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Bedrock geology of the nunataks and semi-nunataks in the Frederikshåbs Isblink area of southern West Greenland

by

Peter R. Dawes

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(The Geological Survey of Greenland)
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Reports

BEDROCK GEOLOGY OF THE NUNATAKS AND SEMI-NUNATAKS IN THE FREDERIKSHÅBS ISBLINK AREA OF SOUTHERN WEST GREENLAND

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Peter R. Dawes

With 14 figures, 7 tables,
2 plates and 1 map

1970

Abstract

The Precambrian geology of an area of 250 km^2 within the old gneiss block of West Greenland is described. The area is composed of a gneiss-granite-amphibolite complex which is cut by later basic dykes.

The largest part of the complex is made up of folded and migmatised biotite-, hornblende- and epidote-bearing gneisses in which granodiorites and adamellites can be mapped as separate granite units. Different types of amphibolites and ultramafic rocks occur in the complex. The oldest amphibolites occur as migmatised and folded inclusions and tracts within the gneisses and these are cut by different generations of metabasite dykes which are themselves migmatised and deformed. Metavolcanic rocks containing pillow lavas and metagabbro layers exist on some nunataks and these are considered to form cover rocks to an earlier basement.

Aspects of the deformational and metamorphic history are discussed. At least six main phases of deformation can be recognised in rocks which are polymetamorphic. The gneisses and granites of the complex display amphibolite facies mineralogy but greenschist mineral assemblages characterise some of the amphibolite and ultramafic rocks. Relics of an early high-grade metamorphism, possibly reaching granulite facies conditions, are preserved in some basic rocks.

The basic dykes which cut this polymetamorphic complex vary from dolerite to lamprophyre. The late tectonism and metamorphism is described.

An attempt is made to place the area into the regional chronology of this part of West Greenland.

CONTENTS

INTRODUCTION

Extent and location of the study area

The area of western Greenland dealt with in this report includes the semi-nunataks north of the ice-dammed lake Kangârssûp taserssua (62° 30′ N), the nunataks in Frederikshåbs Isblink (including Dalagers Nunatakker) west of 49° 00′ W, and the two groups of nunataks east of 49° 00′ W, the northerly group of which is J. A. D. Jensens Nunatakker. The total area of nunataks and semi-nunataks is approximately 250 km². Figure 1 shows the location of the area in western Greenland.

Toponymic names appearing in the text and on Map 1 are official names of the Geodetic Institute, Copenhagen but in the cases where no such names for nunataks exist, other names are used; for example, "Nasausak" and "Kangarsuk" are taken from J.A.D. Jensen (1879) and Kornerup (1879). Dalagers Nunatakker refers to the nunatak group north of the semi-nunataks Kangârssûp nunâ and "Kangarsuk" which is composed of Isigait, Sagdliata nunâ, Amârtoq, Qáqaq, "Nasausak" and the northern nunatak 1340 m. The "eastern nunataks" refers to the group of small nunataks south-south-east of J.A.D. Jensens Nunatakker, which are situated 80 km from the front of Frederikshåbs Isblink. All names are indicated on Map 1.

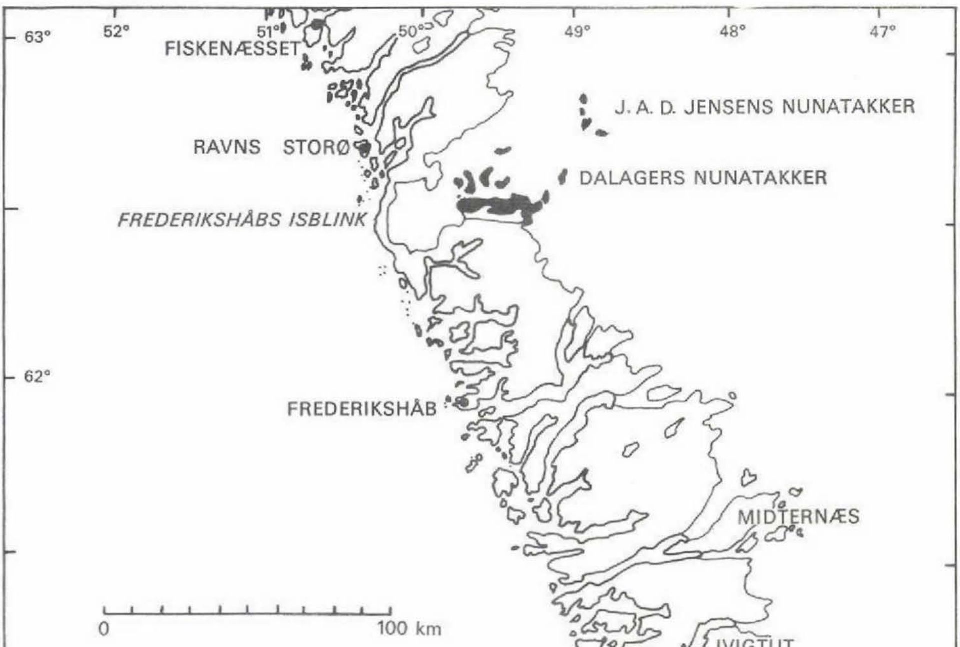

Fig. 1. Map showing the position of the nunataks and semi-nunataks (black) in West Greenland.

Field work

Field work for this report was carried out in the summers of 1967 and 1968 as part of the systematic team mapping undertaken by the Geological Survey of Greenland from the base-camp Mellembygden, north-east of Frederikshåb (62° 00′ N). Transport to and from the field area was by two Bell 47J helicopters, which also moved and supplied the two-man camp throughout the field work. For details of the organisation of the team mapping the reader is referred to S. B. Jensen (1966, 1968).

A total of 70 days were spent in camp on the nunataks and semi-nunataks but poor weather conditions resulted in about 15 days being lost for field work. The work was carried out from 11 camps (see Map 1). In 1968 one month was spent in the ground north of Frederikshåbs Isblink, east of Ravns Storø, where field work was carried out from four camps.

Camps were only established on three nunataks, Sagdliata nunâ, Nûata kangilia and the northern nunatak 1340 m, so that the rest of Dalagers Nunatakker, Nûata kujalia and the eastern nunataks were only visited on helicopter reconnaissance. J. A. D. Jensens Nunatakker were visited on one occasion (see S. B. Jensen, 1968, p. 41), landings being made only on two nunataks of the group. Thus the geological mapping is based on both brief helicopter reconnaissance, leading only to cursory examination of some areas, and more detailed investigations carried out from ground camps.

Most of the area is covered by both vertical and oblique aerial photographs and since the only topographical map available had the scale 1:250 000 (Geodetic Institute, 62 V1, Frederikshåbs Isblink, 1966), enlarged vertical aerial photographs were used in the field. These were supplied by the Geodetic Institute.

The base for the geological map included here (Map 1) was drawn from the vertical aerial photographs at about 1:57 000, using an enlarged outline of the 1:250 000 topographical map to establish the relative positions of the nunataks. For those nunataks where no vertical photograph coverage exists (northern nunatak 1340 m, northern part of Nûata kujalia, Nûata kangilia, J.A.D. Jensens Nunatakker and the eastern nunataks) oblique aerial photographs were used together with an enlarged outline of 1:250 000 topographical map.

Topography and exposure

Topographically the area can be divided into two. The semi-nunataks north of Kangârssûp taserssua are a continuation of the glaciated plateau which typifies the ground north of Frederikshåb, while Dalagers Nunatakker are conspicuously higher in altitude and are more alpine in character, the highest peak reaching 1500 m. Amârtoq is particularly striking for its steep-sided nature and for its snow- and glacier-covered areas. The highest altitudes of all occur on J. A. D. Jensens Nunatakker which reach 1680 m.

In general, exposures are good, especially on the higher nunataks where ice-smoothed surfaces are abundant and where lichen and other vegetation is sparse. However on the semi-nunataks the vegetation is enough to support reindeer and this together with a prominent lichen cover hinders work inland. Lichen-free rock surfaces occur particularly in a zone adjacent to the ice and although moraine cover is prominent in this zone, excellent polished surfaces can be found.

Scope of the report

This report is essentially a summary of the Precambrian geology of the area supplemented by a general study of thin sections. It is not intended as a comprehensive study but rather as a basis from which special topics might be selected and later worked up in detail. Some comments are given on the possibility of correlation with the Frederikshåb area to the south and with the area to the north of Frederikshåbs Isblink. This seems warranted since the nunataks lie in a critical position within the Isblink which forms a break between the Frederikshåb area to the south and mapped from Mellembygden, and the Fiskenæsset area to the north, the mapping of which is scheduled to start in 1970.

Previous investigations

Dalagers Nunatakker are named after Lars Dalager, a merchant of Frederikshåb, who in 1751 undertook a trip on the ice accompanied by four Greenlanders and ascended a prominent nunatak referred to as "Omertlok" (see Dalager, 1915, p. 68–72; Nansen, 1890, vol. 1, p. 462–467). Doubt exists as to which peak Dalager actually climbed (see J. A. D. Jensen, 1879, p. 48). Dalager made some comments on the ice conditions of Frederikshåbs Isblink but it was not until 1878 that aspects of the bedrock geology were recorded. In this year J. A. D. Jensen, A. N. Kornerup and Th. Groth accompanied by Greenlanders made a trip from south of Frederikshåbs Isblink, over Kangârssûp taserssua to Kangârssûp nunâ and over the ice to reach the summit of the nunatak "Nasausak", returning to the coast by much the same route. Later the same summer the same expedition travelled over the ice from the front of Frederikshåbs Isblink to the group of nunataks (J. A. D. Jensens Nunatakker) which Dalager had seen from Omertlok and which he believed to be the mountains of the east coast of Greenland. In 1967 the expedition's original message from 1878 was recovered from the collapsed cairn on the summit of the main nunatak (see S. B. Jensen, 1968) while a tin bearing the date 1878 outlined by punched holes was recovered from the expedition's cairn on the summit of "Nasausak" (see table VII, Meddr Grønland, Bd. 1, 2 op., 1890).

Kornerup (1879, map B) indicated the bedrock as gneiss on Kangârssûp nunâ and "Nasausak" and recognised the contact between folded hornblende schists (containing subordinate mica schists, quartz-rich schists and talc-actinolite schists) and underlying gneiss on J. A. D. Jensens Nunatakker (Kornerup 1879, fig. 8, p. 85, for comment see S. B. Jensen, 1968, p. 42). Kornerup also commented on the presence of diabase dykes cutting the gneisses and schists of the nunatak.

No other geological work was recorded from the present study area until the author's field work in 1967 and 1968 but Windley (1968 and Windley et al., 1966) has described the basement rocks immediately north-west of Frederikshåbs Isblink.

Regional geological setting

The area under consideration belongs to "the old gneiss block" of western Greenland as defined by Pulvertaft (1968, p. 90); a gneiss area which has given isotopic ages between 3400 and 2200 m.y. and which is flanked to the north and south by younger fold belts, i.e. the Nagssugtoqidian and Ketilidian fold belts respectively. The gneissic and associated rocks of this block are mainly pre-Ketilidian (Kenoran) in age although even older basement rocks are thought to exist in some areas. McGregor (1968) for example, through recognition of a swarm of old metamorphosed basic dykes (Ameralik dykes) in the Godthåb area, has suggested the existence of both gneisses and supracrustals older than 2700 m.y. Scattered age dates around 1800 m.y. within "the old gneiss block" indicate some younger plutonic activity. Swarms of basic dykes of various ages cut the gneisses and associated rocks of the block.

The area of this report lies towards the southern end of "the old gneiss block" some 150 km north of the Ivigtut area (see fig. 1) where the pre-Ketilidian gneisses and supracrustal rocks are unconformably overlain by Ketilidian supracrustal rocks (Higgins & Bondesen, 1966; Henriksen, 1969; Bondesen, in press; see also table 7).

General statement of the geology of the study area

The area is made up of a folded gneiss-granite-amphibolite complex which is cut by later basic dykes. The largest part of the complex is composed of gneisses which are biotite-, hornblende- and epidote-bearing and which have been severely migmatised and folded. Autochthonous granitic rocks occur and can be mapped as distinct units. Amphibolitic and associated ultramafic rocks are widespread and occur as layers or inclusions in the gneisses or, on some nunataks, as units overlying the gneiss terrain. Some of these rocks represent metamorphosed volcanic rocks and have relic pillow structures preserved while others are metamorphosed basic intrusions and display original discordances to the gneisses. Various generations of basic dykes post-date the main plutonism of the gneiss-granite-amphibolite complex and these vary in composition from dolerite to lamprophyre.

GNEISS - GRANITE - AMPHIBOLITE COMPLEX

Gneisses

Over half the area is underlain by gneisses which are composed of up to three main components: a grey part composed of fine- to medium-grained biotite and/or hornblende quartzo-feldspathic rock in which the mafics form a foliation, a mafic (amphibolitic) part which is commonly schistose and which forms tracts or schlieren, and a felsic part which forms veins, streaks, bands, pods or layers within both the other components. This last component varies from fine-grained in the small migmatitic veins to coarse-grained in the pegmatitic material.

By far the most common type is a *veined gneiss* in which small, parallel to sub-parallel, rather discontinuous, regular or irregular, white- to cream-coloured quartzo-feldspathic veins exist within a grey, biotite- and/or hornblende-bearing, foliated granitic rock. The felsic veins are concordant to sub-concordant to the mafic foliation. Small tracts of amphibolitic material may occur parallel to the foliation and acid veins. In a few localities such amphibolitic material forms isolated schlieren which are elongated parallel to the foliation of the granitic parts of the gneiss and in these cases gradations to *streaky gneiss* occur. Some areas of *banded gneiss* have been noted and in some cases the banding is due to the alternation of amphibolitic and granitic bands, while elsewhere it is due to the regular development of pegmatitic layers. Where acid veins are irregular and form a continuous network dividing the foliated granitic rock into blocks, *agmatitic gneiss* occurs, but in those cases where amphibolitic rocks form the matrix, the rocks are described as agmatitic amphibolites (page 14). Many of the gneisses are quite granitic in character, and gradations towards the granites of the complex occur through *nebulitic gneiss* in which relics of pre-existing gneissic structure exist. Some of the granitic gneisses which lack veins or bands of differing rock composition but which possess a slight preferred orientation of mafic minerals might be termed *homogeneous gneiss*. Finally some gneisses contain feldspar porphyroblasts up to 3 cm in length which are characteristically aligned parallel to foliation and where this is a conspicuous feature *augen gneiss* exists.

Biotite is the most common mafic mineral of the gneisses, and biotite gneiss forms large areas on Kangârssûp nunâ, "Kangarsuk", Isigait, Sagdliata nunâ and J. A. D. Jensens Nunatakker. It is joined by hornblende in some gneisses and on Nûata kangilia hornblende exceeds biotite in amount and hornblende gneisses exist. In small areas the hornblende gneisses lack biotite. Epidote is a common mineral in both biotite and hornblende gneisses and in some cases it is an essential mafic mineral producing areas of epidote gneiss. Such areas are commonly associated with dislocations. Garnet is only scarcely developed but in localities SW of camp 67-1, garnet occurs in association with amphibolitic rocks in banded gneiss and one crystal reaches 8 cm in size. The biotite gneisses are grey to light grey and cream coloured on fresh surfaces while the hornblende gneisses are characteristically darker in colour and are grey to dark grey, weathering to greyish brown. Where epidote is abundant the gneiss may be lighter in overall colour but in many cases epidote forms megascopic greenish-yellow flecks.

In composition the gneisses vary from tonalitic (K feldspar absent), to granodioritic (plagioclase > K feldspar) to adamellitic (neither plagioclase nor K feldspar exceeds $\frac{2}{3}$ of total feldspar). The majority are granodioritic but many contain only minor amounts of K feldspar. Volumetric analyses of 12 gneisses are given in table 1. Main mineral assemblages are from: biotite, hornblende, epidote, plagioclase, K feldspar (mainly microcline), quartz, myrmekite and garnet, while muscovite, apatite, sphene, calcite, zircon and ore are accessory. Sericite, epidote and chlorite are the main alteration products. Textures are mainly xenomorphic-granoblastic and occasionally porphyroblastic where large feldspar crystals occur within a finer-grained quartz-feldspar matrix. Where biotite flakes form a conspicuous

Table 1. Volumetric analyses of gneisses (excluding amphibolitic bands and leucosome veining material). Accessories include apatite, sphene and ore.

GGU Sample No.	Biotite	Hornblende	Epidote	Plagioclase	K feldspar	Quartz	Accessories
78249	17.9	–	0.4	42.6	0.4	36.1	2.4
78362	14.7	35.3	2.8	26.2	4.4	15.1	1.4
78236	8.3	–	1.4	34.1	24.0	31.7	0.3
86254	9.0	–	0.4	49.0	9.4	31.6	0.5
78311	6.5	6.9	3.4	44.4	4.4	33.5	0.8
78375	18.1	–	2.2	49.4	3.0	26.9	0.4
78237	9.5	–	0.7	25.6	30.6	33.2	0.3
78265	5.5	9.3	0.9	50.8	2.2	29.2	2.0
78365	13.1	37.1	1.2	22.5	–	23.6	2.4
78257	14.1	–	1.0	28.3	14.8	41.3	0.3
78367	12.3	4.4	3.6	50.6	2.0	26.8	0.3
78242	13.9	–	–	35.6	–	49.5	0.8

foliation, lepidoblastic texture exists. In a few cases the felsic minerals show a tendency to be flattened and elongated in the direction of this foliation. Biotite is commonly pleochroic from green to brown; hornblende is always green. Epidote (pistacite) forms subhedral crystals which truncate the biotite foliation and allanite commonly exists in the central part of these crystals. Later epidote (pistacite and clinozoisite) replaces feldspar and forms some vein concentrations. Plagioclase which can be heavily sericitised is replaced by large irregular tracts of quartz.

In the southern part of Kangârssûp nunâ the granodioritic biotite gneisses pass into an area of brown-weathered foliated tonalite, a rock which is characteristically hornblende-bearing and lacks potash feldspar. Boundaries between the biotite gneiss and the hornblende tonalite are transitional and the foliation in the tonalite appears to be parallel to that in the surrounding biotite gneiss. The approximate area of the hornblende tonalite is shown in Map 1.

The tonalitic rocks are typically darker in colour than the surrounding gneisses and they have a fawn and greyish-brown to grey colour. The main type is a medium-grained, equigranular rock which has a conspicuous foliation of hornblende aggregates. Main minerals are plagioclase, hornblende and quartz, with biotite and garnet occurring in some samples. Some quartz-poor rocks occur. Main accessories are apatite and ore.

The affinity of the hornblende tonalite is not clear. The rocks appear to grade into the biotite gneisses, but the character of some of the more melanocratic quartz-poor varieties is not unlike some basic meta-igneous rocks.

Amphibolitic and ultramafic rocks

Amphibolitic rocks occur on the nunataks and semi-nunataks as inclusions, tracts or layers within the gneisses or as units overlying gneiss. Ultramafic rocks are common associates but they are of smaller importance and form layers, discontinuous tracts or lenses in amphibolitic rocks.

Inclusions of all sizes from small enclaves only centimetres in length to tracts some kilometres long occur, and a gradation between such inclusions and more continuous layers in the gneisses exists. It is clear in many cases that inclusions in the gneisses have resulted from the break-down of a once continuous layer and boudinage structure is frequently seen. Other amphibolitic rocks are not flanked by gneiss on both sides but appear as units overlying gneisses, the top of the basic unit not being seen. Such is the case for example on the northern nunatak 1340 m and on J. A. D. Jensens Nunatakker. No discordances have been seen between amphibolitic and ultramafic rocks (excluding in this context the amphibolitic rocks described under "metamorphosed basic intrusions") and gneiss and on a regional scale relations with the gneisses are conformable so that contacts of the layers are parallel to the foliation of both the amphibolite and the enclosing gneiss. On a small scale however foliation of amphibolite may be discordant to that in the host gneisses and this is readily seen in connection with small enclaves (see fig. 11).

Contacts between gneiss and amphibolite rocks are generally migmatitic. They take the form of either an increase in amphibolitic material in the form of lenses, bands or tracts in the gneisses as the amphibolite is neared, or discrete veins of gneiss may penetrate an amphibolitic layer and may lead to a contact zone of agmatitic amphibolite. In other cases a mineralogical transition between gneiss and basic or ultramafic rock occurs in which the gneiss is enriched in biotite and/or hornblende as the amphibolitic unit is approached.

Rock types vary considerably and in some localities it is possible to recognise a rock stratigraphy composed of different types of basic and ultramafic rocks as for example in the outcrops in the vicinity of camp 67-5. For descriptive purposes the rocks are described under four headings, the recognition of rocks as "metavolcanic" being made on the presence of preserved primary structures. Other rocks described here under "amphibolites" and "ultramafics" are probably also metavolcanic rocks. Calc-silicate rocks are described separately.

Amphibolites

A variety of amphibolitic rocks occurs with gradations between them. Main types are as follows:

(1) *Non-schistose amphibolites.* These are fine- to medium-grained equigranular rocks, dark grey to black in colour, sometimes garnet-bearing. In some types a foliation exists where felsic and mafic components have a preferred orientation, and where foliation becomes dominant, a gradation into (2) *schistose amphibolites* (see S. B. Jensen, 1969, p. 34) occurs. These amphibolites vary in colour from dark grey and black to grey and greenish grey. They are mainly fine- to medium-grained but some are heteroblastic and have hornblende crystals up to 1 cm set in a schistose matrix. The rocks commonly have a uniform colouration but in some a colour banding exists and where this is well developed (3) *banded amphibolites* are approached. Banding varies from the millimetre scale up to bands of a few centimetres in thickness. The banding is compositional, the darker bands having a higher amphibole – plagioclase ratio than the lighter. Concentration of epidote in bands parallel to schistosity also leads to a banding in shades of green, yellow and cream. Where felsic material occurs in tracts parallel to schistosity (4) *migmatitic amphibolites* exist (see S. B. Jensen, 1969, p. 34). Such amphibolites may also appear banded where the felsic material occurs in regular tracts but more often felsic material occurs in discontinuous veins, streaks and lenses. Such amphibolite commonly occurs in the contact zone with the enclosing gneiss. Some amphibolites contain porphyroblasts or augen of plagioclase up to 4 cm in size which produce areas of (5) *augen amphibolite.* Augen of feldspar also occur in the migmatitic amphibolites but in one locality north-west of camp 67-5, augen amphibolite forms a distinct

Table 2. Volumetric analyses of amphibolites. Accessories include apatite, sphene, calcite and ore.

GGU Sample No.	Hornblende	Pyroxene	Biotite	Garnet	Epidote	Plagioclase	Quartz	Accessories
78278	49.3	–	–	–	12.5	33.3	3.1	1.8
78369	70.3	–	17.2	–	–	11.8	–	0.7
78212	54.7	–	0.2	–	–	33.1	10.5	1.4
78216	66.5	6.7	–	–	–	26.4	–	0.3
78232	57.6	–	–	5.9	–	22.1	11.1	3.2
78209	45.0	–	1.2	–	32.4	19.1	–	2.3
78228	63.9	–	–	–	–	33.5	–	2.5

layer in the amphibolite-ultramafic succession. Here porphyroblasts are aligned parallel to the schistosity. In many amphibolites, felsic veining has been intense and irregular leading to (6) *agmatitic amphibolites* which are composed of blocks of amphibolite, often angular, set in a granitic matrix. Such amphibolites occur commonly in the margins of an amphibolite layer but in some localities complete layers of amphibolite up to tens of metres in thickness are characterised by agmatitic development.

Textures vary from granoblastic in the non-schistose rocks to nemato-lepidoblastic in the schists. In many porphyroblastic types hornblende and garnet may be poikiloblastic containing plagioclase inclusions. Epidote may also contain aligned strings of plagioclase. Mineralogically all are amphibolites (table 2) with hornblende (and tremolite-actinolite) and plagioclase as main minerals. Garnet, epidote and biotite occur in some rocks in large enough amounts to warrant the terms garnet, epidote and biotite amphibolites. Pyroxene (?diopside), although present in some rocks, never reaches proportions large enough for the rocks to be called pyribolites. Quartz can reach 11% and calcite is common in some slides. Main accessories are sphene, ore (mainly magnetite) and apatite. Epidote, sericite and chlorite are the main alteration minerals.

Where pyroxene exists it is partially replaced by hornblende. Garnet, hornblende and biotite appear in equilibrium but occasionally large hornblende crystals have recrystallised into sub-grains. Epidote in places replaces hornblende and also plagioclase, the latter mineral being commonly sericitised.

Calc-silicate rocks

Calc-silicate rocks occur as lenses or larger tracts in association with amphibolitic layers or inclusions in the gneiss. Some calc-silicate rocks occur in association with the metavolcanic rocks of the northern nunatak 1340 m. The rocks are characteristically lighter in colour than the host amphibolite but they lack a uniform colour, and they can vary in one exposure from pale green to dark green, pink to shades of red, yellow to greenish yellow and pale green to buff in colour. In some cases a crude zonation occurs in a lens or an outcrop, the centre being pink in colour and garnet-rich surrounded by diopside- and epidote-rich zones. This zoning resembles that described by Sørensen (1968) in calc-silicate lenses from the area around Frederikshåb. In some localities it can be clearly seen that an originally larger calc-silicate occurrence has been broken up into lenses and isolated patches in the amphibolite. Agmatitic development is common. Excellent exposures of calc-silicate rocks occur on the northern slope of peak 1200 m on Sagdliata nunâ.

Main minerals are garnet, epidote, quartz, diopside, calcite, green biotite, tremolite, sphene and plagioclase. The feldspar can be heavily altered, sericite, epidote and calcite being the main secondary minerals. Epidote also replaces amphibole and diopside. Ore is accessory.

Metavolcanic rocks

While it is probable that other amphibolites in the complex represent metavolcanic rocks, only on the northern nunatak 1340 m do amphibolitic rocks display preserved primary volcanic structures, some of which simulate pillow lavas. Such pil-

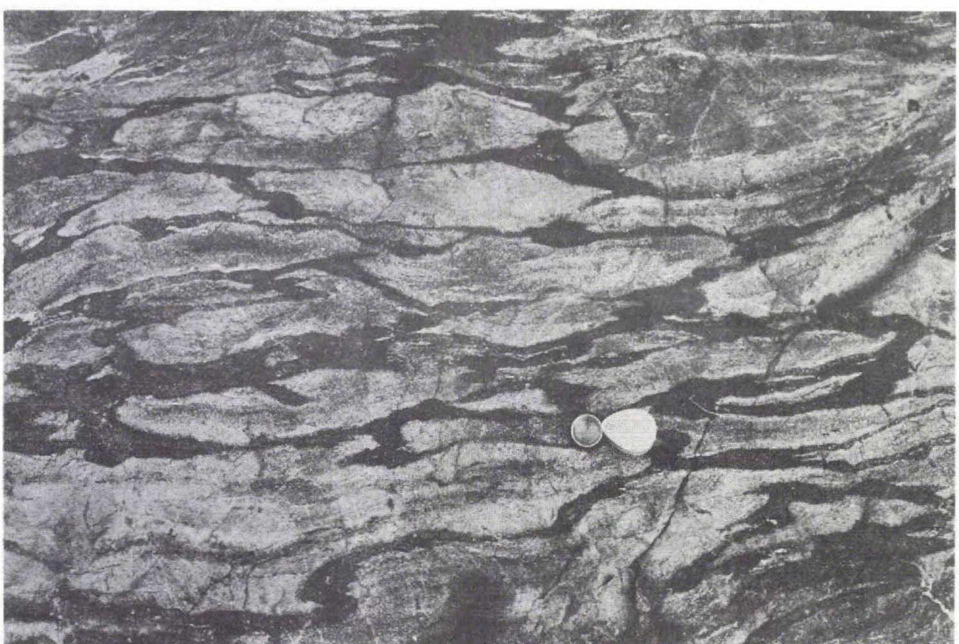

Fig. 2. Deformed pillow lava on the northern nunatak 1340 m. Note the irregular outlines of some of the pillow structures and the crude zoning.

lows vary from being smooth, rounded, lens-shaped bodies to structures having irregular borders (fig. 2). They are commonly lighter in colour than the matrix in which they are situated although darker structures have been noted. In some cases the pillows are closely spaced together and little matrix occurs, in others the matrix has weathered out so that the pillows are separated by cavities. The matrix is commonly hornblende-rich and is dark grey to greenish black in colour, the pillows being grey to greenish grey. Crude zoning has been seen in some pillows but this is not common (fig. 2).

The pillows are flattened and elongated in the plane of the regional schistosity; they vary in thickness from less than a centimetre to 25 cm and in length from over 10 cm to 1.5 m, but there is a notable difference in lengths measured in the strike and dip direction. The pillows have clearly been stretched in the dip direction of the regional schistosity so that for example a pillow having a thickness of 5 cm and a width of 25 cm has been stretched to over 1.25 m in the direction of the dip. Hence the appearance of pillows differs markedly with the plane of the exposure surface (fig. 3). Gradations between localities showing pillow structure to amphibolites bearing elongated pods, lenses and streaks of differing compositions and even to a banded amphibolite can be seen on the northern nunatak 1340 m. Vesicles and cavities, some containing calcite and epidote, are commonly associated

Fig. 3. Deformed pillow lava on the northern nunatak 1340 m illustrating the severe elongation of the pillow structures in the direction of dip of the lava. Hand-lens gives scale.

with the pillow lavas and some calc-silicate rocks with diopside and garnet also occur in association. Some irregularities in the structure of the amphibolites on the nunatak may represent pyroclastic horizons and not pillow lavas.

Schistose amphibolites are associated with the rocks containing pillow structure and towards the eastern end of the nunatak medium-grained amphibolite occurs which in places displays a centimetre-scale layering (fig. 4). The layers have sharp bottom contacts with the underlying layer and there is a gradation in mafic content from base to top of each layer. This layering has a magmatic aspect and the medium-grained amphibolite is considered to be a metagabbro.

Main minerals of the rocks bearing pillow structure are hornblende, epidote, diopside, plagioclase and calcite while the associated schists and metagabbro are amphibole-plagioclase rocks with or without epidote and biotite. One type of schist contains approximately equal amounts of biotite and hornblende. Quartz can exist in all the rocks. Sphene, which can form grains up to 1 mm in size, and ore are the main accessories.

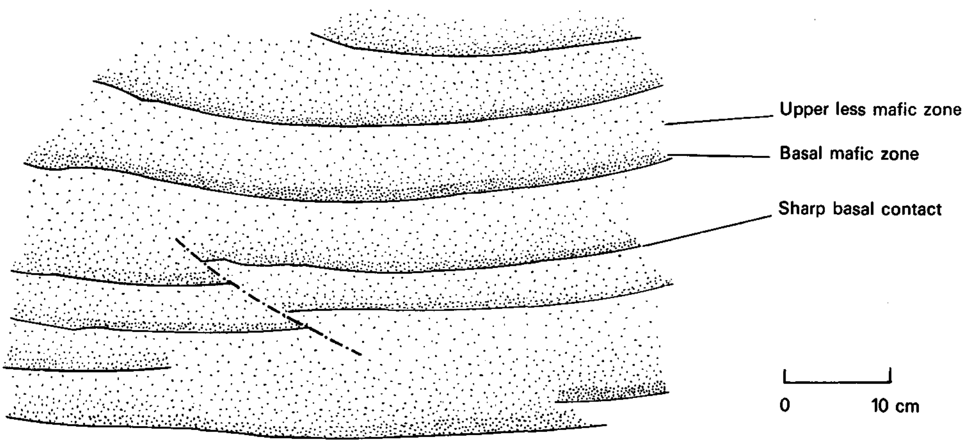

Fig. 4. Layering in metagabbro on the northern nunatak 1340 m. Each layer is characterised by a sharp basal contact and a change in composition upwards.

Ultramafics

Three main types of ultramafic rocks can be distinguished in the field. These are: (1) non-schistose ultramafics, (2) schistose ultramafics and (3) ultramafic rocks showing zoned-ball structures. Gradation exists between the types. Where ultramafic rocks occur as inclusions in gneiss they may be agmatised by gneissic material. Many of the rocks display on weathered surfaces a brownish-rusty colour and this is usually distinct enough to contrast against the darker colour of the associated amphibolites.

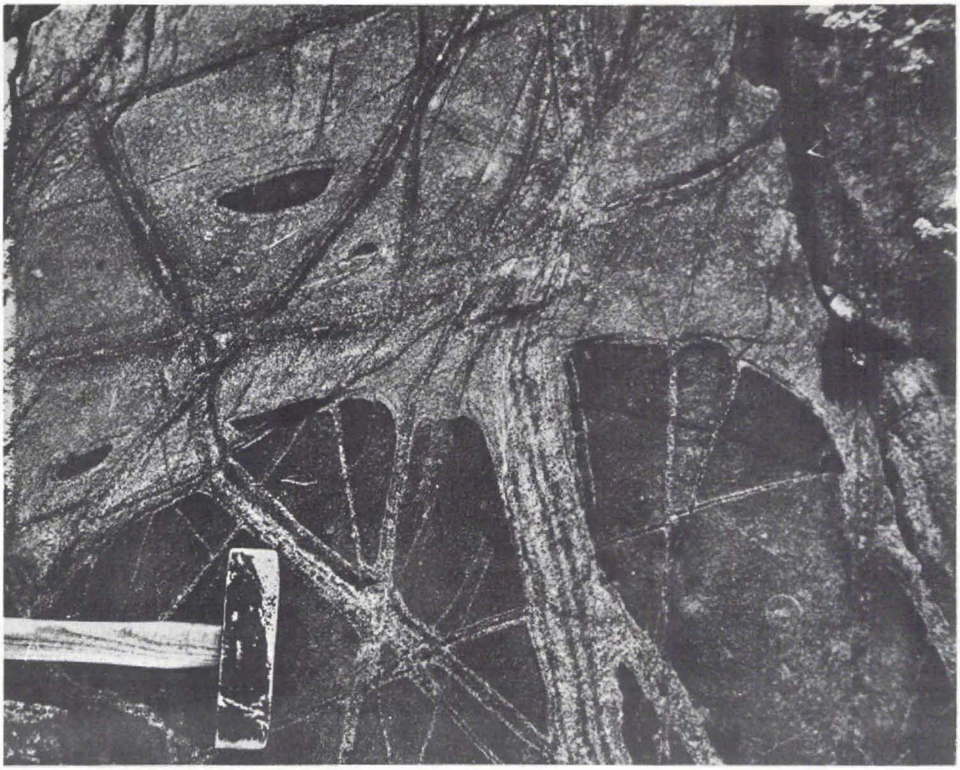

Fig. 5. Original darker ultramafic rock veined and replaced by talc-amphibole material. Note the dark relic patches in the talc-amphibole rock. Eastern Kangârssûp nunâ.

Rocks of the first group vary from dense homogeneous, fine- to medium-grained rocks, dark grey to black and greenish black in colour, to coarse-grained rocks in which amphibole crystals may reach approximately 7 mm in size. Some rocks are heteroblastic, one notable type existing north-east of camp 67-5 where orthopyroxene crystals over 1 cm in size are situated in a greenish-grey olivine-bearing matrix.

The schistose ultramafics are fine-grained and rather massive in type varying from grey and greenish grey to dark green and black in colour. Variation of essential mineral content forms hornblende-, actinolite- or talc-bearing schists. Such schists occur on J. A. D. Jensens Nunatakker.

The third type of ultramafic rocks is the product of alteration of non-schistose ultramafics (1). In two localities isolated ultramafic rock is intensely traversed by a vein network composed of talc and fibrous amphibole and in places the original rock is completely altered to a talc-amphibole rock (fig. 5). Elsewhere isolated lenses of ultramafic rock, either in gneiss or in amphibolite, show an alteration rim adjacent to the host rock. This zoning may typify a complete horizon of rock as for example in the succession on "Kangarsuk", NW of camp 67-5, where ultra-

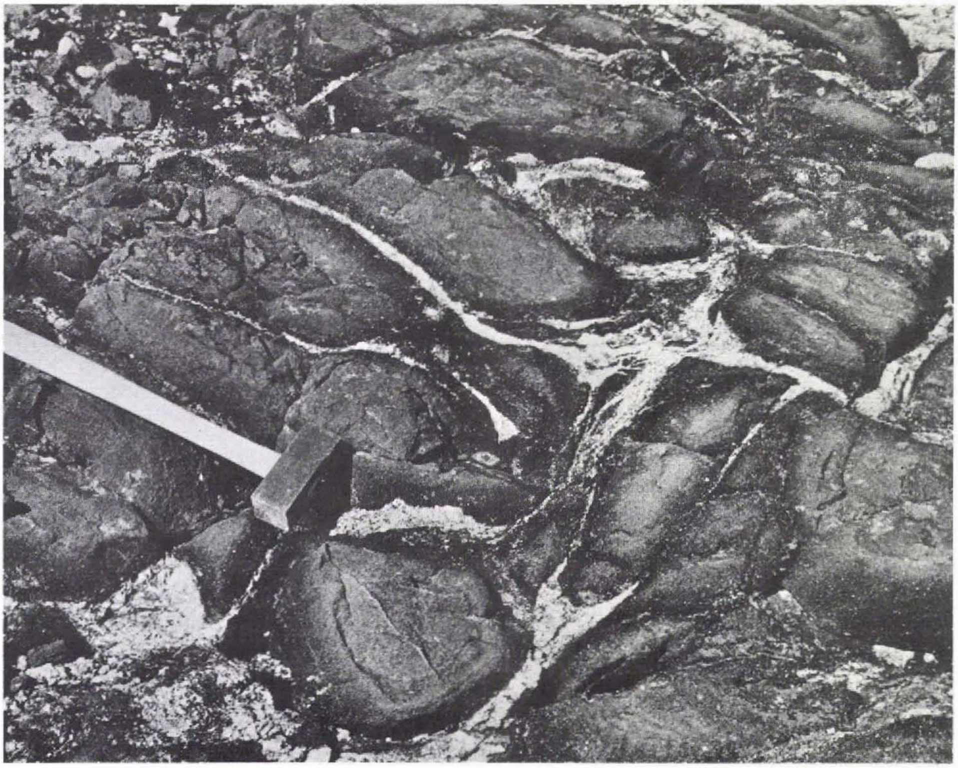

Fig. 6. Ultramafic rock broken down into rounded blocks. Darker actinolite-rich reaction zones have developed in the outer parts of the blocks. Eastern "Kangarsuk".

mafic ball structures form a unit over 20 m thick. Such structures are clearly developed by the break-down of a homogeneous ultramafic layer followed by alteration of the rock (fig. 6). Spaces between ultramafic blocks are commonly filled by acidic material although some ball structures occur in contact. The structures are essentially lens-shaped, the largest noted reaching 4 m in its longest direction. The smallest structures can be less than 10 cm across.

The largest balls are composed of four main zones: an outer relatively thin biotite-rich zone, zones rich in actinolite-tremolite (green) and anthophyllite (grey) which are characterised by crystals arranged at right angles to the surface of the ball, and a core of original ultramafic rock (peridotite) which may or may not be serpentinised. Gradations from a relatively unaltered olivine-bearing ultramafic to a serpentinite, through all stages of replacement of the mafic minerals by antigorite, can be recorded. Talc may occur in the outer zones and in some balls the core is talc-rich, in places containing conspicuous crystal clusters of biotite. In the smaller lenses the serpentinised or talc-rich core is missing or is very small, and the

Table 3. Volumetric analyses of ultramafic rocks. Accessories include apatite, sphene, calcite, spinel, epidote, quartz and ore.

GGU Sample No.	Amphibole	Pyroxene	Mica	Olivine	Plagioclase	Accessories
78317	39.7	13.2	–	45.1	–	2.0
78314	18.6	–	41.0	34.8	–	5.4
78318	34.3	8.8	–	54.0	–	2.8
78322	59.3	38.4	–	–	–	2.3
78369	89.9	–	6.1	–	3.9	0.1
78321	70.7	–	16.1	–	–	13.1
78316	31.8	40.3	–	23.3	–	4.5
78266	14.3	–	12.1	68.6	–	4.9

centre of the ball is anthophyllite-rich grading outwards into the greenish actinolite-rich zone. In other balls actinolite-tremolite occurs in the core inside the anthophyllite zone. The outer biotite zone may be thicker in the smaller than in the larger structures.

The zoned-ball occurrences are similar to those described by Walton (1966b) from the Frederikshåb area to the south and have much in common with zoned structures described from elsewhere (see Read, 1934; Matthews, 1967).

In composition many of the ultramafic rocks are peridotitic, having olivine as an essential mineral along with varying amounts of pyroxene and/or amphibole and/or mica. No dunites have been recorded but monomineralic rocks (hornblendites) exist composed essentially of hornblende or tremolite-actinolite and there is a gradation to peridotites with increase of olivine content. Some hornblendites have biotite as an important mineral. Many rocks are amphibole peridotites containing amphibole and olivine while others are mica peridotites with biotite and/or phlogopite forming an essential mineral, in places in amounts equal to olivine. Volumetric analyses of a variety of rocks are given in table 3.

Main minerals are olivine, orthopyroxene, clinopyroxene, hornblende, tremolite-actinolite, anthophyllite, ?cummingtonite, biotite, muscovite, phlogopite, calcite, talc, antigorite, chrysotile and epidote while sphene, spinel and ore minerals (magnetite and pyrite) are the main accessories. Picotite is common in some slides. Plagioclase forms 5–10% in some samples; usually it is sericitised. Textures vary from granoblastic in the massive rocks to nemato-lepidoblastic in the schists and to strikingly nematoblastic in the asbestos anthophyllite and actinolite rim zones to the ultramafic balls. Some heteroblastic textures occur and in these porphyroblasts of amphibole or pyroxene can display poikiloblastic structure.

Most textures are interpreted as metamorphic but in some cases for example in the mica peridotites, olivine and mica appear to have an igneous relationship, and poikilitic texture is displayed with olivine forming the oikocrysts and the mica the chadocrysts. Where mica occurs abundantly and in large flakes, it may form a network, in the spaces of which olivine and amphibole are situated.

In some cases hornblende replaces pyroxene but elsewhere hornblende, pyroxene and olivine appear in equilibrium. In some slides large orthopyroxene crystals show a strain-shadow effect and have partly recrystallised into sub-grains. Anthophyllite, biotite and tremolite-actinolite forming the zones of the ultramafic balls are late minerals post-dating the olivine, pyroxene, phlogopite and their alteration products antigorite and talc. Such late tremolite-actinolite and anthophyllite can itself be altered and cut by talc, calcite and epidote veins.

Metamorphosed basic intrusions

Metamorphosed basic intrusive rocks occur mainly in the form of discordant dykes but one main body and other smaller outcrops exist on Kangârssûp nunâ. The rock type of the dykes differs markedly from that of the main body.

Metabasite dykes

Approximately 90 metamorphosed basic dykes were recorded in the basement complex. This figure does not include many concordant metabasite layers in the gneiss the intrusive character of which cannot be conclusively proved. The main localities of dykes are indicated on Map 1.

The dykes vary in width from a few centimetres to 4 m. They have been deformed and folded and this has resulted in variation in dyke trend even in a single locality. However swarms of dykes in some localities tend to show a general trend – for example those on Sagdliata nunâ, SE of camp 67-7, have a NNE-NE trend while those on the northern edge of "Kangarsuk", N of camp 68-6 trend N-NNW. The dykes are generally not persistent and can only be followed over some tens of metres but in one case (locality on the northern edge of "Kangarsuk", north of camp 68-6) almost 100 m continuous exposure of a dyke less than 1 m wide occurs.

The form of the dykes varies considerably. Some dykes are curved or sinuous in form and generally have irregular contacts with the host rock (plate 1) while others are more dyke-like in character and display sharp, straight contacts with the host rock and have more consistent directions (plate 2). Many of the former dykes bear leucocratic material either in migmatitic streaks or veins or as acid margins or they even may be mixed with pegmatitic material while dykes of the latter type are relatively unmigmatised but are cut by pegmatites and quartz veins. The dykes can have irregular branching outcrops and commonly display apophyses. Some dykes with curved or sinuous outcrops vary considerably in width along their length, while elsewhere irregular form is associated with shear zones in the gneisses (fig. 7). In

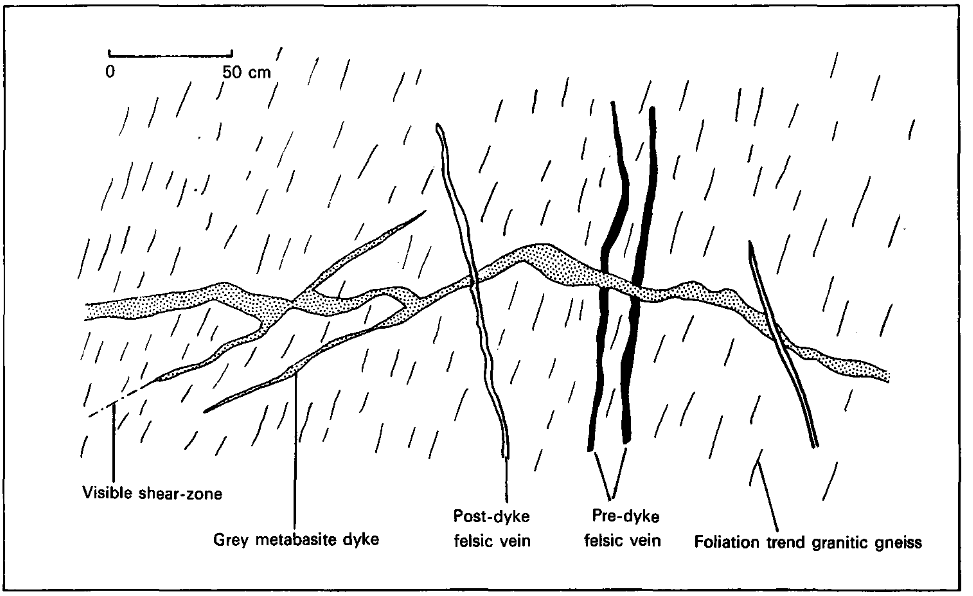

Fig. 7. Thin, grey, metabasite dyke cutting biotite gneiss. The dyke cuts the gneiss foliation and early discordant felsic veins in the gneiss, and is cut by late felsic veins. The shape of the dyke has been partly controlled by shear-planes in the gneiss. Northern Kangârssûp nunâ.

some cases dykes have been broken up and agmatised and now only survive as inclusions in the gneiss. Recognition of such inclusions as being of dyke origin depends on the presence of continuous exposure from dyke to agmatite. Similarly amphibolitic layers in the gneiss are found to be of dyke origin only in cases where a layer locally becomes discordant to gneiss foliation, cuts discordantly across older amphibolitic material (fig. 8) or intersects another metabasite dyke (fig. 9). Thus many amphibolite layers in the gneiss may be of intrusive origin.

The dyke rocks vary from black and dark grey to brownish grey and grey and some display small flecks either yellowish green (epidote) or brown (sphene) in colour. The dykes vary from fine to medium in grain size and are mostly homogeneous but some are porphyritic and contain plagioclase crystals up to 8 mm in length. Some dykes show a variation in composition either in the form of less melanocratic patches within the dyke or as tracts or zones of varying basicity parallel to the dyke. Basic margins may border a less basic core but in some cases a central core is flanked by less basic marginal zones. In one example a less melanocratic tract occupies one half of the dyke. Contacts between the different compositional types in the dykes are diffuse and irregular. Some dykes are conspicuously less basic than others and quartz is megascopically visible. Cross-cutting relationships between basic and less basic dykes have been seen (fig. 9 and plate 2a).

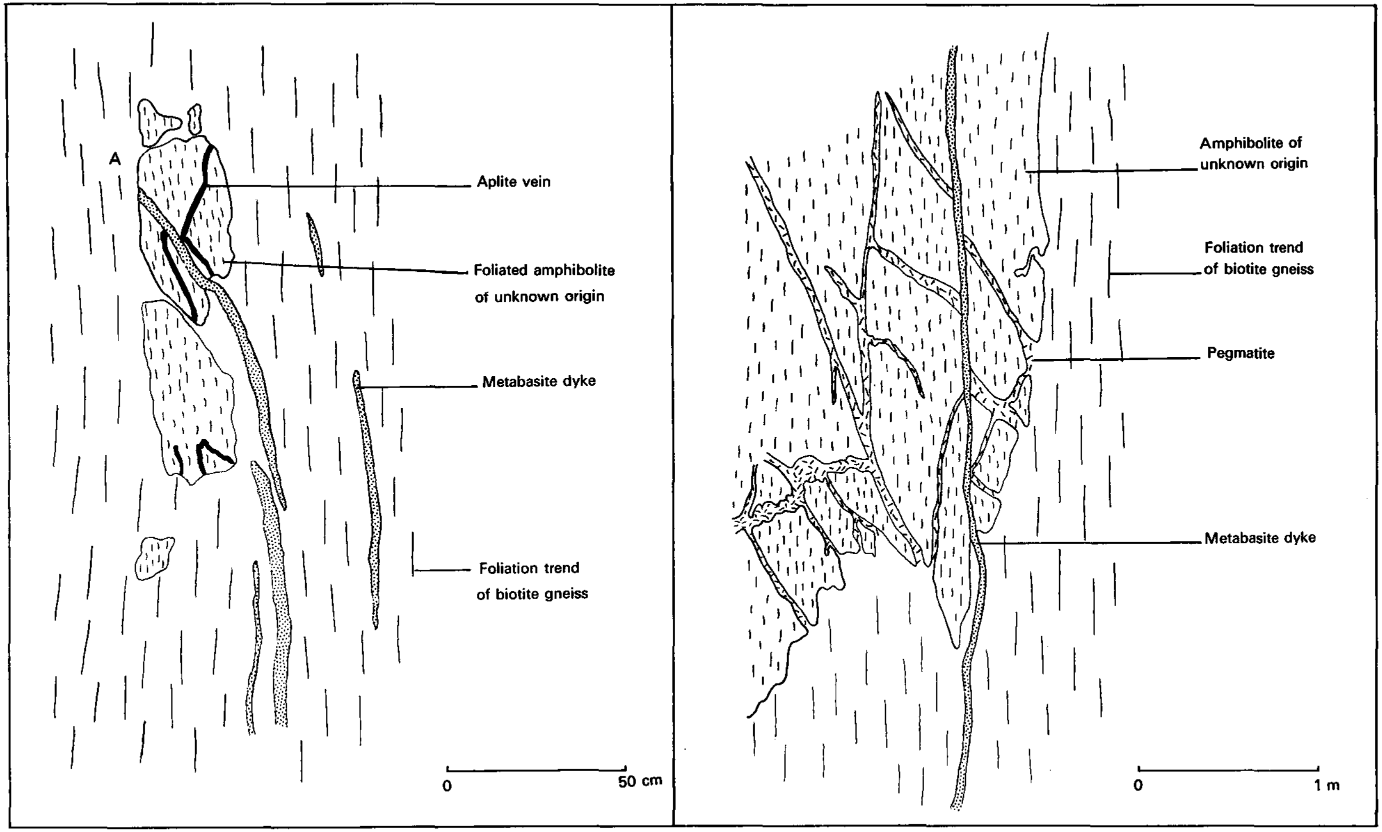

Fig. 8. Two examples in which the intrusive nature of amphibolite layers in the biotite gneiss is revealed by their contact with older amphibolitic material. In both cases the metabasite dykes are younger than the migmatisation of the older amphibolite. In the lower example the dyke has been deformed and broken. Due to reimposition of the gneiss foliation no sign of the dyke exists in pôsition A. Kangârssûp nunâ.

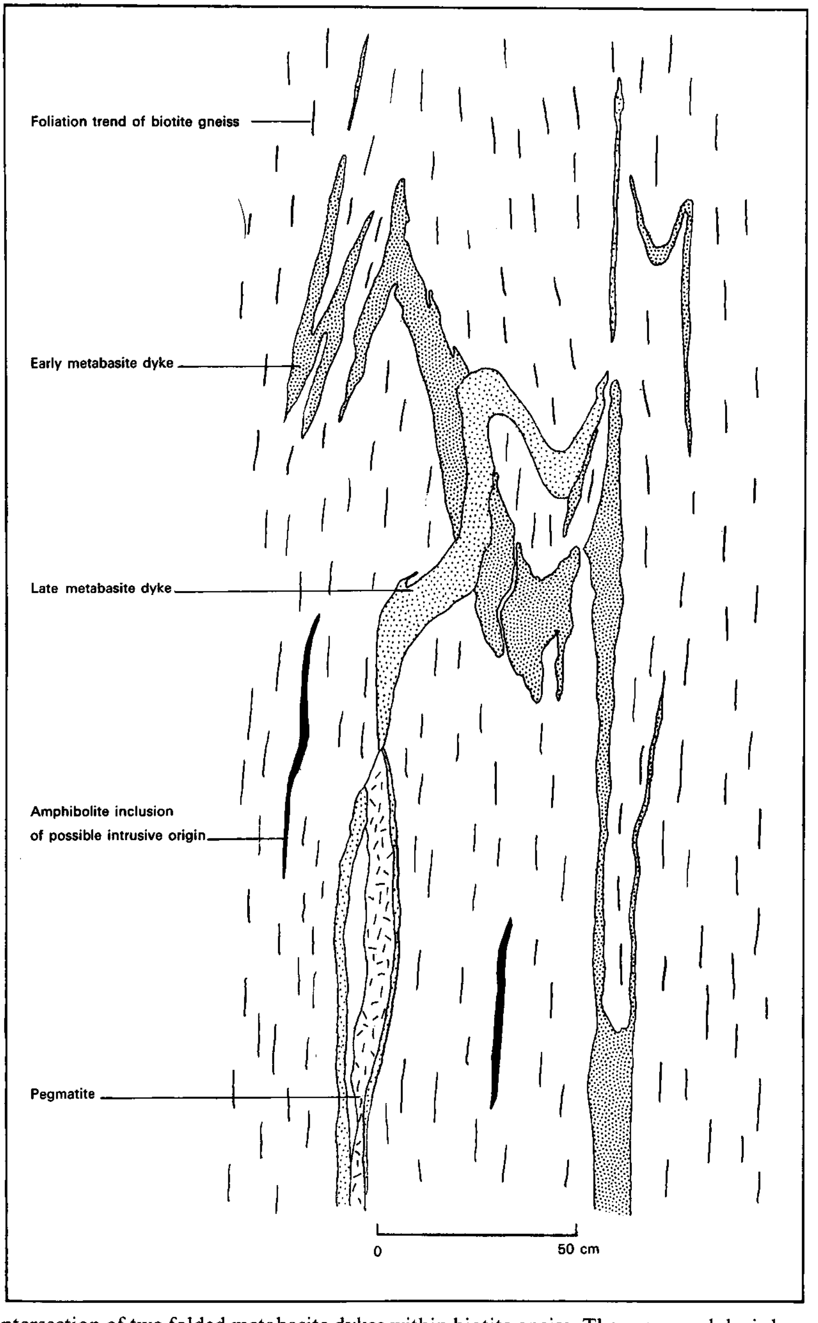

Fig. 9. Intersection of two folded metabasite dykes within biotite gneiss. The younger dyke is less melanocratic than the older. Material from both metabasite dykes exists as isolated inclusions in the biotite gneiss. Sagdliata nunâ.

Foliation is present in some dykes and is formed either by alignment of mafic minerals or by orientation of veins, streaks and flecks of leucocratic material. Mineral foliation may display three patterns. It may be either parallel to the outcrop of the dyke and may even be folded around the crests of folds or may be at an angle to the dyke outcrop, either parallel to the foliation of the host gneiss or at an angle to gneiss foliation showing a sigmoidal pattern within the dyke. This latter feature is similar to that described by Watterson (1965, 1968) and Windley (1966).

Mineralogically the majority of the dykes are amphibolites or epidote amphibolites with hornblende forming the most important mafic mineral, but in some dykes hornblende is subsidiary to epidote and/or biotite, or may even be lacking (see in table 4). Epidote (mainly pistacite) is present in all but a few dykes and it forms up to 33% by volume of the rock. Quartz exists in the majority of dykes, and in less basic types the quartz content can reach up to 15%. A notable feature of the dyke suite is the distribution and quantity of sphene. This mineral is present in most dykes but in many it is an essential mineral and forms 20% by volume (sphene amphibolites). In many dykes it exceeds epidote in amount and may even exceed hornblende. In contrast however, some dykes are conspicuously lacking in sphene. Main and accessory minerals are given in the volumetric analyses in table 4.

Textures are xenomorphic-granoblastic, some being directional with hornblende, epidote and biotite forming a foliation. Plagioclase (andesine) and quartz also have a preferred orientation parallel to any mafic foliation. Plagioclase may be severely

Table 4. Volumetric analyses of metabasite dykes. Accessories include apatite, ore and calcite.

GGU Sample No.	Hornblende	Epidote	Biotite	Sphene	Plagioclase	Quartz	Accessories
78372	54.9	8.5	–	1.0	26.0	4.8	4.8
86247	32.9	7.6	4.4	9.3	33.4	9.7	2.5
78280	26.0	–	14.4	–	46.1	10.2	3.3
78326	2.6	33.0	24.6	9.1	18.2	11.1	1.4
78393	54.2	–	–	–	33.8	–	11.9
78391	30.2	21.0	6.5	2.2	39.7	–	0.3
78392	58.6	1.1	0.5	–	35.2	–	4.5
78301	48.9	17.9	1.2	17.8	5.8	5.5	2.8
86257	33.9	–	1.9	–	43.6	19.2	1.4
78307	–	25.1	40.6	8.7	9.9	13.4	2.2
78286	42.3	13.9	–	–	34.4	3.9	5.5
78259	36.1	1.8	1.0	–	53.3	4.6	3.2
78272	64.4	2.5	–	4.0	22.5	2.2	4.3
78282	48.6	16.5	–	18.4	10.3	4.5	1.5

altered into sericite and saussurite, and penninite occurs in a few dykes. Epidote, penninite, sphene and calcite in some dykes occur in veins. Biotite in some slides is a green variety; hornblende is always green. Epidote frequently contains inclusions of quartz and displays a texture varying from poikiloblastic to an intense intergrowth not unlike myrmekitic structure. Sphene in some slides is associated with ilmenite.

Following initial investigations in 1967 it was suggested from field features that two ages of dykes might be present in the area, one group pre-dating and one post-dating the granites (Dawes, 1968). However, field work in 1968 failed to produce new evidence to strengthen this hypothesis. All the metabasite dykes post-date S_2 (see page 36) and some are clearly younger than the granites. However the age relationship between the granites and the dykes occurring in the gneisses is not known and no dyke was found in the gneisses which failed to cut the granite. Furthermore, although it is clear that various generations of dykes exist through cross-cutting relationships of dykes of similar type, no intersections were recorded between migmatised dykes and younger relatively unmigmatised dykes – a relationship critical to a dyke chronology.

One interesting point is the distribution of sphene in the dykes. All the thin sections examined which contain abundant sphene correspond to the dykes which from field features in 1967 were thought might be "older" dykes while those found to be deficient or lacking in sphene were those considered to be post-granite in age. The important question is whether the presence of sphene in the dykes reflects parentage from a magma rich in titanium, or whether the distribution of sphene is simply metamorphically controlled.

Many of the features of the metabasite dykes have been described from the "discordant amphibolites" occurring in other areas of South Greenland: the irregular shape and outcrop patterns of the dykes, the irregular dyke contacts, the association of dykes with shear zones, the presence of a sigmoidal foliation pattern and the inhomogeneity of some dykes are all features described in detail by Watterson (1965, 1968) as typical of late-kinematic dykes. It is considered most probable that the metabasite dykes represent one extended episode of basic to intermediate intrusion which took place at much the same time as the formation of the granites, when country rocks were at elevated temperatures.

Metadolerite rocks

Excluding the metagabbro associated with the metavolcanic succession on the northern nunatak 1340 m (see page 17), three other occurrences of metamorphosed basic igneous rocks exist in the area. The term metadolerite is used here on account of the blastophitic texture present in some samples, but its use for these rocks must not allow them to be confused with the much younger so-called metadolerite MD igneous rocks of the Frederikshåb area to the south (see page 50 and S. B. Jensen, 1966).

The main occurrence is a body about 1 ×2 km in size on Kangârssûp nunâ. Contacts with the surrounding gneisses are not particularly well exposed but the body is quite conspicuous through its contrast in colour and weathering characteristics with the host gneisses. The rock type characteristically breaks down into a brown sand and the development of spheroidal weathering is common.

On a large scale the body is discordant to the gneisses but on a small scale contact relationships are complex. Discordant contacts exist in places but undisturbed, sharp, typically igneous contacts to the gneisses have not been seen. Since intrusion the body has been affected by metamorphism, migmatisation and deformation and contacts have been generally "parallelised" to the structure of the gneisses. On this evidence the body is considered most likely to be pre- or syn-S_2 in age although, since reimposition of regional foliation may have occurred in connection with D_5 (see page 37), it is possible that the body could post-date S_2. Originally the body was possibly stock-like although now contacts vary in attitude from being steeply inclined to shallow-dipping and they are generally sub-concordant to the gneissic structure. In some places at the contact of the body tracts of gneiss are intercalated in the basic rocks; elsewhere contacts are transitional with basic rock grading into host-rock gneiss or granite. In places, especially near the contacts, the metadolerite is agmatised by acid material. Pegmatites, some of which are garnet-bearing, cut both the normal basic rock and such agmatitic localities.

The rocks of the body are medium-grained but there is a variation in type. In fresh samples the rock has a mottled appearance being composed of approximately equal amounts of mafic and felsic minerals; relic ophitic texture may be preserved. There is a gradation from this through a foliated metadolerite where mafic and felsic components have a preferred orientation, to dark grey amphibolitic rocks some of which display a foliation. Some rocks have a distinct greenish colour due to predominant hypersthene and these have an appearance typical of some basic granulite facies rocks. In one locality (immediately NW of camp 68-7) small dykes up to 15 cm in width and composed of a fine-grained facies of the metadolerite, cut the metadolerite. Small pegmatite-filled shear zones disrupt the outline of the dykes.

In composition the rocks are pyribolites (pyroxene-amphibole-plagioclase), pyriclasites (pyroxene-plagioclase) and amphibolites (amphibole-plagioclase) but in a few types, where plagioclase percentage is low, ultramafic rocks occur (see volumetric analyses in table 5). Main minerals are pyroxene (hypersthene and some clinopyroxene), amphibole (mainly hornblende with some actinolite and cummingtonite) and plagioclase. Biotite is often present in accessory amounts and may reach 8%. Main accessories are apatite, calcite and ore. Hypersthene is common and may be strongly pleochroic from grey to pink and pale red.

Textures vary from blastophitic to granoblastic-xenomorphic. Poikiloblastic texture occurs where hypersthene contains rounded inclusions of plagioclase. In the blastophitic textures the original shape of the plagioclase laths is still preserved but the feldspar has recrystallised into sub-grains. Furthermore some relic pyroxene occurs in the centre of hornblende crystals or aggregates but elsewhere hypersthene is stable and in equilibrium with the amphibole. In the granoblastic-xenomorphic-

Table 5. Volumetric analyses of metadolerite from bodies in gneiss. Accessories include apatite, sphene, epidote, quartz, ore and calcite.

GGU Sample No.	Hornblende	Pyroxene	Biotite	Plagioclase	Accessories
78248	47.5	17.9	–	33.0	1.6
78243	48.8	–	–	50.5	0.7
86260	31.2	49.5	7.2	11.9	0.1
86250	59.4	33.6	–	6.5	0.5
86255	33.4	13.7	–	45.2	7.7
86259	42.7	–	2.5	53.4	1.3
78649	29.3	14.6	–	55.3	0.8
78247	23.1	64.2	3.1	8.5	1.0
78201	47.3	–	–	49.9	2.7

textured rocks metamorphic hypersthene is in some samples the dominant mafic mineral; it is slightly replaced by pale green amphibole.

The recognition of the other occurrences of metamorphosed basic igneous rocks is based purely on the presence of blastophitic texture in amphibolitic rocks which form small outcrops in the gneiss. In places such rocks are associated with schistose amphibolites but the snow-cover obscured contact relations with the surrounding gneisses. One outcrop occurs to the south-west of camp 67-1 and the other to the north of camp 67-2, but it is most probable that other amphibolitic rocks in the vicinity of camp 67-2 are of the same age and type. The rocks are medium-grained and non-schistose, and in the locality north of camp 67-2 the rock displays a brown weathering which forms smooth, rounded rock outcrops, a feature characteristic of the main body described above. The rocks are composed essentially of hornblende and plagioclase and no relic pyroxene has been recorded. The original form of the plagioclase laths is crudely preserved but the feldspar has recrystallised into equigranular sub-grains. Hornblende forms large clusters forming the oikocrysts in the blastophitic texture. Garnet occurs in both localities with ore as accessory. Epidote is absent.

Age relationship of dykes to metadolerite rocks

The age of the metadolerite rocks in relation to the metabasite dykes is not definitely known. No metabasite dykes have been seen in the vicinity of the contact zone of the main body and the only dykes seen cutting the metadolerite are clearly genetically connected to the metadolerite (see page 27). The relationship of both the metabasite dykes and the metadolerite rocks to the regional foliation (S_2) suggests that the dykes are younger since they cut S_2 while the metadolerite rocks appear to be pre- or syn-S_2 (see page 27).

Mineralogically the metadolerite is strikingly different to the metabasite dykes, the former being characterised by the absence of epidote and sphene and by the presence of pyroxene. Much of the orthopyroxene in the pyribolite and pyriclasite rocks is interpreted as metamorphic and this suggests high-grade metamorphism which was followed by a retrogression resulting in the replacement of the pyroxene by amphibole. On the other hand, the abundance of epidote in the metabasite dykes indicates a metamorphic assemblage of lower grade. The important question is whether any of the dykes have passed through a high-grade metamorphism and have been subsequently retrogressed to epidote-bearing amphibolites. It is argued later (page 41) that a high-grade metamorphism could pre-date the development of the regional foliation (S_2) and if this is so this metamorphism certainly pre-dates the metabasite dykes which cut S_2.

Granites (granodiorite and adamellite)

A little under half the area is underlain by granitic rocks which can be mapped as units distinct from the gneisses. Gradations exist between the gneisses and granites through nebulitic and homogeneous gneisses (granitic gneisses), and within the granite units marked on the geological map (Map 1) local transitions to granitic gneisses may exist where the granites display a foliation. Areas earlier indicated as gneiss such as "Nasausak" and the northern part of "Kangarsuk" (Kornerup, 1879, Map B) are described here as granite.

The most common type is a medium-grained, more or less equigranular granite which displays a slight foliation produced by biotite and by the alignment of feldspars. Some porphyroblastic types occur in which feldspars may reach 3 cm in length. These may or may not show an alignment parallel to the biotite foliation. In places on the northern nunatak 1340 m, the granite displays rapakivi texture where K feldspar megacrysts are mantled by plagioclase. The megacrysts may contain biotite inclusions. On Kangârssûp nunâ parts of the granite are conspicuously foliated with widely spaced biotite clusters situated in a white- to cream-coloured quartzo-feldspathic matrix. Elsewhere the granites have a grey colour varying from light to dark grey depending on the mafic content.

Compositionally the granites vary from granodioritic to adamellitic with increase in K feldspar percentage (see volumetric analyses in table 6). Main minerals are biotite, plagioclase, K feldspar, quartz, epidote, hornblende, muscovite and myrmekite, while calcite, apatite and ore are accessory. Sericite and epidote are the main alteration products. Biotite is present in all granites and is the most important mafic mineral. In the granite on Kangârssûp nunâ hornblende occurs along with biotite and in some samples it exceeds biotite in amount. Hornblende also occurs in one sample from "Kangarsuk" but in small amounts. Epidote is present either as an accessory or as an essential mineral. In some granites it exists in larger amounts than

Table 6. Volumetric analyses of granodiorites and adamellites. Accessories include apatite, sphene, ore and calcite.

GGU Sample No.	Biotite	Hornblende	Epidote	Plagioclase	K feldspar	Quartz	Accessories
78347	8.0	–	–	31.6	25.5	34.2	0.7
78309	21.3	6.7	6.4	36.2	–	27.4	2.0
86245	7.7	–	0.3	26.3	30.6	34.5	0.4
78377	19.5	1.2	6.9	43.4	1.0	26.5	1.3
78350	22.8	–	11.3	32.8	2.5	29.4	1.1
78207	7.6	23.7	1.4	50.8	1.2	12.9	2.3
86248	8.9	–	0.3	37.6	24.9	27.8	0.5
78284	16.4	5.9	2.0	40.3	1.8	32.6	0.9
86244	11.5	–	0.2	41.5	27.8	18.1	0.8
86246	21.8	–	8.6	25.3	13.5	28.7	2.1

biotite and can clearly be seen megascopically. Allanite forms separate crystals as well as the central part of larger pistacite crystals. In some cases pistacite forms a thin outer zone to allanite crystals. Muscovite is common as large irregular flakes in some granites. Sphene and apatite are common accessories, the former mineral can form large crystals up to 4 mm long. Plagioclase is replaced by sericite and epidote. In some slides microcline replaces plagioclase, elsewhere microcline inclusions in optical continuity occur within larger plagioclase crystals suggesting that some K feldspar pre-dates the plagioclase. Quartz replaces both K feldspar and sericitised plagioclase. Myrmekite exists in many granites at K feldspar-plagioclase boundaries.

Textures vary from xenomorphic-granoblastic to heteroblastic. Porphyroblastic textures are common with larger feldspar crystals set in a finer-grained quartz-feldspar-biotite matrix. Biotite flakes are aligned.

The granites are autochthonous and no evidence exists for the development of a mobile phase. Contacts with the gneisses are transitional and, on a regional scale, concordant. Foliation in the granite is parallel to the contacts of the granite and to the foliation of the gneisses. Locally discordant contacts exist and in these it is clear that the granite post-dates the formation of the regional foliation (S_2) of the gneisses and the included migmatitic amphibolitic enclaves. The granite has developed by granitisation of the pre-existing rocks rendering the gneisses more homogeneous. Microcline occurs in larger amounts than in the gneisses, and microclinisation was an important process. Phases of pegmatisation occurred after the granite formation and numerous generations cut the granite (see page 38). Early pegmatites are lacking or are deficient in K feldspar, while later generations are characteristically K feldspar-rich. Metabasite dykes exist within the granites and in some places they are associated with pegmatitic material.

Structure of the complex

Over half the area is composed of gneissic and schistose rocks and although many of the gneisses are gradational through granitic gneisses to the granites of the complex, foliation trend and/or lithological layering of the gneisses are generally evident. The included basic and ultramafic rocks in the gneisses act as structural "markers" (fig. 10) and although only few are continuous for any distance, they show on a small scale structural patterns which demonstrate that the complex has passed through a long and complicated structural history. However the presence of discordant amphibolitic rocks in the gneisses which exist as dykes and sub-concordant to concordant layers proves that not all amphibolitic material in the gneisses is of a similar age. Furthermore the possibility cannot be ignored that some of the metavolcanic rocks (see page 55) post-date early gneissic rocks. Not all amphibolitic material in the gneisses

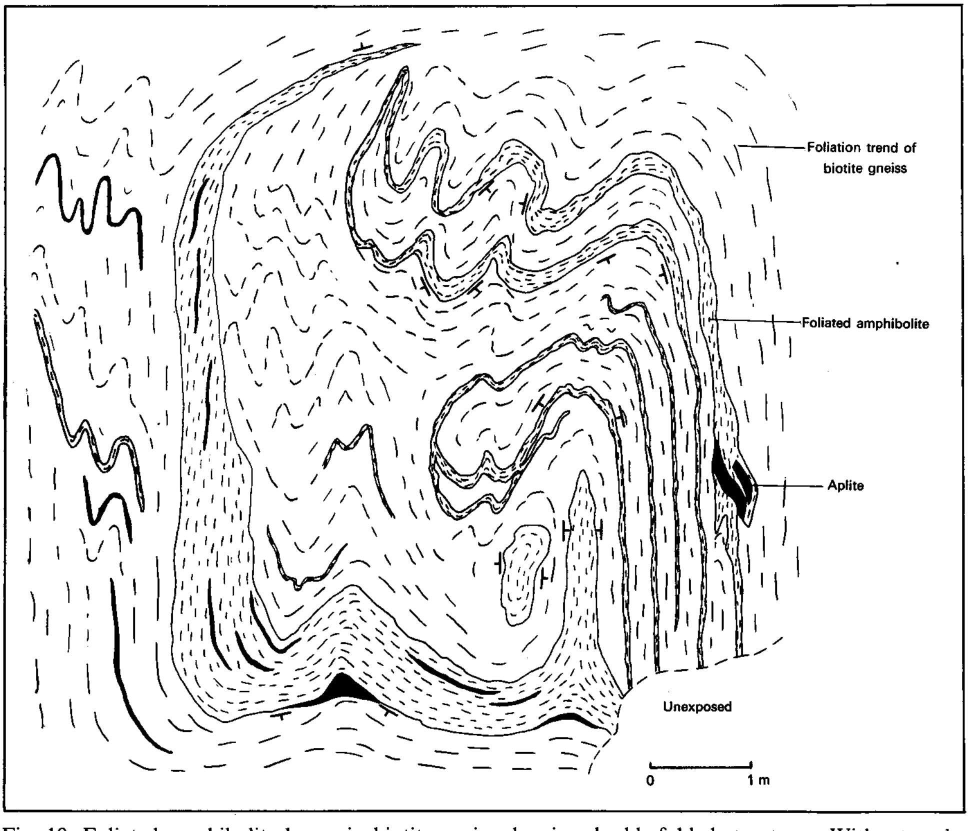

Fig. 10. Foliated amphibolite layers in biotite gneiss showing double-folded structures. Without such amphibolitic material the structural pattern of the gneiss in this locality would be impossible to discern. NE trending, possible D_5 structures, refolding earlier isoclines. Eastern "Kangarsuk".

has passed through the same deformational history and some structural elements recognised in the gneisses may not be correlatable with structures in the amphibolites.

Minor structures

The gneisses usually display a foliation due to the parallel arrangement of mafic minerals, and this set of planar surfaces is referred to here as the regional foliation. Where amphibolitic material forms layers and tracts within the gneiss, regional foliation of the gneiss is generally parallel to the schistosity in the amphibolite and also to any compositional banding. Where metavolcanic rocks occur, the foliation is parallel to the lithostratigraphic banding of these rocks. However, as a consequence of what has been said above regarding the varying age of amphibolitic rocks, the relationship between regional foliation and the primary structure of the rocks from which the gneisses have been derived is not known, except in local cases where feldspathisation of amphibolite has resulted in a gneiss inheriting the parental foliation. The present regional foliation of the gneiss may bear no relationship to the structure of the pre-gneissic parental rock. In places it is even discordant to the structure and schistosity of associated amphibolites, as seen by the discordant relationships between gneiss and structure of the amphibolitic inclusions (fig. 11) due to reimposition of regional foliation. In some localities more than one set of planar surfaces can be recognised and intersections of two sets may occur. In some cases the earlier foliation is completely obliterated by the later (fig. 11). It is clear that the regional foliation is not of one age and that reimposition may have occurred several times during the whole structural history.

Other minor structures occurring are fracture cleavage, axial-plane cleavage, linear structures and mineral lineations. Folds are of both small and large scale and throughout the area there are many examples of interference patterns due to superimposed folding. Small-scale dome and basin structures, eye folds, and examples of folded axial planes of earlier structures are common (figs. 10, 11, 12).

Pattern of regional foliation and folding

Over the whole area the regional foliation shows a preference for a NE trend but in parts of "Kangarsuk" and Kangârssûp nunâ, and on "Nasausak" and the northern nunatak 1340 m, it swings to the NW. The gneiss foliation on "Kangarsuk" and Kangârssûp nunâ characteristically dips to the south and the small-scale NE folds there have southerly plunging fold axes. The flexuring of the regional foliation on these semi-nunataks to the north of Kangârssûp taserssua is considered to be due to a series of southerly plunging folds with general NE-trending axes. Local variations in the trend of the regional foliation, seen particularly on Kangârssûp nunâ, are considered to reflect a separate set of NW-trending open folds, since small-scale NW-trending folds having axes plunging both to the NW and SE refold NE-trending folds. The NE-trending structures post-date at least two ages of folds since double-

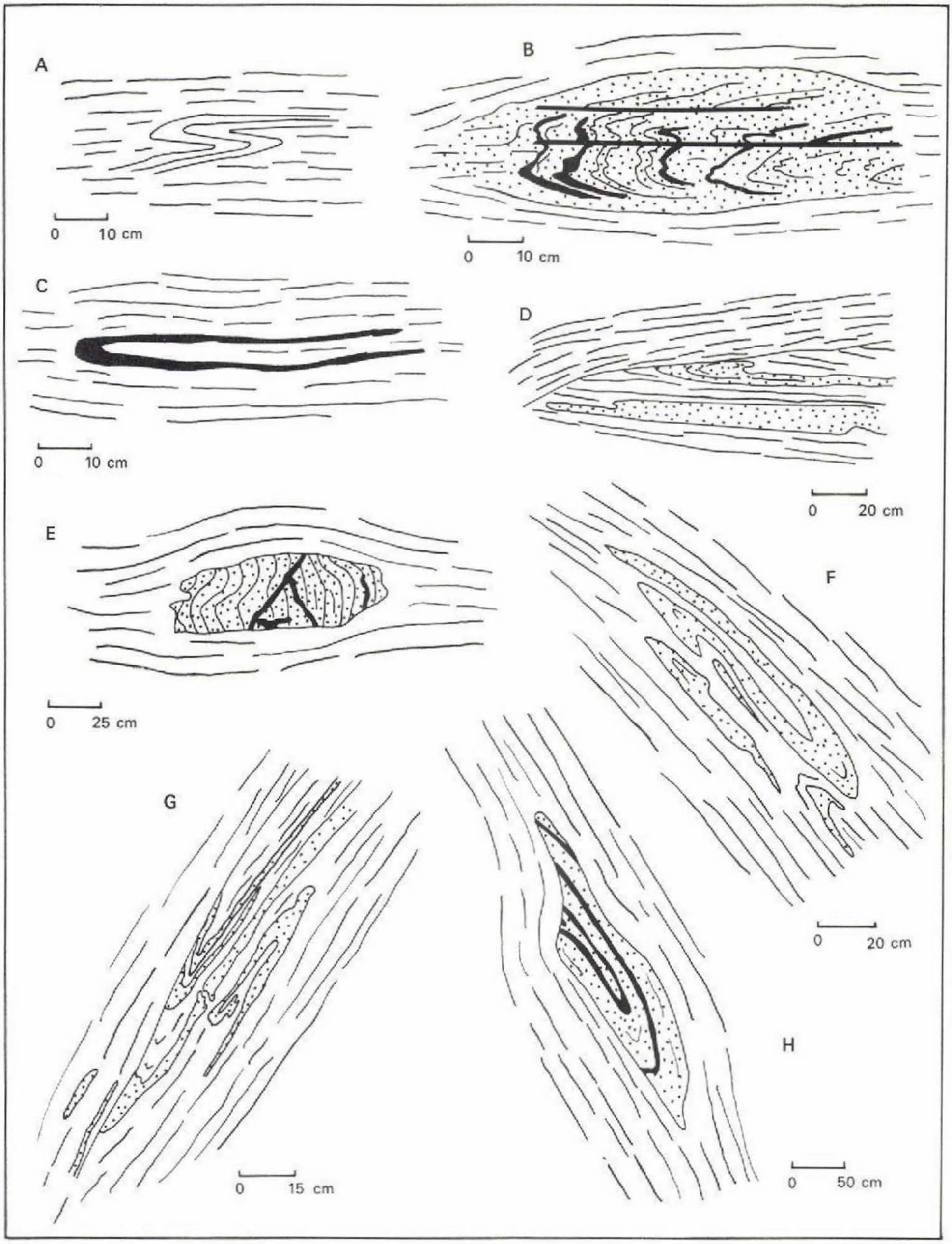

Fig. 11. Composite sketch of small-scale fold structures illustrating the reimposition of gneiss foliation. Black veins represent acid material, amphibolite is stippled. Intrafolial folds (A, B, C), intersection of two gneiss foliations (D, G), inclusions of folded migmatised amphibolite within a discordant gneiss foliation (E, H) and folded amphibolite relics in uniformly trending gneiss (F).

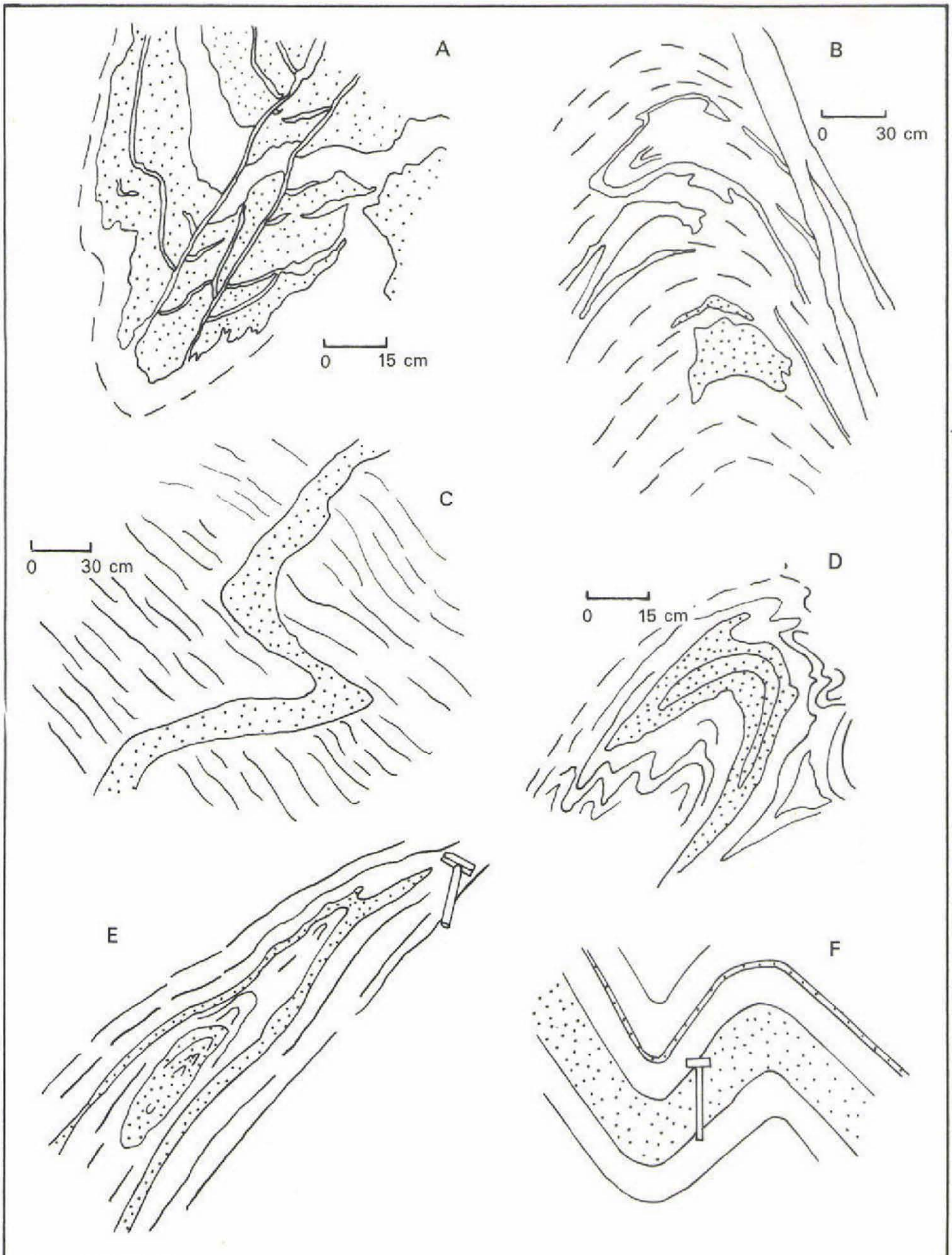

Fig. 12. Composite sketch showing the type of folds in the gneisses which are younger than those structures illustrated in figure 11. Open veins represent acid material, amphibolite is stippled. A: D_6 fold with axial-plane migmatisation, B: D_5 fold coaxial with earlier isoclines, C: open D_5 fold in metabasite dyke, D: D_5 fold refolding an earlier double-folded close structure, E: D_5 isoclinal fold with a close structure in core, F: concentric open fold.

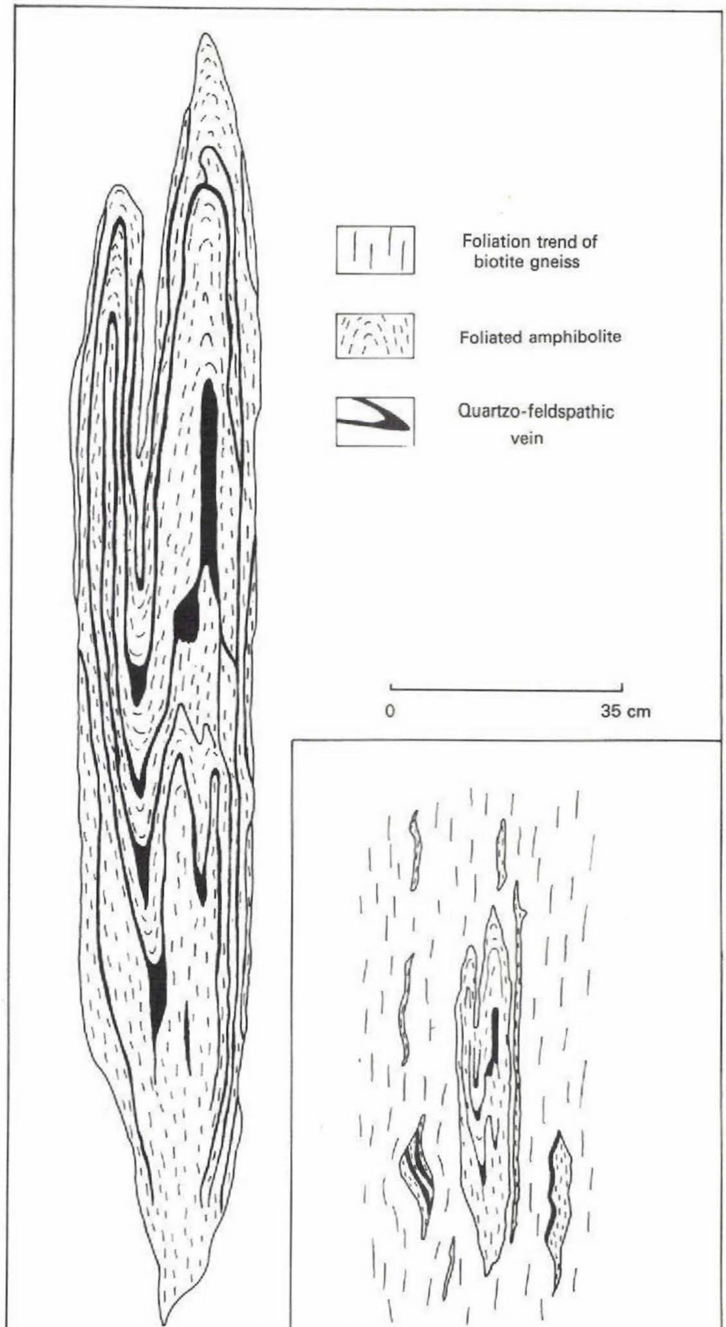

Fig. 13. Double-folded (D_2 and D_3) migmatised amphibolite inclusion enclosed within the S_2 foliation of the biotite gneiss. The two ages of isoclines in the inclusion are depicted by the quartzo-feldspathic veins. Southern "Kangarsuk".

folded amphibolite enclaves (fig. 13) exist isolated within, and in places are truncated by, the regional foliation which itself is folded by the NE-trending folds.

On Sagdliata nunâ the position of two closely-spaced tracts of amphibolite suggests that they may be the limbs of a tight isoclinal fold (small-scale folds of such a type are common in the surrounding gneisses) with the hinge zone hidden by the ice on the extreme south-eastern side of the nunatak. If so, this isocline has been refolded around an open, NE-trending, steeply plunging fold, the hinge of which is seen in the main amphibolite to the south of peak 1200 m. This is the only major structure depicted by amphibolite layers, all other structures in the amphibolites being on a relatively small scale. Since amphibolite layers cannot be traced for long distances due both to their inconsistent nature and also to the character of the study area as isolated nunataks and semi-nunataks, correlation of particular folds cannot be made in detail.

In many places the presence of metabasite dykes reveals the effects of deformation which are not conspicuous in the gneisses. For example a NW-trending dyke cutting through NE-trending gneiss may be folded so that axial traces are parallel to the gneiss foliation (fig. 14). The gneiss has suffered the same stress conditions as the dyke but has been flattened while the dyke has been folded. Although use of metabasite dykes is limited in the structural study since it is not definitely known if all dykes are of similar age, it is clear that the majority have been deformed at least twice and they are folded on both NE and NW axes. Such dykes post-date the regional foliation (S_2) and the isolated double-folded inclusions existing within that foliation.

Phases of deformation

The maximum number of deformation phases determinable in a single locality from interference patterns in gneiss and amphibolite is four but by comparison of fold styles, relationship of folds to the planar surfaces of the gneiss and to migmatisation, and from information from the deformation of the metabasite dykes, at least six main phases of deformation can be recognised, termed here D_1 to D_6:

D_1: Formation of early schistosity and foliation (S_1), including some concordant migmatitic streaks and veins in old amphibolite seen as the earliest event in double-folded inclusions of amphibolite within gneiss (see fig. 13).

D_2: Folds now represented by small-scale isoclinal structures which fold S_1 and the early migmatitic veins in the double-folded inclusions within the gneiss. Such folds may also exist in the gneiss as isolated intrafolial folds (see fig. 11).

D_3: Represented by folds which are now isoclinal and which fold the axial planes of the D_2 structures. Such folds exist in the double-folded inclusions in the gneiss and probably in the gneiss as intrafolial folds in which limbs of folds are truncated by gneiss foliation. Only hinges of such folds may be preserved.

D_4: Major reimposition of regional foliation (S_2) indicated by the isolation as enclaves of the double-folded amphibolitic material and by the truncation of D_2 and D_3 structures by the foliation.

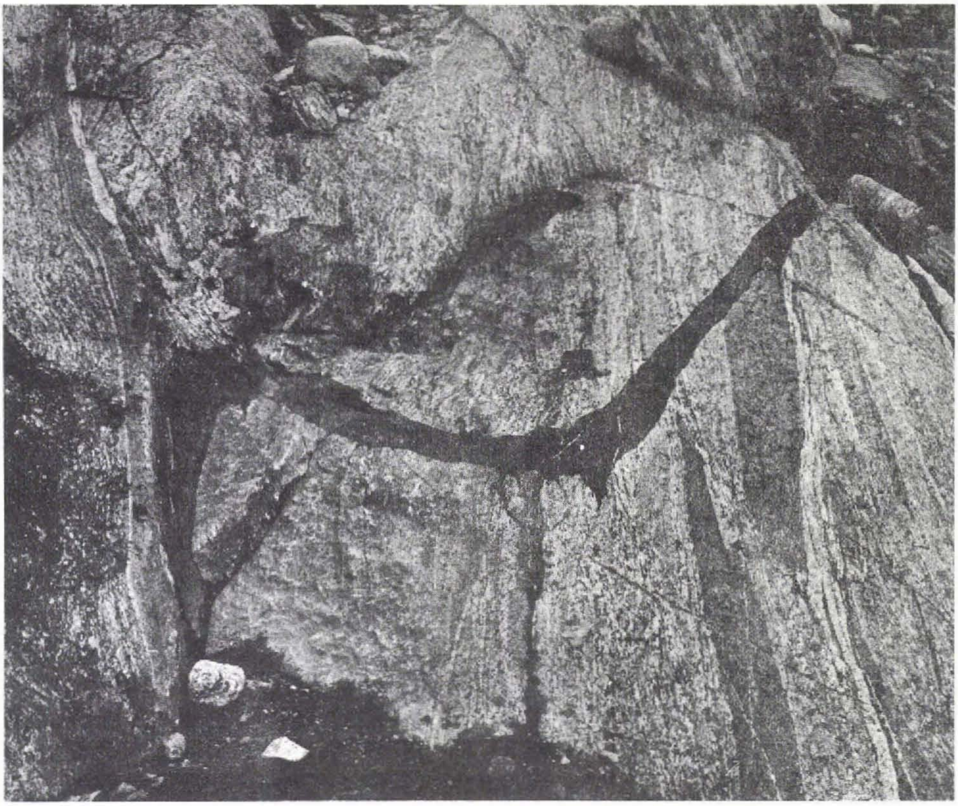

Fig. 14. Open NE-trending folds developed in metabasite dyke within NE-trending biotite gneiss. Sagdliata nunâ. Compass, 10 cm long, as scale.

The granites of the area are considered to have been formed at about this stage in the structural history and could be associated with the D_4 deformation. The granites post-date at least two phases of folding since tracts of complexly folded gneiss exist as relics within the granite.

D_5: A main phase of deformation which folded S_2 and produced open to close, large- and small-scale structures, which now have both southerly and northerly plunging fold axes. General trend of the folds is NE but folds vary in trend due to later deformation and NNE to ESE axes may occur. Axial planes vary in attitude considerably but axial-plane migmatisation is common, in places along shear surfaces. Mineral lineation especially of hornblende is common along fold axes. The deformation may also be connected to a local reimposition of a gneiss foliation (S_3) since some metabasite dykes which cut S_2 are truncated by a second foliation (fig. 8).

D_6: The deformation produced general NW-trending folds which refold the D_5

structures and which are mainly open in style. Fold axes plunge both to the SE and NW with axial planes commonly dipping to the SW. Some axial-plane migmatisation occurred (fig. 12) but other folds appear to post-date the migmatisation.

Later deformation (D_7) affected the complex after the formation of the NW-trending D_6 folds and some of the fractures and shear zones described under "post-orogenic events" (page 42) may have been initiated at this time. Some of the shear zones are followed by undeformed pegmatites which are genetically connected to the gneiss-granite-amphibolite complex.

The main fold types are illustrated in figures 11 and 12.

Migmatisation and pegmatisation of the complex

The gneisses and to a lesser extent the granites and amphibolites of the complex all bear quartzo-feldspathic material, either as migmatitic streaks, veins or layers, or as coarser-grained material to which the term pegmatitic is better suited. By relationships to the deformation phases and to the metabasite dykes of the complex, a number of phases of quartzo-feldspathisation can be recognised.

Phases of quartzo-feldspathisation

The earliest migmatitic material recognised occurs as small quartz-feldspar veins which are folded by D_2 and D_3. They are all fine-grained and rarely reach more than a few millimetres in width. The veins are concordant to the early schistosity (S_1) of the basic enclaves which occur within the later schistosity (S_2) of the gneiss. The veins clearly pre-date larger tracts of felsic material which developed in connection with D_4 and which now exist as veins, streaks and layers parallel to the regional foliation (S_2). Such layers can reach metres in thickness but the majority are below 30 cm. More than one generation of felsic material is present and metabasite dykes clearly truncate migmatitic veins parallel to S_2 but are themselves cut by later migmatitic veins. In general, sub-concordant to discordant veins and layers in the gneisses post-date earlier concordant material. All generations are folded by D_5 and D_6. Some migmatisation also occurred during D_5 and D_6 as illustrated by the development of quartzo-feldspathic material along axial-plane surfaces of the later folds (fig. 12).

Excluding the quartzo-feldspathic material mentioned above two main groups of pegmatites of different ages can be recognised. One group is genetically related to the granites of the complex and the other is a later development post-dating D_5 and D_6.

Pegmatites of the earlier age group are the sheets and dykes cutting the granite (page 30) which are particularly conspicuous on the eastern side of Sagdliata nunâ and on the western side of Amârtoq. The pegmatites vary from a few centimetres wide up to several metres and they can be irregular and form an anastomosing pattern. Some sheets are closely spaced and this produces a banding in the granite. Numerous generations of pegmatites occur as seen from the cross-cutting relationships. Pegmatites of this group can be deformed and in the gneisses examples of pinch and swell structure occur. Large irregular masses and layers of pegmatitic material also occur such as those which cut the amphibolite on the west side of "Nasausak". The oldest pegmatites of this earlier age group are mainly composed of plagioclase and quartz with muscovite, biotite and epidote while later pegmatites are K feldspar-bearing and contain in addition plagioclase and quartz with biotite, muscovite, epidote and ore. Some myrmekite exists and muscovite replaces plagioclase.

The second group is represented by sharp-bordered, regular dykes up to 5 m wide which are undeformed. Many pegmatites occur in shear and fault zones and such pegmatites tend to occur in small swarms, for example on the south-east side of Kangârssûp nunâ where many dykes have a NW trend, while on south-west "Kangarsuk", SW of camp 67-5, pegmatites have a 60-70° trend. The majority of pegmatites are of the simple type (Landes, 1933) but some have quartz or quartz-rich central zones. Different generations exist and some dilatational cross-cutting relationships have been noted. Such pegmatites are mainly composed of K feldspar (much of which is perthitic microcline), plagioclase, and quartz, with biotite, garnet, muscovite, myrmekite, epidote (pistacite and allanite) and ore in lesser amounts. Magnetite forms clots up to 5 cm in size in some dykes.

Relationships on the northern nunatak 1340 m

As described elsewhere (page 13) amphibolites in the gneisses have been invaded by quartzo-feldspathic material to produce various types of amphibolitic rocks, but on the northern nunatak 1340 m, a contact between metavolcanic rocks, and granite and granitic gneiss is conspicuous in that the contact is banded, and the passage from granite to unmigmatised metavolcanics takes place over 2 km. The metavolcanic rocks are at least 3 km thick and they overlie granite and granitic gneiss. The succession dips to the east between 35 and 60°. The quartzo-feldspathic layers cutting through the metavolcanics are in detail discordant to the metavolcanic rocks. The general trend of the felsic layers is NW and they dip steeply to the east while the metavolcanic rocks vary in strike from NNE to NNW.

In the east the quartzo-feldspathic material forms discrete layers and veins in the metavolcanics. The largest vein here is 10 m wide but the majority are thinner. The layers become more frequent and generally wider towards the west where they frequently branch. In the region of the summit of the nunatak, metavolcanic and quartzo-feldspathic rocks form approximately equal amounts while to the west isolated patches of metavolcanic rocks exist within granitic rocks. Further to the west the granite and granitic gneiss underlying the metavolcanics contain no conspicuous inclusions of amphibolitic rocks.

The quartzo-feldspathic veins and layers in the metavolcanics vary in type. In the east they are fine-grained (microgranite) being composed mainly of quartz, plagioclase, muscovite and garnet with or without epidote and biotite. Sphene is accessory. The garnets are conspicuous but are always below 1 mm in size. In thin section biotite is pleochroic from green to brown. Muscovite may form a foliation. Epidote crystals may contain a centre of allanite and in some cases epidote is a late mineral occurring in dislocations. The veins and layers are cream in colour with tints of pale green and pink. Some veins are quartz-rich but in some places a later generation of thin quartz veins post-dates the layers. Towards the west some coarser-grained layers exist in which muscovite flakes may reach 1 cm in size. In places the layers are composite being composed of an intercalation of zones of varying grain size. Quartz can be smoky and in some places feldspars have a grey-bluish colour. Garnets are restricted to the fine-grained rocks. In some places the coarser-grained rock truncates the foliation of the microgranite and is clearly younger. K feldspar, which is absent in the microgranitic veins, characterises the coarser-grained material. The veining material in the region of the summit of the nunatak is grey, biotite-bearing and is a fine- to medium-grained granitic rock. It is cut by later pegmatites some of which are sharp-bordered dykes, others of which are more diffuse layers parallel to the slight foliation in the granitic rock. This granitic rock grades into the granite of the western part of the nunatak which is biotite-bearing and in places porphyroblastic. The granite is cut by both pegmatites and aplitic material.

Similar relationships occur on the eastern nunataks where granitic layers trend WSW but are generally conformable to the amphibolitic schists. Both contacts are strikingly similar to the relationships occurring between gneiss and metavolcanic rocks in the Ravns Storø supracrustal belt (Windley et al. 1966). The relationship on the northern nunatak 1340 m is interpreted as a front of migmatisation since it is clear that the metavolcanics have been encroached upon by acidic material apparently from beneath, but this interpretation holds no implications about the relative ages of the metavolcanic rocks to the underlying gneiss complex (see page 54).

Metamorphism of the complex

The present mineralogy of the complex indicates a metamorphic grade corresponding to the amphibolite facies of Fyfe & Turner (1966) or the almandine-amphibolite facies of Winkler (1967). Little is known about the early metamorphic history of the complex and although metamorphism accompanied the early deformation, the effects of the metamorphism have been severely altered by later recrystallisation.

Indications of an early high-grade metamorphism (possibly reaching granulite facies conditions) is provided by the presence of metamorphic orthopyroxene in both the metamorphosed basic intrusions and some of the ultramafic rocks. The age of this high-grade metamorphism resulting in the formation of orthopyroxene either by simple recrystallisation of igneous pyroxene or as a metamorphic mineral developed from other minerals is difficult to fix in relation to deformation. The basic igneous rocks in which orthopyroxene exists appear to pre-date D_4 deformation since contacts show a tendency to be parallelised by the regional foliation, and in places contacts are made up of intercalated layers of gneissic and basic material (see page 27). Although sampling was not carried out systematically enough to enable accurate conclusions to be drawn about the distribution of orthopyroxene-bearing rocks in the main metadoleritic body, it appears that where intercalated contacts exist, the basic rocks are amphibolitic and at a lower grade than the pyribolitic and pyriclasitic rocks present elsewhere. If this is correct then it would suggest that the high-grade metamorphism pre-dates D_4.

The orthopyroxene-bearing assemblages are relic and in many cases the pyroxene is replaced by amphibole. No orthopyroxene is seen in the gneiss or granites of the complex. The present mineralogy of the gneisses is a result of post-D_3 metamorphism, and biotite and hornblende producing the foliation of the gneisses (S_2) are products of this metamorphism. Hornblende may form a lineation along fold axes while garnets can occur in association with axial-plane migmatisation of D_5 folds. Hornblende and biotite present in schists are bent around D_5 fold crests and it would seem that during the time span between D_4 and D_6, P-T conditions were as high as those corresponding to the amphibolite facies. The main minerals of the gneisses, hornblende, epidote, garnet, biotite, plagioclase, K feldspar and quartz, are products of this metamorphism while diopside, tremolite and sphene developed in the calc-silicate rocks. In the basic rocks hornblende, clinopyroxene, biotite, garnet and epidote developed while in addition to these, tremolite, cummingtonite and sphene formed in the ultramafic rocks.

Some mineral assemblages, for example the talc- and actinolite-rich schists on J. A. D. Jensens Nunatakker, and the talc-, chlorite-, actinolite- and calcite-bearing assemblages in some of the ultramafic zoned-ball structures indicate a lower grade corresponding to the greenschist facies of Fyfe, Turner and Verhoogen (1958). Actinolite-tremolite-calcite assemblages which occur locally in some of the calc-silicate rocks and in the rim zones of the ultramafic balls, are according to Winkler (1967, p. 22) characteristically absent in amphibolite facies rocks while anthophyllite, according to Winkler (op.cit), is not present in the greenschist facies. The anthophyllite is probably a product of amphibolite facies metamorphism while the outer actinolite-rich zone and probably the outer shell of biotite developed at lower P-T conditions corresponding to the greenschist facies. In some balls greenschist facies minerals exist in the central part and their presence suggests a low-grade metamorphism earlier than that producing the anthophyllite rim zone. Epidote is common in the gneisses, granite, amphibolites, calc-silicate rocks and metabasite dykes of the complex and it commonly replaces amphibole. Some of the epidote may thus be due to the retrogression to greenschist facies.

POST-OROGENIC EVENTS

Numerous events post-date the main plutonic development of the gneiss-granite-amphibolite complex. These are divisible into three categories: basic intrusion tectonism and metamorphism.

Basic intrusion

All intrusion of basic magma took place along steep to vertical linear fractures to form basic dykes. In some cases a close relationship can be seen between fracturing and dyking, and some dykes show abrupt changes in trend due to pre-existing fractures. Numerous directions of basic dykes exist and various dyke types can be recognised, but relative ages of types are not known in detail. Dykes are not so common as in the basement farther south. They are relatively small: one dyke reaches 80 m in width, the rest are all below 25 m wide. The smaller dykes are difficult to follow and because the study area is divided by ice into nunataks and semi-nunataks, intersections of dykes are few and only four cross-cutting relationships exist by which relative ages of dyke generations can be established with certainty. It is not known how far the various directions of dykes represent actual generations of basic intrusion.

Ten groups of dykes are recognised below on the basis of all available features, direction, texture, mineralogy, etc. but dykes separated into different groups for description may be of a similiar age. In composition six groups are doleritic, four of them showing a gradation to metadolerites (groups 1 to 4); one group (9) is composed of biotite-olivine dolerites and the remaining dolerite group (8) comprises calcite-bearing dolerites. Four groups are lamprophyric. Of these two groups are spessartites (6 and 7), one group (10) has both biotite and pyroxene, and in places, olivine as essential minerals and has a composition between spessartite (hornblende and/or pyroxene) and kersantite (biotite) while the last group (5) possesses some characters of dolerite, is porphyritic and contains biotite, calcite and olivine.

110-120° dolerite dykes (1)

About twenty dykes of this group have been noted, the most important examples occurring in two small swarms on Kangârssûp nunâ and Sagdliata nunâ. On Kangârssûp nunâ the swarm is composed of one main dyke which reaches 80 m in width plus many thinner dykes all below 6 m in width. On Sagdliata nunâ the largest dykes reach 15 m in width, the rest are all below 5 m. Other occurrences are on J.A.D. Jensens Nunatakker where the largest dyke reaches 20 m in width and in the southern part of "Kangarsuk". Some dykes vary from the 100-120° trend. A single dyke on southern "Kangarsuk" for instance varies from 80° to 130° while the main dyke on Kangârssûp nunâ has a variable trend between 100-125°. Dyke apophyses frequently occur and "en échelon" arrangement is not uncommon in the smaller dykes. On Sagdliata nunâ a 12 m dyke splits up into a number of thinner dykes when traced to the west.

The dykes are dark grey to greyish brown on weathered surfaces and they have sharp, chilled contacts to the host rocks. The largest dykes tend to form ridges in the terrain. Grain size varies from fine, as characteristic of the smaller dykes and in the chilled margins of the larger dykes, to medium and coarse in the larger dykes. The central part of the 80 m dyke on Kangârssûp nunâ is a coarse-grained gabbro which grades outwards into medium-grained dolerite. Ophitic texture is everywhere present. In some localities the dolerite is slightly porphyritic with feldspars up to 2 cm in length being sparsely distributed. Evidence of multiple injection exists in some places and in one locality crude magmatic layering occurs. Here layers up to 15 cm in width of more leucocratic, finer-grained dolerite alternate with darker coarser-grained rock. Contacts between the layers are vertical and parallel to the contact of the dyke.

A notable feature of the main 80 m dyke on Kangârssûp nunâ is the presence of thin, cross-cutting, pale cream-coloured veins in the contact zones. Such veins are not restricted to the margins of the dyke although they are most common there. Some veins have been noted in the central parts of the dyke but these have not been traced continually to the contacts. Only one vein has been seen to continue and pass out and merge into the host rock gneisses. The largest vein noted was 4 cm in width; usually they are below 1 cm. Many strike at right angles to the contact of the dyke but other directions occur. The veins are fine-grained and commonly have sharp, straight contacts to the dolerite. Some are rather irregular, discontinuous and wisp-like. The veins are characterised by intergrowths of quartz and feldspar (mainly plagioclase) which resemble both graphic intergrowth and myrmekite structure. The veins are interpreted as rheomorphic in origin due to a heating of the adjacent country rock during basic magma intrusion, followed by a back-veining into the dolerite. Other veins in the dolerite are tectonically controlled and some small fault and shear planes act as sites for the development of quartzo-feldspathic veins together with darker epidote-chlorite veins. One epidote-rich vein reaches 8 cm in width.

In the northern part of the area the marginal parts of the dykes have been crushed and sheared by movements parallel to the contacts. The chilled margins of the dykes become obliterated and the rock takes on a greenish appearance (for more detail see 30-50° dykes below).

The rocks are metadolerite being composed of pyroxene (colourless to brownish augite), plagioclase and ore together with the transformation products of these minerals – amphibole, biotite, epidote, chlorite and sericite. Apatite and sphene are accessory. Olivine has been noted in some of the least altered types. The pyroxene is rarely fresh and it is either partially or completely replaced by a mixture of pale green to bluish-green amphibole (uralitic hornblende) and epidote. The dykes in the northern part of the area show the most severe replacement, pale green pseudomorphs after pyroxene occurring in ophitic texture with severely altered plagioclase. The least transformed types (J.A.D. Jensens Nunatakker and the southern part of the area) display pyroxene crystals with marginal zones of replacement minerals although some slides show more severe replacement of the pyroxene and pseudomorphs contain cores of pyroxene. Plagioclase is always altered, either mildly sericitised or severely replaced by epidote and sericite. In the severely altered types clusters of epidote crystals replacing plagioclase reach 1 cm in size. Biotite, both green and brown varieties, may occur in association with uralitic amphibole.

30-50° dolerite dykes (2)

About twenty-five dykes of this group exist in the area. Possibly there are two generations, one having a more NNE strike, the other a more NE strike. A cross-cutting relationship between a NNE dyke and a NE one occurs on the nunatak Isigait but the locality has not been visited. Main occurrences are the small swarm of dykes on Isigait and in the northern part of Sagdliata nunâ, the dykes on "Kangarsuk", and the eastern swarm on Nûata kujalia and Nûata kangilia. Dykes of this group also outcrop on the small nunatak 1024 m and on the eastern nunataks. The largest dyke is 25 m in width (Nûata kujalia) but the majority are smaller and vary between 4 to 10 m. Irregularities in trend of the dykes are common and one dyke in southern "Kangarsuk" varies from NE to almost E-W. En échelon arrangement is common, especially in thinner dykes and some have apophyses, branch or divide along their lengths or terminate by splitting into many smaller dykes.

Many features of the dykes resemble those of the 100-120° dykes described above. The colour of the majority of dykes is dark grey; chilled contacts and ophitic texture exist but no evidence of multiple injection or of magmatic layering has been seen. The dykes are fine- to medium-grained and in places porphyritic with feldspars up to 3 cm in length. Commonly feldspars are below 1 cm. Rheomorphic veins of the same nature as described for 100-120° dykes occur at many places along the 15-20° dyke on "Kangarsuk" to the NW of camp 67-4. At one locality a small 1.5 cm acidic vein is cut and offset by an 80° internal shear in the dyke. Away from the intersection, the shear plane has been partially healed and this confirms the syn-intrusion age for the acidic veins.

Some dykes are epidotised and bear epidote-rich veins in connection with shear zones. Such dykes tend to have a lighter grey colour than "normal" dykes. The dykes of the swarm in northern Sagdliata nunâ are characterised by a greenish-grey colour and by sheared and foliated marginal zones. For example one 4 m dyke has two marginal zones each of 20-25 cm wide composed of a fine-grained, crushed, green rock with a well-developed fissibility – a rock which easily weathers and is difficult to sample. Such marginal zones may contain small lenses of leucocratic material or may be traversed by sub-parallel quartzo-feldspathic veins. Epidote also is abundant in such zones and may exist in the acid veins. Many of the dykes in this swarm have irregular trends but in one 50-80 cm dyke the change in trend from 50° to 150° appears to be due to deformation. The dyke is composed of a green fine-grained rock which resembles the margin of the larger dykes.

The mineralogy of the dykes greatly resembles that of the 100-120° dykes described above. All dykes show some transformation and pyroxene exists in all stages of replacement. In the most severely transformed types amphibole pseudomorphs after the pyroxene occur. Plagioclase is replaced; nowhere has it recrystallised into sub-grains. No olivine has been noted. Adjacent to the rheomorphic veins, brown pleochroic amphibole exists, as well as the pale green uralitic amphibole. In the sheared margins ophitic texture has been destroyed and the texture is fine-grained and can be schistose. Main minerals are epidote, a colourless to pale green amphibole, feldspar, quartz, biotite, muscovite and ore. Calcite in places forms clots. Nearer the centres of the dykes the texture is heteroblastic with crystals of amphibole and epidote situated in a fine-grained matrix of epidote, mica, quartz, feldspar and amphibole. Some small calcite-quartz veins exist.

NW dolerite dykes (3)

Two dykes of this group exist on Kangârssûp nunâ, both of which have a remarkable similarity in mineralogy, texture and state of transformation to dykes of groups 1 and 2. They are placed as a separate group solely on account of their distinctive trend. One is 3 m wide, the other 2 m. They are fine-grained, brownish in colour and have sharp, chilled contacts to the host rocks. Other NW-trending dykes which have been seen but not sampled may belong to this group.

The dyke rock is a metadolerite and the texture varies from sub-ophitic to ophitic. The pyroxene is in a state of replacement by pale green to brownish-green uralitic hornblende which in some cases forms a rim to the pyroxene crystals. Elsewhere it forms complete pseudomorphs after pyroxene. No olivine has been seen. Ore is common and apatite and sphene are accessory. Plagioclase laths are somewhat saussuritised and in some cases are encroached upon by uralitic hornblende.

100° black feldspar porphyritic dykes (4)

Three dykes of this group occur as part of the WNW swarm of dykes crossing Sagdliata nunâ (see above). One cross-cutting relationship with a 100-120° dyke suggests that the 100-120° dykes are older. All three dykes vary in width, the largest varies from 8 m in the east to 2 m in the west. The other two dykes are both small varying from 1 to 3 m. The dykes have a constant strike direction but they vary in attitude from dipping steeply to dipping as low as 50° to the south. They are dark grey to brownish grey and are characterised by sharp, chilled contacts to the host rocks and by the presence of large feldspar phenocrysts which in many places are black. Distribution of these feldspars within a dyke varies and in some places they are randomly scattered while elsewhere even within the same dyke they may be concentrated in half of the dyke, the other half being non-porphyritic. Some sections of a dyke may be almost lacking in megacrysts. In some places, where the dykes have a dip of 50-70° feldspars are concentrated in the upper part of the dyke and may be aligned parallel to the dyke wall. Even where no concentration of feldspars occurs crude alignment of crystals can occur. This is flow layering and is indicative of magmatic alignment of feldspar crystals, while the feldspar concentration in the upper parts of some dykes is a direct result of the tendency for the feldspar megacrysts in the magma to rise upwards. The feldspar crystals are commonly euhedral and vary from less than a centimetre up to 15 cm in length. The majority are between 2 and 5 cm. Some feldspars, commonly the smaller ones, are completely black in colour but the majority have a mottled appearance with mixed black and cream-coloured feldspar. The feldspars are situated in a typically fine-grained dolerite matrix which displays sub-ophitic texture, the mafics occurring interstitially between the feldspar laths.

Main minerals of the dolerite are pyroxene, plagioclase and ore plus the transformation products pale green amphibole, epidote, sericite and chlorite.

The plagioclase, both that of the matrix and of the megacrysts, is altered, and sericite and epidote are the main alteration products. Flow textures are clear in thin section and the small plagioclase laths of the dolerite show flow alignment around the larger feldspar phenocrysts.

115-120° olivine-bearing basic dykes (5)

Two dykes of this group occur in the southern part of "Kangarsuk". The largest dyke reaches 5 m in its widest part, the other is 3 m. The latter dyke divides into two in the east. The dykes have regular straight trends and are vertical to steeply dipping to the south. Apophyses are common in the eastern part of "Kangarsuk". The dykes have sharp contacts with the host gneiss but chilling is not conspicuous.

The dyke rock is black to dark grey in colour and is porphyritic having phenocrysts of olivine, pyroxene and plagioclase in a fine-grained matrix. Olivine and pyroxene reach up to about 8 mm in length but all sizes from this to those of the matrix exist. Plagioclase laths reach 4 mm in length and are conspicuous in the fine-grained rock towards the margins of the dykes. Where the dyke rock is coarser grained as in the central parts of the dyke, feldspar laths are randomly orientated. As phenocrysts olivine is as common as pyroxene but it is not common in the matrix, where pyroxene forms small grains within a network of plagioclase laths. Pyroxene (augite) is grey to pale brownish in colour and in the phenocrysts zoning is common. Brown biotite forms small flakes and it can be present in the matrix in amounts equal to pyroxene. Ore is also important; it forms small grains in the matrix and is conspicuous forming rims to the olivine phenocrysts. Apatite is accessory. In rock from the contact zone vesicles up to 2 mm across occur containing a fine-grained colourless amphibole, together with other vesicles filled with calcite. Feldspar laths in thin section can be seen to be flow aligned parallel to the contact.

The dyke rock is only slightly altered. The phenocrysts of augite and olivine are fresh and no alteration rims, so characteristic of the dykes of groups 1, 2 and 3, occur. Some green to brown hornblende, epidote and some of the biotite appear to be of secondary origin while the plagioclase is slightly sericitised.

50° olivine-bearing spessartite dykes (6)

Three dykes of this group occur in western "Kangarsuk". The widest is 6 m, the other two are 4 m and 2 m wide. All three have straight trends, dip steeply to the NW and are characterised by sharp, conspicuously chilled margins. In places some compositional layering parallel to margins exists in the contact zones of one dyke and some of these layers are porphyritic containing calcite patches up to 1 cm in size. Evidence of multiple injection is present with veins of finer-grained material cutting through "normal" dyke rock.

The dyke rock is dark grey to black in colour and is fine-grained. On weathered surfaces the rock may be pitted due to weathering of calcite, and the rock in places contains olivine phenocrysts up to 2 mm in size. Some brown flecks appear to be pseudomorphs after olivine.

In composition the dyke rock is basic and feldspar never forms more than about 25%. In places in some of the layers mentioned above, the rock is ultramafic with plagioclase content falling below 10%. The plagioclase does not form the well-shaped laths that are typical in ophitic or sub-ophitic textures but it forms subhedral to anhedral crystals, commonly situated in clusters, within the network formed by the mafic minerals. Main minerals are olivine, pyroxene, brown pleochroic hornblende, ore, plagioclase and calcite. Quartz occurs in some calcite cavities. Brown hornblende is always present and it occurs in some slides as the main mafic mineral while olivine and ore are everywhere common. Apatite and biotite are accessory. The olivine has been transformed into antigorite, epidote, muscovite and secondary magnetite. In places only pseudomorphs after olivine exist. The pyroxene is replaced by amphibole and some biotite. The plagioclase is usually heavily sericitised.

130° globular-feldspar spessartite dyke (7)

Only one dyke of this type has been seen; it was located during a helicopter reconnaissance on Nûata kujalia. The dyke is 8 m wide and dips to the SW at 75°. It has sharp contacts to the host gneisses but chilling has not been observed. The dyke is grey in colour, in places with tints of green, and it is characterised by a sort of porphyritic texture marked by feldspar globules. The largest globule reaches 1 cm in diameter but the majority are between 1 and 5 mm. In the only locality where the dyke was examined the globules have a random distribution in the dyke rock but this does not exclude the possibility that some variation in distribution of globules occurs across the width of the dyke. In some places small, discontinuous, pale pink feldspar veins up to 1 cm in width cut the dyke rock and in places these veins pass into the globules, suggesting a similar age and origin.

Main minerals of the dyke matrix are brown pleochroic hornblende which forms euhedral to subhedral prismatic crystals up to 1.5 mm long, plagioclase which forms a matrix in which the hornblende is situated, and calcite, epidote and ore. No pyroxene or olivine occurs. The texture is spherulitic and hornblende may form a conspicuous sheath around some of the globules. The globules are composed mainly of plagioclase but, in some, calcite occurs in equal amounts. Epidote occurs as discrete crystals commonly in the centres of globules but it can also occur in the outer parts. Ore grains up to 1 mm exist in the centres of many globules. Epidote and ore also occur outside the globules. Chlorite, mainly as a replacement of plagioclase, occurs in clusters both in the matrix and in the globules. The plagioclase is also altered to sericite, and epidote and muscovite can occur in small flakes. A few flakes of biotite exist.

NW calcite-bearing dolerite dyke (8)

One dyke on Kangârssûp nunâ 4 m wide, is characterised by calcite aggregates. The dyke rock is dark grey in colour and displays a pitted surface due to the weathering of the calcite. The pits can reach 5 mm in diameter. The dyke has sharp, chilled contacts with the host rocks and a near vertical attitude.

The texture is mainly sub-ophitic but in places ophitic where pyroxene (grey to pale brownish augite) crystals are up to 2-3 mm in size. Some patches of pale green antigorite suggest the presence of original olivine. Ore is the remaining essential mafic mineral. Plagioclase is fresh and forms an interlocking network but in the vicinity of the calcite aggregates the laths may form a sheath around the aggregates. The aggregates are rounded in shape and the majority are between 1 and 3 mm in diameter. The calcite forms an equigranular texture and in many cases concentric banded structures exist within the aggregates. Zeolite crystals occur in some aggregates in association with calcite.

NW biotite-olivine dolerite dykes (9)

Two dykes of this group occur on Kangârssûp nunâ. The dykes are grey to greyish brown in colour and they weather easily and tend to form gullies. Spheroidal weathering is common and the dykes are not particularly well exposed, the presence of the dyke in some cases being confirmed only by spheroidal blocks within a gully. The dykes have sharp chilled contacts with the host gneisses and they have a steep to vertical attitude. One dyke reaches at least 20 m in width, the other varies from 4 m to about 10 m. The rock is homogeneous and non-porphyritic.

In thin section the texture is nesophitic (Walker, 1957) composed of an interlocking network of plagioclase in which the mafic minerals are situated. The pyroxene (colourless to grey augite) – plagioclase ratio is low. Olivine, biotite and ore are the other essential mafic minerals and in some cases olivine and also biotite may equal or exceed pyroxene in amount. The size of the mafics is small, the majority of grains being less than 1 mm; the plagioclase laths reach up to 5 mm. Apatite is a common accessory and one grain reaches over 1 mm in length. The rock is slightly altered and olivine is transformed to antigorite and secondary magnetite while pale green amphibole and some biotite occur as an alteration of the pyroxene. Elsewhere biotite is primary. The plagioclase is fresh in some slides, elsewhere it is saussuritised, the central part of the laths being cloudy and brownish in colour.

40-80° lamprophyre dykes (10)

Lamprophyre dykes are common in the area and have been seen particularly on Kangârssûp nunâ. They are typically thin and range in width from a few centimetres to 4 m. The majority are between 50 cm and 1.5 m. Individual dykes cannot be traced for any great distance but at least 30 dykes make up the wide swarm which crosses Kangârssûp nunâ. Others occur on "Kangarsuk" and Sagdliata nunâ.

The lamprophyres have parallel sides and sharp contacts to the country rocks. Usually the dykes have straight trends but a single dyke may vary from 40° to E-W. Many lamprophyres have a trend between 40° and 50° while others are between 65° and 80°. Whether this reflects the presence of more than one generation is not known. The lamprophyres also show a variation in attitude and while the majority are steep to vertical some dykes may change in attitude and dip to the south as shallowly as 30°. Lamprophyres exposed on the western edge of Kangârssûp nunâ where the main river reaches the ice, are very irregular. The dvkes branch along their lengths and apophyses occur.

The dykes are dark grey to grey in colour and are brownish on weathered surfaces. Some weather into a brown sand. They are conspicuously porphyritic. Augite forms euhedral crystals up to 2 cm in length, biotite occurs as hexagonal crystals, the largest noted being 8 cm in diameter, while olivine phenocrysts in places can reach over 1 cm in size. Calcite vesicles also add to the inhomogeneity of the rock and they form white to cream patches up to 2 cm in length, although normally they are smaller. The calcite patches may be concentrated in irregular layers parallel to the dyke contacts, in which case the patches themselves may be elongated markedly in that direction. Other types of layering also occur. In some places finer-grained non-porphyritic zones having sharp contacts to the "normal" lamprophyre exist parallel to the dyke walls. The nature of these layers suggests multiple injection. Elsewhere such finer-grained layers grade into coaser-grained lamprophyre which may bear calcite patches. In many places, especially in the contact zones, small layers or veins of feldspar-rich rock exist with sharp contacts to the lamprophyre. These veins are genetically connected to the lamprophyre. They are parallel to the contacts of the dykes and never penetrate out into the country rocks. Other parts in the lamprophyre may be conspicuously rich in biotite, olivine or pyroxene. An important feature is that the texture of a single dyke may vary considerably along the strike and in one locality large pyroxene, olivine or biotite crystals may exist in an otherwise homogeneous rock while further along the strike of the dyke the pyroxene, olivine and biotite may occur in smaller crystals or maybe lacking as phenocrysts, or the minerals may be aligned in zones in the dyke. Distribution of calcite patches is also irregular and some parts of a dyke may be rich in calcite while elsewhere calcite patches may be absent.

Main minerals are biotite, pyroxene, plagioclase, calcite and ore. Olivine is an essential mineral in some dykes. The lamprophyre is quite basic and some rock samples are ultramafic. Plagioclase never reaches more than 20% except in the small feldspar-rich layers or veins mentioned above, where it is associated with green amphibole and ore. Amphibole is restricted to these layers or veins but in them, it is very common and forms large crystals. Plagioclase only occurs in the groundmass and in some vesicles with calcite. The phenocrysts of biotite, augite and olivine are all euhedral and fresh. The former two minerals also occur in the groundmass but olivine has been seen only as phenocrysts. Ore is always present in abundance. Calcite occurs as large interlocking crystals in the vesicles and also occurs as smaller crystals in the groundmass. Phlogopite occurs in the groundmass. Zeolite crystals occur in some vesicles. Apatite and sphene are accessory. The lamprophyre is little altered.

Age and correlation

The dykes are placed in a tentative chronology on the basis of information from four intersections, from relationships to fractures, on their state of transformation and on correlation with established dyke chronologies elsewhere in the Frederikshåb area.

On Kangârssûp nunâ the main 80 m dyke of group 1 is cut by a 20 m dyke of group 9 and also by a lamprophyre of group 10. On Sagdliata nunâ another dyke of group 1 appears to be cut by a dyke of group 4 while on "Kangarsuk" a dyke of group 2 is cut by a dyke of group 5. Dykes of groups 1 to 4 can be clearly separated from the other dykes of the area by the fact that the pyroxene in them is conspicuously replaced by uralitic hornblende and some of the dykes show the effects of deformation. They are considered to be the oldest dykes. In the northern part of the Frederikshåb area, three generations of MD (metadolerite) dykes have been recognised (S. B. Jensen, 1966 and pers. comm.) having trends N-S to NW (MD_1), NE (MD_2), and ESE (MD_3) in that order of age, and it seems most probable that the dykes of groups 1 to 4 are correlatable with these MD generations. Dykes of group 1 are thus correlated with the MD_3 dykes, those of group 2 with the MD_2 dykes and those of group 3 with the oldest MD_1 dykes. The dykes of group 4 probably represent a sub-generation of the MD_3 dykes.

The rest of the dykes post-date the MD dykes. Their precise age however is not known, some may be Precambrian, others Phanerozoic. Basic dykes of both Ketilidian and Gardar age are known from the Frederikshåb area and ages of 164 m.y. (Larsen, 1966) and 138 m.y. (N. H. Gale, Oxford, pers. comm. to GGU) have been obtained from a lamprophyre and a dolerite respectively. The swarm of lamprophyric dykes comprising group 10 also occurs to the south of the nunataks. Biotite from one of these dykes has given a K/Ar date of 168 ± 5 m.y. (Bridgwater, 1970). This age is taken to be close to the time of dyke intrusion and proves the TD (Mesozoic) age for the lamprophyres. Some are rich in calcite and resemble the "carbonatite-lamprophyre dykes" of Mesozoic age described by Walton (1966a) from the southern part of the Frederikshåb area. The NW biotite- and calcite-bearing dolerites of groups 8 and 9 may belong to the same dolerite-lamprophyre suite and are possibly TD in age. Their direction parallel to the coast, and the fact that other NW, TD dykes occur in the area immediately to the south (B. Chadwick, B. J. Walton, J. Wroe, pers. comm.) support this.

The spessartite dykes of groups 6 and 7 are cut by NW faults and thus they appear to be older than the TD intrusions. The olivine-bearing dykes of group 5 may be of a similar age, i.e. either Ketilidian or Gardar, but their relationship to the NW faults is not known and they could be of Phanerozoic age.

North of Frederikshåbs Isblink dolerite dykes having directions NW, NE and ESE have been noted and these may well be of the same age as the MD_1, MD_2 and MD_3 dykes of the Frederikshåb area. Other NW dykes cut dykes of supposed MD_3 age (B. F. Windley, pers. comm., see S. B. Jensen, 1968, p. 44). The main 80 m dyke of group 1 (MD_3) crossing Kangârssûp nunâ can be tentatively correlated across the Isblink with an ESE dyke of similar habit. No sheared margins have yet been seen in dykes of supposed MD age north of the Isblink. Some ESE dykes contain black feldspars and are correlatable with dykes of group 4. In addition small lamprophyre dykes occur which are identical in mineralogy, texture and habit to those of group 10.

Tectonism and metamorphism

Tectonic features post-dating the main plutonic development of the gneiss-granite-amphibolite complex are represented mainly by linear fracture zones. Some of these fractures involved only displacement of blocks of rock in relation to one another, others were associated with mylonitisation and mineralogical changes such as epidotisation and quartz-feldspathisation.

NW fractures

Faults and shear zones of this trend are common on "Kangarsuk", Nûata kujalia and Kangârssûp nunâ. At least two ages of movement can be recognised on steeply dipping fault planes, one pre-dating the NE, MD_2 dykes and one post-dating the MD_2 and MD_3 dykes and also dykes of group 6. All dyke offsets indicate a sinistral transcurrent movement. There is a close relationship between NW faulting and the NW dolerites of group 9 on Kangârssûp nunâ where in places fault planes are barren and contain sheared and mylonitic rock, while elsewhere they are injected by fresh dolerite. These dolerites have clearly utilised old fault directions and the inconsistency of the dykes is a primary feature and not due to later deformation. On Nûata kangilia NW faults contain mylonites and epidote enrichment occurs in adjacent gneisses. The movement on the NW faults pre-dates the lamprophyres of group 10.

E-W to ESE fractures

Main faults and shear zones with this direction occur especially on "Kangarsuk" and on Sagdliata nunâ where transcurrent sinistral movement has displaced some MD_2 dykes up to 20 m. As is the case with the NW fractures, these faults were initiated earlier than the MD_2 dykes since some dykes of that age are unaffected by ESE faults. The faults have sub-vertical fault planes which are commonly marked by the presence of sheared rock, a notable feature being an epidote enrichment and a reddening of the feldspars of the adjacent gneisses. Some quartz veining occurs in association with mylonite zones.

NE fractures

NE-trending shear zones occur on "Kangarsuk"; along these, gneissic rock is mylonitised and epidotised, and reddening of feldspar is conspicuous. Epidote veins up to 6 cm wide can occur. Such zones appear to post-date the MD_2 dykes. One small fault on northern Sagdliata nunâ cuts a MD_2 dyke and shows sinistral movement.

N-S to NNW fractures

A few faults having a general N-S trend exist on "Kangarsuk". In one case a fault was initiated before the MD_2 dykes. Lack of intersections with basic dykes or amphibolites in the gneisses prevents an estimate of the age of movement on the faults. No mylonites have been noted.

NW joints

NW joints are present in many areas and a prominent set occurs in the northern part of "Kangarsuk", where the joints form gullies and trenches in the topography. These linear features are clearly visible on aerial photographs. Amphibolites in the gneisses continue uninterrupted across the joints and no movement appears to have occurred along the fractures. Some joints are clearly late structures and post-date the lamprophyres of group 10 but others were formed prior to the lamprophyres and may be old Precambrian fractures. The relationship between such early joints and the NW-trending faults, which are utilised in places by dykes of supposed TD age (group 9) is not known.

Deformation and metamorphism in relation to basic dykes

Fault-dyke intersections indicate that fault movements took place intermittently during the time span of the intrusion of the MD dykes (groups 1 to 4). The relation of fracturing to the MD_1 dykes is not known but main NW- and ESE-trending faults were initiated before the emplacement of the MD_2 and MD_3 dykes. These faults were later rejuvinated after MD_2 and MD_3 intrusion, and possibly after the intrusion of dykes of group 6. This rejuvination of pre-Ketilidian fractures is probably of Ketilidian or Gardar age.

In addition, crushing and shearing occurred within the dyke margins of both the MD_2 and MD_3 dykes especially in the northern part of the area. This deformation resulted in the formation of a new fabric in the contact zones of the dykes and in the flexuring of one dyke, and it can be assumed that the transformation to a metadoleritic mineralogy was contemporaneous with the deformation. The transformation seen in the MD dykes is of a different nature and scale to that seen in the other, later, basic dykes where sericitisation, saussuritisation and slight alteration of the mafics may well be due to hydrothermal and deuteric processes. It is probable that the MD dykes on the semi-nunataks and nunataks have been affected by a low-grade regional metamorphism due to a local rise in the thermal gradient.

AGE AND ORIGIN OF THE BASEMENT COMPLEX

The main plutonic activity affecting the basement of the nunataks and semi-nunataks is assumed to be of pre-Ketilidian age from comparison with the basement in the Frederikshåb area (see S. B. Jensen, 1966, 1968, 1969). The so-called MD dykes are believed to be pre-Ketilidian in age and to pre-date the Ketilidian supracrustals of the Ivigtut area (S. B. Jensen, 1966, p. 34). Hence the slight metamorphism seen on the nunataks and semi-nunataks affecting dykes correlatable with dykes of MD age in the Frederikshåb area is considered to be a Ketilidian effect due to local thermal activity. The fact that some samples of gneiss and schist from areas both to the north and south of the nunataks and semi-nunataks within the "old gneiss block" (Pulvertaft, 1968, see also page 8) have given Ketilidian K/Ar age dates (see Larsen, 1966; Larsen and Møller, 1968, p. 85), indicates that Ketilidian plutonism did affect certain areas and was strong enough to up-date pre-Ketilidian rocks.

The bedrock of the nunataks and semi-nunataks has affinities with both the Frederikshåb area to the south, which is typified by a highly folded amphibolite-gneiss complex (S. B. Jensen, 1966, 1968), and the Ravns Storø area in the north-west where a dominantly metavolcanic supracrustal succession occurs in association with highly folded and migmatitic gneisses (Windley et al., 1966; Windley, 1968). Some of the amphibolites occurring as inclusions and layers in the folded gneisses of the nunataks (including banded amphibolites, schistose amphibolites, agmatitic amphibolites, migmatitic amphibolites, calc-silicate-bearing amphibolites) have a similar aspect to amphibolites of the Frederikshåb area and they appear to have passed through a similar plutonic history. On the other hand certain amphibolitic rocks, particularly those overlying the gneiss on the northern nunatak 1340 m and those outcropping on J. A. D. Jensens Nunatakker and on the eastern nunataks resemble very much the supracrustal belt of metavolcanic rocks outcropping in the Ravns Storø area north of the Isblink, a belt of rocks up to 5 km wide which is characterised by metavolcanic structures. These supracrustal rocks are regarded as post-dating the surrounding gneisses, so that the supracrustal-gneiss contact represents a transformed basement-cover relationship (Windley, 1968, p. 29). In the absence of original discordances, the recognition of basement-cover relationships in crystalline rocks is difficult, particularly when both groups of rocks have a similar metamorphic grade. Subsequent plutonism can obliterate direct traces of relative age, and rocks of different ages may become inseparable chronologically. For example, it can be demonstrated that more than one age of amphibolitic material occurs in the gneiss-granite-amphibolite complex of the present area, and it can be proved that in addition to the clearly discordant metabasite dykes, some inclusions, layers and discontinuous tracts of amphibolite are initially of intrusive origin (see page 22). These amphibolites post-date other migmatised amphibolites which also form inclusions, layers and discontinuous tracts in the gneisses. The two groups of amphibolites have been deformed together with the gneisses and recognition of the two types is only possible in areas where original discordances and cross-cutting relationships have been preserved.

Detailed structural work in the Frederikshåb area has demonstrated that some amphibolite rocks have passed through a long and complicated deformational history and Andrews (1968) has described amphibolitic layers in the Nigerdlikasik area (east of Frederikshåb) which have been subjected to at least five distinct deformations and associated migmatisations. Some amphibolitic material on the nunataks and semi-nunataks (i.e. that pre-dating the metabasite dykes) has also passed through such a long deformational history but other amphibolitic material, for example the metavolcanics of the northern nunatak 1340 m, the eastern nunataks and at Ravns Storø, and the amphibolites derived from metabasite dykes, do not seem to have passed through such a complex sequence of events. One explanation for this is that the metavolcanics (like the metabasite dykes) are younger in age than earlier folded and migmatised gneisses and amphibolites. Evidence supporting this is provided by the metabasite dykes which occur in the gneisses, in places abundantly, and have been seen in the ground north of the Isblink. In contrast no metabasite dykes have been seen cutting the less transformed amphibolitic material nor were any seen in the Ravns Storø metavolcanic succession, a situation conducive to the suggestion tentatively put forward here that the metavolcanic rocks are younger than, and form a cover to early gneisses and associated amphibolites, being younger than, or contemporaneous with, an episode of basic dyking.

Table 7 attempts to illustrate diagrammatically the position of the present study area in relation to areas to the north and south. The chronologies proposed for the Midternæs-Ivigtut area (Higgins & Bondesen, 1966; Henriksen, 1969) and for the Ravns Storø area (Windley, 1968) are similar in that a pre-Ketilidian supracrustal group overlies a gneissic basement. The Ravns Storø supracrustals may be of a similar age to the Tartoq Group of the Midternæs area. Little more can be stated since the two areas in question are separated by 150 km.

Whether a division of amphibolitic rocks such as suggested for the present study area can be extended to the Frederikshåb area to the south is difficult to say since recognition of "old" or "young" amphibolites becomes impossible if reworking of the gneisses has been severe (see Dawes, 1969).

Table 7. Tentative correlation chart showing the position of the nunataks and semi-nunataks in relation to areas north and south

	Ravns Storø (Windley, 1968)	Dalagers Nunatakker (Present report)	Frederikshåb (Jensen, 1966, 1968)	Midternæs-Grænseland (Higgins & Bondesen, 1966)	Ivigtut (Henriksen, 1969)
KETILIDIAN	?	Slight metamorphism of dykes – shearing	Some plutonic activity giving K/Ar dates of 1830 and 1780 m. y in SE (Larsen, 1966)	Plutonism (Deformation and weak metamorphism)	Plutonism (Deformation, metamorphism and migmatisation)
KETILIDIAN				Supracrustals (sediments and volcanics) unconformity	Supracrustals (sediments, volcanics and derived gneiss) unconformity
PRE-KETILIDIAN	Basic dykes	Basic dykes	Basic dykes (MD dykes)	Basic dykes	Basic dykes
PRE-KETILIDIAN	Plutonism	Plutonism	Plutonism	Plutonism	Plutonism
PRE-KETILIDIAN	Ravns Storø supracrustals and derived gneiss	Metavolcanics, associated ultramafic rocks and derived gneiss	?Amphibolites	Tartoq Group supracrustals	Tartoq Group supracrustals and derived gneiss
PRE-KETILIDIAN	Basement gneiss	Basement gneiss and associated amphibolites	Highly folded amphibolite–gneiss complex	Basement gneiss	Basement gneiss with gabbro-anorthosite and amphibolite layers and inclusions

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Plates

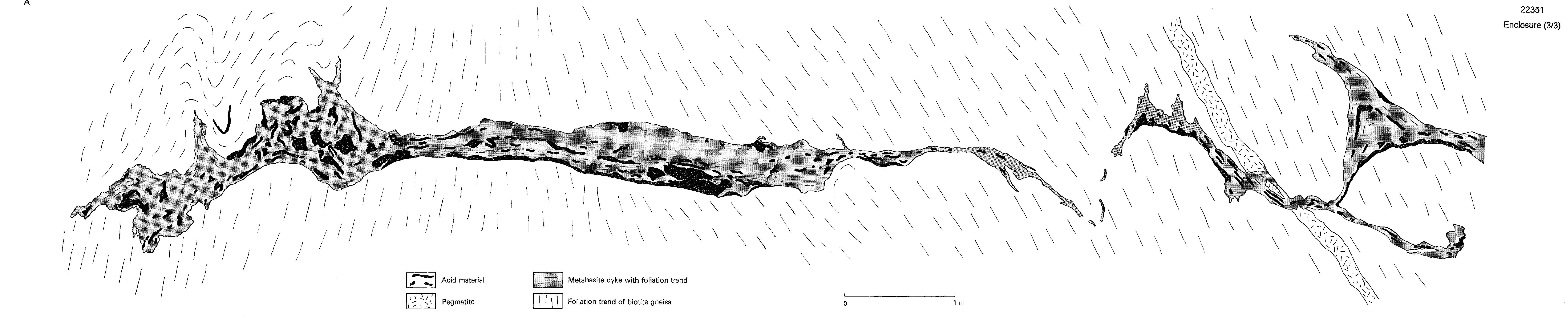
Plate 1. Diagram to illustrate the variation in type of metabasite dykes (cf. plate 2). A: Foliated and folded dyke having irregular contacts to the gneisses. The dyke contains much acid material in streaks, veins and patches and it is cut by a later pegmatite. At one place the dyke is thin and has been broken by the biotite gneiss but its trend is still clearly visible. Northern "Kangarsuk". B: An anastomosing, thin dyke which shows no visible signs of internal foliation. The dyke is tightly folded and displays angular hinges. It post-dates a discordant set of quartzo-feldspathic veins in the gneiss and is cut by later pegmatites. Sagdliata nunâ.

Plate 2. Diagram to illustrate the variation in type of metabasite dykes (cf. plate 1). A: Straight, unfoliated dyke which cuts two generations of older amphibolitic material in the gneisses. Foliated migmatised amphibolite inclusions in the gneiss are cut by small metabasite dykes, which are themselves cut by the main dyke. The main dyke is cut by later aplites and a pegmatite. Sagdliata nunâ. B: Straight, irregular branching dyke which contains inclusions of country rock gneiss. The dyke has no internal foliation. Its trend is offset in places by small fractures which are now filled by acid material. The dyke cuts the gneiss foliation and an early discordant acid vein, and is cut by later pegmatites and acid veins. Kangârssûp nunâ.

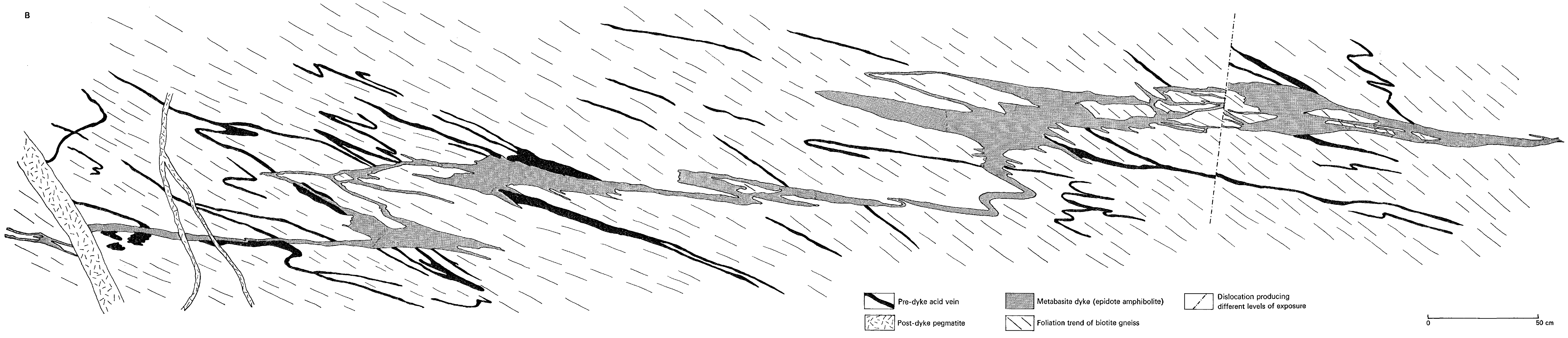
Map

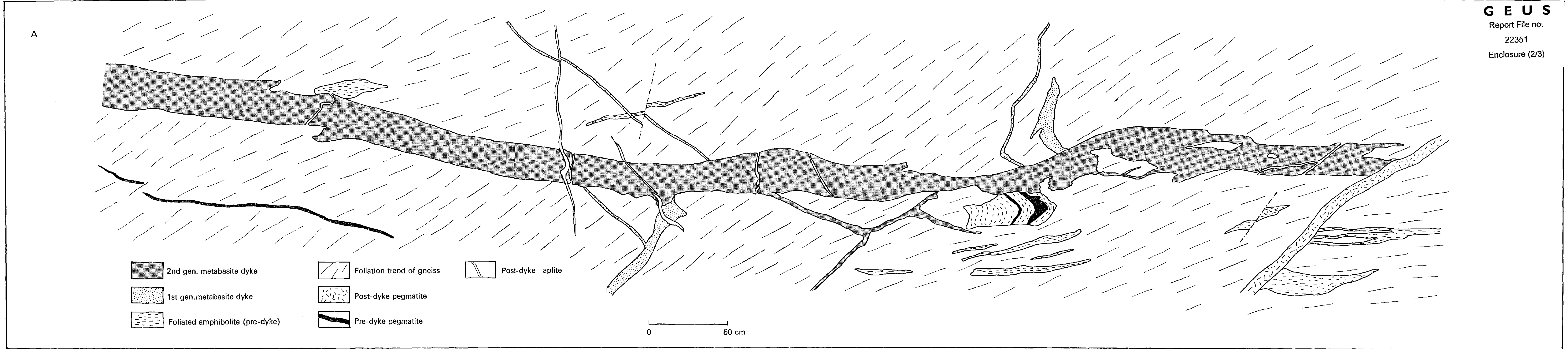
Map 1. Geological map of the nunataks and semi-nunataks in the Frederikshåbs Isblink area.

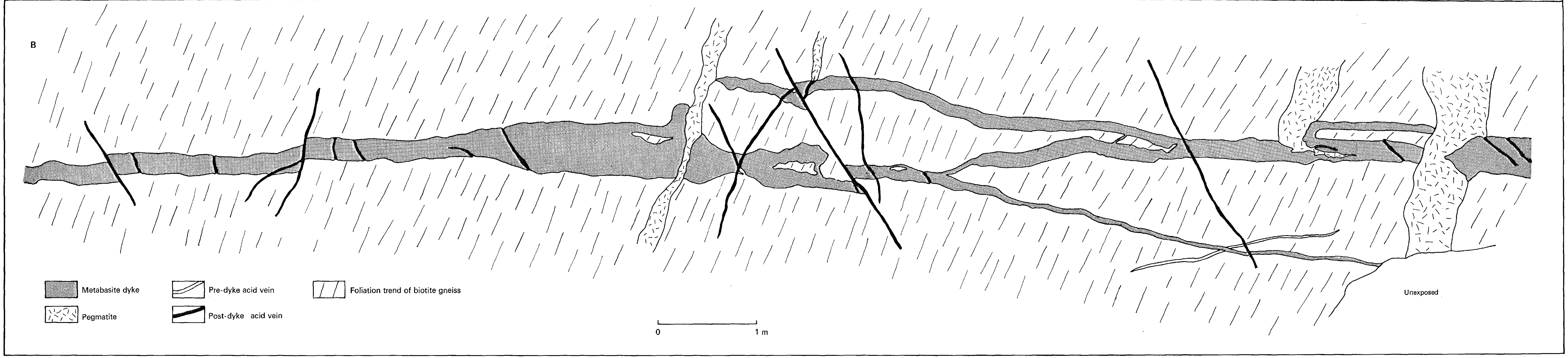
A


Acid material
Pegmatite
Metabasite dyke with foliation trend
Foliation trend of biotite gneiss
0
1 m

B


Pre-dyke acid vein
Post-dyke pegmatite
Metabasite dyke (epidote amphibolite)
Foliation trend of biotite gneiss
Dislocation producing different levels of exposure
0
50 cm


A
2nd gen. metabasite dyke
1st gen. metabasite dyke
Foliated amphibolite (pre-dyke)
Foliation trend of gneiss
Post-dyke pegmatite
Pre-dyke pegmatite
Post-dyke aplite
0
50 cm


B
Metabasite dyke
Pegmatite
Pre-dyke acid vein
Post-dyke acid vein
Foliation trend of biotite gneiss
Unexposed
0
1 m

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND