period in which the Tugtutôq central complex, Ilímaussaq complex, etc. were intruded).

The tectonics associated with the igneous activity present are somewhat complicated. It is known that a number of NW.–SE. striking faults had been developed in the area prior to any of the Gardar intrusions and that several were utilised by the early NW. (to WNW.) olivine dolerite dykes. These faults (which, incidentally, played an important part in controlling the present-day coastlines) tended to act as barriers to the later ENE. dykes, many of which are terminated abruptly against these old fracture zones. In spite of their influence on both the NW. and ENE. trending dykes there is no evidence of any movement along these lines of weakness during the Gardar, although the postulated faulting between Tugtutôq and the mainland peninsula of Narssaq and Igaliko may conceivably have occurred along such a rejuvenated zone in late or post-Gardar times.

An extensive set of faults and crushes extending along the ENE. –WSW. direction is responsible for the distribution and alignment of

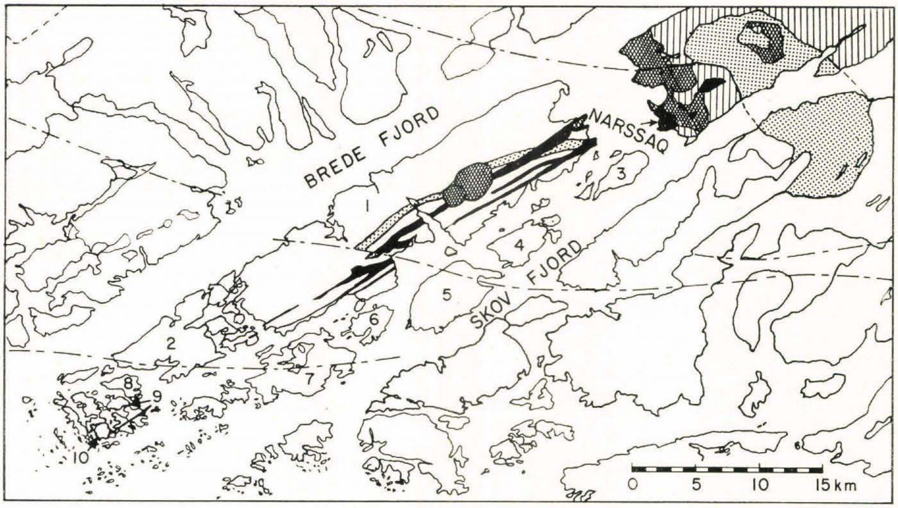

Fig. 1. Sketch-map of the Tugtutôq islands and the Ilímaussaq area. (Redrawn from a provisional geological map compiled by A. Berthelsen). 1. Tugtutôq. 2. Tugtutôq Lille Ø. 3. Igdlutalik. 4. Kangue. 5. Igdlukasik. 6. Ilaufait. 7. Niaqornaq. 8. Takisôq. 9. Tugtupait. 10. Kakatusôq. White, older granites and migmatites: Lined; Gardar surficial series: Black; gabbros: stippled; undersaturated syenites: Cross-hatched; quartz syenites and alkali granites.

the major fjords in the district. This direction of faulting was also initiated very early on, probably well before the opening of the Gardar, but movements continued over a long period. Gardar movement along these lines was however slight, but did lead to severe crushing of the intrusive rocks in some places on Tugtutôq.

The extensive suites of ENE.-WSW. dykes periodically erupted into the area during phases of tension occurring through the Gardar were, to a large extent, injected along the planes of weakness already provided by these faults. It is estimated that along a traverse perpendicular to the dyke-trend from the Bredefjord coast across Tugtutôq to the south-eastern coasts of the Skovfjord islands, between 10 and 20 % of the ground is occupied by these dykes, representing a very considerable dilation of the granitic crust in the region. Nevertheless, large sinistral displacements along transcurrent faults having a nearly east-west trend occurred during the Gardar and, in the area under discussion at least, underwent their main movements before the latest ENE. dykes were intruded. It is probable that movement along these faults and intrusion of dykes were both responses to an overall stress operating throughout most of the Gardar. (Small thrust-faults(?) trending approximately ENE. and dipping towards the south at angles of 20-40° have been located on Tugtutôq and the Skovfjord islands and these may have originated during a compressive phase normal to the regional strike in late pre-Gardar times).

After the complete change in tectonic conditions which must have attended the intrusion of the late Gardar plutons, further dyke formation along the ENE. direction was very restricted and when, at a much later date (conceivably as recent as the Tertiary), a further swarm of olivine dolerite dykes appeared, the trend had reverted towards NW.–SE., roughly parallel to some of the earliest Gardar dykes.

The islands under discussion are entirely free from permanent ice and, to a very large extend, free from glacial moraines. Around the coast there is excellent exposure on the clean glaciated slabs although inland there is fairly extensive vegetation. The topography is strongly influenced by the geological structure and a series of valleys running parallel to the length of Tugtutôq originated through the preferential excavation of the ENE. dykes and shatter-belts. The intervening ridges of pre-Gardar granites rarely rise above 400 m although Igánarssuánguaq, the highest point in the area, has a height of 515 m.

Pre-Gardar Granites.[1])

The oldest rocks in the neighbourhood are the nebulitic granite-gneisses which occur as a strip about 3 kms wide along the Bredefjord coast of Tugtutôq Lille Ø in the western part of the area. These represent a small part of the extensive area of nebulitic granite-gneiss occurring to the north-west of Bredefjord. This series is, as seen in the Tugtutôq and the Tugtutôq Lille Ø area, almost entirely composed of very leucocratic, quartz-rich rocks in which the gneissic banding is normally faint and discernible only in very clean exposures. In general these rocks tend to be isogranular, although a distinctly porphyritic facies also occurs. (In this section on the older granites, the term porphyritic is used only to describe the texture and has no genetic implications). The streaky and discontinuous gneissose features show a rather constant strike from ENE.–WSW. to NE.–SW. Amphibolites play a minor role within the sequence occurring as sporadic horizons, seldom over 1 m thick, which lie concordant to the dip and strike of the surrounding granite-gneisses. Frequently these layers are highly agmatitic with the leucocratic granite intervening between widely separated blocks of amphibolite. The latter consists mainly of hornblende, chlorite, and oligoclase together with some quartz.

Although close to the Bredefjord the dips are very low, often scarcely deviating from the horizontal, there is an overall dip towards the north-west. However, on Tugtutôq Lille Ø, in a traverse across the strike away

[1]) i. e. granites *sensu latu* including adamellite and granodiorite.

Fig. 2. A surface of nebulitic granite-gneiss from the south coast of Tugtutôq Lille Ø, showing lensoid bodies of amphibolite and the development of microcline megacrysts.

from the fjord, it is found that the dip becomes predominantly south-easterly suggesting that the nebulitic granite-gneiss series has a broad anticlinal disposition.

Further to the south and south-west the series passes quite gradually into massive hornblende biotite granites. It is believed that the nebulites represent a rock series folded and, metamorphosed during the Ketilidian orogeny which, during subsequent crustal heating, underwent recrystallisation to granitic material. Conceivably the original rocks in the area were predominantly arenaceous and the subordinate amphibolites now seen may initially have been calcareous sedimentary horizons whose disruption began with 'boundinage' during the orogenic period.

The greater part of the Tugtutôq area, however, consists of granitic rocks devoid of obvious gneissose features, lacking foliation or preferred orientation of the constituent minerals. Nevertheless, these granites are rarely free from small basic inclusions which are commonly lenticular and in approximate parallelism. Melanocratic schlieren, rich in biotite and hornblende, occur locally in the various granites and, on Igdlukasik island, there is a faint foliation of the ferromagnesian minerals. This foliation is thought to have been inherited from earlier rocks rather than to have been superimposed upon the crystallised granite. Taken over the whole area and excepting minor local variations the evidence from inclusions, schlieren and foliation shows the granites to have a common overall structural pattern directed ENE.–WSW., parallel to that of the granite-gneiss described above and to much of the later faulting and dyke intrusions.

The main granite of the area, forming the islands of Niaqornaq and Ilaufait, the greater part of Tugtutôq itself (and extending over a large area to the north of Bredefjord, outside the region dealt with in this account) is coarsely porphyritic. The microcline megacrysts range from 3–5 cms in length and are entirely lacking any preferred orientation. The megacrysts are found in profusion in the neighbourhood of concentrations of the mafic inclusions and are also grown porphyroblastically within the inclusions. A strong, macroscopically visible zoning within the big feldspars, apparently of an oscillatory nature, is characteristic of the main Tugtutôq granite (Fig. 3). The zones are seen as concentric whitish layers within the otherwise pink feldspar. The compositional significance of this colour zoning is as yet unknown and may only involve differing content of haematite inclusions. The crystals generally show about four clearly defined 'white' zones, but with an indeterminable number of less distinct zones. An oscillatory zoning of the oligoclases has also been noted. The contact of this main porphyritic granite against the granite-gneisses is usually complete within ca. 5 m and runs parallel to the strike of the latter series. It is of particular interest to find that within the granite-gneiss series there is a porphyritic facies forming a zone up to one kilometre wide and traceable for many kilometres along the strike, which, apart from its relict gneissose banding, is identical to the main porphyritic granite. Although, in view of the more detailed work being undertaken by other members of the Geological Survey on this and other granites in the neighbouring mapping-areas, it is premature to arrive at any definite conclusions concerning the origin of the main porphyritic granite, the weight of the evidence from the Tugtutôq region suggests that this granite formed *in situ* at the expense of the nebulitic granite-gneisses. Possibly a selective recrystallisation of the nebulites occurred along particularly favourable structural or compositional layers to produce a more homogeneous, porphyritic and (partly magmatic?) granite. The mafic inclusions may represent melanocratic material from the granite-gneisses which remained relatively unchanged in position and composition during the growth of the porphyritic granite.

Two other essentially replacive granites occurring within the area covered by the map (Plate 2) have been recognised. These form two more or less arbitrarily defined zones lying to the south-east of the main porphyritic granite. Immediately alongside the main granite is a zone from one to three kilometres wide, consisting of porphyritic granite in which the feldspar megacrysts are markedly smaller than in the main or 'big-

Fig. 3. A typical surface of the main Tugtutôq big-feldspar granite, showing the characteristic zonation of the large feldspars. (The coin used as scale guide has a diameter of 27 mms).

feldspar' granite, generally being 1–2 cms across. On the Tugtutôq main island the division of this granite from the big-feldspar granite is fairly clear-cut and, on coastal exposures, contacts are seen which are sharp within a few centimetres. To the south-east of this zone of 'slightly porphyritic granite' is another characterised by absence of porphyritic texture. The granite of this non-porphyritic zone forms the islands of Igdlutalik and Kangue and outcrops across the corner of Tugtutôq adjacent to Narssaq. It is realized that this zonal classification tends to oversimplification and that slightly porphyritic granite occurs within the area of bounded by the three islands Tugtutôq, Kangue and Igdlutalik in the otherwise 'non-porphyritic zone' and that irregular areas of non-porphyritic granite are to be found within the mainly porphyritic granites on Igdlukasik. Nevertheless there is a real tendency towards a zonal distribution from NW. to SE. across from rocks with 3–5 cms megacrysts to those with 1–2 cms megacrysts and then to those which are predominantly non-porphyritic, in spite of local ambiguous intermediaries. Each of these zones consists of hornblende/biotite granites and each contains the ubiquitous dark inclusions. None of these granites possesses chilled contact facies and pegmatitic development in unknown. (Where pegmatite veins are found cutting the main porphyritic granite, for example on Niaqornaq, they are believed to belong to a distinctly later phase of granite formation). As in the case of the main granite the presence of inclusions etc. within the two less porphyritic granites having a common orientation parallel to that of the granite-gneiss is thought to imply that they were not intruded, but formed *in situ* from older rocks. As noted above, however, the big-feldspar granite can have rather sharp contacts against the less porphyritic variety and, on the southern coasts of Tugtutôq there are occasional apophyses of big-feldspar granite within the latter. Conceivably these are due to irregularities in the crystallisation 'front' associated with the growth of the big feldspars.

It may well be that the Tugtutôq area was composed of Ketilidian granite gneisses having a regional ENE.–WSW. strike which were subjected to successive recrystallisations corresponding to local rises and lowerings of the geothermal gradient. The gneisses became more or less homogeneous granite, which subsequently acquired a slightly porphyritic texture and, at a later stage, the more pronounced porphyritic texture of the big-feldspar granite. The different phases probably overlapped in space and time. Anatexis was never sufficient to produce a mobile granite magma capable of developing strongly discordant contacts and in fact the recrystallisations never succeeded in completely obliterating all of the structural elements inherited from the Ketilidian rocks.

In the central part of Tugtutôq is a body of granite which differs widely from those considered above. This granite, which is about 5 kms across, is relatively poorly exposed and is much dissected by later intrusions. Unlike those granites just described, this has highly irregular contacts which are strongly discordant to the structures of the porphyritic granites in which it occurs, but, like the others it lacks fine-grained chilled facies and pegmatite development. The granite consists of approximately isometric anhedral crystals of quartz, microline and oligoclase, with small quantities of hornblende and biotite; it is entirely free of internal structure and does not contain the dark inclusions so widespread in the surrounding granites. Hence it is inferred that the manner of emplacement differed in the case of this granite and that it is an intrusive granite emplaced within the porphyritic granites. In addition to the main outcrop of this granite there are numerous localities on the Bredefjord side of Tugtutôq where it appears forming intrusive breccias with the big-feldspar granite.

Early Gardar Intrusions.

Among the earliest of the 'younger intrusives' are the broad dykes of olivine dolerite which traverse the western part of the area. These dykes, trending between NW.–SE. and WNW.–ESE., are relatively scarce but may be 100 m or more wide. On account of their crumbly and rapid weathering the bigger dykes are clearly expressed by the topography. Several have been mylonitised by shearing parallel to their length and it is likely that in these instances the dykes had been intruded along old fault-planes which were re-juvenated at a later date.

So far as the author is aware, there is no evidence bearing on the age relationship between these dykes and the early Gardar volcanism on the mainland. Various small doleritic dykes found on Tugtutôq trending ENE.–WSW. may be contemporaneous with the early lavas, but again this is purely speculative in the absence of any direct evidence.

The earliest major intrusive episode on Tugtutôq gave rise to a broad composite dyke of syenite and gabbro which runs along the centre of Tugtutôq island. However, the age of this dyke relative to the mainland lavas and the NW.–SE. dykes is also unknown. This dyke is described below.

The Hviddal Giant Dyke.

The great composite dyke which runs from the eastern coast of Tugtutôq for some 20 kms to the WSW. has, along the greater part of its course, gabbroic margins and a wide central component of syenite. The latter varies from slightly undersaturated ferroaugite-bearing syenite in the westerly extension of the dyke to strongly undersaturated nepheline syenites in the east. The easterly nepheline-rich facies gives rise to the barren, sandy ground characteristic of the south Greenland nepheline syenites. Further to the west, however, the outcrop of the dyke is marked by a broad flat-bottomed valley, the floor of which supports a cover of grasses and light coloured lichens, whereas the confining granite areas grow little other than an incrustation of dark lichens. Consequently this ‘white valley’ or ‘Hviddal’ stands out with clarity on the aerial photographs. (Fig. 21). The syenites themselves are largely obscured by drift and shallow lakes and the dyke as a whole is interrupted by later intrusions of gabbros, syenites and granites. The whole composite dyke averages between five and six hundred metres in width of which the marginal gabbroic zones (where these are present), account for some 50–100 m.

The outer contacts against the basement granites are sharp with the gabbroic rocks showing moderately well-chilled contact facies. Contact metamorphism is believed to have been insignificant. At one locality where the contact can be investigated, the big feldspar granite alongside the gabbro chill shows some crushing, but except for the shearing the granite is fresh and unaltered, to within at least 30 cms from the chill.

Although the contacts between the syenites and the marginal gabbros are seldom exposed it is clear that the syenites do not develop a finer-grained facies adjacent to the latter but, on the contrary, are coarse grained and pass transitionally into them. The relationships are well

Fig. 4. View to the WSW. along the Hviddal composite giant-dyke in central Tugtutôq. The flat valley-floor is underlain by syenite. This is bounded on either side by olivine gabbro which outcrops sparingly at the foot of the steep granite walls.

displayed in excellent cliff sections on either side of the central Tugtutôq fjord which intersects the dyke. Here the syenite becomes increasingly pegmatitic outwards and the transition zone consists largely of hybridised gabbroic rocks cut by veins of syenite pegmatite. Thus the field evidence suggests that the gabbroic rocks were formed as an early dyke 100–200 m wide into the centre of which syenite magma was intruded to produce a composite dyke.

Intrusion of syenite magma along the centre of the gabbroic dyke before this was completely solidified would serve to explain the hybridization, the absence of chilled contacts to the syenite and the constancy in width of the marginal gabbro zones which contributes to the overall bilateral symmetry of the whole dyke. The alternative view that the composite dyke represents a single intrusion which has differentiated *in situ* into basic wall rock and alkalic centre is regarded as untenable. Militating against this proposal is the fact that the gabbroic zones appear to be constant in composition along the whole dyke whereas the central syenitic components vary widely. Furthermore, it would not be easy to explain on this basis the concentration of pegmatitic material along the 'mixed-zone' between centre and margins. The fact that later composite dykes in the area show clear evidence of having been formed through two magmatic injections also argues in favour of the dyke having acquired its composite nature by a similar process. Composite sills involving closely comparable rock types have been described from Sakhalin by IWAO (1939) and YAGI (1953).

For the westernmost 12 kms of its course, the dyke centre is found to be an essentially homogeneous medium-grained, hypidiomorphic and mesocratic syenite consisting of greyish-white feldspars and black aggregates of ferromagnesian minerals. The tolerably well-formed feldspars occur as tabular crystals averaging between 6 and 10 mms across and between 1 and 4 mms thick. These are found to be coarsely antiperthitic and show a characteristic chequer pattern in suitably oriented sections resulting from pericline and albite twinning in the plagioclase constituent. Occurring as an accessory in interstitial areas at irregular intervals are small crystals of nepheline. These are generally turbid and somewhat decomposed.

Clinopyroxene is an important constituent, occurring as idiomorphic prisms of up to 3 mms long and ·5–1 mm across. These show the normal alkali pyroxene zoning from mauvish-grey cores out to pale green margins. Associated with the pyroxene, partly as its replacement product, is a brown barkevikitic hornblende which is itself zoned outwards to a blue-green variety. Ilmenomagnetite crystals are common and are usually surrounded by a reaction zone of lepidomelane. Rather scarce early crystals of fayalitic olivine in various stages of replacement by 'iddingsite' are also present, and, as may be expected with such an assemblage, stout euhedral crystals of apatite are also fairly abundant. Of these components, it is inferred from the textural evidence that, as in the case of various other "augite syenites" in this province, the feldspar, pyroxene, ore, olivine and apatite (in order of their relative abundance) were the first to begin crystallizing. The amphibole, biotite and nepheline separated late from the residual alkali and hydroxyl enriched liquid fraction. As the composite dyke is traced towards the ENE. it is found that the content of interstitial nepheline increases until, in the sector preserved between the later intrusions of the central ring-complex and giant-dyke gabbro in the neighbourhood of the Stor Pile Sø (*lit.* "Big Willow Lake"), it is a major constituent of the rock. However, in this important sector, the syenites have been slightly hydrothermally altered and the nepheline is rarely found fresh. Still further to the east, where the composite dyke is seen between the two broad, cross-cutting gabbro dykes, the nepheline accounts for some 15–20 % of the rock. The relationship of the nepheline to the feldspar here is still essentially interstitial although, in the extreme east, the nephelines are found more nearly idiomorphic.

The tabular habit of the feldspars in the westernmost part of the syenite dyke (parallel to (010), becomes increasingly exaggerated towards the ENE. to produce the thin platy crystals typical of foyaitic rocks. All trace of fayalite is lost in the more easterly rocks. Ti-magnetite and apatite become more and more scarce and the pyroxenes become progressively more sodic. The pyroxenes in the foyaitic eastern facies generally retain the strong zoning, but rather than zoning from mauvish-grey to pale green, they pass from pale green cores (which may or may not be pleochroic) outwards to bright green pleochroic aegirine-augite. Hence, it may be inferred that the bulk pyroxene composition apparently changes along the dyke in the direction of Fe-Na enrichment and Mg depletion. Amphibole is less evident in the nepheline-rich syenites and, when it is present, it is as a green hornblende superficially quite dissimilar to those of the syenites in the WSW. Biotite remains as a minor constituent.

The nephelines of the foyaitic rocks are commonly pseudomorphed by a reddish-brown aggregate of break-down products although more rarely they are found partially replaced by cancrinite. Interstitial albite, analcite and, occasionally, sodalite occur in small amount between the irregularly orientated tablets of microcline microperthite. The feldspars are generally Carlsbad twinned and finely antiperthitic with the albitic phase lacking the pericline twinning present in the feldspars from the more westerly rocks.

It may be concluded that, in passing along the syenite dyke in the ENE. direction there is a more or less gradual change from rocks characterised by possession of a relatively high temperature mineral assemblage to those containing assemblages of an increasingly low temperature nature. It is probable that the syenite magma in the ENE. contained a higher content of water, sodium and aluminium and that crystallization at this end of the dyke took place over a lower temperature range than in the WSW.

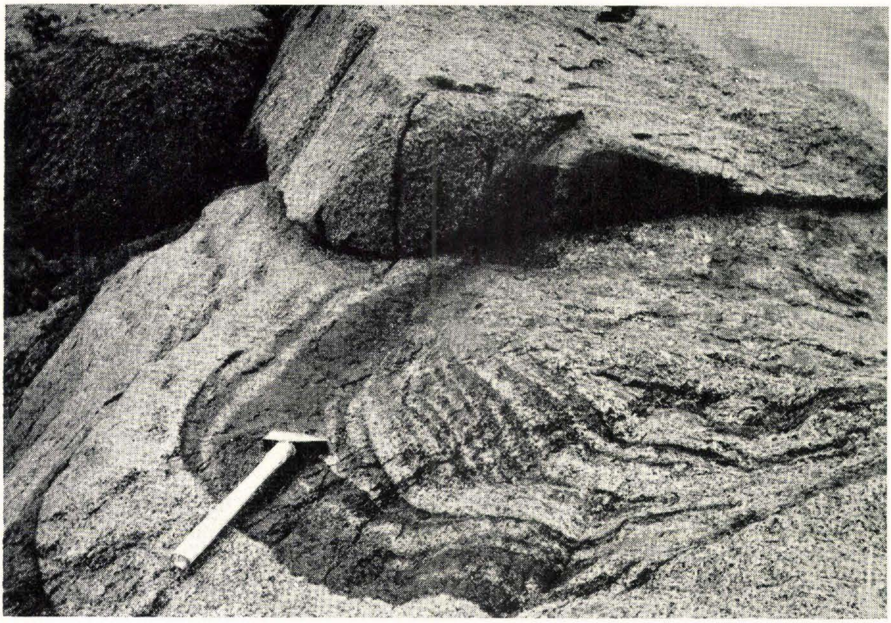

Fig. 5. Part of an asymmetrical 'pipe-structure' in the Hviddal syenite. The banding, which is predominantly due to pyroxene concentration in the syenite, forms a vertical cylindrical structure.

The typical basic rock from the marginal parts of the composite dyke is not dissimilar to some of the more alkalic variants of the Kûngnât ring-dyke gabbro and may have a similar origin. The rocks are evidently very iron-rich and have a high content of olivine (hyalosiderite to hortonolite) and ore. The plagioclase is zoned over a range of ca. An_{57}–An_{44} and considerable amounts of interstitial cryptoperthitic feldspar are normally present. Small crystals of apatite are abundant.

Internal structures within the syenite dyke: over the greater part of its course the syenites are devoid of any particular macro-structures and are essentially homogeneous away from the more complex transitional facies found against the gabbros. Nevertheless, there are a few enigmatical pipe-structures within the massive syenite. These are vertical, sub-cylindrical bodies, one or two metres in diameter defined by more or less concentric layers in which the ferromagnesian minerals (mainly pyroxene) are concentrated. One of these (Fig. 5) occurring on the west coast of the central Tugtutôq fjord, is the best example of the three or four so far discovered. One suggestion for their origin is that these may represent pipe-like magma ducts which remained open for a time in the semi-crystalline syenite. These may have been closed by crystallization around the walls, the banding possibly reflecting vapour pressure fluctuations in the melt or variations in composition of the moving magma.

In the easternmost parts of the syenite dyke there is frequently a marked parallelism of the flat feldspar crystals to give the typical texture of a foyaite. The strike and dip of the ensuing lamination is however, related only to localised swirl-patterns.

The Olivine Gabbro Giant-Dykes.

Following the consolidation of the composite giant-dyke, basaltic magma intruded regionally along the old ENE.–WSW. planes of weakness gave rise to newer giant-dykes on Tugtutôq and to the gabbro body on the mainland in the vicinity of Narssaq. The Narssaq rocks were first described by Ussing (1912) as essexites and later by Wegmann (1938) as essexite-gabbros, but since none of these rocks are feldspathoid-bearing and the quantity of alkaline feldspar present is consistently low, there would seem to be no pressing reason to designate them as other than slightly alkaline olivine gabbros. The gabbro occurs as two broad dykes on Tugtutôq which subdivide and die out to the west. Over much of their length the giant dykes are up to 500 m broad, locally attaining a width of over 800 m. The dykes have largely been preferentially eroded by the ice and have given rise to broad U-shaped valleys. A distinctive form of topography is exhibited along stretches of the dykes where there are two sets of joints strongly developed, one joint set parallel to and the other normal to the dyke walls. In such areas the gabbro is divided up in a rectilinear pattern with upstanding blocks of gabbro many metres across.

The southern giant-dyke, followed south-westwards from Sigsardlugtôq, divides into two branches, both of which are terminated rather bluntly against old crush-lines in the basement granite a few kilometres to the WSW. However, the northern dyke system is very persistent, running the entire length of the main island and traversing the small outer islands, a distance of over 45 kms. In the extreme WSW., where it crosses Kakatusôq island, the width has diminished to ca. 40 m. However, on the mainland around Narssaq the gabbros occur as a single large intrusion which has no obviously dyke-like form and which has been truncated by later Gardar intrusions of quartz syenite and alkali-granite. Originally this body may have been as broad as 5 kms across from NNW.–SSE.

On Tugtutôq, the contacts of the gabbros are mainly vertical and this is also true of the contact against basement granite beside Narssaq settlement. However, about 1 km to the east of Narssaq, just above the basal Gardar unconformity, the contact against quartzite is distinctly

Fig. 6. A view to the ENE. along a gabbro giant-dyke south of the main Tugtutôq tear-fault. The 'ridge and trough' topography shown in the foreground is due to preferential glacier erosion along longitudinal joints and microsyenitic dykes within the gabbro body. The gabbro dyke is approximately 700 m wide at this locality. The bay in the middle distance is the Itivdlip Sarqâ. The Ilímaussaq complex forms most of the distant mountain area seen in the left background.

low angled. Mr. J. W. Stewart, mapping in the adjoining area to the east, reports large sills of closely related gabbros and dolerites occurring conformably within the Gardar lava series and, since there is no report of the gabbro dykes to the east-north-east of the Ilímaussaq centre, it is likely that the giant-dyke system had its easterly termination in sill-like extensions around Narssaq (Wegmann, 1938, p. 72). The difference in the form of the gabbro intrusions in the Narssaq and Tugtutôq areas is explicable in terms of the different erosional levels at which they are seen on either side of the fault-zone which is believed to separate the two areas. In the former area the gabbro is seen at or above the level of the basal unconformity of the stratified series whereas in the latter it is seen within the massive granites at an unknown depth below the unconformity.

The contacts between gabbro and older granite are typically knife-sharp with the gabbro possessing fine-grained chill zones of ca. 1 m width. Back-veining from the granite is normally absent and, even when it is present, it is on a very small scale. Nevertheless, in spite of fairly extensive sampling, it was difficult to select a speciment of chilled gabbro which might reasonably represent the uncontaminated and undifferentiated

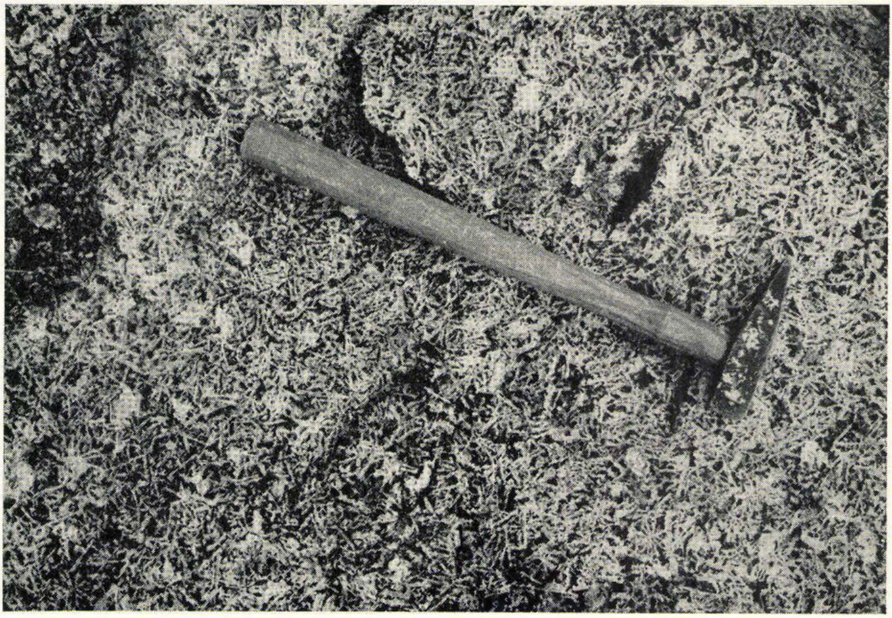

Fig. 7. A variety of olivine gabbro occurring in the southernmost giant-dyke branch on Tututôq. The gabbro in this particular sector is unlayered. The plagioclase crystals are seen to have crystallized out in small star-like aggregates.

magma. It was found that the marginal facies gabbros are usually rich in biotite and alkali feldspar, suggesting that there may have been some metasomatic migration of alkaline material inwards from the hot granite wall-rock. Granophyric texture present in the granite close to be contact may be due to crystallization of rheomorphic liquid produced in small amount by re-heating. In some marginal facies the gabbros contain star-shaped aggregates of early plagioclase crystals which evidently had begun to crystallize prior to intrusion.

Occasionally banding parallel to the cooling wall was observed in the gabbros. Of particular interest in this respect are the vertical layers or zones of 'perpendicular feldspar rock' developed on the inner side of the normal fine-grained marginal facies of the northern gabbro dyke in the western part of Tugtutôq. These resemble the rocks of the perpendicular feldspar reefs in the Skærgaard marginal border group (Wager and Deer, 1939), possering elongate curved plagioclase, standing perpendicular to the cooling wall, with the convex surface uppermost.

Whilst the northern branch of the southern dyke system ends abruptly against an older crush zone in the country rock, the southern branch, 250 m wide, is only partially arrested by a similar crush and is

Fig. 8. Melanocratic banding seen in a section across the southernmost giant-dyke branch. The layering steepens to the right of the illustration, becoming vertical as it approaches the dyke margins. To the left, the inclination decreases until, in the axial region of the dyke, the layering is horizontal and at its maximum development. Note the minor disconformities in the bedding.

frayed-out into a dense swarm of small dolerite dykes which continue for many kilometres through Tugtutôq and Niaqornaq island.

The southern giant-dyke system is largely composed of gabbros with idiomorphic tabular plagioclase, occasionally displaying a preferred orientation. The same degree of idiomorphism is not generally found within the northern dyke system and feldspar lamination is almost entirely absent. Some aspects of the plagioclase lamination and related banding features of these olivine gabbros have already been discussed in a previous publication (Upton, 1961). Synformally disposed layered structures occur at intervals along the dykes although, along much of its length, the northern dyke body is entirely massive. The layering may be displayed by banding due to differences in the relative amounts of plagioclase and dark minerals (principally olivine) or by the parallelism of the plagioclase crystals. In rare instances both banding and concordant lamination occur. Gravity stratification is seldom displayed in the banding which generally dips inwards from the dyke walls at angles lower than 45 $^0/_0$ to become horizontal in the axial region. However, there are a number of localities where the internal structure is considerably more complex with, for example, two or more synforms occuring side by

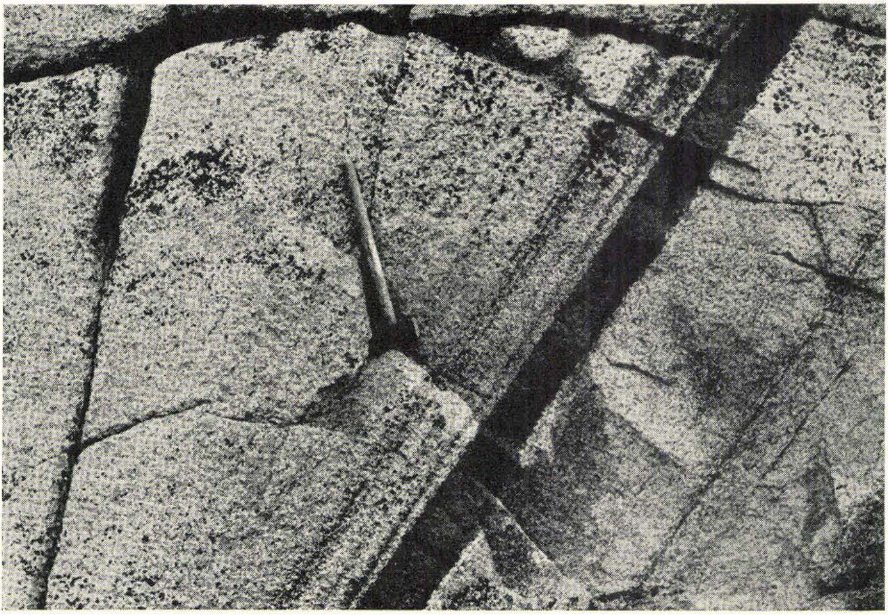

Fig. 9. An extreme case of olivine banding in layered gabbros from the giant-dyke at Itivdlip Sarqâ. The illustration is of a large block detached from a rock-face in which the layering dips inwards towards the dyke centre at 30–40°. The black speckling across the gabbros in the upper part of the figure is due to growth of lichens and does not represent textural irregularities in the rock.

side. A fuller discussion of the layered structures will be presented in a later paper dealing with the petrology of these gabbros.

Although the typical gabbros are feldspathic, and contain 60–70 % plagioclase, dark khaki-grey layers of olivine-rich rock (containing up to 60 % olivine), as much as 1 m thick, occur within the more strongly banded sectors (Fig. 9). The troctolitic gabbros most representative of these giant-dykes are even-grained, mesocratic rocks with whitish-grey labradorite crystals (averaging 2–3 mms), small brown olivine crystals up to 1 mm across and black grains of ore and pyroxene. Small flakes of biotite are often distinguishable in the hand specimen.

In thin section the plagioclase crystals are found to display a moderate normal zoning from centres of ca. An_{65}. Superimposed on this there is generally a faint oscillatory zonation; interstitial to the plagioclase and the olivines are small amounts of cryptoperthitic feldspar which is usually much sericitised. The olivines, ranging from Fa_{30-40} (according to 2V measurements) occur idiomorphically and usually unaltered. Ilmenomagnetite is typically an important constituent which appears to have had a crystallization range extending from very early to late in the cooling history. Often the oxide grains are fringed by lepidomelane.

Small quantities of pale mauve-grey titanaugite occur sub-ophitically between the early minerals and apatite is invariably present as an accessory. The composition of the gabbros is essentially the same throughout the dyke system and there is little variation amongst the individual minerals.

The Anorthosites.

The main gabbro intrusion around Narssaq settlement and eastern Tugtutôq is found to contain xenolithic masses of labradorite rock ranging from spectacularly large masses 100 m or more across to small xenocrystic chips derived from single plagioclase crystals. One block of similar anorthosite has also been found included within the earlier gabbro intrusion of the Hviddal composite dyke and, as will be described in a subsequent section, anorthosites and their debris are abundantly present in some of the later basic and microsyenitic dykes. These anorthosites are only known as xenolithic material and the fact that they are found within various Gardar intrusions over a large area in the south Greenland igneous province suggests that they are derived from an extensive anorthosite body at depth.

Thus, although the anorthosites are known to have been available for disruption from relatively early in the Gardar, their lower age limit of crystallization is a matter for speculation. The mineralogy and textures of the large anorthosite body brought up by the giant-dyke gabbros on the Assorutit headland have been briefly discussed in an earlier paper (Upton, 1961), in which it was suggested that this particular mass is part of a gravity-accumulated layered pluton derived from olivine alkali basalt magma. This may have been similar to, or even nearly identical with, the magma which gave rise to the gabbro dykes.

It is convenient at this juncture to consider the anorthosite blocks since their mineralogy shows clearly their close genetic relationship to the olivine gabbros. The greatest concentration of anorthosite inclusions is seen around Narssaq village. To a very large extent these and the enclosing gabbros have been hydrothermally altered whereas those occurring along the outcrop of the northern giant-dyke on Tugtutôq are entirely fresh. The type locality for these inclusions is the Assorutit peninsula, but fragments can be found along the dyke for many kilometres to the WSW., although decreasing in size and concentration in this direction. By contrast, the southern gabbro giant-dyke branches are completely devoid of any anorthositic material.

The inclusions are composed principally of scarcely zoned labradorite, ca. An_{57} occurring in subhedral tablets which range from a few millimetres to 20 cms across. A strong igneous lamination due to parallelism

Fig. 10. View across the large body of anorthosite on the Assorutit headland. The layering features are clearly displayed in the foreground. (As an indication of scale, the piece of driftwood shown in the middle-left is ca. 1 m long).

of these crystals is characteristic and, interstitial to the plagioclase, there are variable quantities of olivine (ca. Fa_{30-32}), with minor amounts of ore, augite, biotite, apatite and alkali feldspar. It appears that the average feldspar is somewhat more sodic than in the gabbros although the olivines are slightly more magnesic.

The anorthosites involved in the Tugtutôq gabbros are all fragments of undeformed layered rocks in which the plagioclase undoubtedly has its original compositional and textural state. In this respect they differ from the majority of the blocks in the Narssaq gabbro and in the later smaller dykes which contain strongly cataclastic and randomly oriented plagioclase fragments. However, even in these instances there are occasional pieces of the non-cataclastic laminated anorthosites, similar to those of the Assorutit peninsula.

The Kryds Sø Syeno-Gabbro and the Assorutit Syenite.

Towards the eastern coast of Tugtutôq the northern gabbro giant-dyke acquires a composite character either side of the abrupt constriction which marks its course a little east of the Kryds Sø (*lit.* 'Cross Lake'). On the western side of this bottle-neck the centre of the giant-dyke is occupied by a lenticular body of syeno-gabbro whereas on the eastern side the dyke has a centre of quartz syenite. Although the more easterly portion of this (Assorutit) syenite is under the sea, it is probable that it occurs as a closed lenticular area within the olivine gabbro, forming as it were a mirror-image to the Kryds Sø syeno-gabbro pod. Alternatively, it is possible that the quartz syenite continues within the gabbro to the ENE. as a continuous dyke to join the syenite assemblage on the mainland. The contacts of the syeno-gabbro and the quartz syenite against the enclosing gabbros are precisely parallel to the outer gabbro-granite contacts. The symmetrical setting of these two more alkalic masses within the gabbro dyke leads to the supposition that they were formed or emplaced within the central unconsolidated parts of the dyke which had hitherto been crystallizing from the walls inwards.

The syenite is approximately 500 m wide and can be followed inland from the coast for ca. 1 km before it wedges out into the gabbros in the vicinity of the dyke constriction. In its inner parts the syenite is a medium-grained rock with a (feldspar) grain-size of 6–10 mms. Ferromagnesian minerals account for some 20 % of the rock, and, in its freshest condition, the rock is bluish-green in colour. Whereas the main mass of the syenite is compact and devoid of macroscopic quartz, the marginal zones close to the gabbros are notably quartz-rich with pegmatitic cavities. The quartz enrichment is such that in some facies the rock grades into alkali granite. The contact itself is more or less smoothly gradational over one or two metres into hybridised gabbro which, in turn, is gradational outwards into the standard olivine gabbro. The contact relationship between the Assorutit syenite and the host gabbro is thus not unlike that observed between the syenite and gabbro in the Hviddal composite dyke. In both cases there is an absence of a sharply defined chilled contact to the alkalic component and in both instances there is a relatively narrow transitional zone of syeno-gabbroic rocks which are believed to have originated through alkaline metasomatism of hot gabbro by the syenite magma. An unusual feature seen in the Assorutit contacts which has no counterpart in the Hviddal dyke is the development of small elongate assemblages of ferromagnesian minerals in the contaminated gabbros alongside the syenite. These are several centimetres in length and lie perpendicular to the syenite margin. At first sight this contact facies resembles the 'perpendicular feldspar gabbros' referred to on page 22, but it is the ferromagnesian minerals and not the individual feldspar crystals which are responsible for the peculiar bladed appearance of the rock. It is inferred that this feature originated during recrystallization of the gabbro close to the syenite. Although there is no evidence of any simple layered structure within the syenite, there are a few thin, low-angled bands of melanocratic material which have no consistent strike or dip pattern. There is no suggestion of any preferred orientation of the feldspars in this intrusion.

The principal component of the syenite is antiperthitic alkali feldspar occurring as tabular crystals, slightly flattened parallel to (010). These euhedral crystals of alkali feldspar are invariably mantled by clear albite which is quite distinct from the albitic component in the antiperthite. Whereas the early feldspars normally show a pronounced antiperthitic exsolution pattern, the centre zones are occasionally cryptoperthitic. Early ferromagnesian phases include titaniferous magnetite, clinopyroxene and olivine. The olivines are fayalites, ca. Fa_{95} which, in the typical syenites, are usually pseudomorphed by yellow-brown 'iddingsite'. The pyroxenes resemble those from the westernmost facies of the Hviddal syenite and zone outward from pinkish-grey centres to greenish margins. Small rods of early apatite are common throughout the rock. The ferromagnesian minerals display complex reaction relationships and are associated with a variety of amphiboles and micas. The pyroxenes have been largely corroded and made over to a brownish-green hornblende which zones outwards to a more blue-green sodic variety. This in turn is often surrounded, more or less sharply, by a member of the arfvedsonite-riebeckite series. This riebeckite variety is also found closely associated with the olivines and as isolated interstitial wedges between the feldspars. Finally, a mica pleochroing from red-brown to olive-green, is frequently present as a reaction fringe around the riebeckite. This mica, which is a characteristic accessory in the Assorutit syenite, is identical to the mineral tentatively identified as cryophyllite in the Kûngnât syenites (Upton, 1960). The ilmenomagnetite crystals also commonly possess reaction zones of mica, but in this case it is a lepidomelane, quite dissimilar to the cryophyllite.

The reaction sequences were not complete with the micas and amphiboles and some of the latest materials to crystallize are found as brownish interstitial areas probably consisting mainly of goethite and limonite. Also occurring interstitially (and later than the albite rimming around the antiperthites) are quartz and carbonate.

The occasional melanocratic bands in the syenite are due to concentrations of idiomorphic fayalite and pyroxene. In this environment the olivines are conspicuously fresher than in the typical syenite and the accompanying feldspars are mainly cryptoperthites seldom showing the pronounced exsolution textures of the feldspars from the standard rock. The reaction sequences, continuous and discontinuous, are also largely suppressed in the melanocratic bands.

Although, as stated above, the main contacts of the Assorutit syenite are concordant with those of the gabbro against the older granite, there are many small dyke-like apophyses extending from the syenite along the regional ENE.–WSW. direction. These have been found cutting the giant-dyke gabbros as far as 4 kms to the WSW. of the main syenite outcrop. One of these dykes cuts the nepheline syenites of the Hviddal composite dyke a little to the south of the Kryds Sø. In mineralogy and grain-size these offshoots resemble the pegmatitic patches found marginally around the Assorutit syenite, and, like these, they are granitic rather than syenitic. The feldspars are, like those of the typical syenite, coarse antiperthites surrounded by clear albite, but occur up to 3 or 4 cms long. These are accompanied by large quantities of interstitial quartz and riebeckite, the latter frequently broken down into a fibrous crocidolite.

The syeno-gabbro outcrop around the Kryds Sø forms a rather barren lowland area within the giant-dyke which can be mapped out fairly rapidly on the grounds of topography alone. The rocks are rapid weathering and have a rich rusty-brown hue as a result of heavy iron-staining of the feldspars. The biotite content of these rocks is conspicuously higher than in the surrounding olivine gabbros and the clear ophitic texture of the latter is lacking.

Poorly-defined olivine-rich bands within the syeno-gabbro, striking parallel to the contacts and dipping inwards at angles of under 30°, show the body to have a shallow synformal structure. (The surrounding gabbros in this sector of the giant-dyke are devoid of any banding or other structural elements). The actual contacts between the syeno-gabbro and the gabbro are nowhere visible, but it is inferred that the contacts are sharp to within one or two metres. The relatively rapid change from the one rock-type to the other, in conjunction with the synformal structure confined to the syeno-gabbro alone, suggests that the syeno-gabbro pod was not formed through any *in situ* differentiation of gabbroic magma. However, the mineral assemblage in the two cases is much alike and in thin section the close relationship of the syeno-gabbro and the enclosing gabbro is readily apparent.

The feldspars consist of strongly zoned plagioclase, with andesine cores becoming more sodic and grading out into cryptoperthite. In contrast with its subordinate role in the gabbros, the cryptoperthite is a major constituent of the rock. Biotite and clinopyroxene (pinkish-grey, zoning out to pale green) are more prominent and the abundant olivine is still more iron-rich than in the typical gabbro. Ore and apatite are present in significant quantity. In general these syeno-gabbroic rocks are very similar to those formed adjacent to the syenites in the earlier Hviddal composite dyke and alongside the Assorutit quartz syenites. The Kryds Sø syeno-gabbro is believed to have been crystallizing at the same time as the Assorutit syenite, but since it is cut by the pegmatitic alkali granite dykes from the latter, it had evidently reached a state of rigidity by the time that the late-stage granitic residual liquids from the quartz syenite were available for intrusion.

It seems reasonable to conclude that the Kryds Sø syeno-gabbro outcrop overlies an intrusion of syenite and that the rocks have formed through enrichment of the semi-crystalline magma in the central part of the gabbro dyke by alkalies and iron derived from underlying syenite magma. The explanation may be that quartz syenite magma was intruded up the centre of the cooling gabbro dyke to give, not a continuous composite dyke as in the earlier instance of the Hviddal dyke, but two (or more?) lenticular bodies around each of which a mantle of hybridised gabbro developed. The fact that syeno-gabbro is seen in the one area and quartz syenite in the other is thus attributed to differences in the height reached by the syenite magma on either side of the giant-dyke constriction and hence to the differences in structural level now revealed.

Although there are a number of large quartz syenite and alkali granite intrusions on the mainland precisely where any east-north-easterly extension of the Assorutit syenite may be expected to occur, none of these corresponds closely to it petrographically (personal communication from J. W. Stewart). The ENE. swarms of microsyenite dykes, both porphyritic and non-porphyritic (described in a later section), cut and chill against the Assorutit syenite whereas it appears that the mainland syenites were either intruded contemporaneously with these dykes or else were not fully consolidated at the time of dyke intrusion. (Further personal communication from J. W. Stewart). Thus there is some evidence for considering the Assorutit syenite to have been intruded a little earlier than the mainland syenites, which were collectively described by Ussing (1912) under the heading 'nordmarkites'.

The Pyroxenites.

At some time following the solidification of the main olivine gabbro intrusion, but preceding the eruption of the alkaline dyke swarms described in the next section, a suite of ultramafic rocks was intruded around the Narssaq-Tugtutôq region. The main outcrops of these pyroxenite ultramafites are found in the gabbros north of Narssaq where the upper surface of a large pyroxenite body is seen dipping gently towards the north-east. It may well be that the pyroxenite here is part of a large sill, the lower part of which lies out to sea. These magnetite-pyroxenites were briefly discussed by Ussing (1912, p. 204) who presented a chemical analysis of the rock. This showed a strikingly high content of iron, titanium, magnesium and calcium, low silica (ca. 32 %) and an apparent absence of alumina. Typically, the rocks consist of small idiomorphic grains of clinopyroxene and ilmenomagnetite, together with subsidiary amounts of olivine and poikilitic biotite. Accessory minerals include perovskite and carbonate. As may be inferred from the analysis, feldspars are entirely lacking. The diopsidic pyroxene is always strongly coloured (greenish-yellow or light brown), but is non-pleochroic.

Two outcrops of nearly identical rock have been found on Tugtutôq. (These are small and are not shown on the maps accompanying this account). One of these takes the form of a circular plug, about 40 m diameter, intruded between older granite and gabbro at the constriction of the northern gabbro dyke between the Kryds Sø and the coast. The contacts are unexposed, but probably have the same sharp intrusive features as those on the mainland. The plug is composed of a tough, fine-grained dark grey variety containing clear olivine phenocrysts (ca. Fa_{25}) up to 5 mms across. The second occurrence is at the eastern end of the Stor Pile Sø where a small poorly-exposed body of pyroxenite is situated between the nepheline syenite and olivine gabbro. This rock, also fine-grained but olive-greenish coloured, resembles the mainland pyroxenite in having a heterogeneous nodular appearance due to the varying proportions of pyroxene, ore and biotite.

The magnetite-pyroxenite suite comprises rocks grossly different from the olivine gabbros in texture, mineralogy and bulk composition and there is no likelihood of them being directly related. Ussing compared these pyroxenites to the Brazilian jacupirangites and they are undoubtedly closely allied to the biotite-pyroxenites described from numerous nepheline-syenite and carbonatite areas.

Mid-Gardar Dyke Swarms.

Of the large number of small dykes (mainly 1–10 m wide) trending parallel to the length of Tugtutôq, the great majority are believed to have been intruded during the interval between the solidification of the gabbros (and the Assorutit syenite) and the emplacement of the late Gardar plutonic centres. However, as referred to on p. 23 there is one early swarm of dolerite dykes which was intruded contemporaneously with the gabbros.

The distribution of the dykes across a portion of central Tugtutôq can be seen from map plate 2, on which all dykes exceeding 1 m across have been indicated. (The exposure over this ground is sufficient for it to be claimed that at least 80 % of all the dykes have been mapped in for some part of their outcrop). The greatest dyke concentration is found in the strips of older granite separating the giant-dykes although there are many actually lying within the giant-dykes themselves. Large numbers also traverse the Skovfjord islands, but to the NNW. of the giant-dykes the smaller dykes become increasingly scarce until, close to the Bredefjord coast of Tugtutôq, they are extremely rare. Along a NNW. traverse of Tugtutôq from coast to coast in the vicinity of the central complex, some 70–80 dykes are encountered. In addition to these are the four giant dyke branches with an aggregate width of 1500 m. Assuming an average width of ca. 2 m for the smaller dykes there is thus some 1650 m of dyke material occurring along a 7.5 km traverse line, representing a local dilation of the granite basement by ca. 28 %.

The dyke swarms comprise a variety of quartz microsyenitic, alkali microgranitic, doleritic and hybridic types. In view of the close parallelism of the dykes and the consequent rarity of intersections, in addition to the diversity of compositional and textural features exhibited, it has been difficult to distinguish the several component swarms with certainty. This is aggravated by the fact that lithologically similar dykes can, in some instances, be shown to belong to different intrusive episodes.

The earliest post-gabbro swarm consists principally of a complex suite of basic dykes which are conspicuously rich in shattered plagioclase and anorthosite inclusions. These dykes are very persistent and individuals can often be traced undiminished for several kilometres through the Skovfjord islands. These dykes occur along a belt some 8 kms broad; generally the dykes themselves range from 4 to 7 m in width. A preliminary examination of several thin sections from these dykes suggests that they represent olivine dolerite in varying states of alkaline contamination. This may have arisen through contact with syenitic material during intrusion. Phenocrysts of olivine, ore and apatite are frequently present although the olivines are usually pseudomorphed by serpentinous material. The groundmass has frequently so much alteration as to be unresolvable, but has been noted to contain olivine, ore, biotite, augitic pyroxene, apatite and occasionally hornblende. The groundmass feldspars appear to consist mainly of strongly zoned oligoclase and antiperthite. The large plagioclase fragments characteristic of these dykes are normally severely sericitised, but may be found as glassy-clear, scarcely-zoned labradorite, An_{50}–An_{60}. In many dykes there is a marked tendency for the size of the labradorite insets to increase towards the centre of the dyke and cleavage fragments of individual crystals over fifty centimetres long have been noted. The bulk of the plagioclase is believed to be xenocrystic rather than phenocrystic material on the grounds of the following evidence.

1) The plagioclase is found as badly broken cleavage fragments which are commonly accompanied by xenolithic masses of anorthosite (Figs. 11 and 12). These anorthosite blocks themselves commonly show a cataclastic texture, but occasionally xenoliths of laminated anorthosite with unbroken crystals, apparently identical to those of the gabbro giant-dykes, are present.

2) Similar labradorite crystal fragments occur in a range of the hypabyssal rocks independent of age and composition.

Although it is normal to find that only the central parts of these dykes have brought up feldspar debris, in some cases the reverse situation

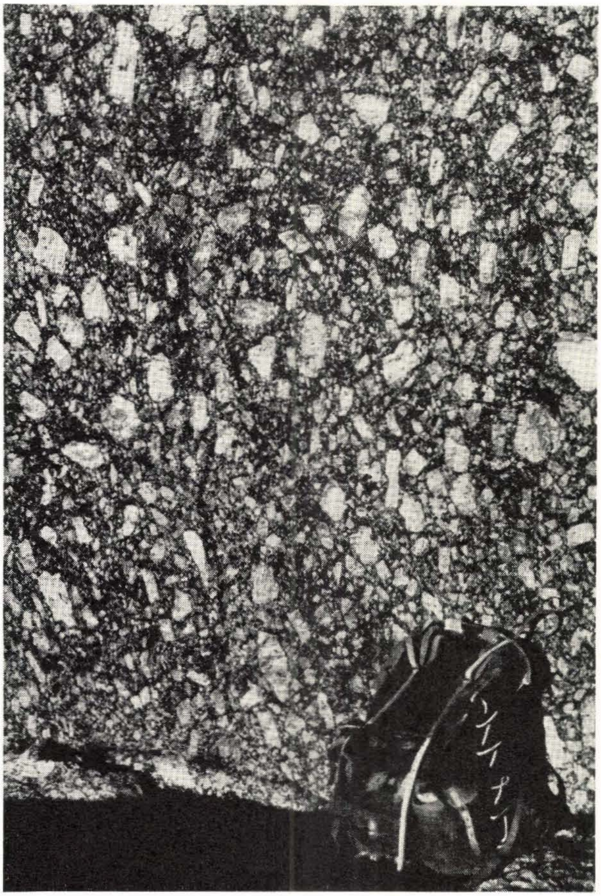

Fig. 11. Labradorite fragments brought up in a large basic dyke exposed on a small island WSW. of Tugtutôq. The xenocrysts are orientated roughly parallel to the dyke walls.

prevails and the plagioclase chips are confined to the border facies. In still rarer instances the feldspar distribution is asymmetric with regard to the dyke.

In several otherwise typical dykes it was discovered that the marginal xenocryst-free zones were not identical to the hybridised basic material forming the bulk of the dyke, but consisted of a microsyenite containing small, well-formed phenocrysts of alkali feldspar. The width of these porphyritic microsyenitic border facies is variable and indepen-

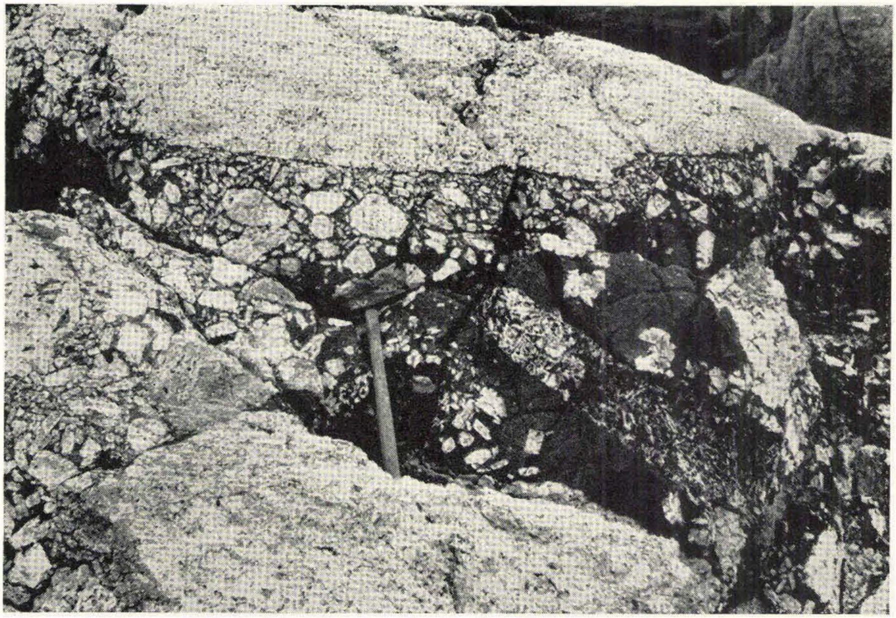

Fig. 12. Large xenoliths of various anorthositic rocks together with smaller plagioclase xenocrysts in a basic dyke exposed on a small island between Sigsardlugtoq and Igdlutalik.

dent of the total width of the dyke. In most, but not all, instances the microsyenitic border facies was seen to grade rapidly, but smoothly into the basified xenocryst-bearing inner zones. In the course of tracing one such dyke it was found that over a distance of three kilometres the character of the dyke changed entirely; in its west south-westerly extension this dyke, averaging 20 m (an unusually large dyke for its class), possesses porphyritic microsyenite borders which extend inwards from the outer contacts for ca. 1 m. These have dark bluish porphyritic selvedges which pass inwards towards the coarser brownish micro-syenite. The latter in turn passes rapidly into the darker, more doleritic rock that constitutes the greater part of the dyke and the transition is accompanied by a loss of the alkali feldspar phenocrysts and the appearance of the labradorite inclusions. Traced towards the ENE., from the islands of Tugtupait, Takisôq and Tugtutôq Lille Ø towards the main island of Tugtutôq, the marginal microsyenite zones expand at the expense of the inner basic zone until, on Tugtutôq, the dyke is entirely composed of porphyritic microsyenite. On the east coast of Tugtutôq Lille Ø a transitional phase of the dyke is well exposed where the central basified zone is already lacking, but where the labradorite xenocrysts are still found in the centre of the dyke, along with the alkali feldspar phenocrysts. Subsequent mapping revealed other dykes which similarly undergo progressive changes along their strike from predominantly microsyenitic to predominantly basic. This phenomena underlines the risk of error involved in mapping the dykes by extrapolating between too widely spaced traverses, since a single dyke may have an entirely dissimilar appearance from one locality to another.

The conclusion drawn from the study of these relatively early dykes is that in some cases the basic magma took advantage of dyke fissures which had recently been opened and occupied by syenite magma. This gave rise to a peculiar type of complex dyke in which the basic magma was erupted immediately after the felsic and not *vice versa* as in classical composite dyke instances. It is clear that, wherever this occurred, the basic magma was injected into the central partially or non-crystalline zone of the alkaline dyke before this had completed crystallization, precisely as the Hviddal and Assorutit syenite magmas had been injected into the still-cooling gabbro dykes. The change in character along some of these complex dykes is thus ascribed to the independent attenuation and wedging-out of one or other of the two dyke units. Although the basic material of all these early dykes is believed to represent olivine basalt magma which has suffered varying degrees of alkaline contamination at depth, there has undoubtedly been some *in situ* contamination between the two components in several of these complex dykes. The fact that the earlier syenitic components of the complex examples rarely carry plagioclase pieces whereas the basic components invariably do, (whether distributed evenly or restricted to particular zones) may imply that the basaltic magma source lay at greater depth than that of the syenite magma. The source of the plagioclase material may take the form of a horizon of anorthosite at an intermediate position such that, through most of the Gardar period, it was available for disruption by deep-source dolerite and gabbro dykes, but that only very exceptionally was it brecciated by, and involved in, the syenitic magmas.

This major phase of dolerite-hybrid plus microsyenite dyke injection (plus anorthosite fragments) was succeeded by the intrusion of a number of porphyritic alkali rhyolite dykes. These are relatively scarce and the majority have been found in the eastern part of Tugtutôq, – mainly in association with the giant-dykes, and also on Igdlutalik. The majority of these dykes die-out rapidly towards the WSW. The largest, a 20–30 m dyke running just north-west of the giant-dykes, is an exception to this and is traceable for some 35 kms before ending on Lille Tugtutôq Ø. Most of these dykes however, have widths of less than 5 m. The dykes contain both quartz and alkali feldspar phenocrysts set in a groundmass that is commonly glassy or in a state of partial devitrification. Spherules (generally formed around phenocryst nuclei) often attain a diameter of over 1 cm and flow banding near the contacts is commonly accentuated by selective devitrification along particular flow-planes. Many of the dykes are very colourful and have blue or green chill-zones passing inwards to reddish-brown centres, although others are very pale buff-coloured. The dominant ferromagnesian minerals, almost always restricted to the groundmass, are riebeckite and aegirine, although these do not necessarily occur together within the same dyke. Small phenocrysts of hedenbergite have been noted in some of the dykes. Apart from their occurrence as strongly corroded and partially resorbed phenocrysts quartz and microperthitic feldspar constitute much of the groundmass. Altogether these dykes have much in common with the comendites and they invite close comparison with the spherulitic alkali-rhyolites described from British Columbia by MATHEWS and WATSON (1953), and from Kenya by CAMPBELL-SMITH (1931). Several of the dykes in this acid suite are of particular interest in that they occur as the central component in composite dykes. However, in contrast to the complex and composite dykes so far described, the dyke centres almost always exhibit sharp chilled contacts against the marginal rock, in this case dolerite.

The largest of the quartz porphyry dykes, referred to above, is itself a composite, being insulated from the surrounding granites along the greater part of its outcrop by narrow zones of very fine-grained aphyric dolerite. In comparison with the great width of the acid component, the doleritic margins are extremely narrow and the acid magma was evidently intruded accurately along the median plane of a small but persistent 60° dolerite whose width could scarcely have exceeded 1 m. It is noteworthy that this conspicuous dyke does not outcrop on the mainland although, on the south side of the Narssaq valley, more or less in line with an easterly extrapolation of the dyke, there is a large body of porphyritic rhyolite which (in hand specimen at least), closely resembles the more rapidly chilled facies of the dyke rock. This rhyolite has recently been mapped by Mr. J. W. STEWART, who considers it to be part of a sill intruded into the lower Gardar volcanic series. In the circumstances it may be inferred that the dyke on Tugtutôq, which is micrographitic in its central parts, functioned as a feeder to this sill and that the completely different form adopted by the intrusion on the downfaulted mainland area reflects the different intrusive tectonics which pertained above the basal Gardar unconformity.

The next dykes to occur in the region varied from microsyenitic to microgranitic; these dykes are all saturated to oversaturated with respect to silica but differ from those of the preceding swarm in that the quartz, when present, always crystallised late. They have been roughly subdivided into an earlier group of porphyritic dykes and a later non-porphyritic group. However, this twofold classification is anything but clear-cut since there are a number of dykes which are intermediate in

Fig. 13. Dykes of the mid-Gardar swarms cutting nepheline syenites (light weathering) and older granites south of the Kryds Sø.

character e.g. having feldspar phenocrysts confined to the marginal zones or being sparsely porphyritic throughout. Many of the porphyritic microsyenite dykes which are later than both the quartz porphyry dykes and the basic dykes with plagioclase inclusions, are extremely similar to the earlier generation which preceded these two swarms.

It is clear therefore, that the porphyritic syenite magma was available for intrusion over an extended period after the intrusion of the gabbro giant-dykes. The greatest concentration of microsyenite dykes is to be found on the Skovfjord side of Tugtutôq and on the islands of Igdlutalik, Kangue and Igdlukasik. Traced towards the WSW. the dykes become scarcer and individually thinner until, for example on the islands of Niaqornaq and Tugtutôq Lille Ø they are relatively insignificant.

The dykes seldom exceed five metres across; most are light-brown to light-grey coloured in their central parts and have chilled zones which are characteristically dark bluish-black and often glassy and spherulitic. In the porphyritic dykes, the alkali feldspar phenocrysts are found up to 1 cm long, generally light grey or pink coloured and commonly showing signs of incipient resorbsion. Normally, the phenocrysts show approximately rectangular outlines but, in several dykes, it was noted that the insets had a strong tendency towards a rhombic form. This was sufficiently marked in some dykes to give a rock-type similar in appearance to the classic rhomb-porphyry flows of the Oslofjord. Some of the porphyritic dykes from this area have been discussed by Bondam (1955, p. 13) who gives a brief petrographic description of three dyke specimens collected from Tugtutôq and Igdlutalik. The microsyenite dykes encompass a considerable range of composition and all variants can be found from those devoid of quartz to those in which it is abundant interstitially. The modal quartz content in many must run well over 10 %, in which cases they may be more properly designated microgranites. Nevertheless, the strongly acidic varieties are best considered together with the 'true' microsyenites which they resemble closely mineralogically and texturally rather than with the earlier suite of quartz-feldspar porphyry dykes. Typically, the groundmass of these dykes is composed of idiomorphic laths of antiperthitic feldspar which not infrequently show a well-defined trachytoidal flow texture. Quartz, when present, occurs interstitially amongst the antiperthite crystals. Other common interstitial groundmass minerals which may be present together or singly in these dykes are biotite, amphiboles (either blue-green hornblendes or members of the riebeckite-arfvedsonite series), aegirine-augite, haematite, limonite and other ferruginous breakdown materials, albite and carbonate. The large feldspar phenocrysts appear to be restricted to the less acid dykes. Unlike the groundmass feldspars, the phenocryst feldspars seldom show coarse exsolution structure and are more commonly glassy clear in the inner zones whilst more or less turbid in their outer parts. Carlsbad twinning is common in both generations of feldspar. In none of the dykes, whether carrying phenocryst feldspar or not, is there any suggestion that more than one feldspar phase was crystallized from the magma at any one time. Along with the corroded feldspar phenocrysts it is common to find phenocrysts of pale mauve-grey ferroaugite and also early crystals of apatite, and (Ti-) magnetite. Occasionally completely pseudomorphed phenocrysts are found, thought to be replacing primary olivine. In every case whether the dykes are aphyric or porphyritic, alkali feldspar is not only the major constituent, but was among the first to crystallize. Commonly it was accompanied by clinopyroxene, ore and apatite and, sometimes at least, by olivine, precisely as in the case of the western sector of the syenite giant dyke.

In those dykes which were intruded before any crystallization had commenced, the ferromagnesian minerals are generally found as hydrous phases occurring interstitially. There is little doubt that these mid-Gardar dykes contain the hypabyssal equivalents of the augite-syenites, nordmarkites and alkali granites in the various south Greenland plutonic centres and that they represent preliminary tappings of the magma source which was subsequently to produce the rocks of the Tugtutôq central ring-complex.

In the Skovfjord district, in the more westerly part of the area, are numerous ENE. dolerite dykes. These sparcely porphyritic dolerites are later than the main microsyenite swarms and possibly represent a minor phase of re-intrusion of the olivine basalt magma. Although the age relationship of these dykes to the central complex rocks is unknown they will provisionally be grouped with the 'mid-Gardar' swarms.

Diatremes.

A number of small agglomeratic pipes occur within the area; these vary from eliptical to circular in plan. (Having diameters from 40–80 m they were considered too small to be adequately represented on the accompanying black and white map-plate and are not shown). Three have been found on Igdlutalik island close to the north coast, one on Niaqornaq island, and one on Tugtutôq within the granites on the peninsula between the Bredefjord and the channel occupying the crush-belt of the main transcurrent fault. The Niaqornaq agglomerate is later than the microsyenite dykes on the island and the Igdlutalik vents are earlier than the latest movements of the ENE. shear-zones along the Skovfjord region. It is possible that all these agglomerate pipes are contemporaneous and were produced at the same time as the agglomerate pipes that cut the olivine gabbros close to Narssaq harbour. If this is so, then they may have been formed in the late Gardar during the period when the major eruptive complexes were developing.

The Narssaq vents contain assorted angular blocks of the early quartzites and basalts but, surprisingly, almost no fragments of the gabbros through which they are drilled. The group of vents on Igdlutalik lie directly to the WSW. and undoubtedly represents a continuation of these Narssaq occurences. Pre-Gardar granite forms the country rock on Igdlutalik and yet, in one of the vents exposed on the coast the only material present is basalt together with small white masses of feldspathic rock. The vent is severely crushed and the rocks so altered and epidotised that it is not certain whether or not the feldspathic blocks have been derived from the granite. The basalt blocks, which form the great bulk of the vent-filling, are well rounded and usually less than 10 cms across. In contrast, a nearby vent is filled with an assortment of angular fragments of granite, basalt and quartzite. This particular vent does not show the clean-cut contacts exhibited by most of those found, but has a broken, irregular boundary. The Niaqornaq pipe occurs within the main big-feldspar granite and intersects two microsyenitic dykes. Here, the infilling material is mainly crystal tuff (largely derived from the granite), studded with blocks of granite up to 40 cms diameter. Small fragments of the microsyenites are present, together with some basaltic material.

The individual blocks are invariably well-rounded and approximate to spherical form.

The rounding of vent material is again very pronounced in the Tugtutôq occurrence (Fig. 14). Although this also occurs within the

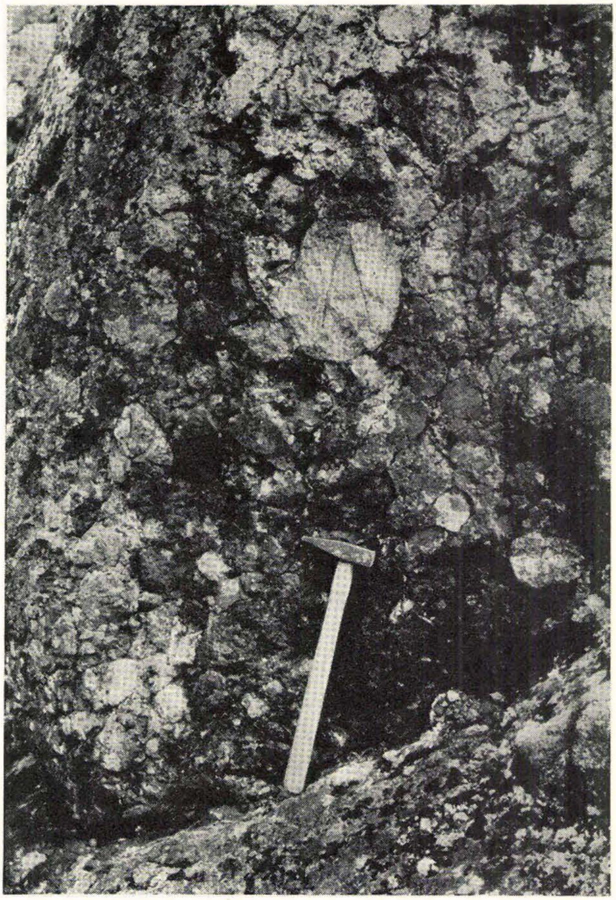

Fig. 14. Well-rounded blocks of Gardar volcanics and older granites in an agglomeratic pipe, near the Bredefjord coast a little north of the main Tugtutôq transcurrent fault.

main big-feldspar granite, the principal component of the vent infilling is leucocratic and non-porphyritic granite similar to that described from central Tugtutôq. (This granite type is, however, rather abundantly present in the neighbourhood of the vent as irregular veins and sheets within the porphyritic granite). In addition, there are pieces of big-feldspar granite and basalt. As in the Niaqornaq example, the maximum size of block is rather less than half-a-metre across and much of the matrix material is composed of finely cominuted crystal tuff. The Niaqornaq and Tugtutôq pipes contain material which has evidently acquired rounding by abrasion during gas discharges, whereas the contrasting angular fragments of the Narssaq agglomerates probably represent fall-back material from surface explosions. These Narssaq outcrops may represent a high level phenomenon associated with 'tuff-pipes' which have drilled their way up from depth. The crystal 'tuff' and rounded blocks in the deep-level sections have almost certainly never been airborne ejectamenta, and yet the basaltic fragments within them have undoubtedly been brought down from an original cover of lavas.

The Central Ring-Complex.

During the new phase of major intrusion following the microsyenite dykes, syenite and alkali granite magmas were admitted to form a small ring-complex straddling the composite giant-dyke and the northern gabbro giant-dyke. Since both this complex and that at Ilímaussaq, some 25 kms away, succeed the main microsyenite swarms and yet precede a still later ENE. dyke swarm (see p. 57), there is little doubt about their approximate contemporaneity. (A recent age-dating on Ilímaussaq rocks by MOORBATH et al. (1960) gave a result of 1086 ± 19 m.y). Although it is quite clear that the intrusions penetrated through the basal Gardar unconformity and into the overlying effusives and sediments, it is not certain whether the complex marks the location of a central volcano. The rock types present have much in common with those of the Nunarssuit and Kûngnât centres which are also believed to be contemporaries of this ring-complex. In overall size, the Tugtutôq complex compares closely with the Kûngnât and Puklen centres (UPTON, 1960 and PULVERTAFT, 1961). The existence of this complex appears to have been unknown previous to the aerial photography of the region undertaken by the Geodetic Institute. The perthosite stock in the west of the complex stands out with particular clarity on the air-photographs (Fig. 21) and was consequently reconnoitred by A. BERTHELSEN (Greenland Geological Survey, unpublished report, 1956).

In the eastern centre, using this term to include all the intrusions around the easterly focus of ring-faulting, the mutual relationship of some of the component units is still rather obscure owing, in part, to insufficient exposure away from the outcrops of the more homogeneous granites and quartz syenites. None the less, the age relationships are mostly clear enough and, in the following interpretive account, an attempt is made to reconstruct the main sequence of events.

Intrusion of microsyenite.

It is deduced, admittedly on somewhat slender evidence, that the complex was initiated by the formation of two independent ring-

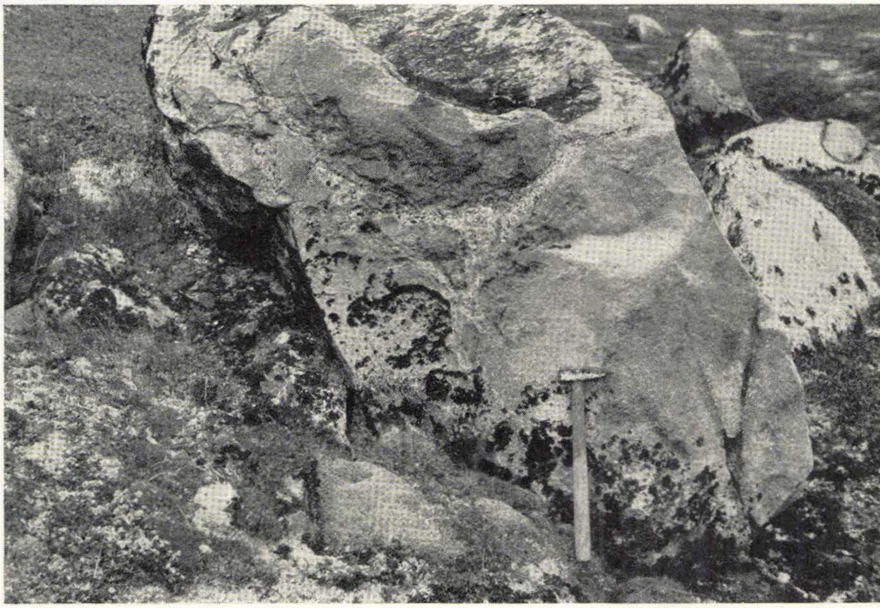

Fig. 15. Typical relationships in the Unit 1 western microsyenites where veins of coarser-grained quartz syenite brecciate the earlier microsyenite and disect it into pillow-like masses.

intrusions of microsyenite of a type closely related to that of the foregoing dyke swarms. The smaller and more westerly of these intrusions was localised at a knee-bend in the giant composite dyke whilst the other may have occupied a ring-fault involving both the composite and the northern gabbro giant-dykes. This larger microsyenite ring was subsequently nearly obliterated by four more ring-intrusions whose centres were approximately coincident with that of the microsyenite.

All that is seen of the smaller of the supposed ring-dykes is an arcuate outcrop of microsyenite situated across the Hviddal giant-dyke and intersected by the later perthosites. The outcrop encloses a core of coarser-grained syenite which is provisionally correlated with the giant-dyke syenite, although so far no trace of nepheline has been detected within it. The 'ring-dyke' may originally have had a diameter of ca. 600 m. The microsyenite itself is pervaded by ramifying and diffuse-edged veinlets of a coarser-grained bluish-green quartz syenite which divide the rock up into rounded and rather shadowy masses seldom larger than 1 m across (Fig. 15). Furthermore, much of the outcrop is dissected by veins of syenite pegmatite extending from the perthosite intrusion. The outer contacts of the microsyenite intrusion-breccia against the composite giant-dyke are wholly unexposed although the smaller dykes of porphyritic microsyenite are seen to be sharply truncated by the 'ring-dyke' rock and to be cut by the same quartz syenite veinlets close to the contact.

Similar brecciated microsyenites occur amongst the quartz syenites and granites east of the Blå Måne Sø where they form narrow zones of up to 40 m wide, lying more or less concentric to the general ring-structure of the eastern centre. Two principal 'breccia zones' have been distinguished in the northern part of the complex. Although at first these zones were thought to be late ring-dykes which had been strongly back-veined by the surrounding rocks, it was eventually concluded that they are screens of early rapidly-chilled syenite preserved between subsequent ring-dykes. The brecciating matrix is certainly not rheomorphic in origin; where one zone abuts against poikilitic textured quartz syenite, the intrusive veinlets have a similar texture; where the other is in juxtaposition with porphyritic nordmarkitic granite, the intruding veins possess zoned feldspar phenocryst identical with those in the granite.

At one locality, almost due south of the 450 m mountain top (Syenittinden), the inner screen acquires a composite character, involving not only brecciated microsyenite, but an extensive slice of the pre-Gardar big-feldspar granite on its outer side. This slice, measuring approximately 400×40 m, shows signs of thermal metamorphism. The outer contact of the breccia zone against this country-rock granite is nearly vertical and, on the basis of this evidence it is postulated that the outer limit of the breccia zones may approximately correspond to the outer contacts of an early microsyenite ring-dyke (or stock?) ca. 2 km in diameter.

The inner and outer breccia zones resemble each other closely and originally must have formed a single body which became bisected by a branch of the later hornblende granite ring-dyke. In the northern part of the complex the breccia zones form resistant low ridges between the faster weathering syenites and granites (Fig. 16). However, in the south they are less easily distinguishable and consequently have not been fully mapped out. On the probability that the microsyenite screens of the eastern centre originated at the same time as, and in similar circumstances to, the microsyenite of the western breccia outcrop, these will be regarded collectively as forming Unit 1 of the central complex. The main greenish-grey rock comprising the breccia zones appears fairly constant in composition and has an average grain size of ca. 2 mm. Euhedral phenocrysts of alkali feldspar up to 5 mm long are commonly present. Nevertheless, there is some variation to be found in the contents of the breccia zones and occasional masses of fine-grained, biotite-rich varieties occur which are probably metamorphosed basalt

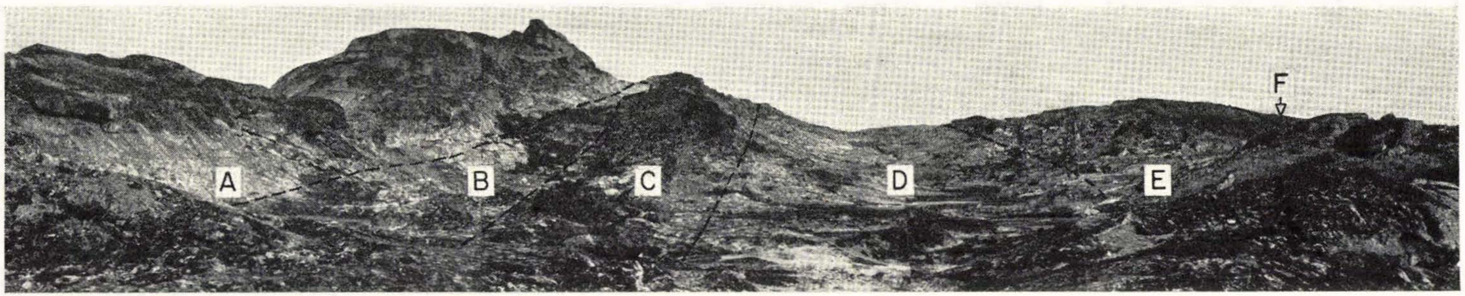

Fig. 16. A panoramic view of Syenittinden from the SW., showing the ridges formed from the nordmarkitic granite and the microsyenite breccia zones. A, Nordmarkitic granite: B, Unit 5 quartz syenite ring-dyke: C, 'Outer breccia zone': D, Inner branch of the Unit 4 hornblende granite ring-dyke: E, 'Inner breccia zone': F, part of the area of xenolithic Unit 2 granites etc.

blocks. At one locality in the inner breccia zone of the eastern centre blocks of altered gabbro were discovered, but pieces of quartzite and pre-Gardar granite have not been noted.

In the few sections so far examined, the microsyenite is seen to have a groundmass consisting of strongly perthitic feldspar, and green hornblende, occasionally with aegirine-augite and pseudomorphs after fayalite. The phenocrysts are tabular parallel to (010), Carlsbad-twinned and not infrequently cryptoperthitic in their central parts.

Intrusion of quartz syenites and alkali granites of the eastern centre.

The field-evidence suggests that four further episodes of roof-fracturing and block-subsidence took place around the eastern focus. The first of these is thought to have taken place within the confines of the eastern microsyenite body producing a small circular intrusion of heterogeneous and strongly xenolithic quartz syenites (Unit 2). The second,

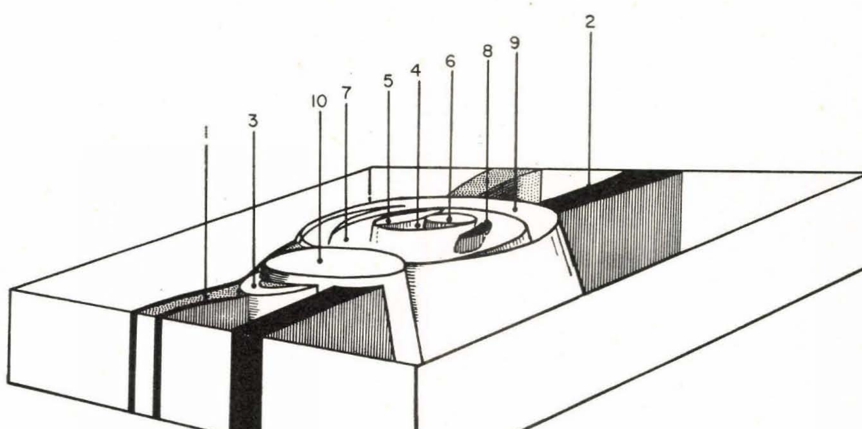

Fig. 17. Block diagram of the central ring-complex. 1, Composite giant-dyke: 2, Gabbro giant-dyke: 3, Western microsyenite breccia: 4, Unit 2 quartz syenites and granites: 5, Down-faulted block of basement granites: 6, Down-faulted block of basalt and quartzite: 7, Unit 3, nordmarkitic granite: 8, Inclusion of olivine gabbro: 9, Unit 4, hornblende granite: 10, Unit 6, Blå Måne Sø perthosite.
(The breccia zones and Unit 5 ring-dyke of the eastern centre are omitted for the sake of clarity).

occuring after a very short time interval, admitted a large volume of 'nordmarkitic' granite magma which as Unit 3, almost entirely surrounds the closely allied Unit 2 area. A further ring-fault is thought to have developed around the periphery of the Unit 3 granites before these were

Fig. 18. Sub-angular blocks of the Hviddal syenite brecciated by alkali granite of the eastern centre. A small xenolith of dark microsyenite dyke-rock is also shown. Locality at base of cliff-face on the northern side of the Blå Måne Sø.

fully consolidated, permitting the intrusion of a broad ring-dyke of hornblende granite (Unit 4). Thus Units 2, 3 and 4 are thought to have been emplaced within a relatively short space of time and to represent three successive pulses from the same magma chamber. Units 2 and 3 are separated in the field only with considerable difficulty; the age relationship is inferred and the contacts are probably gradational. Similarly the main body of the outer (Unit 4) ring-dyke shows no obvious chilling against the Unit 3 rocks (although chilled contacts are shown by smaller soda-granite sheets believed to be off-shoots from the unit 4 granite, wherever these are seen in contact with the Unit 3 rocks).

A narrow ring-dyke of quartz syenite (Unit 5) intersects both the Units 3 and 4 and was the latest intrusion of the eastern centre.

Unit 2: This comprises the complex area of variegated syenites and alkali granites enclosing masses of intrusion-brecciated roofing materials, outcropping on the steep slopes north of the Store Pile Sø. The area is approximately circular with a diameter of ca. 1200 m. The intrusive rock ranges from olivine-rich mafic syenite to coarse and often pegmatitic quartz syenite or alkali granite. Over much of the area the intrusive rock is crammed with xenolithic material, among which the following constituents have been recognised:

1) Pre-Gardar granites identical to those forming the country rock around the complex. Two varieties, a. big-feldspar granite and b. the leucocratic and non-porphyritic variety.
2) Basalts and basaltic-agglomerate.
3) Quartzite.
4) Olivine gabbro.
5) Porphyritic microsyenite etc. derived from local mid-Gardar dykes.
6) Porphyritic microsyenite believed to be remnants of the Unit I intrusion.

In the northern part of the area the xenolithic constituents are found to be almost entirely of pre-Gardar granites. This granite-rich area measures about 1000×400 m and is of unknown thickness. The granite in the western part of this area is almost exclusively of the big feldspar granite type, whereas the eastern part contains mainly blocks of the leucocratic non-porphyritic granite. The line marking the change-over from one granite type to the other approximately coincides with the line drawn by extrapolating from the contacts of these two granites outside the intrusive complex. The relative lack of mixing of the two granites is one line of evidence suggesting that the initial roof-fracturing was of a scarcely disturbed mass whose disintegration was mainly accomplished after it had sunk to its present level. Along with the granite blocks it is common to find masses of porphyritic microsyenite derived from the mid-Gardar dykes.

To the south-east of this area characterised by granitic xenoliths is one in which the masses are almost entirely of basalt and quartzite. The basalts and quartzites are, without doubt, the equivalent of those comprising the lower Gardar continental series in the Ilímaussaq region. The basalts show considerable variety and include fine-grained aphyric types as well as porphyritic types containing small star-like aggregates of plagioclase phenocrysts. Some are strongly vesicular. Superficially at least, it seems that many of these basalt types can be closely matched with those around the Ilímaussaq. Granite blocks are scarce in this basalt-quartzite zone, again demonstrating that mixing has been slight. Furthermore, the basalt-quartzite area could be subdivided into zones in which basalt and quartzite respectively predominate almost to the exclusion of the other and it seems clear that, even after intrusive brecciation, the 'primary' stoped blocks tended to retain their identity and an approximation to their original stratigraphic order. In spite of the fact that these xenolithic areas sit squarely across the former course of the composite giant dyke it is remarkable that there are no pieces of the latter present. Consequently it would appear that in this region, immediately prior to the first intrusions inaugurating the central complex, early

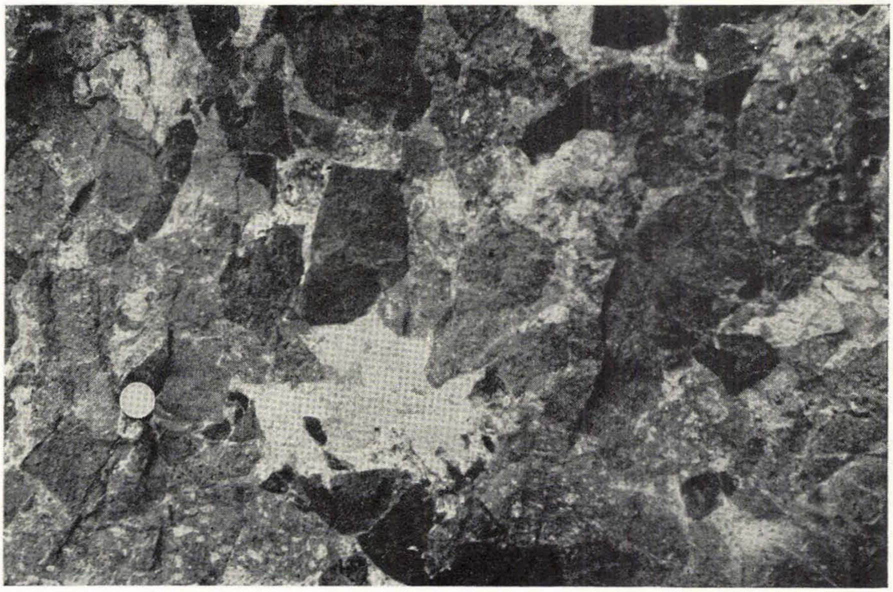

Fig. 19. Part of a large mass of explosion breccia, consisting mainly of fragments from Gardar basalt flows, preserved within the Unit 2 xenolithic granites and syenites of the central complex.

Gardar lavas and sediments overlay the contact between the leuco-granite and the main Tugtutôq big-feldspar granite and that the composite giant dyke did not extend upwards far enough to intersect the basal Gardar unconformity. The view that the giant dyke never penetrated the overlying stratified rocks receives some support from the fact that no sign is ever seen of this dyke in the basalts, sandstones and older granites to the east or north-east of Ilímaussaq although it is reasonable to consider that it continues in this direction as far as the Igaliko complex but below the present erosion surface. The process of emplacement envisaged for the Unit 2 rocks is better described as overhead stoping on a large scale rather than as 'cauldron subsidence', with fragmentation of the subsiding core. The mapping suggests that a relatively small number (initially perhaps not more than four) of large block-faulted masses sank into underlying magma and that, of these, two are now seen at the current level of erosion. The situation may be compared with that in the main western centre at Kûngnât where a raft-like mass of the roof collapsed and underwent brecciation during settling or after finally coming to rest.

The alkaline rocks of Unit 2 differ from those of the surrounding nordmarkitic granites in lacking the porphyritic habit (zoned feldspar phenocrysts) which characterises the latter. In the xenolith-rich parts the heterogeneity of the intruding rocks is very marked and there is rapid transition from coarse quartz-rich leucocratic types to mafic rocks composed largely of fayalite and hedenbergite, enclosed poikilitically in feldspar. The mafic rock is generally dark-brown or nearly black in colour, the feldspars being badly iron-stained. Although the fayalite-rich facies recall those described from Kûngnât, there is here no question of them having a regular banded relationship to the associated feldspathic rock as they did at this other locality.

Unit 3: Although the nordmarkitic granite comprising Unit 3 of the eastern centre may have been emplaced by simple ring-faulting, it does contain several large inclusions of earlier rocks. The largest of these is of olivine gabbro, measuring 300 × 100 m approximately. This, which is undoubtedly a piece of the main gabbro giant-dyke, is exposed on the northern shores of the Store Pile Sø, just outside the contact of the Unit 3 granite and the quartzite-basalt breccia area in the Unit 2 rocks. The upper surface of the gabbro mass dips northwards towards the centre of the complex at ca. 30° but the lower contacts are not exposed. The gabbro is very dark grey, probably a consequence of plagioclase clouding resulting from slight metamorphism. The only other important inclusions in Unit 3 are found on the peninsula in the Store Pile Sø, near the outer contact of the complex, where numerous blocks of big-feldspar granite have been envoloped by the intrusive granite.

In the typical rock as seen, for instance, above the cliffs skirting the Blå Måne Sø (Fig. 20), the slightly porphyritic texture of the nordmarkitic granite is readily apparent. (In this and other features the Unit 3 granites strongly resemble the Cape Ann granites of Massachusetts described by Warren and McKinstry (1924)). The earlier feldspars average 1 cm in length and show a strong zoning which is easily seen in the field on cleanly exposed outcrops. The tendency toward porphyritic texture, the zonation of the feldspar phenocrysts and the presence of small rusty fayalite pseudomorphs were the chief field criteria used for distinguishing this rock from the enclosing alkali granites. The content of macroscopic quartz was usually of no help in separating these two very closely related rocks. The name nordmarkitic granite is chosen to emphasize the fact that the Unit 3 rocks vary from distinctly syenitic to granitic, according to local variations in quartz content.

Contact relations against older rocks: Near the southern margin of the complex the nordmarkitic granite comes close against basement big-feldspar granite but is separated from it by an intervening dyke-like body (ca. 30 m) of very mafic syenite. The age of this is not precisely known (although it is older than the Blå Måne syenite to the west). The marginal facies of the nordmarkitic granite is pegmatitic, with strongly zoned feldspars of 2 cms or over associated with quartz and interstitial wedges of hornblende. In amongst the coarse quartz-rich material are masses of rusty-brown and finer grained fayalite-rich syenite thought to be relicts surviving the recrystallisation accompanying the growth of the more pegmatitic rock. The relationship is comparable to that described from the eastern contact zone of the Kûngnât syenites where early-chilled 'higher-temperature' facies are partially replaced and made over to pegmatitic, drusy, quartz-rich material.

In the steep cliffs at the north of the Blå Måne Sø the nordmarkitic granite comes into contact with the earlier Gardar syenites of the composite giant dyke. The relationships in this area are partly obscured by veins of alkali granite which are believed to post-date the consolidation of the nordmarkitic-granite (Fig. 18).

To the south of Syenittinden (*lit.* The Syenite Peak) the nordmarkitic granite is found in contact with the Unit 1 'inner breccia zone'. The contact is sharp, dipping outwards at ca. 20°. In the marginal zone, lying parallel to the contact, are some irregular dark bands rich in olivine. Pegmatitic development is not seen here and was probably confined to those outer contacts against the basement granites where there was a stronger thermal gradient.

On the high ground separating the Blå Måne Sø from the Store Pile Sø the nordmarkitic granite is well exposed and seen to be almost entirely free from inclusions and, for the most part, extremely homogeneous. However, the intrusion was at its broadest in this region and thin, sporadic and discontinuous schlieren and bands of fayalite-rich material nake their appearance. Some of these are low angled and, in some instances, appear to have been gravity controlled with sharp mafic bases grading upwards into the normal feldspathic granite. In this region at least it is probable that the nordmarkitic granite is a cumulitic rock and that many, if not all, of the mafic schlieren have arisen through density-sorting of early mineral phases by magmatic currents. The strike and dip of these features is highly irregular and is related to no simple structure. At one locality the rather contorted aspect of the banding suggested slight folding and distortion after deposition and another outcrop showed a mafic horizon in which there was a displacement but with no obvious fault-plane visible. The general impression gained was that the granite, in this particular area, had had a disturbed and restless consolidation history, possibly in causal connection with the intrusion of the outer granite ring-dyke before crystallisation of the nordmarkitic granite was at an end. More or less bounding this area to the north is a discontinuous line of rusty-weathered, mafic syenite outcrops of a type indistinguishable from the fayalite-rich facies occurring in association with the xenoliths in the innermost part of the complex. Again, the feldspar is poikilitic to the olivine and strongly iron-stained. Although at

Fig. 20. A view eastwards across the Blå Måne Sø intrusion. The Unit 3 nordmarkitic granites of the eastern centre form the 250 m rock-face on the far side of the lake.

first it appeared that it was due to a line of mafic inclusions in the nordmarkitic granite, it was later established that this fayalitic rock forms a sheet within the more normal rock, dipping steeply towards the south. This sheet, which can be traced some 800 m although it is only 1–2 m thick, is broadly conformable to the general ring structure of the eastern centre. The fact that the rock type appears identical to the mafic facies of the Unit 2 intrusion, into which it seems to pass laterally, is cogent reason was supposing that the Unit 2 and Unit 3 intrusions were nearly contemporaneous and that their crystallisation periods overlapped widely. Possibly this problematical fayalitic 'screen' represents a temporary cooling wall on the northern side of the main magma body, on which crystals were forming at a time when conditions either favoured precipitation of olivine and hedenbergite or inhibited early crystallisation of feldspar.

Petrography of the nordmarkitic granite: The zonation in the early phase feldspars of the typical nordmarkitic granite is due to differing degrees of perthitic development from core to margin. In general the cores are clear and cryptoperthitic whereas the margins are more coarsely exsolved. The zonation is commonly abrupt rather than gradational and occasionally it was noted that the textural zoning was oscillatory rather than simple. The feldspars are generally idiomorphic to subhedral although the zoning in the inner parts of many crystals reveals that the form was euhedral during much of the growth. The crystals show a marked tabularity to (010) and both Carlsbad and Manebach twins are common. The plagioclase constituent of the antiperthites show albite twinning and, more rarely, pericline twinning. The smaller feldspars are similar to the larger ones but tend to be more fully exsolved, lacking the cryptoperthitic centres. Quartz is normally present in considerable amount, occurring anhedrally. Clinopyroxene shows zoning from pale green hedenbergitic centres to darker green pleochroic margins of aegirine-augite, and is nearly always partly altered to green hornblende. Fayalite is typically represented by yellowish pseudomorphs, usually enveloped by hornblende. However, in the more mafic facies of these rocks, which incidentally, are often quartz-free and tending to contain less coarsely exsolved feldspar, the olivine can be fresh and well-formed. Biotite, ore, fluorite, apatite and zircon are constant accessories in the standard rock.

The outer soda-granite: The outer granite ring-dyke, which is up to 800 m broad in the east, lies slightly eccentric to the nordmarkitic granite which it nearly surrounds. This (Unit 4) granite was distinguished on mainly textural grounds from the inner intrusives. The zoned phenocrysts of the nordmarkitic granite are absent and soda-hornblende, occurring as lustrous black interstitial wedges, is the principal ferromagnesian mineral. The outer granite is noticeably lighter in colour, having pearly-white feldspars in contrast to the brownish stained feldspars typical of the inner rock, and tends to be more rapidly weathered. Nevertheless it is frequently difficult to map the contact between the two rock types especially when slight crushing makes the colour and textural criteria difficult to apply. The conclusion was reached that the main contacts between the two rock types are entirely gradational over a distance of ca. 10 m and that the rocks represent two intrusions of very similar magma, the one injected shortly after the other. Many small sheets of alkali-granite, related to the main outer granite, intrude the inner nordmarkitic facies. These however do possess sharp contacts against the latter and often have banded hornblende-rich contact facies. The dips of these minor intrusions is invariably outwards, away from the complex and it is inferred that the gradational contact between the main outer and inner granite bodies has also an outward hade. The later age of the outer granite is also inferred from the relationship between the inner granite and the smaller granite sheets.

Thin pegmatitic veins are not uncommon in the outer granite. Pegmatitic films are frequently found along joint-planes and among the minerals associated with these are feldspar, quartz, zircon, astrophyllite and a silvery-white lithia-mica.

In many places around the outer soda-granite a distinctive peripheral zone has developed where the hornblende occurs, not as interstitial wedges but as small 'poikilitic' spots, 2–3 mms in diameter. (Since it is believed that this texture has come about through feldspar-quartz replacement of the amphibole rather than by late growth of the hornblende, the term pseudopoikilitic or 'mossy' may be preferable). The grain size of these 'mossy' granites is less than that of the normal variety. The contacts against the basement granite, well seen both to the north and south of the complex, are sharp (quite representable in a single hand-specimen) and commonly show marginal 'flow-banding' features. Wherever seen, the contacts dip outwards at angles of 45° and over.

The outer granite is not present around the nordmarkitic granite in the west and south west of the eastern centre, although it may be represented by a conspicuous sheet of soda-microgranite which cuts it close to its southern contact. This has a shallow outward hade, not exceeding 20°, is not more than ca. 10 m thick and appears to thin rapidly towards the west. The contacts with the earlier granite are knife-sharp and, again there is conspicuous hornblende banding in the marginal zones, parallel to the contact. The microgranite contains acicular rods of riebeckitic amphibole and small flakes of astrophyllite, both visible in the hand-specimen. The outer granite is largely free from foreign inclusions although, in the northern part of the centre, some lenticular masses of quartzite occur within it. These are 5 to 10 m long and may be relicts of a disintegrated screen of roofing rocks. In two of the river sections through the outer granite in its northern sector, areas of brecciated older rocks are encountered. These include basalts, quartzites and the two local varieties of pre-Gardar granite. A restricted area of a greyish micro-granite was discovered in which there are assorted blocks of basalt, gabbro (?) and possibly fragments of the giant syenite dyke. The masses of intrusion-brecciated microsyenite within the outer granite south of the Store Pile Sø are, in all probability, continuations of the 'breccia zones' of the Unit 1 microsyenite described above.

Petrography of the outer granite: The feldspar of these rocks is typically coarsely antiperthitic, lacking the strong zoning of the feldspars in the inner granites and never showing cryptoperthitic facies. However, in the more marginal variants, discrete crystals of albite and cross-hatched microcline appear together with the perthitic feldspars (which are here often obviously microcline-perthites, with the cross-hatched twinning visible within the potassic lamellae). Evidence of late-stage recrystallisation is widespread in the marginal facies rocks and the quartz, albite and microcline are often seen to be replacive towards the earlier minerals, particularly towards the perthitic feldspars and the hornblendes. Olivine and its pseudomorphs are scarce or absent in the outer granite and aegirine-augite is only preserved as small cores within the hornblendes. However, in the marginal facies rocks, aegirine appears in association with amphibole which is commonly riebeckitic. Small zircons and a mineral of the pyrochlore group appear as rare accessories.

The Unit 5 quartz syenite ring-dyke: A narrow ring-dyke, in places not more than 4 m across, can be traced within the northern half of the eastern centre through nearly 180° of arc. It is possible that this ring has its continuation within the outer granite on the south side of the Store Pile Sø but lack of time precluded a sufficiently thorough examination of this area.

The ring-dyke has sharp contacts against the Unit 3 and 4 granites, sometimes with flow-banding parallel to the walls, and with a constant steep outward hade of ca. 40–60°. In one sector, immediately south of Syenittinden, the ring-dyke becomes intimately involved with the 'outer breccia zone' of Unit 1 and appears to form much of the brecciating matrix. The average rock from the ring-dyke is much finer grained than most of the rocks comprising the eastern centre. The constituent feldspars occur as euhedral tablets, 1–2 mms long and are, for the most part, poikilitically surrounded by hornblende. The well-formed feldspars and the poikilitic hornblende give a characteristic texture to this rock and it was on this basis that the field-mapping was conducted. The feldspars are seen in thin section to be coarsely exsolved, displaying the 'herring-bone' lamellar pattern on (010) as a result of Manebach twinning. Quartz occurs interstitially and aenigmatite is present in small amounts, associated with the blue-green soda hornblende.

The perthositic syenites of the western centre.

In contrast to the complexity of the eastern centre, the rocks outcropping around the Blå Måne Sø appear to belong to one final intrusive episode which produced a stock-like body of coarse perthosite. Emplacement of this latest major intrusion was again probably by ring faulting but this time with the geometrical centre shifted some two kilometres toward the south-west. The stock itself is sub-circular with a diameter of approximately 1.5 kms. On account of the rapid rubbly weathering of the syenite exposure is comparatively poor and much that is not covered by the waters of the Blå Måne Sø is blanketed by coarse feldspathic sand. In the exposures around the southern and western sides of the lake the syenite is very variable in texture, changing from medium-grained facies with an average grain size of 1 cm to pegmatitic facies in which the individual crystals commonly attain lengths of 15 cms and over, within a matter of one or two metres. The general impression gained was of a medium grained syenite in which very roughly spherical pegmatitic facies were abundantly developed.

In thin-section these syenites are found to contain interstitial quartz although quartz is rarely identifiable in the hand-specimen. Ferromagnesian minerals also tend to be scarce. In the more normal textured syenites interstitial hornblende and ferruginous decomposition products are characteristically present but, in the pegmatitic rocks, large biotite crystals are common, up to 1 cm across. The outer contacts of the Blå Måne Sø intrusion (Unit 6 of the whole complex) are made irregular by the presence of small feldspar-biotite pegmatite veins which radiate out for a short distance into the country rocks. Some of these veins are locally rich in zircon crystals. The feldspars from the Blå Måde Sø pegmatites have a characteristic light bluish-grey colour which distinguishes them from those of the pegmatites associated with the Kûngnât eastern border group and those of the Ilímaussaq augite syenite, with which they are otherwise comparable. Individual crystals very commonly show signs of strain and cleavage surfaces are almost invariably curved. Much of the feldspar in this intrusion appears to be cryptoperthitic, often Carlsbad twinned and tabular parallel to (010).

The eastern contacts of the Blå Måne Sø syenite against the more resistant and quartz-rich rocks of the eastern centre are practically unexposed, being covered by the scree slopes that underlie the steep cliffs of nordmarkitic granite (Fig. 20). However, there is at the foot of these cliffs, on slabs washed by the small waterfall stream falling from just north of the 360 m point, a problematic syenite variety not easily matched with any others in the complex. It is most remarkable in containing large poikilitic biotite crystals (up to 10 cms across) which envelope white tabular feldspar crystals whose average length is ca. 1 cm. This rock-type shows a pronounced feldspar lamination dipping steeply eastwards away from the Blå Måne Sø. Since this rock is highly feldspathic, quartz-poor and contains biotite – which is notably scarce in the plutonic rocks of the eastern centre, it is judged to belong to the younger perthosite stock. Although meagre evidence, the orientation of the constituent feldspars may be indicative of the eastern contact wall having an outwards hade.

Marginal contact alteration of the big feldspar basement granite around the Blå Måne Sø stock appears to have been slight and to be confined to a limited aureole not exceeding 2 m in width. Within this, the granite loses its freshness and is found to be somewhat friable. There is no evidence of significant remobilisation and the changes brought about by contact metamorphism or metasomatism) are small. One large

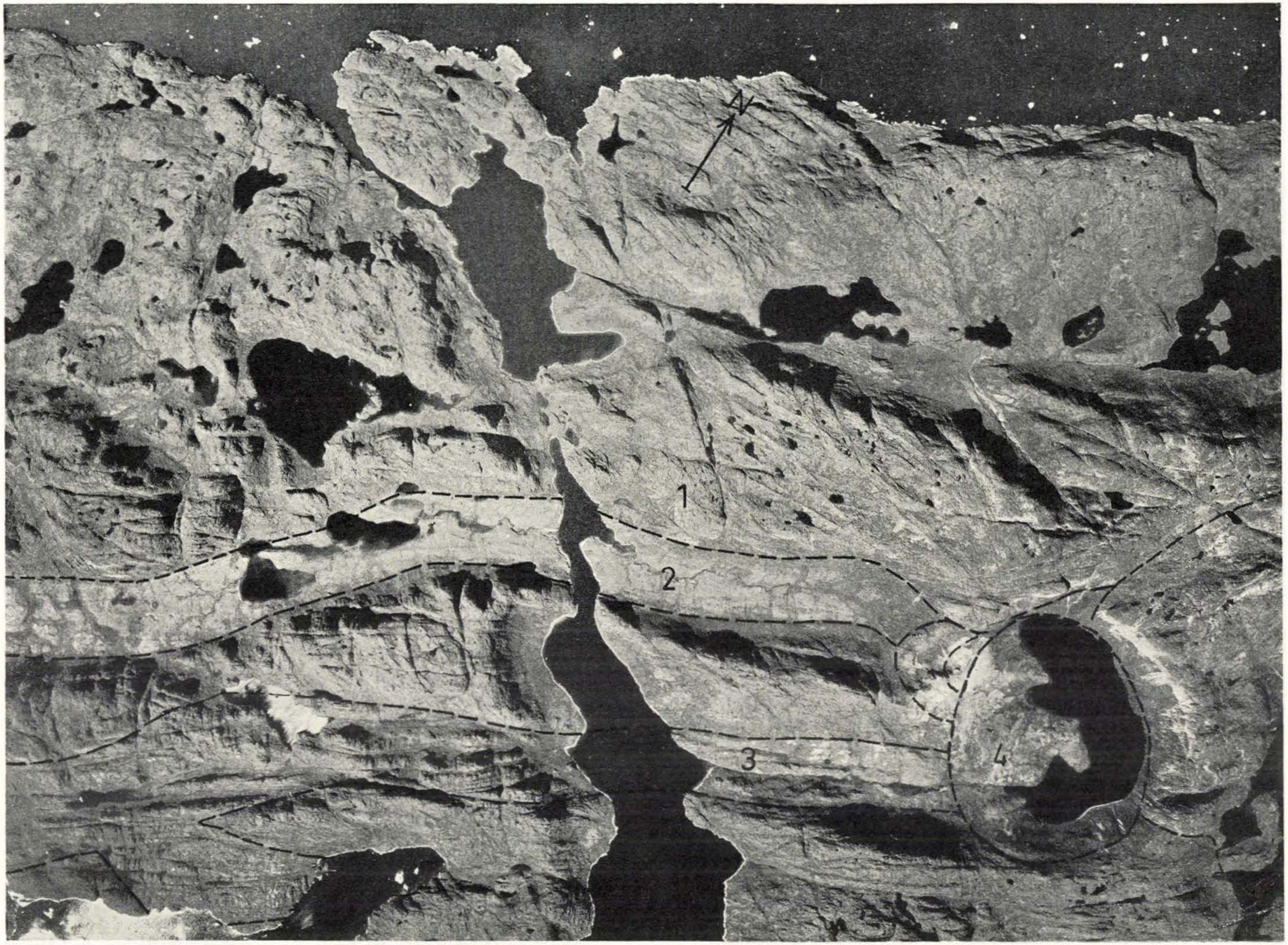

Fig. 21. An aerial photograph of central Tugtutôq showing the Blå Måne Sø and giant-dykes. 1. Big-feldspar granite: 2. Hviddal composite giant-dyke: 3. Gabbro giant-dyke: 4. Blå Måne Sø perthosite stock.

mass of slightly altered granite is enclosed by the pegmatitic syenite close to the western contact of the intrusion.

To the south of the river draining the lake, within the perthosite intrusion, is an outcrop composed of two varieties of badly weathered, mafic syenites. Of these, one is a rather fine-grained syenite which can be obtained in a fresh blue-green condition and in which there is a conspicuous feldspar parallelism, whereas the other is of a badly rotted fayalite-biotite-rich variety resembling that forming the dyke-like body between the Unit 3 nordmarkitic granite and the big feldspar granite on the southern side of the eastern centre. This isolated outcrop is in line with the 'dyke', suggesting that the latter had a westward extension which was intruded and brecciated by the perthosite and that the outcrop itself represents a large inclusion of the 'dyke'. It is significant that the southern contact of this perplexing 'dyke' of Fa-syenite should be almost directly in line with the southern contact of the yet-earlier olivine gabbro giant-dyke where it reappears to the west of the complex.

Microsyenite Dykes associated with the Central Complex.

With the consolidation of the Blå Måne Sø stock, eruptive activity was almost at an end in the central complex area. Nevertheless, a number of small NE.–SW. striking dykes of felsitic and microsyenitic type were intruded after the perthosite. These seldom exceed 1 m in width and die-out rapidly beyond the confines of the complex. The dykes usually possess a trachytic texture with flow-oriented laths of antiperthitic feldspar. Small wedges of semi-opaque minerals (mainly haematite), occur interstitially.

Later Dykes and Sills.

A further set of ENE. dykes was intruded subsequent to the cooling of the central complex. The members of this swarm are dark-grey 'basaltic' dykes which are almost invariably vesicular (with calcite or epidote), and which display a well-pronounced flow-banding parallel to the dyke-walls. Thin sections of two dykes considered representative of the swarm show a strong trachytoid texture due to the flow-orientation of plagioclase and prismatic crystals of basaltic-hornblende. The feldspar (which is generally altered) shows strong zoning and is thought to lie mostly in the labradorite-andesine range. Small crystals of Fe-Ti oxide occur abundantly; well-defined chloritic aggregates are possibly pseudomorphs after former olivine. One of the sections also shows the presence of a relatively early, nearly colourless clinopyroxene. Occasionally these dykes contain larger plagioclase crystals which may have the same origin as the labradorite xenocrysts in the earlier dykes described above. This latest ENE. swarm is very dispersed compared to the earlier ones and the dykes occur across the whole width of Tugtutôq and the Skovfjord islands. The general size range for these basic dykes is from ·5–5 m. A number traverse the central complex and are believed to be younger than the late-stage microsyenitic dykes although as yet no intersections have been found to verify this. (A dyke thought to belong to this swarm was noted by the author intersecting the nepheline syenites of the northern part of the Ilímaussaq complex and, in all probability, this swarm post-dates all the larger late Gardar plutons).

In central Tugtutôq and on the islands of Igdlutalik, Kangue, Igdlukasik and Niaqornaq are some thin dolerite sills, rarely exceeding 3 m in thickness and forming gently undulatory sheets which have largely taken advantage of the nearly horizontal jointing (and occasional low-angled mylonites) in the older granites. One of the more prominent of these sills cuts the nordmarkitic granite and outer hornblende granite of the central complex, thus setting a lower age-limit for the period of sill emplacement. The dolerites consist mainly of small strongly-zoned plagioclase laths (An_{46-57}). Scarce plagioclase micro–phenocrysts may also be present. Titanaugite, sometimes mantled by basaltic hornblende, occurs together with small amounts of biotite. There are sporadic serpentinous pseudomorphs after olivine and the dolerites are typically rich in interstitial chlorite. Small idiomorphic crystals of ore are abundant and apatite occurs as a minor constituent. Irregular patches of carbonate are present throughout the rocks. Thus, petrographically the sills are found to be not unlike the dykes described above and it is quite likely that they comprise a single intrusive suite of lamprophyric dolerite representing the closing stages of the Gardar igneous cycle in the area. The presence of brown hornblende replacing clinopyroxene together with (primary) chlorites and carbonates suggests intrusion of a basaltic magma similar to that of the earlier gabbros, but slightly richer in water and carbon dioxide.

The final episode of dyke intrusion gave rise to numerous, but widely separated NW.–SE. dolerites. The marginal zones of the dykes typically show a strong 'flow-banding' parallel to the walls and a well-developed columnar jointing normal to this direction. Thin-sections of dolerite from three such dykes show them to be composed of two generations of intensely zoned plagioclase, almost colourless augite, olivine (generally serpentinised) and early crystals of Fe-Ti oxide. Biotite and apatite are very minor constituents. Just on the basis of these three examples it would appear that the dykes are of alkali olivine basalt parentage, but that they differ from the typical Gardar gabbros and dolerites in having less biotite, apatite and residual alkali feldspar and in not having acheived a comparable degree of iron and alkali enrichment. These dykes, commonly 5–15 m broad, are certainly later than the ENE. dykes referred to above and are thus probably later than the dolerite sills. The NW. dykes are representatives of the widely dispersed swarm which crosses the whole Ivigtut-Julianehaab region. They are entirely unaffected by any of the faulting in the area and several workers consider them to substantially post-date the rocks of the Gardar alkaline province, although it is not known with any certainty how recent they actually are.

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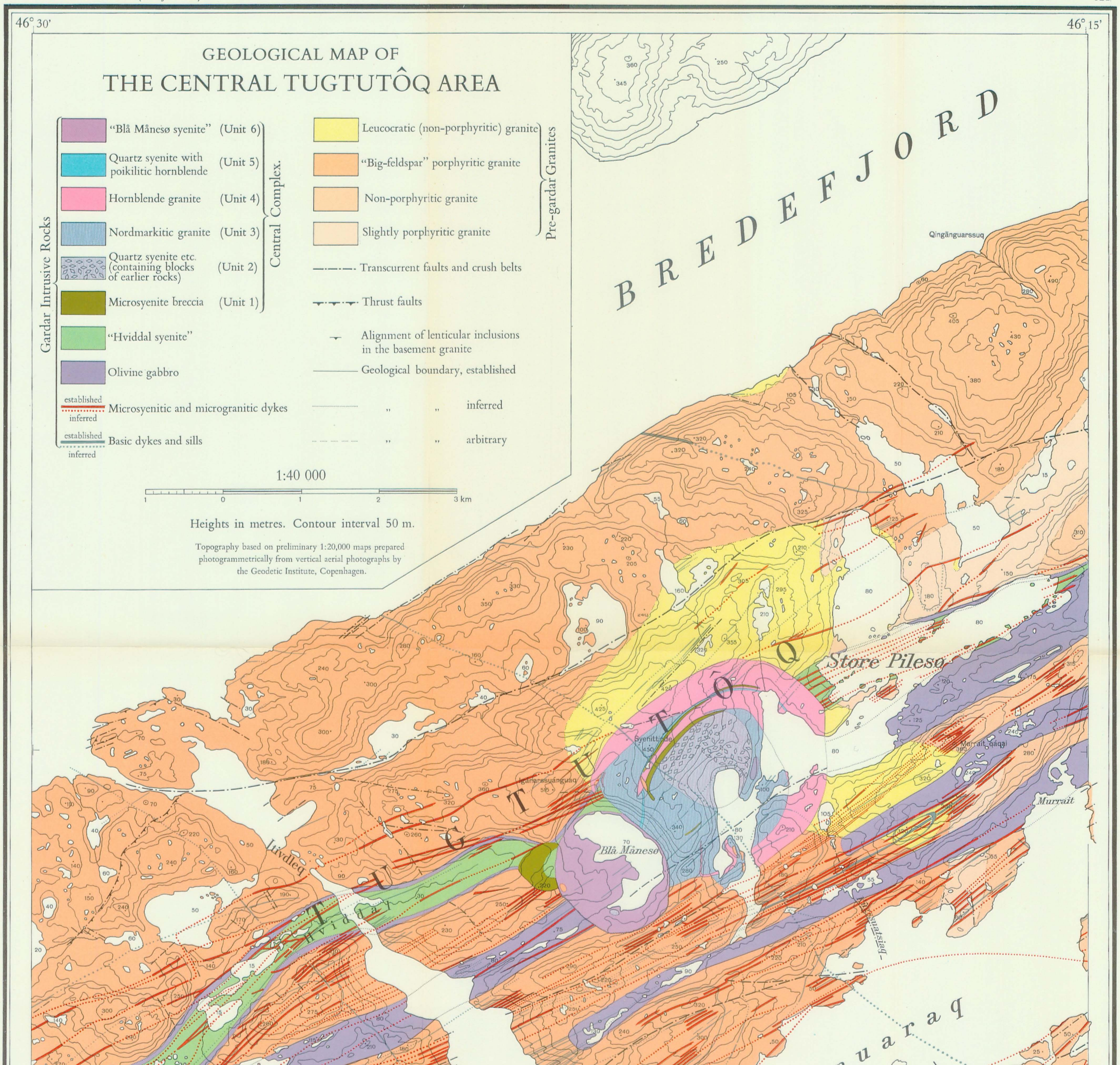
GEOLOGICAL MAP OF
TUGTUTÔQ AND NEIGHBOURING ISLANDS
Blå Månesø syenite (Unit 6)
Hornblende granite (Unit 4)
Nordmarkitic granite (Unit 3)
Quartz syenite etc. (Unit 2)
Microsyenite breccia (Unit 1)
Central Complex
Dolerite-microgranite composite dyke
Assorutit quartz syenite
Krydssø syeno-gabbro
Faults (normal or transcurrent)
Faults (thrust)
Established boundaries
Hviddal syenite
Olivine gabbro and dolerites
Anorthosite
Leucocratic (non porphyritic) granite
Big-feldspar porphyritic granite
Slightly porphyritic granite
Non-porphyritic granite
Nebulitic granite-gneiss series
Inferred boundaries
Arbitrary ,,
1:50 000
Heights in metres. Contour interval 100 m.
The topography is based on maps of The Geodetic Institute, Copenhagen
BREDEFJORD
NARSSAQ SUND
TUGTUTÔQ
TUNUARAQ
SKOVFJORD
TUNO
Igdlutalik
Qânguê
IGDLUKASIK
Ilaytait
NARSSAQ
Stephensens Havn
Assorutit
Nasaussardle
Sigssardlugtoq
Store Pilesø
Syenittinde
Blå Månesø
Iganarssuanguaq
Marrait
Itivdlip sarqâ
Umiatsiaqarfik
Mathæus Havn
Karra
30'
46°15'
60°52'

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND



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