GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT Nr. 46

The Geological Survey of Greenland
Report no. 46

Regional geology of early Precambrian high-grade metamorphic rocks in West Greenland

Part 1: Kângnaitsoq to Ameralik

by
Brian F. Windley

KØBENHAVN 1972

Grønlands Geologiske Undersøgelse

(The Geological Survey of Greenland)
Østervoldgade 10, DK-1350 Copenhagen K

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
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REGIONAL GEOLOGY OF EARLY PRECAMBRIAN HIGH-GRADE METAMORPHIC ROCKS IN WEST GREENLAND

Part 1: Kângnaitsoq to Ameralik

by
Brian F. Windley

1972

Abstract

Within this region three types of area are distinguished:

1. Amphibolite-grade areas which did not reach a granulite grade
2. Granulite-grade areas
3. Amphibolite-grade areas, many of which have been retrogressed from the earlier granulite grade.

The main rocks are hypersthene-biotite gneisses, biotite-hornblende gneisses, amphibolites with or without orthopyroxene, sillimanite mica schists, rare marbles, skarns and quartzites, layered calcic anorthosites, a great variety of meta-ultramafic rocks including rare zoned talc lenses, abundant pegmatites, several generations of dolerite dykes locally amphibolitised by deep-seated faults. The fold structure of the region is characterised by abundant large-scale interference patterns.

The history of the region is interpreted on the basis of a deformed cover/basement relationship, all major units being now mutually conformable.

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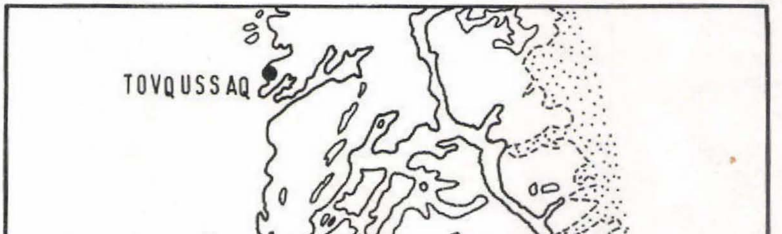

Fig. 1. Sketch map showing the location of the region described in West Greenland.

INTRODUCTION

The Kângnaitsoq–Ameralik region

This region lies between the mouth of Ameralik fjord (just north of latitude 64°) and Kângnaitsoq fjord (latitude 63° 10′), West Greenland (fig. 1), a north-south distance of ca 100 km. The coastal area described, ca 2000 km^2, lies between the islands and the inner part of the fjords. The region overlaps to the south with that described by McGregor (Oxford Isotopic Geology Laboratory & McGregor, 1971). Færingehavn, a fishing station, is the only settlement in the region but Fiskenæsset and Godthåb lie just to the south and north respectively.

The relief varies considerably: some areas, such as east of Tre-Brødre and Qilángârssuit island, barely rise above 100 m whilst the highest peaks rise to about 800 m.

The bedrock is largely very well exposed except for the Tre–Brødre–Marraq area which is covered by extensive Quaternary terrace deposits up to a height of about 100 m. There is no permanent ice in the coastal region described.

Field work

Field work in this region was carried out mainly in the three month summer of 1965, the second of a four summer project which was part of GGU's programme for producing the 1:500,000 maps of West Greenland. The Qilángârssuit area was mapped in 1967.

Mapping was undertaken on 1:20,000 topographic maps of the Geodetic Institute which cover the whole region. Extensive use, both before and during the field work, was made of aerial photographs although the 1:40,000 vertical photographs were of little help because of extensive snow cover and it was therefore the oblique photographs that were mostly used.

Scope of the project

Although this was fundamentally a reconnaissance project it was possible to make detailed maps of selected areas of particular interest, such as the anorthosites of Buksefjorden, Færingehavn and Tre Brødre, and the fold structures on Qilángârssuit island. Most of the coast line was examined, either with a boat or on foot, and traverses were made inland locally to confirm stratigraphy seen on aerial photographs. In this way it was possible to make a basic stratigraphy-structure map of the whole region with sufficient details from the well-exposed coastal outcrops to establish age relationships and to make petrogenetic interpretations.

This report is a summary of the field geology of the region supplemented by a general thin section study together with three chemical analyses. Emphasis has been placed on establishing the regional picture rather than on solving local details. It is a preliminary account of the regional geology which, it is hoped, will contribute useful background information for future detailed studies in particular areas.

Previous work

Very few geological investigations have previously been made in this region: some specialised studies have been undertaken but no regional maps have been made.

Giesecke (1910) in the early nineteenth century made observations on the talc body and major ultramafic body at Qarajat, east of Narssaq village (no longer permanently inhabited). He recorded the many minerals that occur in the latter and these are quoted in Bøggild (1953).

Ellitsgaard-Rasmussen made a reconnaissance of the region in 1952 and his unpublished diary provided useful local information, in particular on the dyke-fault relations in Amitsuarssugssuaq fjord and the domal structure on Sanerâta timâ, between Tre Brødre and Marraq.

Sørensen (1955) briefly described the anorthosite in Buksefjorden and Berthelsen (1955) the small diorite body on SE Qilángârssuit, for which locality he also erected a chronology of events. Jensen (1962) studied the petrology and geochemistry of some dolerite dykes in the Amitsuarssugssuaq area. Appel (1971) recorded a sulphide-bearing pebble conglomerate that occurs within amphibolite layers in the Kângnaitsoq area.

Regional geological setting, synopsis and isotopic age determinations

The region concerned lies near the middle of the Archaean gneiss block of West Greenland (Pulvertaft, 1968) which has been stable since about 2500 m. y. (Larsen, 1971). Fig. 2 shows the broad structure of this region.

In the north-eastern part of the area, at least as far south as Qilángârssuit, McGregor (1968, 1969) suggested the presence of a very old gneissic basement containing a swarm of amphibolite dykes. The Oxford Isotopic Geology Laboratory has confirmed this with whole rock Rb/Sr and Pb/Pb isochron ages of 3980 m. y. and 3760 m. y. (OIGL & McGregor, 1971).

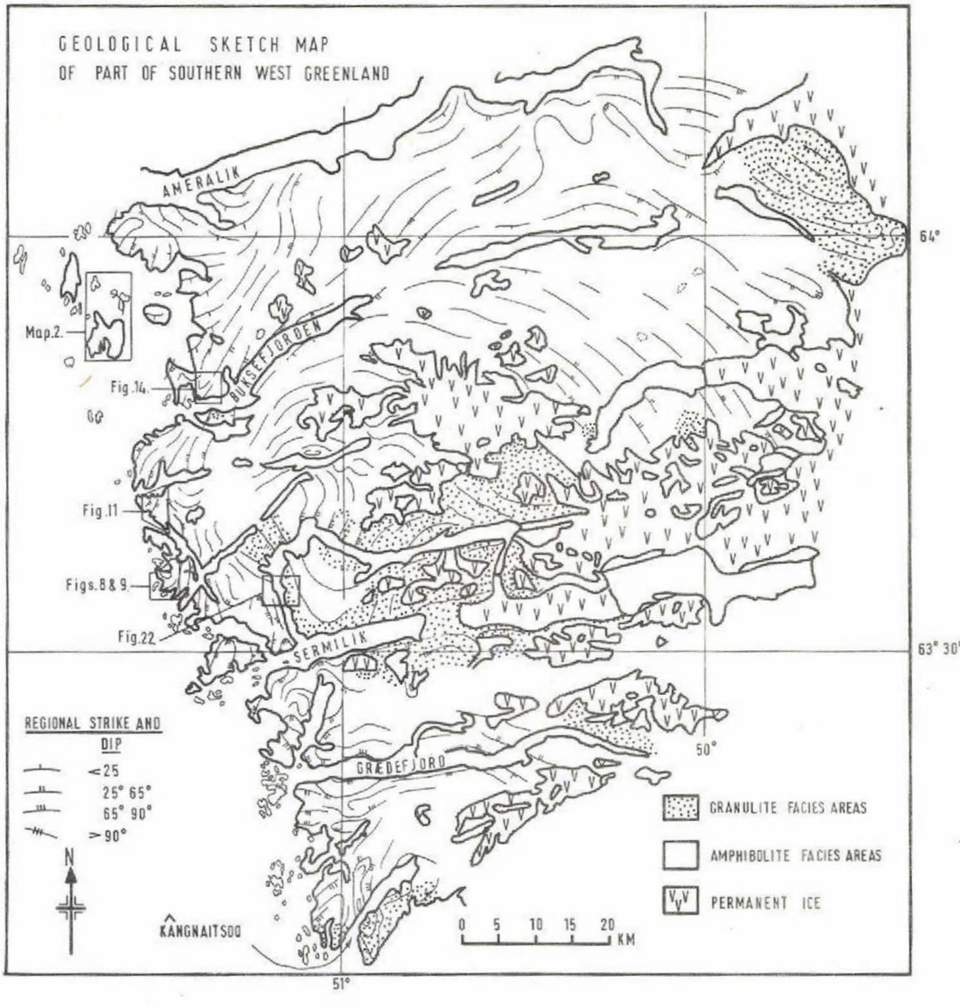

Fig. 2. Geological sketch map of part of southern West Greenland showing the location of map 2, figures 8, 9, 11, 14 and 22, and the main granulite- and amphibolite-grade areas.

Between 3980 m. y. and 2850 m. y. supracrustal rocks (now represented by meta-volcanic amphibolites, mica schists and rare marbles and quartzites) were laid down on the old crystalline basement, and layered anorthosite complexes and granitic rocks were emplaced in sheet-like bodies. In Godthåbsfjord the supracrustal rocks (the Malene supracrustals of McGregor, op. cit.) are locally associated with anorthosites, and this same association is seen in the Tre Brødre and Færingehavn areas. The anorthosites are best developed in the Fiskenæsset area, just to the south of Kângnaitsoq fjord, where they are chromite layered and belong to an extensive layered meta-igneous complex with a well-preserved igneous differentiation trend (Windley, Herd & Bowden, in press) and cryptic mineral variation trends (Smith & Windley, in prep.). A general compilation of the anorthositic rocks of West Greenland including those of the present region was made by Windley (1970a).

After tectonic interleaving of the supracrustal rocks with their associated anorthosites and the crystalline basement, granitic sheets were emplaced along the deformed cover/basement contacts in the Godthåb area. High-grade metamorphism then affected all previous rock units. In the Godthåb–outer Ameralik–Qilángârssuit area this reached a high amphibolite grade but apparently it did not isotopically affect the 3980 m. y. gneisses of outer Ameralik. Throughout most of the region which extends from Buksefjorden to Kângnaitsoq this metamorphism reached a granulite grade giving a Pb/Pb isochron age of 2850 m. y. (Moorbath, personal communication). Granulite-grade areas are preserved as scattered relics in the Archaean unit of West Greenland and in the present region occur in the Kângnaitsoq and Sermilik areas (fig. 2). A very small but distinct relic also occurs on the south side of Buksefjorden. A new granulite facies area was found by the writer in 1971, near the Inland Ice east of Ameralik and Buksefjorden (fig. 2), when working for Cominco Ltd of Vancouver.

There is evidence of widespread retrogression of the granulite- to amphibolite-grade rocks, especially in Kângnaitsoq fjord and on the borders of the other granulite areas mentioned above. There is a common K/Ar isotopic event of about 2500 m. y. in this part of West Greenland which might be associated with this downgrading.

Several generations of dolerite dykes traverse the region, most of which have been faulted. A K/Ar age of 1865 m. y. has been obtained from a faulted amphibolitised dolerite on the west side of Amitsuarssugssuaq fjord, just to the north of Sermilik (Larsen, 1971, p. 47). The amphibolite is derived from a 20 m E-W trending dolerite dyke that has been displaced and amphibolitised by a N-S trending fault. This date probably gives a fair approximation of the age of the last major tectonic movements in this Archaean terrain.

A synopsis of the geology of the region extending from Frederikshåb Isblink to Sukkertoppen was made by Windley (1970b) and this includes the present region. At the time of writing that publication (late 1967), as a result of the writer's reconnaissance mapping, it was not possible to establish the character of the pre-anorthosite basement and therefore the anorthosites were provisionally stated as the oldest rock units; however the detailed work of McGregor (op. cit) established the pre-anorthosite chronology near Godthåb. A revised model chronology for the Archaen of Greenland is given by Bridgwater, McGregor & Windley (in press).

It is important to note that the chronology of OIGL & McGregor (1971) is only definitely applicable to the Godthåb area described by McGregor, although it can probably be extended southwards to the northern shore of Færingehavn fjord, as McGregor (personal communication) has recognised Ameralik dykes as far south as there. The application by the writer of much of McGregor's chronology farther south to Kângnaitsoq fjord is an assumption, warranted by the marked similarity in major stratigraphy and structure, as well as observed chronological relationships, with those in McGregor's area. The absence of Ameralik dykes south of Færingehavn makes it difficult to 'prove' that the early part of McGregor's chronology is applicable, but at the same time it must be realised that all dyke swarms must end somewhere and the absence of the dykes merely makes subdivision of early rock units more difficult. The above assumption is also supported by the following *a priori* reasoning: there are two ages of gneisses as McGregor shows, and it is unlikely that *all* gneisses in the southern part of the region were emplaced later than the anorthosites and supracrustals, conveniently leaving them as thin, extensive layers in gneiss, especially when many are often poorly migmatised or penetrated by granite/gneiss material. If there was no Amîtsoq gneiss basement here, the oldest rock units were presumably the supracrustals, which were penetrated by so much later granite/gneiss material that only shreds remain. The fact that many gneiss layers contain virtually no remains of meta-supracrustal rocks (cf. Nûk gneisses in the Godthåb area) makes this hypothesis unlikely. The stratigraphy north and south of Færingehavn is sufficiently similar (see map 1) to suggest that there is probably no fundamental change in major chronological relationships, i. e. sudden absence of basement.

Chronology of events

The most up-to-date chronology appropriate to the Archaean of West Greenland is that of McGregor (OIGL & McGregor, 1971). The revised version of Bridgwater, McGregor & Windley (in press) is used in this report and, modified for the present region, is as follows:

	Time Unit	McGregor's terminology (OIGL & McGregor, 1971)
oldest	1. Formation of 'granitic' rocks	Amîtsoq gneisses
	2. High-grade metamorphism and deformation	
	3. Intrusion of basic dykes	Ameralik dykes
	4. Deposition of supracrustal rocks on the earlier crystalline basement	Malene supracrustals
	5. Emplacement of anorthosite complexes into the supracrustal rocks, perhaps along or near the cover/basement contacts	
	6. Tectonic interleaving of previous major units	
	7. Emplacement of calc-alkaline, granodioritic to tonalitic rocks as large complexes, sills and minor dykes	Nûk gneisses
	8. Granulite- to high amphibolite-grade metamorphism and deformation to form major interference patterns	
	9. Largely static retrogression of granulites to amphibolite-grade rocks	
	10. Intrusion of several swarms of dolerite dykes	
	11. N-S faulting associated with metamorphism	

A result of the unit 6 interleaving, the subsequent emplacement of unit 7 granitic rocks commonly as sub-concordant bodies (sills), and especially the subsequent very intense deformation is that all major rock groups are mutually conformable. Because of the regional metamorphism of units 8 and 9 all rock groups are in a high-grade metamorphic state.

Some rock groups, such as the anorthosites (unit 5) of Buksefjorden, Færingehavn and Tre Brødre, are sufficiently similar to be presumed as broadly equivalent in age; conversely the similarity in amphibolite-grade gneisses developed in units 8 and 9 may be such as to obscure their possible subdivision.

REGIONAL DESCRIPTION

Three types of area are described:

1. Those which only reached an amphibolite grade in time unit 8.
2. Those which reached a granulite grade in unit 8.
3. The remaining amphibolite-grade areas, many of which were retrogressed in unit 9 from an earlier granulite grade.

Amphibolite-grade areas which did not reach a granulite grade

The main area of this type is in the north-west corner of the region, on Qilángârssuit and surrounding islands and along the strike near Narssaq village. The following account applies particularly to Qilángârssuit which was studied in most detail (map 2.). This area has the best preserved early chronology as it forms the southern continuation of the outer Ameralik area described by McGregor (op. cit.).

Chronology of events (Modified after Berthelsen, 1955)

oldest Formation of granitic rocks containing ultramafic bodies and amphibolites now in the form of tectonic relics in gneisses

Metamorphism and deformation giving rise to folded gneisses

Intrusion of a diorite body

Formation of rare hornblende pegmatites

Basic dykes intruded (now amphibolite dykes)

Deposition of supracrustal rocks (now amphibolites, schists and marbles)

Tectonic interleaving of the above major units; amphibolite-grade metamorphism and deformation giving rise to large-scale interference patterns

Formation of pegmatites of several generations

Intrusion of E–W dolerite dykes

In Ameralik fjord, however, Ameralik dykes occur in gneisses that continue southwards along the strike to inner Buksefjorden and Færingehavn fjord with rare, but distinct, granulite facies relics occurring in Buksefjorden. These areas may therefore contain pre-amphibolite dyke rocks that reached a granulite grade of metamorphism but were thoroughly retrogressed under amphibolite-grade conditions.

Structure

The general structural chronology is as follows:

D_1 Pre-amphibolite dyke deformation expressed locally as the foliation and minor folding of the gneisses. These minor folds are truncated by the amphibolite dykes.

D_2 Tectonic interleaving of the supracrustal and gneiss units.

D_3 Folding of the interleaved cover/basement sequence giving rise to large-scale interference patterns with prominent N-S and E-W trending folds. Formation of lineation in gneisses, amphibolite dykes and supracrustal amphibolites and schists.

Gneisses

Most of the gneisses on Qilángârssuit are Amîtsoq gneisses and several samples from this island were found to lie on Rb/Sr and Pb/Pb isochrons together with Amîtsoq gneisses from the type area at the mouth of Ameralik fjord (OIGL & McGregor, 1971).

The gneisses vary from granitic to tonalitic, mafic to felsic, and banded to homogeneous. Common mineral assemblages are:

garnet – hornblende (colourless) – plagioclase – K feldspar – ore
garnet – hornblende (green) – biotite – plagioclase – quartz – ore
biotite – plagioclase – quartz – ore

Garnets reach up to 10 cm across and may be concentrated in the axial planes of late folds. Although a foliation with a biotite lineation is most common, there are some pencil gneisses with just a feldspar lineation. Some rocks have a very regular banding made up of biotite-rich and quartzo-feldspathic (biotite-free) bands up to 1-2 cm in width.

The gneisses contain inclusions, up to several metres across, of meta-ultramafic rocks which are the oldest in this region. They may consist of layered very coarse anthophyllite rock with rare actinolite and layered fine-grained hornblendite. There are also small inclusions of brown weathered, intensely migmatised amphibolite. The diorite body described by Berthelsen (1955) was apparently intruded into the gneisses.

Meta-supracrustal rocks

In order of decreasing size and importance, these are a) amphibolites, b) mica schists, and c) marbles.

These three rock types are closely associated on Qilángârssuit. The amphibolites occur in the gneisses as major layers, up to 1 km wide at Narssaq and in fold cores on Qilángârssuit. They are conformable with the gneisses and form conspicuous marker horizons on the west of the island (map 2). No primary structures have been recorded in the amphibolites, but they may well occur as in Godthåbsfjord the comparable major amphibolite layer on SE Bjørneøen contains pillows and conglomerate pebbles (cf. Appel, 1971) in one locality recognised so far. The amphibolites are fine- to coarse-grained, black, foliated, lineated rocks often rich in garnet and biotite. They have a 'supracrustal' meta-volcanic appearance, a subjective diagnosis based on comparison with amphibolites that do have relic primary volcanic structures; they have a distinctive compositional banding composed of mafic and felsic units a few centimetres wide which have a marked regularity in strike and dip and persist along the strike for several metres, or even tens of metres. Common mineral assemblages are:

garnet – hornblende – biotite – plagioclase – (quartz)
hornblende – biotite – plagioclase
hornblende – garnet – plagioclase – biotite
diopside – hornblende – plagioclase – epidote – sphene

In these rocks most hornblende forms independent grains but some is clearly after diopside, occurring as rims and along cleavages. There are garnet- and epidote-rich layers 10 cm wide at Narssaq.

Within the major amphibolite at Narssaq there is an ultramafic lens measuring about 200 m by 30 m, with its longest axis lying within the plane of the regional foliation. It is situated some 200 m inland from the harbour and is poorly exposed with about 60 % grass cover. Most of the body consists of actinolite rock which forms a 14 m wide marginal zone surrounding a central core of talc about 5 m wide; there is also some orthopyroxene-cummingtonite rock and, along the southern border of the lens, a concentration of carbonate (probably magnesite)-phlogopite-quartz rock, 4 m long and 2 m wide. Such zoned ultramafic lenses are common in the Archaean of West Greenland and where they retain cores of serpentine it can be seen that they are derived from peridotites or dunites by metasomatism, involving ingress of silica and water and expulsion of magnesium. It is rare to find evidence of the expelled material and so the carbonate here is of particular interest.

According to Giesecke (1910) the largest talc occurrence in Greenland occurs at Qarajat, about 7 km east of Narssaq; no such talc, however, has been found there by the writer and it is thought that the reference may be to the Narssaq body.

Mica schists with biotite, sillimanite, garnet and graphite occur as layers up to several metres wide within the amphibolites described above. They have behaved incompetently during deformation with the formation of many minor folds. The rocks weather with a characteristic yellow rusty colour caused by their fairly high sulphide content. Coarse garnet-rich layers have the assemblage garnet–anthophyllite–biotite–plagioclase–zircon.

One layer of marble has been found on the north of the island, at the locality marked on map 2. It contains calcite – diopside – tremolite – sphene and occurs within the major amphibolite as a layer up to 1–2 m wide and at least 10 m long; it is bordered by a layer of fuchsite quartzite about 30 cm wide. This is the only marble known so far in the coastal region between Fiskenæsset and Hamborgerland, north of Sukkertoppen.

Fig. 3. Two amphibolite dykes cutting discordantly the gneiss foliation on south Qilángârssuit.

Amphibolite dykes

Many amphibolite dykes occur on Qilángârssuit island, the greatest concentration being on the south coast at the locality marked on map 2. They have been observed only in the gneisses, not in the supracrustal rocks (amphibolites, schists and marbles). They reach at least 20 m in width and are characterised by frequent apophyses, mostly 10–40 cm wide, extending parallel and perpendicular to the dyke walls. The major dykes trend about 020 and the perpendicular apophyses about 120.

The dykes consist entirely of black, foliated-lineated (or homogeneous) amphibolite with few relic igneous textures; Berthelsen (1955) records blasto-porphyritic texture in one dyke with relic plagioclase phenocrysts up to 1 cm long. Chilled margins are common. The dykes have the mineral assemblage hornblende (dark to light green) – plagioclase ± biotite ± epidote – sericite after plagioclase – quartz – sphene ± apatite – ore (mostly magnetite); some biotite is after hornblende but most forms independent grains and there are also mafic clots of hornblende – biotite. The blue colour of the dyke amphibolite can be distinguished easily from the brown of earlier truncated amphibolite lenses in the gneisses. The dykes have, in places, responded to spheroidal weathering.

The dyke foliation is parallel to the walls and the dykes truncate the foliation of the gneisses at all angles (figs 3 & 4); a few are conformable but high angle discordances are most common. Within the gneisses the dykes truncate amphibolite fragments and minor folds 10–30 cm across (fig. 5), and one dyke cuts the diorite

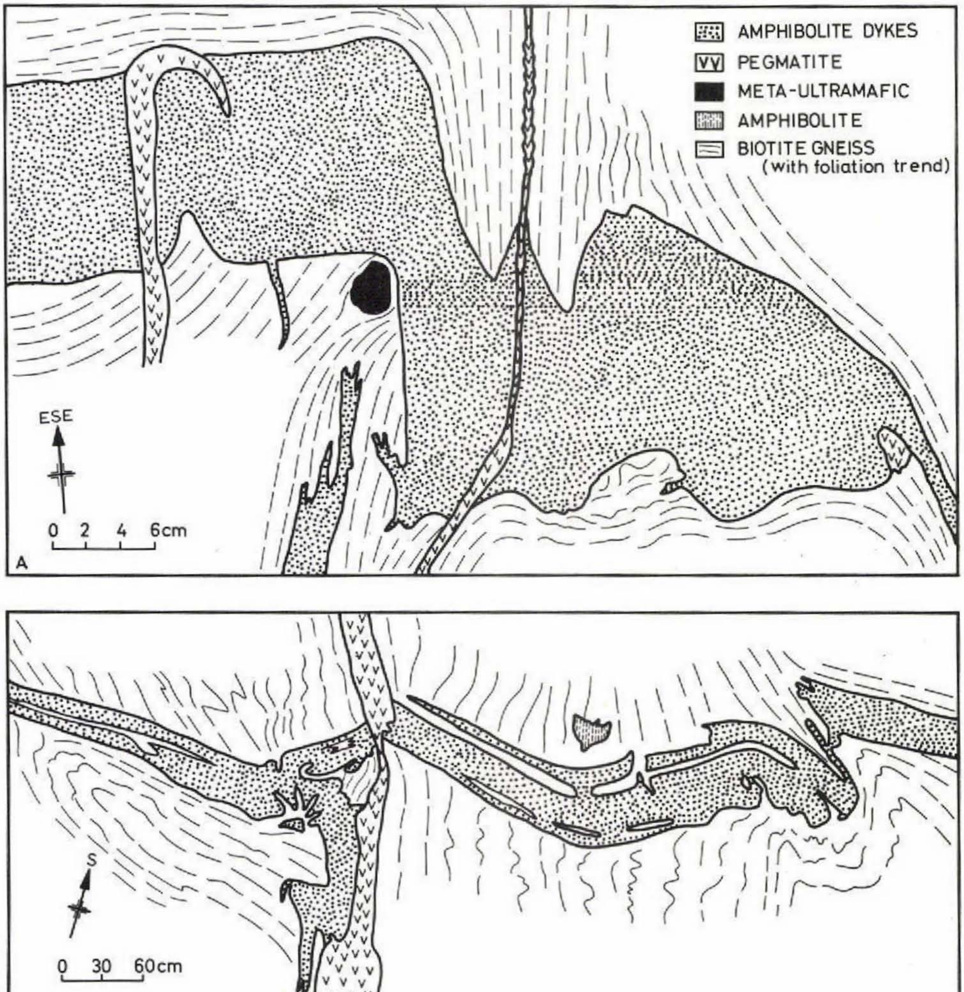

Fig. 4A & B. Showing the discordant relationship between amphibolite dykes and earlier Amîtsoq gneisses, south Qilángârssuit.

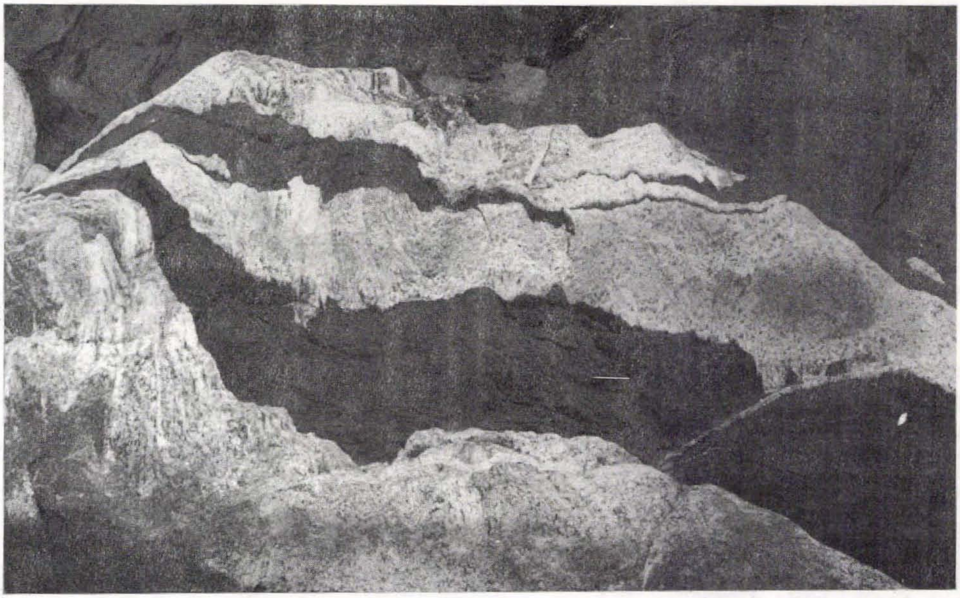

Fig. 5. Unmigmatised amphibolite dyke apophyses, one of which truncates a minor fold in gneiss. South Qilángârssuit.

body described by Berthelsen (1955). Some dykes contain anorthositic fragments flattened in the foliation and the earlier diorite body has anorthosite inclusions (Berthelsen, op. cit.).

The dyke lineation is marked by a preferred orientation of hornblende, and in places plagioclase, on the foliation planes and is distinctly co-linear with that in the adjacent gneisses. These lineations are also parallel to minor fold axes in the gneisses and to the axis of the major southerly plunging synform on the SW corner of the island demarcated by the major amphibolite horizon. The dykes therefore pre-date this folding phase.

The major dykes are continuous but thinner dykes and apophyses are in places broken, this fragmentation appearing to have taken place in association with minor folding. Some apophyses have apparently been broken off their parent dykes which then retain protuberances at the break-off points. The dykes are only weakly migmatised by granitic material passing from the gneisses (fig. 6).

Pegmatites

There are many pegmatites on these islands; most occur in the gneisses with no relationship to the amphibolite dykes, but a few pre-date and many post-date the dykes, and there are also some distinctive layered aplite-pegmatites. The pegmatites are up to 5–10 m in width and most of the widest trend either E–W or N–S.

Berthelsen (op. cit.) suggests that hornblende-bearing replacement pegmatites formed in the diorite body before the amphibolite dykes were intruded. They cut the diorite foliation and its contact with the gneisses.

Several generations of pegmatites cut the amphibolite dykes. Berthelsen (op. cit.) shows that within the dykes there are segregation pegmatites surrounded by basic fronts; they consist of An_{38-39} plagioclase and formed in a late crystallisation phase of the dykes. Pegmatite veins up to 1–2 m wide cut across the dykes and several veinlets are folded with them, suggesting that the dykes have undergone flattening deformation.

In the gneisses there are garnet–biotite–magnetite pegmatites several metres wide, with magnetite crystals up to 5 cm across, which are older than non-biotite pegmatites of a similar width. On the SE of the island the biotite-bearing pegmatites generally trend E–W to ENE and consist of plagioclase (An_{25-26}), quartz, biotite and zircon (Berthelsen, op. cit.).

Layered aplite–pegmatites up to several metres in width are common on the island, many occurring on the south coast at the locality marked on map 2. Where they are flat–lying the pegmatite tends to occur along the upper margin and garnet–layered aplite along the lower, although there are several exceptions. Some

Fig. 6. An amphibolite dyke that has undergone migmatisation by granitic veins extending from the gneisses. South Qilángârssuit.

Fig. 7. Fold interference patterns in banded gneiss, north coast, Sanerâta timâ.

bodies are of pegmatite with thin bands, 5 cm wide, of aplite along the contacts. The pegmatite appears to have formed largely after the aplite as internal pegmatite layers cut across earlier aplite layers and also as there has been local disruption of the aplite layers but not of the pegmatites. The upper pegmatite is often zoned with a conspicuous black quartz core and some sheets have two layers of zoned pegmatite with such cores; these layered aplite-pegmatites are strongly reminiscent of those described by Windley & Bridgwater (1965) from south-west Greenland which are spatially associated with late micro-granite intrusions. Layered aplite–pegmatites are associated with the Qôrqut granite (McGregor, 1966) in Ameralik fjord and they probably belong to the same generation as those on Qilángârssuit.

Granulite-grade areas

There are two main areas where granulite–grade rocks predominate: Kângnaitsoq, and Sermilik–Alángordlia fjords. There is also a small isolated, but well-preserved, relic in Buksefjorden. Granulites occur in inner Grædefjord as well, but this is outside the area of map 1.

Structure

Map 1 shows that the structure of the region is characterised by large-scale fold interference patterns – this applies to both the granulite-grade and the remaining amphibolite-grade areas, many of which have been through the granulite facies event (see later). One of the simplest eye-fold (dome/basin) interference patterns extends across Kângnaitsoq fjord, the structure being outlined by amphibolite horizons in gneiss. Other large-scale patterns are shown in figs 8, 11 and 14; similar examples occur on a minor scale (fig. 7).

During the field work fold phase chronologies were erected for each sub–area and the development of these fold phases followed throughout the region; these, however, are not listed here as they will shortly be superseded by more detailed work. Briefly the earliest structures are minor intrafolial folds in the gneisses or in amphibolite fragments within the gneisses. There are one or two subsequent phases of isoclinal folds, with axial traces parallel to the regional foliation, followed by two phases of more open folds; it is probable, however, that many fold phases developed most contemporaneously under high-grade metamorphic conditions of high temperature partial melting and low viscosity flow.

Gneisses

Granulite facies gneisses are characterised by a reddish, yellowish or greenish greasy weathered surface. The high red mountains in inner Alángordlia fjord suggest that the granulites continue inland well beyond the end of this fjord. These felsic rocks look more basic than they really are, being sodic to potassic quartzo-feldspathic gneisses with only small amounts of hypersthene, diopside, hornblende and biotite. It is the presence of orthopyroxene which characterises them as granulite facies rocks. Typical mineral assemblages are:

orthopyroxene – hornblende (green) – biotite – K feldspar – plagioclase – quartz
biotite – orthopyroxene – clinopyroxene – plagioclase – quartz
orthopyroxene – clinopyroxene – biotite – hornblende (green) – plagioclase – quartz
biotite – orthopyroxene – clinopyroxene – K feldspar – plagioclase – quartz

They are very homogeneous rocks with ill-defined foliation and lineation: at times it is difficult to see the foliation until close upon the rocks. They are very uniform or monotonous for considerable distances with little internal stratigraphy or banding.

The gneisses contain inclusions of amphibolite forming layers up to ca 30–60 cm in width, and also rounded, angular or lens-shaped fragments of similar width and up to a metre or so in length. Some of these may well have been amphibolite dykes and should be looked at closely for relic primary structures. The presence of such dykes would help in distinguishing these as Amîtsoq-age gneisses (McGregor, 1968, 1969).

In the Sermilik fjord hypersthene gneisses there are small ultramafic inclusions of diopside–hornblende rock and orthopyroxenite with some hornblende.

Hypersthene–bearing pegmatites occur in the gneisses as small irregular–shaped veins, but they are rare and small compared with the common wide pegmatite dykes in the amphibolite–grade areas.

On the south side of Buksefjorden there is a 200 m wide relic of red–weathered, hypersthene–bearing gneiss containing agmatitic amphibolitic inclusions. In the gneiss there are two types of migmatising white hornblende–biotite gneiss: one forms irregular anastomising veins, the other more extensive conformable layers up to 1–2 m wide.

Amphibolites

Except for the presence of orthopyroxene, granulite–grade basic layers do not appear markedly different from those in amphibolite–grade areas. The rocks are usually well layered, hornblende, diopside, garnet, biotite and plagioclase often being concentrated in different layers which individually may have a poorly developed tectonic fabric. Common mineral assemblages are:

garnet – hornblende (green to light brown) – orthopyroxene – plagioclase – quartz
garnet – hornblende (green to light brown) – diopside – plagioclase – quartz
garnet – hornblende (green) – orthopyroxene – plagioclase – quartz – apatite
hornblende (green) – diopside – plagioclase
orthopyroxene – diopside – hornblende (brown) – plagioclase – quartz

On the north side of Sermilik fjord there is a distinctive wide red–weathered basic layer rich in orthopyroxene and garnet. The garnets occur in layers and lenses up to 60 cm wide whilst diopside–rich layers and lenses, up to 1 m wide, are traversed by plagioclase veins and in this rock the green diopside is rimmed with black hornblende.

The amphibolites contain hypersthene–bearing pegmatites up to 30 cm wide in which brown orthopyroxene is commonly megascopically rimmed with black hornblende; such pegmatites often retain better evidence of retrogression than other rock types. The Sermilik amphibolite is also traversed by hornblende–biotite pegmatites with zoned quartz cores, probably formed during or after the subsequent amphibolite–grade metamorphism.

Amphibolite-grade areas largely retrogressed from an earlier granulite grade

These form the largest part of the region, generally occurring between Kângnaitsoq and Sermilik, and between Alángordlia and Buksefjorden. There is substantial evidence suggesting that several parts, but not necessarily the whole, of this terrain were previously at a granulite grade; the northernmost indication of such an earlier metamorphism is on the north side of Buksefjorden. The following evidence from different areas is suggestive of an earlier granulite–grade event:

a) The granulite–grade areas themselves contain minor mafic and felsic layers with amphibolite–grade mineral assemblages (see above) as well as pegmatites in which hypersthenes have clearly undergone partial breakdown to hornblende.

b) The eastern border of the Kângnaitsoq granulite area has the form of a transition zone in which there are many relics of hypersthene gneisses within biotite–hornblende gneisses which also contain lenses of orthopyroxenite rimmed by hornblendite. Various rock types in this transition zone contain hypersthene rimmed with hornblende.

c) The granulites on the north side of Sermilik pass along the strike northwards to amphibolite–grade rocks, with intermediate retrogressive mineral assemblages (i.e. hypersthene to hornblende) and relic hypersthene in most rock groups except the gneisses. In these areas it is clear that the quartzo–feldspathic gneisses have equilibrated rapidly and completely under amphibolite facies conditions leaving no indication of their former history. Conversely basic, ultramafic, anorthositic and pegmatitic rocks equilibrated less easily to the new metamorphic conditions and thus retain partial granulite-grade parageneses.

d) The Buksefjorden granulites occur as a 200 m relic in an otherwise stable amphibolite facies area. Opposite, on the north side of the fjord, there are several much smaller inclusions of hypersthene gneiss in the biotite gneisses (H. Sørensen, personal communication).

e) Within the extensive amphibolite–grade areas there are occasional rocks that contain relic orthopyroxene:

Buksefjorden (N side)
orthopyroxene in 1 m mafic layer in anorthosite

Buksefjorden (N side)
orthopyroxene – hornblende (brown) in amphibolite inclusions in biotite – hornblende gneiss

Buksefjorden (inner fjord)
100 m wide inclusions of hypersthene gneiss in biotite gneiss

Tre Brødre
orthopyroxene – hornblende (dark green to brown) in major amphibolite horizon bordering anorthosite

Amitsuarssuk (inner fjord)
orthopyroxene in major amphibolite horizon in gneiss

Auverfigssat
hornblende (brown) in biotite gneiss

Bay north of Kângnaitsoq
orthopyroxene in major amphibolite horizon in gneiss

Bay north of Kângnaitsoq
orthopyroxene – hornblende (green to brown) in segregations within amphibolite horizons

Bay north of Kângnaitsoq
10 m wide orthopyroxene layer within amphibolite horizon

Bay north of Kângnaitsoq
olivine – clinopyroxene – orthopyroxene – hornblende (brown) – magnetite – spinel layer 10 m wide in amphibolite horizon

When these relationships are viewed together they suggest that much of the terrain has undergone an extensive retrogressive reconstitution under amphibolite facies conditions from an earlier granulite facies state.

Gneisses

These amphibolite–grade gneisses are the most common rock type in the map area. There are many variations that can be mapped out on a regional scale in the form of a lithology of gneiss types, depending for example on whether they are potassic to sodic, homogeneous to banded, mafic to felsic or whether or not they contain amphibolitic fragments. In order to understand the mode of occurrence and origin of these rocks, it is necessary to map out their stratigraphy in a detailed manner; an understanding of their lithological differences would then give meaning to their chemical variations. It is impossible here to give an adequate account of such a varied and extensive group of rocks. Probably the most frequent type is a biotite or biotite–hornblende, dioritic to granodioritic gneiss, but garnet gneisses are also common in some areas. Garnet–bearing mafic gneisses have the assemblages:

North Buksefjorden
garnet – clinopyroxene – hornblende (green) – plagioclase – (quartz)
North Sermilik
garnet – clinopyroxene – hornblende (green to greenish brown) – plagioclase – (quartz)

The brown hornblende is a relic from the earlier granulite–grade metamorphism.

Amphibolite dykes

The gneisses at Buksefjorden and Færingehavn fjord (Kangerdluarssoruseq), which contain amphibolite dyke relics, continue along the strike to Ameralik fjord where they are cut by distinctive Ameralik dykes; some Amîtsoq gneisses may therefore have been metamorphosed to a granulite grade in the Buksefjorden – Færingehavn area.

South of Færingehavn fjord no amphibolite dykes have been seen by McGregor (personal communication) and it is therefore not known whether the gneisses here are of 'Amîtsoq' or 'Nûk' age.

Amphibolites

Within the gneisses there are a great many extensive amphibolite layers, up to 1.5 km in width, which provide excellent marker horizons for outlining the regional fold structures (map 1). These rocks are banded, foliated and lineated, but contain no primary structures, such as pillows, although it is thought most likely that they are meta–volcanics; however locally, as at Tre Brødre, they do contain mica schist layers. At both Færingehavn and Tre Brødre they border the anorthosites, presumably being volcanic rocks into which the layered anorthosite complexes were emplaced; this relationship can be demonstrated on the basis of chemical, petrological and textural evidence in the Fiskenæsset region (Windley, Herd & Bowden, in press). Typical assemblages are:

Bay north of Kângnaitsoq
garnet – clinopyroxene – hornblende (brown) – plagioclase – quartz
Bay north of Kângnaitsoq
garnet – clinopyroxene – hornblende (green to brown) – biotite – plagioclase
Tre Brødre
garnet – hornblende (dark green to brown) – quartz – plagioclase – biotite
Grædefjord and Tre Brødre
garnet – hornblende (green) – plagioclase – quartz – magnetite
Tre Brødre
hornblende (green) – biotite – plagioclase – quartz
Grædefjord
hornblende (green) – biotite – epidote – plagioclase
Amitssuarssugssuaq
hornblende (green) – plagioclase – epidote – quartz
Alángordlia
clinopyroxene – hornblende (green) – plagioclase – ore
Buksefjorden
garnet – hornblende (green) – sphene – plagioclase – quartz – ore

The first three assemblages contain brown hornblende, a relic from the granulite-grade metamorphism.

Mica schists

Schists occur as layers both in the broad amphibolites and in the gneisses; they range from less than 1 m to at least 60 m in width and are developed in the Buksefjorden and Tre Brødre areas in particular. They are presumed to have been pelitic sediments of the same general age as the above meta–volcanic amphibolites. Their widths and mineral assemblages are:

Tre Brødre, 25 m
sillimanite – garnet – biotite – quartz – plagioclase – cordierite after garnet (a chemical analysis of this rock is given in table 1)
Tre Brødre, 60 m
garnet – biotite – quartz – plagioclase – scapolite
Buksefjorden, 2 m
talc – phlogopite – clinopyroxene – anthophyllite – molybdenite
Buksefjorden, 3 m
pyrite – hornblende – biotite – epidote – plagioclase
Buksefjorden, 1 m
garnet – biotite – quartz – plagioclase
S Færingehavn, 60 cm
biotite – plagioclase – quartz

The Tre Brødre garnet mica schists extend northwards to Íkátoq fjord; the three Buksefjorden layers occur on the south side of the fjord, near the mouth, although

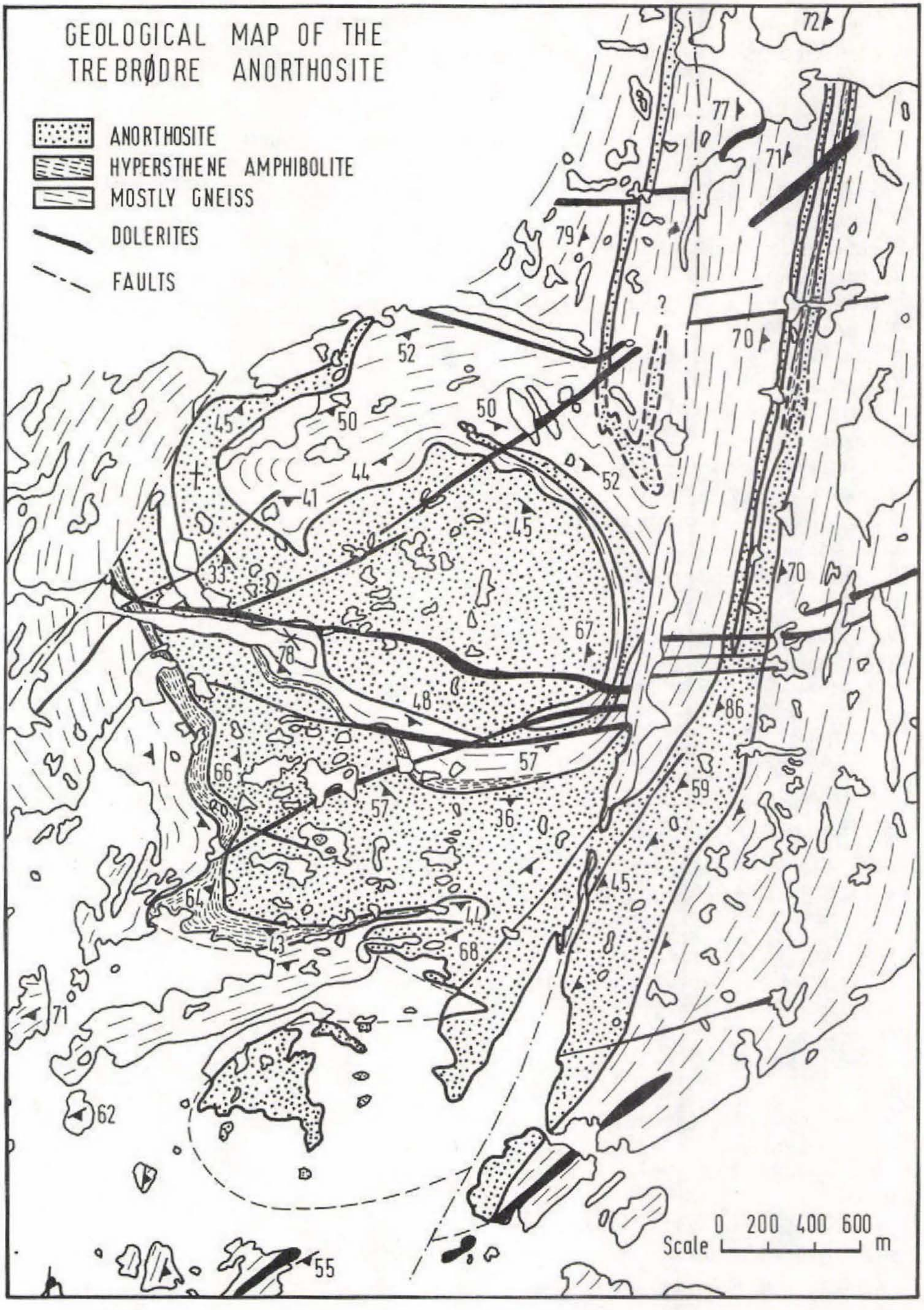

Fig. 8. A geological map of the Tre Brødre anorthosite.

Fig. 9. A vertical aerial photograph of the Tre Brødre anorthosite; compare with figure 8. Geodetic Institute copyright.

there are also well–developed mica schists on the north side, both on the coast and inland in the highly folded zone between the two anorthosite layers (fig. 14).

Calc-silicate skarns occur as small inclusions within the schists and gneisses. No marbles have been recorded. The mica schists on the north side of Buksefjorden contain 1 m wide inclusions of very coarse–grained diopsidite, with green diopside crystals reaching 50 cm in length, and with the general assemblage diopside – epidote – hornblende – plagioclase. In the gneisses on the south side of Grædefjord there are epidote skarn lenses up to 4 m across with assemblages epidote – cummingtonite – plagioclase – hornblende – sphene – pyrite and epidote – hornblende – chlorite – plagioclase – sphene – quartz.

Anorthosites

Anorthosites and associated rocks are concentrated in three areas which are broadly along the strike and therefore probably remnants of the same original layer.

a) Tre Brødre

East of Tre Brødre anorthosite occurs in two areas: the more important, western one is described below and shown in fig. 8; the other was not visited.

The anorthosites show up well on aerial photographs (fig. 9) as they are comparatively lichen–free. There are two main folded layers within the gneisses, both reaching a maximum width of 1 km. The central domal layer is of medium-grained garnet–free homogeneous gabbroic anorthosite to anorthositic gabbro; it lacks layering which makes it difficult to obtain structural readings. Conversely the southern anorthosite, south of the central gneiss strip, consists of fine–grained layered garnet–bearing anorthosite (for chemical analysis see table 1). The garnets are concentrated in discrete layers alternating with others which are plagioclase–rich, thus implying compositional control of garnet growth; individual garnets reach 3 cm across. Fig. 10 shows graded plagioclase–rich layers in a 2 m wide mafic layer in anorthosite.

The main gabbroic anorthosite contains plagioclase – hornblende – sphene – epidote. The sphene is concentrated within hornblende whilst the epidote occurs in plagioclase. This rock contains occasional inclusions of epidote–rich anorthosite with plagioclase – epidote – hornblende, the epidote forming a spectacular mosaic along plagioclase–plagioclase grain boundaries.

The southern, garnet anorthosite consists of plagioclase – garnet hornblende (blue-green) – biotite with the garnet–rich mafic layers containing garnet – plagioclase – biotite – corundum – sericite after plagioclase (for chemical analyses see table 1). This anorthosite contains layers and inclusions, up to 1 m wide, of garnet – biotite – hornblende rock which weathers to a deep brown colour and contrasts sharply with the white anorthosite.

In the north-east of the area are the remains of an anorthosite horizon which now occurs as elongate inclusions, up to 1.5 m in length, with the assemblage

Table 1. Three bulk chemical analyses

GGU No	74584	74574	74570
SiO_2	69.49	47.56	42.77
TiO_2	0.60	0.23	0.20
Al_2O_3	13.08	26.71	27.63
Fe_2O_3	0.36	1.55	0.70
FeO	6.06	5.70	12.69
MnO	0.07	0.09	0.30
MgO	6.08	2.02	2.86
CaO	1.11	10.94	9.03
Na_2O	0.26	3.00	1.47
K_2O	2.14	1.14	0.99
P_2O_5	0.09	0.03	0.08
H_2O^{+}	0.81	0.70	0.73
	100.15	99.67	99.45

74584 Garnet – sillimanite – mica schist. 25 m wide layer in gneiss. (sillimanite – garnet – quartz – plagioclase – biotite – cordierite). Tre Brødre.

74574 Garnet anorthosite. Main rock. (plagioclase – garnet – biotite – hornblende – ore). Tre Brødre.

74570 Garnet-rich layer in garnet anorthosite. (garnet – plagioclase – biotite – corundum – sericite). Tre Brødre.

Analyst: Ib Sørensen, GGU.

plagioclase – hornblende – epidote – biotite. These inclusions are concentrated within a gneiss 'horizon' and result from the intrusion of an anorthosite by granite/gneiss material.

To the south and north of the southern garnet anorthosite there are conformable amphibolite layers which were probably volcanics. They are quartz–rich lineated hornblende – biotite – plagioclase rocks, with or without garnet. The features that differentiate them from the basic meta–igneous rocks, which occur within and belong to the anorthosite complex, are their high quartz content, their disequilibrium fabric of sutured grains and their marked lineation.

The Tre Brødre anorthosites have some interesting, although minor, ultramafic rocks:

1) At the contact of the southern layered anorthosite and the northern amphibolite layer there is a relic ultramafic lens, 60 m by 20 m, which is more than 95 % grass covered. The principal rock is an orthopyroxenite with orthopyroxene cummingtonite – ilmenite – magnetite associated with a magnetite – olivine – orthopyroxene – phlogopite – ilmenite rock; these are locally interlayered to form magnetite–layered orthopyroxenite.

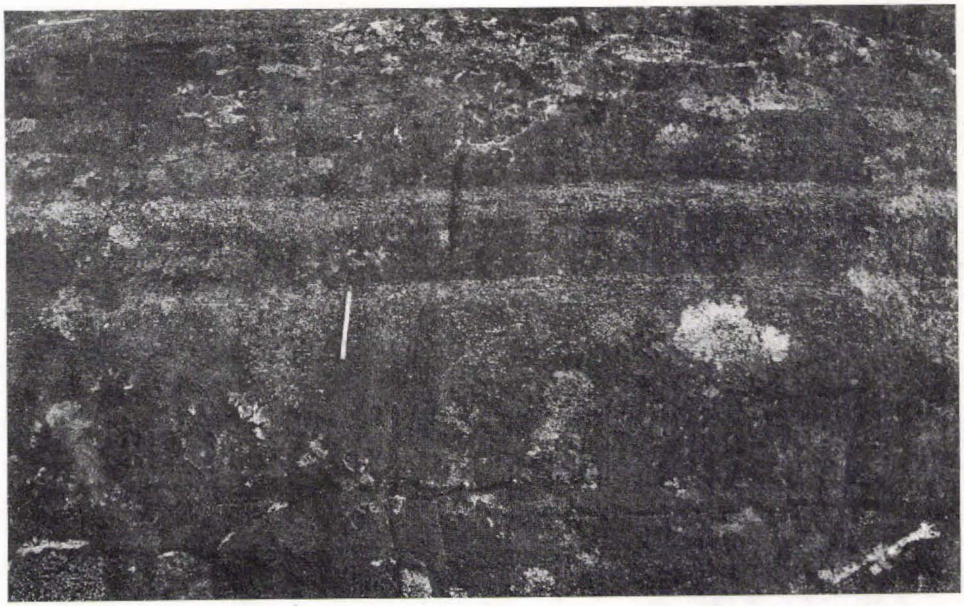

Fig. 10. Graded plagioclase-rich layers in a 2 m wide mafic unit in anorthosite, Tre Brødre.

2) Within the southern layered anorthosite there is an elongate inclusion, 40 m by 20 m, of dunite with olivine – orthopyroxene – magnetite, the olivines being highly strained in an advanced stage of polygonisation; a variation of this rock has olivine – hornblende – magnetite. The dunite weathers to an intense red–brown colour and stands out markedly from the white anorthosite. It is traversed by a few 1 cm wide veins with orthopyroxene – olivine – anorthite – magnetite, and between the dunite and the anorthosite there is a 1 cm wide layer of coarse–grained garnetite with garnet – hornblende – biotite – plagioclase.

3) The eastern of the two thin anorthosite layers, in the north-east of the area, contains 2 m wide ultramafic layers with assemblages garnet – hornblende (green to brown) – quartz – plagioclase and magnetite – garnet – hornblende – biotite – plagioclase. This rock contains 2500 p.p.m. vanadium.

4) In the gabbroic anorthosite there are rare but distinct inclusions, with a maximum size of 60 cm by 20 cm, of garnet hornblendite with the assemblage garnet – hornblende (green to brown) – biotite – plagioclase – quartz; these elongate inclusions are aligned so that they outline the otherwise poor layering of this type of anorthosite. The adjacent anorthosite contains epidote – plagioclase – garnet or clinopyroxene – epidote – garnet, the garnet and clinopyroxene forming cores to epidote.

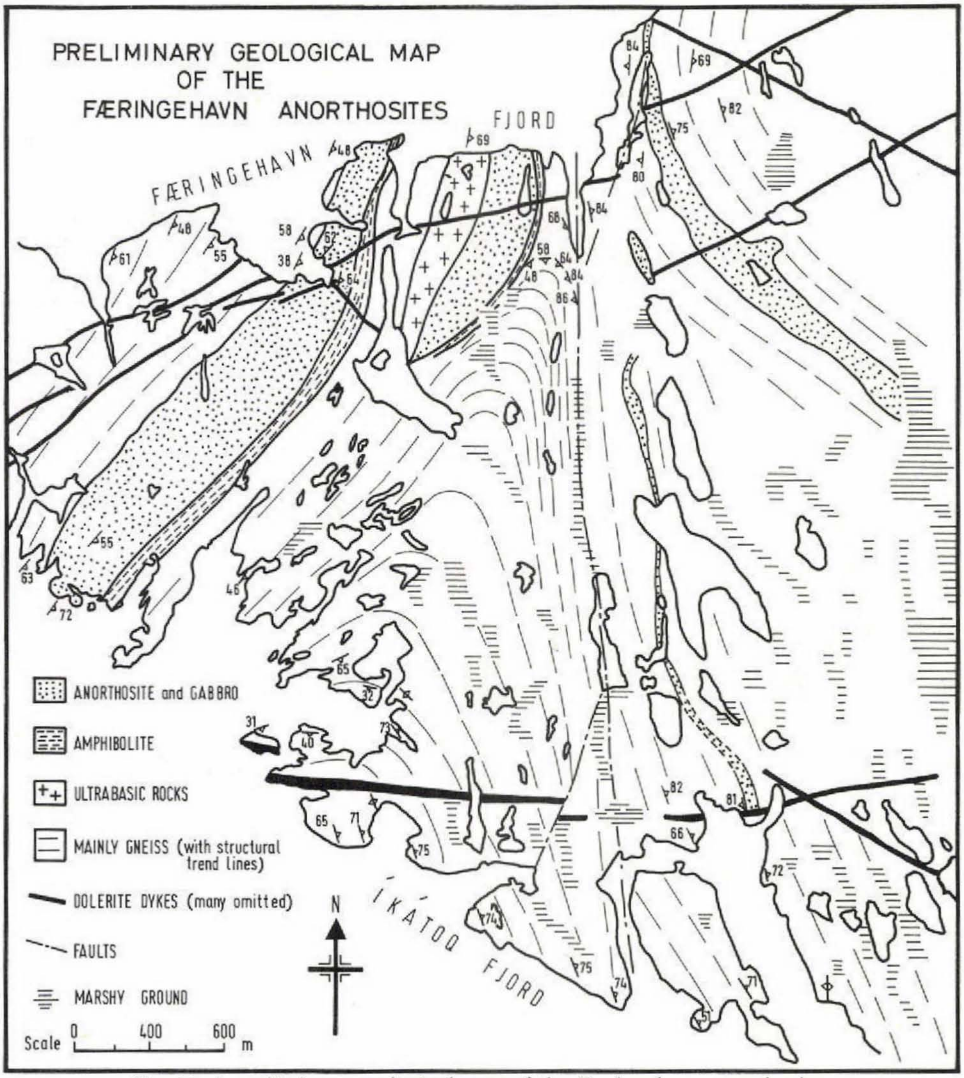

Fig. 11. A preliminary geological map of the Færingehavn anorthosites.

b) Færingehavn

On the south side of outer Færingehavn fjord there are the remains of two anorthosite horizons, up to 450 m wide and folded around a major southerly plunging synform (fig. 11); the fold and the anorthosites can easily be seen on the aerial photographs, but the fold core is only preserved in the gneisses.

The eastern- and westernmost anorthosites are the best preserved and are presumed to be the same horizon. The easternmost is layered and contains ophitic gabbro layers up to 40 cm wide with assemblages hornblende – plagioclase – biotite – magnetite and plagioclase – garnet – hornblende – biotite – quartz. The westernmost anorthosite is intensely layered with hornblende–rich (hornblende – plagioclase – [quartz] – [epidote]) and plagioclase-rich (plagioclase – epidote – hornblende – biotite) layers up to 30 – 40 cm wide (fig. 12). This is a rhythmic phase layering of igneous type and in places it is associated with possible slump structures.

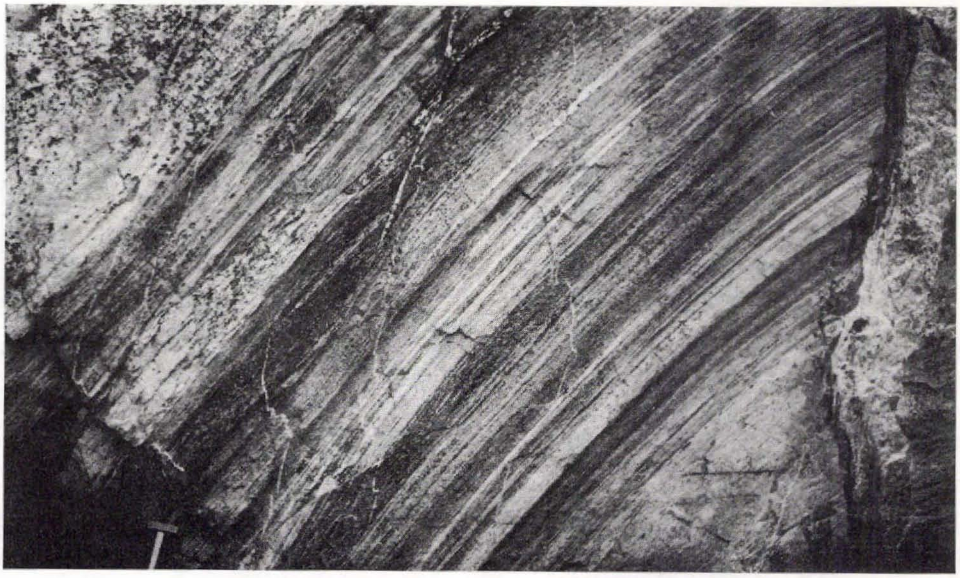

Fig. 12. Well-defined layering of plagioclase- and hornblende-rich layers in the westernmost anorthosite, Færingehavn.

The two central horizons consist of layered anorthosite made up of hornblende- and plagioclase–rich laminae about 1 cm wide with assemblages plagioclase – hornblende – epidote – sphene and plagioclase – hornblende – biotite – epidote – quartz. These horizons, however, have been so intensely pegmatised that at least 50 % of the rock volume consists of pegmatite; it is a common feature for the anorthosite horizons of West Greenland to be selectively pegmatised in this manner, the anorthosite occuring as inclusions in what has become a pegmatite horizon. The eastern of the two horizons has been thinned by deformation and is discontinuous, although it does reach southwards to Íkátoq fjord where it has the assemblage plagioclase – hornblende – (biotite). The anorthosite here is well layered with alternating leucocratic (1–20 cm wide) and melanocratic (1–10 cm wide) layers (fig. 13). Locally the hornblende–rich darker layers are absent, leaving those which are plagioclase–rich to reach 1 m in width; garnets are confined to the mafic layers.

Intercalated with the anorthosite horizons are intensely layered ultramafic rocks with common assemblages of hornblende – anthophyllite – biotite and cummingtonite (biotite).

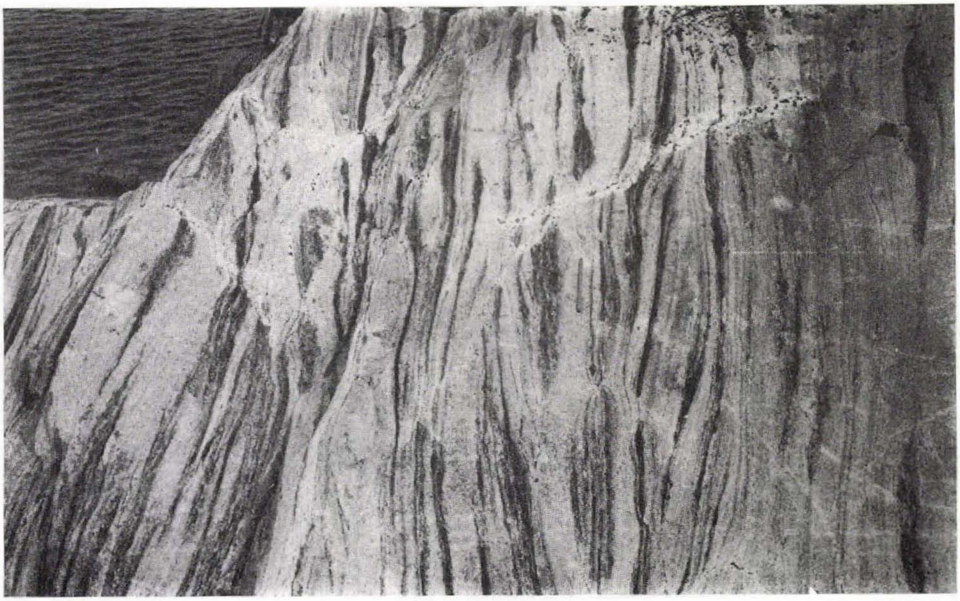

Fig. 13. Layering in anorthosite defined by hornblende-plagioclase lenses and laminae, north side of Ikátoq fjord; compare this with figure 24 from the Fiskenæsset complex (Windley, Herd & Bowden, in press).

c) Buksefjorden

On the north side of outer Buksefjorden there are two anorthosite horizons with maximum widths of about 600 m (fig. 14). Both layers continue northwards to Ameralik fjord and are isoclinally folded: the western synformally, the eastern antiformally. The eastern layer, on the coast, was described briefly by Sørensen (1955).

The anorthosites, in particular the western one, are layered with hornblende-rich streaks and laminae up to 5–10 cm wide. There is a common white speckled anorthosite containing scattered hornblendes. Some layers show excellent grading (fig. 15). expressed by a relative increase of plagioclase versus hornblende—this is better layering than has been seen by the writer in the Fiskenæsset complex.

The anorthositic rocks have the following common assemblages:

Leucocratic
- plagioclase – hornblende – epidote
- plagioclase – epidote – hornblende – biotite
- plagioclase – hornblende – biotite – epidote

Melanocratic
- hornblende – plagioclase – epidote – biotite
- hornblende – plagioclase – biotite – epidote – quartz – chlorite – apatite – (sericite)
- hornblende – plagioclase – biotite

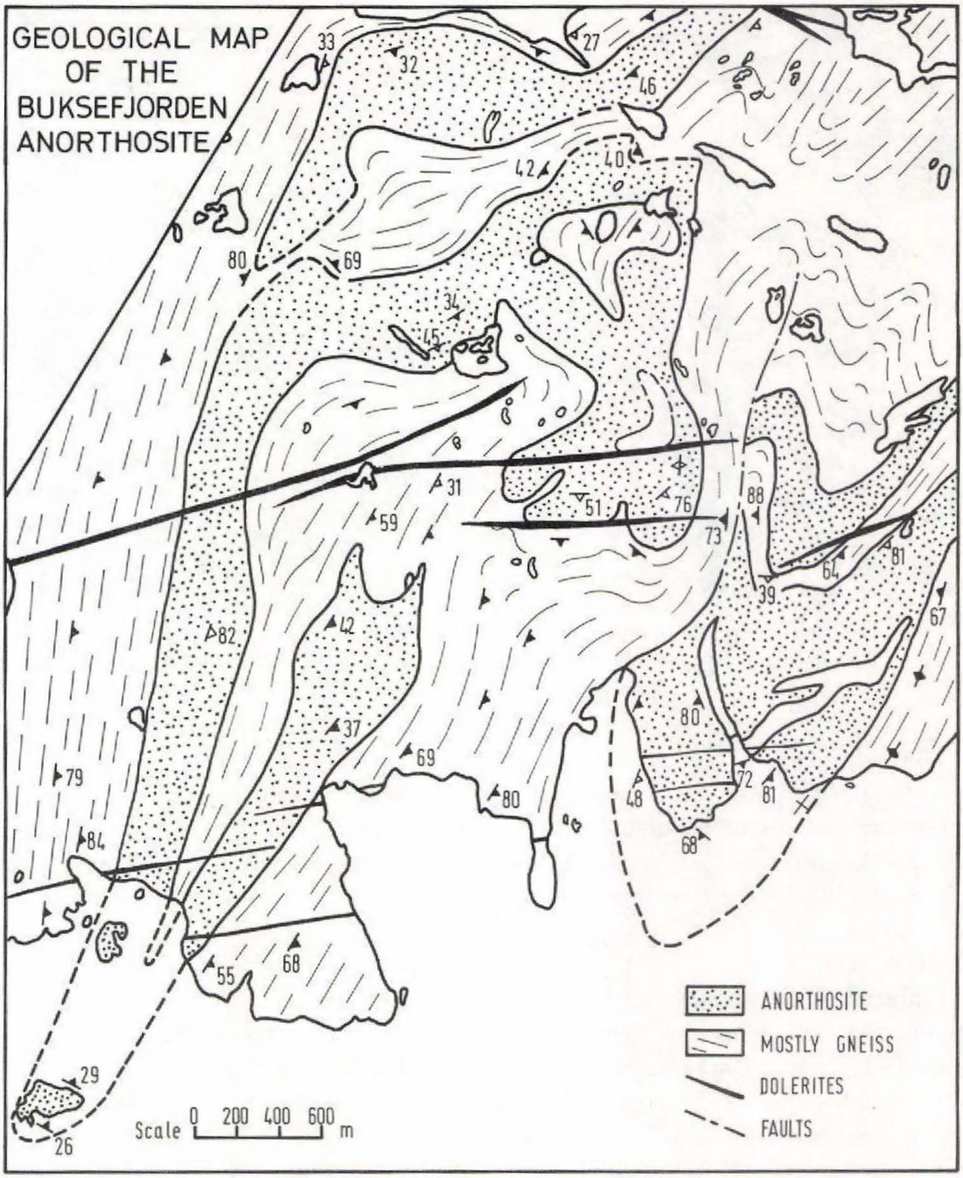

Fig. 14. Geological map of the Buksefjorden anorthosite.

The anorthosites contain zoned inclusions, 25 cm long, with a green clinopyroxene core rimmed by black hornblende, and 1 m wide mafic layers rich in orthopyroxene and clinopyroxene.

The eastern horizon is in an advanced stage of break–up by gneiss material: it is traversed by many migmatising garnet gneiss layers up to about 15 m wide, and it contains two broader gneiss units up to 200 m wide (fig. 14).

The western horizon, in particular, has been heavily pegmatised. Pegmatites are also abundant in the adjacent gneisses, immediately to the east of the western anorthosite; some of these are discordant, others conformable, and they reach a width of 50 m and contain abundant relics of anorthosite or gneiss.

Ultramafic rocks

Apart from the ultramafic rocks associated with the anorthosites and which have already been mentioned, there are also ultramafic lenses within the gneisses. It is a varied group, with rocks of many different compositions and a great range in mineralogies, as the original ultramafic rocks were reconstituted in different places under granulite-, amphibolite- or greenschist-facies conditions. The present complex parageneses, therefore, reflect the various metamorphisms which the bodies have undergone as well as the original rock compositions.

The ultramafic lenses vary from a few metres to more than a kilometre in size. Whilst they are disseminated throughout the entire region, the most important ultramafic area is due east of Narssaq village where there are several bodies of considerable size. In addition to the talc body already mentioned at Narssaq, there is one other talc occurrence in Íkátoq fjord.

a) The ultramafic body at Qarajat iluat.

This body lies 7.5 km ESE of Narssaq (map 1) and is the largest in the region (170 m by 1.2 km). Its brown weathered colour enables it to be seen from a considerable distance and it has been recorded by both Giesecke (1910) and

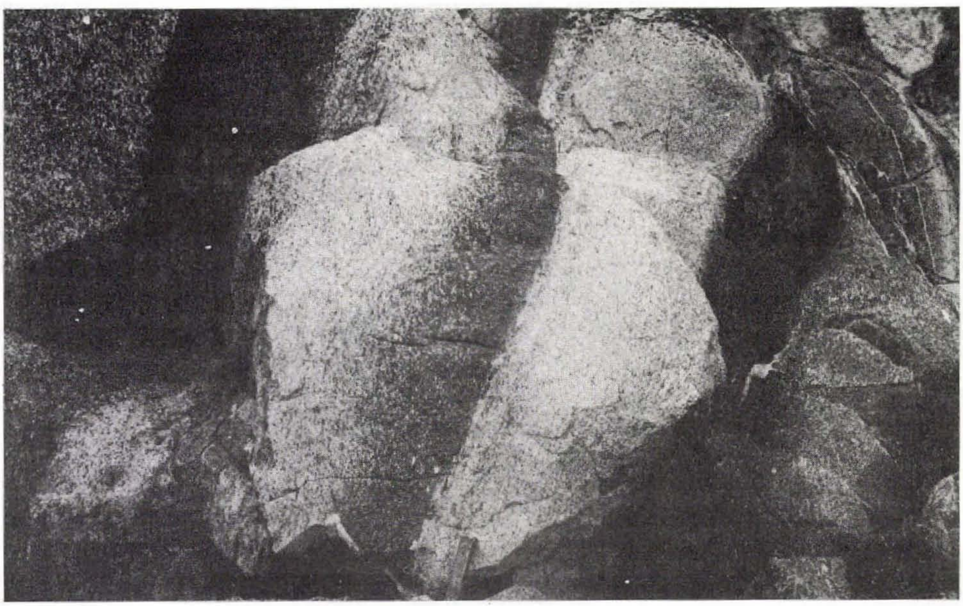

Fig. 15. Grading of hornblende versus plagioclase in a mafic layer in anorthosite, Buksefjorden.

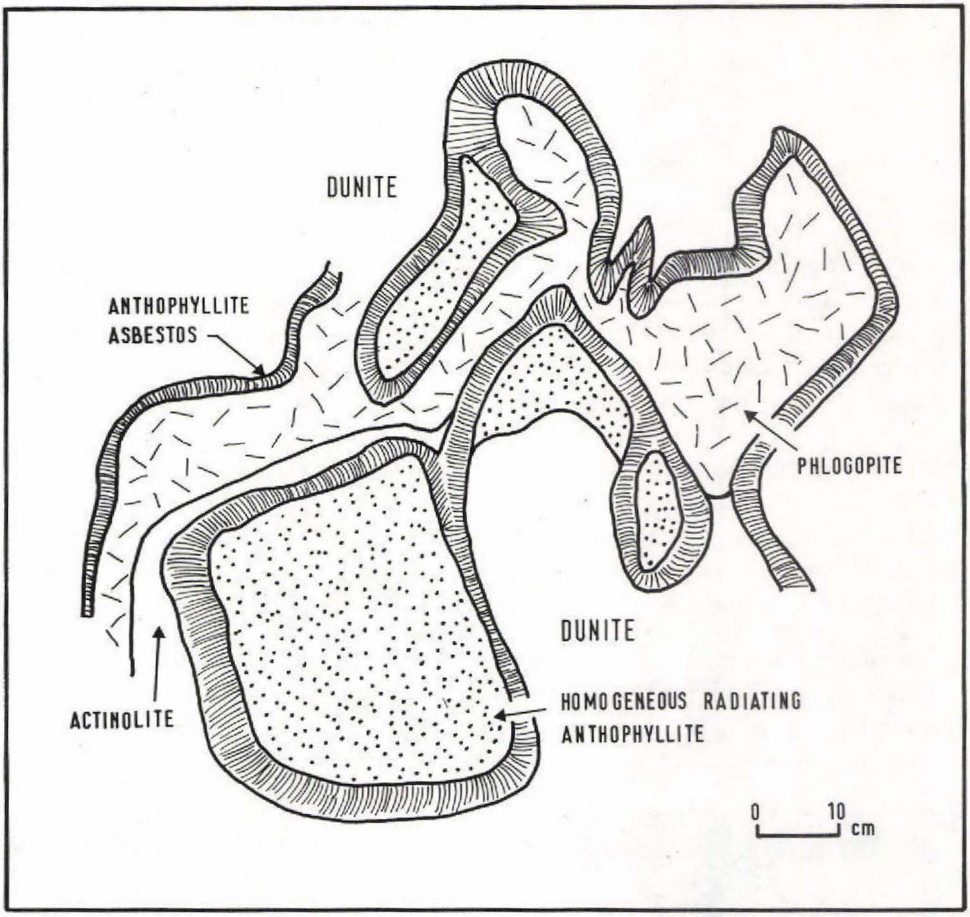

Fig. 16. Monomineralic zones in an alteration vein in dunite in the major ultramafic body at Qarajat iluat, east of Narssaq.

Bøggild (1953). It forms a large inclusion within the gneisses, its southern end just touching the coast, and its NNE strike is conformable with the gneiss foliation. There has been no migmatisation by gneiss material but the body is cut by several pegmatites up to 15 m in width.

The main rocks are homogeneous non–layered dunite containing olivine – phlogopite – cummingtonite, and layered dunite with olivine – cummingtonite – talc. The overall brown rusty weathering obscures the relationships between these and two further types, one of phlogopite peridotite and the other of cummingtonite peridotite. Along the eastern contact of the lens there is an 8 m wide clinopyroxene – hornblende – epidote rock in which green diopside and black hornblende alternate to define a marked layering.

Within the body there are many hydrothermal alteration veins composed of very coarse–grained minerals, the most common of which are actinolite (hornblende?), anthophyllite (gedrite?) and phlogopite (biotite?). Many veins a few centimetres in width consist of either just hornblende or anthophyllite, but these are inter-layered in many others. The most complex veins (fig. 16) contain well–defined, largely monomineralic zones symmetrically arranged. The anthophyllite, actinolite and phologopite often have their *c* axes oriented normal to the vein walls, the anthophyllite then giving rise to an asbestos-type rock with groups of crystals reaching 1 m in length. There is a general regular arrangement of zones whereby anthophyllite occurs at the margin, either in the form of the asbestos type, or

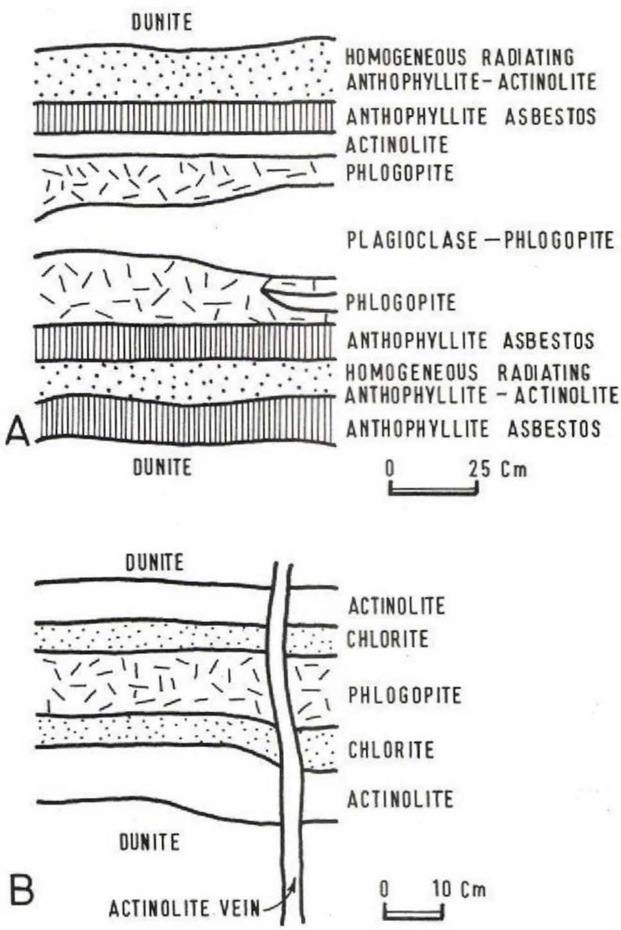

Fig. 17 A. A symmetrically zoned alteration vein in dunite, Qarajat iluat.
B. Monomineralic symmetrical zones in an alteration vein cut by an actinolite vein in dunite, Qarajat iluat.

in a zone with a radiating homogeneous fabric (rare actinolite occurring with it in places); actinolite forms the intermediate zone, followed inwards by one of phlogopite. Locally plagioclase, or plagioclase–phlogopite, forms a central zone (fig. 17A) and chlorite forms a narrow zone between actinolite and phlogopite (fig. 17B). The maximum zonation and general widths of individual zones are:

outermost	100 cm	Anthophyllite with or without rare actinolite
	30 cm	Actinolite
	5 cm	Chlorite
	45 cm	Phlogopite
innermost	45 cm	Plagioclase or plagioclase–phlogopite

Not all the veins are the same age: fig. 16B shows that an actinolite–chlorite–phlogopite vein is cut by an actinolite vein and that 1–2 cm wide anthophyllite veins are cut by actinolite veins of the same width; some 2 cm wide anthophyllite veins contain molybdenite.

b) The 'island' ultramafic body east of Narssaq

Most of the island, 3.5 km south east of Narssaq, is occupied by an ultramafic body, the main rock of which consists of green diopside and cummingtonite. Along its contact with the gneiss there is a pegmatite, 2.5 m wide, within which there are inclusions of the main rock; these inclusions have 2 cm wide reaction rims of recrystallised hornblendes the *c* axes of which are oriented normal to the inclusion walls. Throughout the body there are two types of somewhat similar zoned lenses:

1. A core of diopside–cummingtonite rock is surrounded by a zone of brown orthopyroxene and an outer rim of green hornblende. Both the pyroxene and the hornblende are oriented with their longest axes normal to the zone walls, the crystals reaching at least 60 cm in length. Some hornblendes are clearly recrystallised after pyroxene as they retain basal parting planes.
2. A core of plagioclase–biotite rock containing giant crystals of hornblende, up to 1 m long, and surrounded by a rim of hornblende the crystals of which are aligned radially to the zone walls and reach 50 cm in length.

There are scattered ultramafic inclusions in the gneisses on the mainland opposite this island.

c) The talc occurrence in Íkátoq fjord

On the north coast of inner Íkátoq fjord (map 1) there is an important talc occurrence which is worked by the Greenlanders. There are two lenses in the gneisses: one 2 m by 2 m and the other 12 m by 42 m (minimum length as the lens is cut by the coast) and with a vertical height of at least 30 m. They are conformable with the gneisses, the longest axes lying parallel to the foliation.

The larger lens is zoned (fig. 18) with a central core of serpentine followed outwards by zones of biotite, talc, talc–actinolite in which the actinolite forms

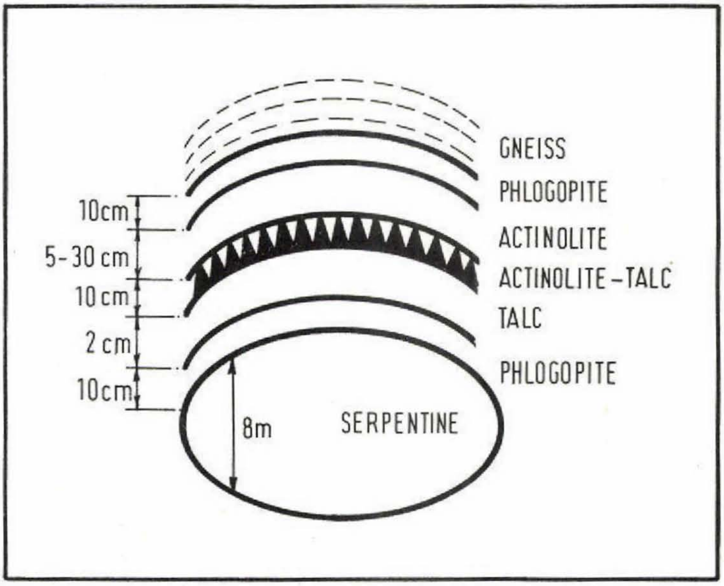

Fig. 18. Schematic representation of the alteration zones around a serpentine core in an ultramafic lens in gneiss, north side of Ikátoq fjord.

tree–shaped arrays, actinolite, and an outermost biotite zone. The smaller lens is also zoned but it has a core of actinolite into which veins extend from the talc.

The zones are cut by monomineralic veins of talc, magnetite, serpentine and some of zoned talc–serpentine; both the zones and the veins show age relationships which should give much information of the time sequences of mineral development in these metasomatically zoned bodies.

d) Other ultramafic lenses

There are many smaller relic inclusions of ultramafic rocks in the gneisses or in amphibolite layers within the gneisses. They may reach a few tens of metres across and display a variety of assemblages.

Færingehavn
30 m lens in amphibolite horizon in gneiss
olivine – phlogopite – cummingtonite

N Buksefjorden
30 cm inclusion in biotite gneiss
clinopyroxene – orthopyroxene – hornblende (brown) – plagioclase. This is a relic granulite facies rock

N Buksefjorden
10 m hornblendite layer in gneiss
hornblende (green) – clinopyroxene

Bay N of Kângnaitsoq
10 m layer in amphibolite horizon in gneiss
olivine – clinopyroxene – orthopyroxene – hornblende (brown) – magnetite – spinel. A relic granulite facies rock

S Buksefjorden
40 m lens in gneiss
gedrite – quartz – cordierite – biotite
S Buksefjorden
pegmatitic patch in above
gedrite – cordierite – sillimanite – muscovite
N Buksefjorden
small lens in gneiss
clinopyroxene – biotite

This account serves to show that the ultramafic rocks display the greatest range of mineral assemblages in the region formed under conditions varying from granulite to greenschist facies.

Pegmatites

Pegmatites abound throughout the Ameralik–Kângnaitsoq region. From a regional study such as this it is possible to demarcate areas that have been more heavily pegmatised than others. The following areas consist of 20–50 % pegmatite:

1. The south side of Færingehavn fjord where the central anorthosite horizons have been preferentially pegmatised.
2. Skinderhvalen, south of Buksefjorden, where the gneisses contain largely replacement or anatectic pegmatites with gradational contacts and basic fronts.
3. The south side of outer Íkátoq fjord; the gneisses here contain mostly conformable pegmatites, up to 25 m wide, with many inclusions of gneiss.
4. The plateau area north west of Buksefjorden; many biotite pegmatites, up to 50 m wide, strike 050–080 and contain streaks and layers of aplite.
5. The north side of outer Buksefjorden where the western anorthosite and the gneisses immediately east of it contain many pegmatites up to 50 m in width.

Other notable pegmatite occurrences are:
a) The entrance of Grædefjord where the finest pinch–and–swell and ptygmatically folded pegmatites in the region are to be found. They are probably best displayed on the south side of the fjord, but they are also well exposed on the islands. The pegmatites occur in an unusual, highly banded, micaceous gneiss (meta–sedimentary?) containing epidote skarn inclusions, and are broadly of two types:
1. Conformable pegmatite layers up to about 1 m in width which have undergone spectacular pinch–and–swell (fig. 19) and subsequent folding, boudins of pegmatite having been rotated and aligned in the fold axial planes (fig. 20).
2. Thin pegmatitic veinlets of several generations that are discordant to the gneiss foliation and have been severely folded ptygmatically (fig. 21).
b) At Færingehavn, near the radio station, there are many excellent pinch-and-swell pegmatites in the gneisses; they range up to 1 m in width and have thin basic fronts of biotite.

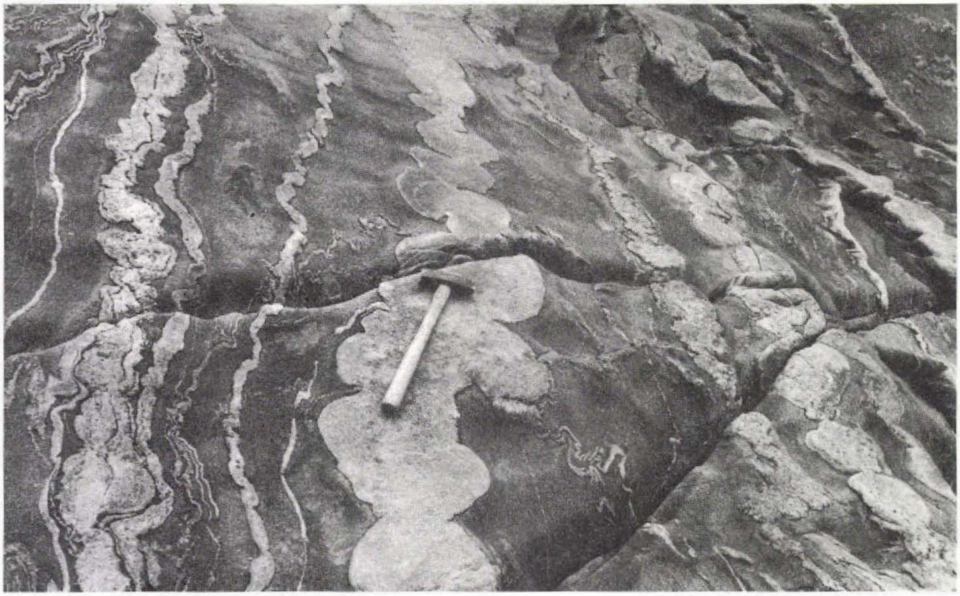

Fig. 19. Conformable pinch-and-swell pegmatites in biotite gneiss, south coast, entrance of Grædefjord.

Fig. 20. Rotated boudins of pegmatite aligned in the axial plane of a minor fold in biotite gneiss. Same locality as figure 18, Grædefjord.

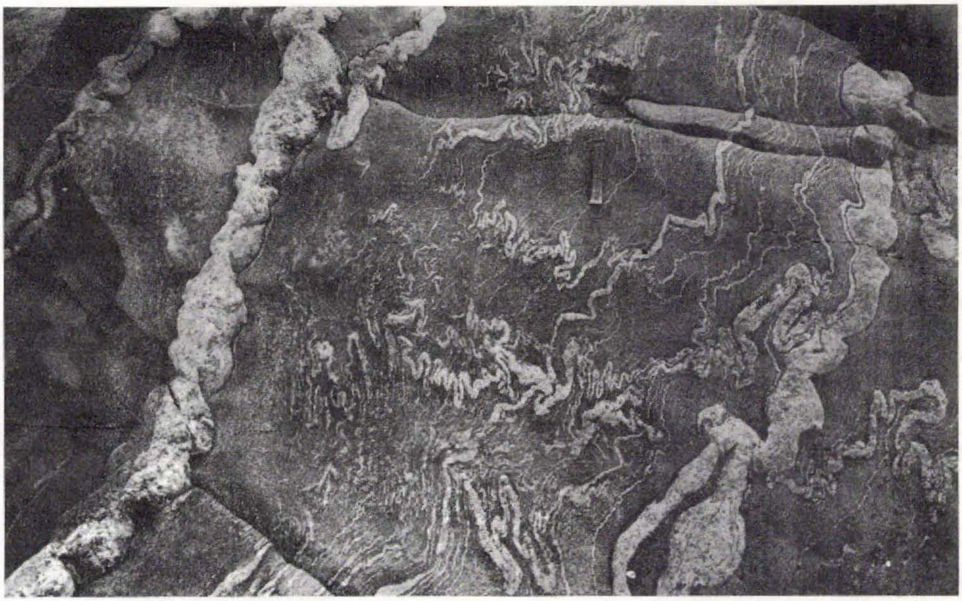

Fig. 21. Ptygmatically folded discordant pegmatitic veinlets in biotite gneiss. Some are apophyses of conformable pinch-and-swell pegmatites. There is more than one generation of veins. Same locality as figures 18 and 19, Grædefjord.

Many pegmatites formed syntectonically with respect to various fold phases, some are folded, some pre–date flattening of the gneiss foliation, and others are entirely post–tectonic.

Dolerite dykes and faults

There are at least 6 generations of dolerite dykes that traverse the basement crystalline rocks, three of which form regional swarms. From map 3, which shows the distribution of major dykes mostly over 10 m wide, it can be seen that few dykes were intruded in the Kângnaitsoq area and the northernmost area south east of Narssaq whereas the broad central region, extending from Færingehavn to Auverfigssat bay, was intruded by many major dykes in several swarms.

Table 2 shows the chronological relationships between dykes in different areas based on observed dyke intersections. There is a common dyke pattern through the region, early NE–trending dykes being succeeded by brown E–W dykes and then by black NW ones. Jensen (1962) provides some petrological and chemical data on E–W and NW–trending dykes in Amitsuarssugssuaq. The age relationship between the early NE dykes, of Grædefjord to Tre Brødre and Færingehavn to Buksefjorden, and the early NNW dyke of Íkátoq fjord is not known. All these dykes are older than the most important faults of the region which strike approximately N–S and clearly displace the dykes, but the age relationship between the brown NNE dyke on the islands south of Grædefjord and the N–S faults is not known. The E–W dykes in Amitsuarssugssuaq fjord show multiple intrusion.

Most of the crystalline basement has been heavily faulted and, since this movement took place after most of the dolerite dykes had been intruded; the dykes act as a good control for assessing displacements (see especially inner Færingehavn fjord, Amitsuarssugssuaq and Tre Brødre). There is a prominent NNE-trending fault that extends from Ameralik fjord, through Buksefjorden, Færingehavn fjord, Íkátoq and Tre Brødre (map 1); at Buksefjorden it has a sinistral offset of ca. 2 km which at Tre Brødre, where it is smaller, appears to have undergone double movements (fig. 14).

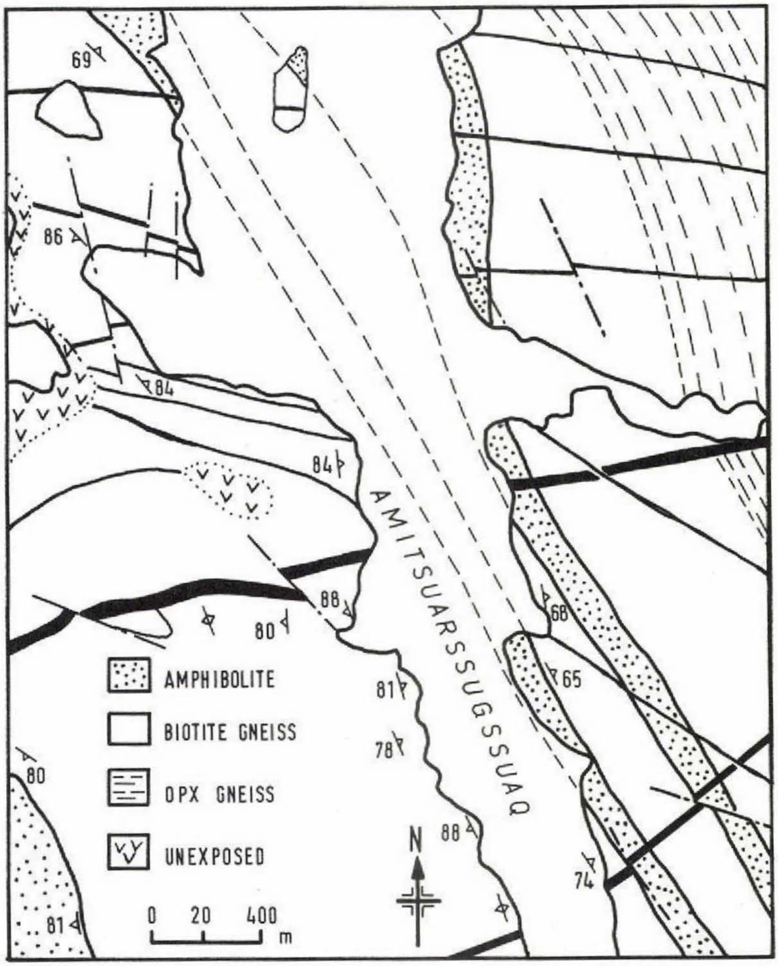

Fig. 22. Map showing the relationships between dolerite dykes and faults in Amitsuarssugssuaq fjord. These faults amphibolitise the dykes.

Table 2. Dolerite dyke-fault chronologies in seven areas

	Islands SW of Auver-figssat	Entrance to Græde-fjord	Amitssuar-ssugssuaq	Tre Brødre	Ikátoq	Færinge-havn	Bukse-fjorden
youngest	NNE (1 dyke)		N-S – NNW Faults	N-S Faults	N-S Faults	N-S Faults	NNE Faults
	NW	NW	NW			NW-WNW	
		E-W	E-W	E-W	E-W	E-W – ENE	E-W
oldest		NE	NE	NE	NNW (1 dyke)	NE	NE

Some interesting dyke–fault relations are seen in Amitsuarssugssuaq (fig. 22) where displaced dolerite dykes have been amphibolitised by the faults. Near the faults the dolerite has been transformed into foliated amphibolite, the foliation striking parallel to the fault plane, but farther from the fault the dyke amphibolite is homogeneous and has a relic igneous texture; in one example 30 cm of amphibolite was produced by a fault with a displacement of 10 m.

Apparently these fault movements were sufficiently deep–seated for high temperature recrystallisation to take place rather than low temperature cataclasis. If the K/Ar date of 1865 m.y. obtained from an amphibolitised dolerite in Amitsuarssugssuaq gives an approximate age of the faulting (Larsen, 1971), then all the major dolerite dyke swarms in this region are older and thus are presumed to have been intruded in the generally stable crustal period 2300–2000 m.y. This faulting of the Archaean craton took place at approximately the same time as regional deformation was affecting the Lower Proterozoic mobile belts to the north and south.

DISCUSSION AND SUGGESTIONS FOR FUTURE WORK

This region highlights one of the main problems of high-grade Archaean terrains: how can one distinguish between progressive and retrogressive amphibolite facies areas? The downgrading of the latter from an earlier granulite grade can be so complete that it is almost impossible to find any 'granulite' evidence (Windley, 1970b); it is a problem of metamorphic convergence on a grand scale. The

Table 3. Simplified chronology of events for the main sub-areas of the region

	South	Kâng-naitsoq	Auverfigssat Grædefjord	Sermilik Alangordlia	Tre Brødre Íkátoq	Færingehavn Buksefjorden	Qilángârssuit* Narssaq	*North*
youngest	Plutonic period		Amphibolite facies retrogression		Amphibolite facies retrogression			
	Plutonic period	GRANULITE FACIES METAMORPHISM AND DEFORMATION					Amphibolite facies deformation and metamorphism	
			Probable late granitic rocks				Emplacement of Nûk calc-alkaline sheets	
		TECTONIC INTERLEAVING OF COVER AND BASEMENT PRESUMED					Tectonic interleaving of cover and basement	
					Anorthosites emplaced			
		Volcanics	Volcanics	Volcanics	Volcanics Pelites	Volcanics Pelites	Volcanics Pelites	
						Basic dykes intruded**	Basic dykes intruded	
oldest	Plutonic period	GNEISSIC BASEMENT INFERRED					Deformation and metamorphism Formation of 'granitic' rocks	

* Chronology after OIGL & McGregor, 1971.
** McGregor (personal communication).

stratigraphy and fold structures in the two types of area are of little help as they are essentially similar. The mineral assemblages may be useful in deciphering the early metamorphic history and care has therefore been taken in this report to list the mineral assemblages in the various rock units in different areas; for example, orthopyroxene or the brown colour of hornblende may be retained when all other minerals have been re-equilibrated under the new amphibolite facies conditions.

The presence or absence of amphibolite dykes, as established by McGregor (op. cit.) in the Godthåb area, is one of the best tools for unravelling this history – that is if the dykes were intruded in the area concerned. It is significant that in the Qilángârssuit-Narssaq-Godthåb area the rocks generally trend NNE, as does also the Ameralik dyke swarm; passing south-eastwards from Narssaq one therefore crosses the strike of the swarm. One of the key problems is to establish what happens between Narssaq, with its 'primary' amphibolite-grade rocks, and Buksefjorden with its 'secondary' post-granulite amphibolite-grade rocks; how can one distinguish between these? Can the Ameralik dyke swarm have been so extensive that it intruded throughout the whole of the Ameralik-Kângnaitsoq region, or does the present distribution of the well-preserved dykes indicate approximately the original extent of the swarm? There is certainly a noticeable lack of amphibolite dykes in the Færingehavn-Kângnaitsoq region, but does this absence mean that all the gneisses are of Nûk-gneiss age or that the dykes were never intruded in this region? To find answers to these questions it will be necessary to study closely the thin amphibolite layers and fragments in the gneisses for relic apophyses, chilled margins, blasto-porphyritic textures and anorthosite inclusions.

The Fiskenæsset area, just to the south of Kângnaitsoq, has an obvious bearing on this problem. Although amphibolite dykes are not common in the Fiskenæsset fjord area, they certainly do exist as relics within the hypersthene gneisses but are not present either in the supracrustal rocks (amphibolites, schists and marbles) or in the associated anorthosite complex (Windley, Herd & Bowden, in press). The conclusion is made here that gneisses constituted the basement on which the supracrustals were laid down, although many of the gneisses may be equivalent in age to the Nûk gneisses.

Many of the chronological relationships in this region are quite clear; the following questions, amongst others, still require answers:

Do the anorthosites have a symmetrical stratigraphy similar to that in the Fiskenæsset complex (Windley, Herd & Bowden, in press)? If so, it could be concluded that they were infolded together with the bordering amphibolitic supracrustals into their gneissic basement. Chemical analyses made across the anorthosites from margin to centre may indicate symmetrical geochemical variations even though stratigraphy is poor.

What effect did the unit 9 retrogressive amphibolite facies metamorphism have on the Qilángârssuit-Narssaq area? Perhaps it was confined to those areas that had previously reached a granulite grade.

What proportion of the gneisses between Færingehavn and Kângnaitsoq are of Amîtsoq- or Nûk-gneiss age?

Acknowledgements

I wish to acknowledge that V. R. McGregor's work in the Godthåb area has assisted me in revising the chronological framework of the Ameralik-Kângnaitsoq region. I am also grateful to Cominco Ltd of Vancouver, Canada, for permission to quote unpublished map data, and to V. R. McGregor for kindly making useful suggestions to improve the manuscript.

The aerial photograph (fig. 9) is reproduced with permission (A.235/72) of the Geodetic Institute, Copenhagen.

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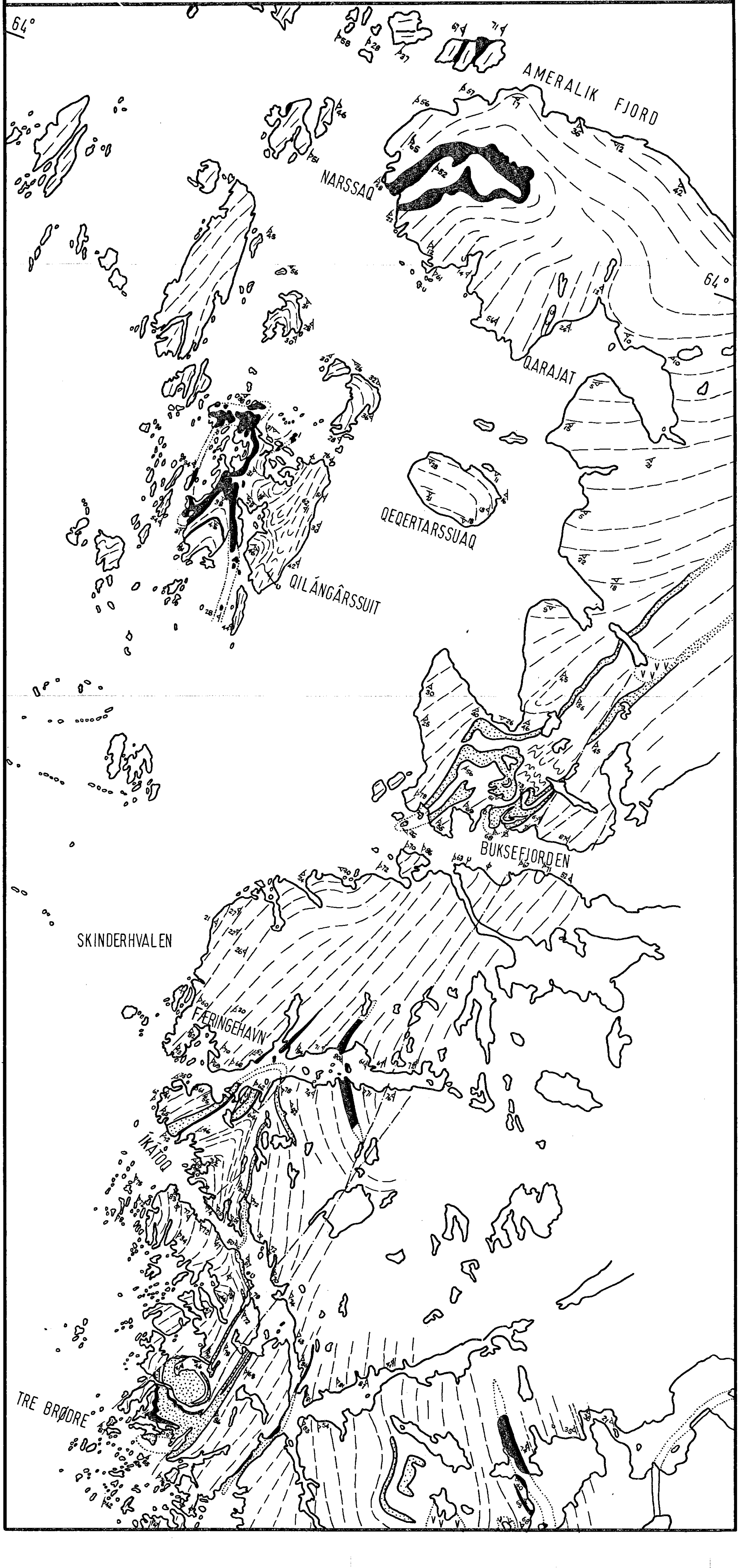
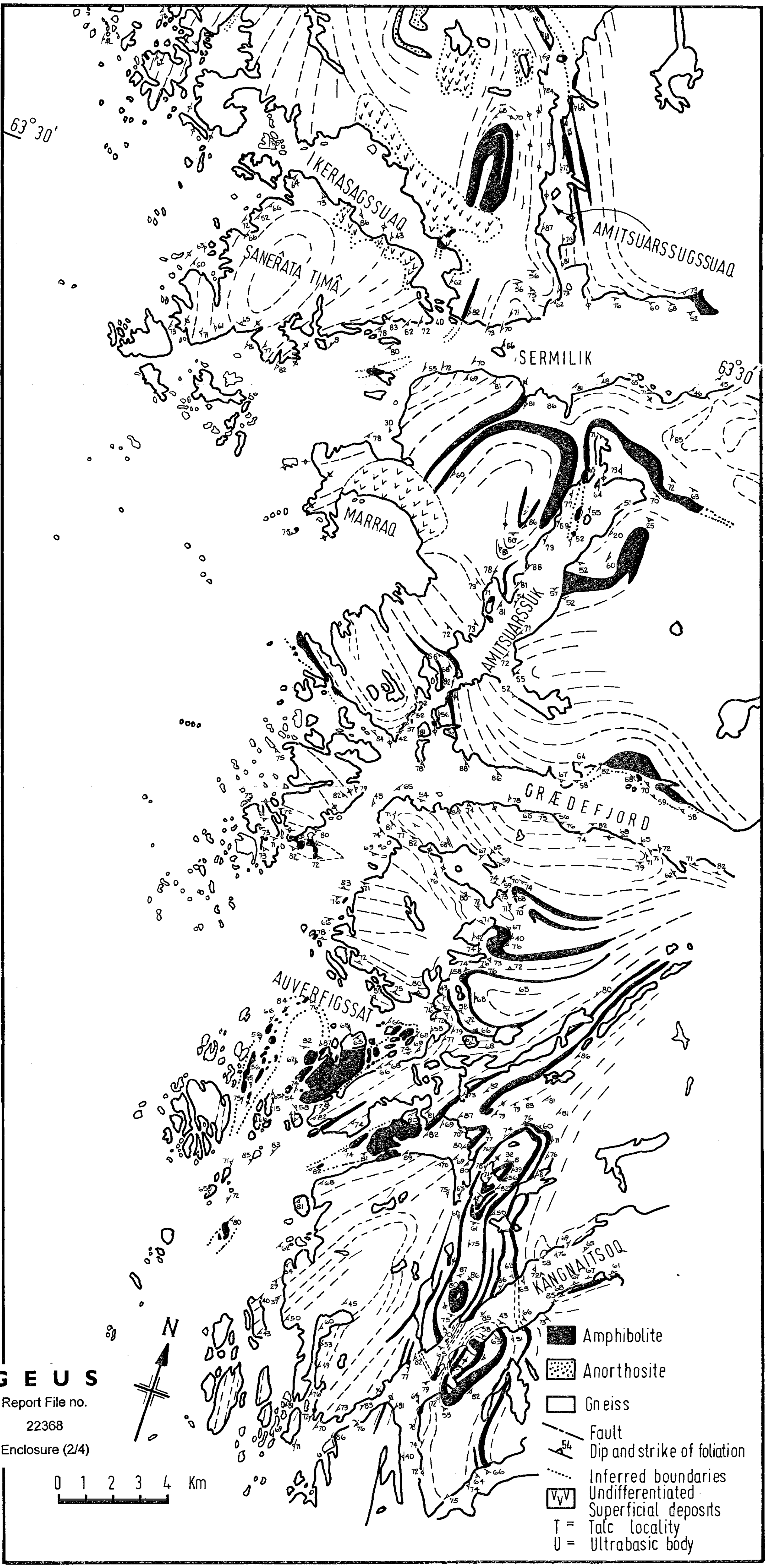
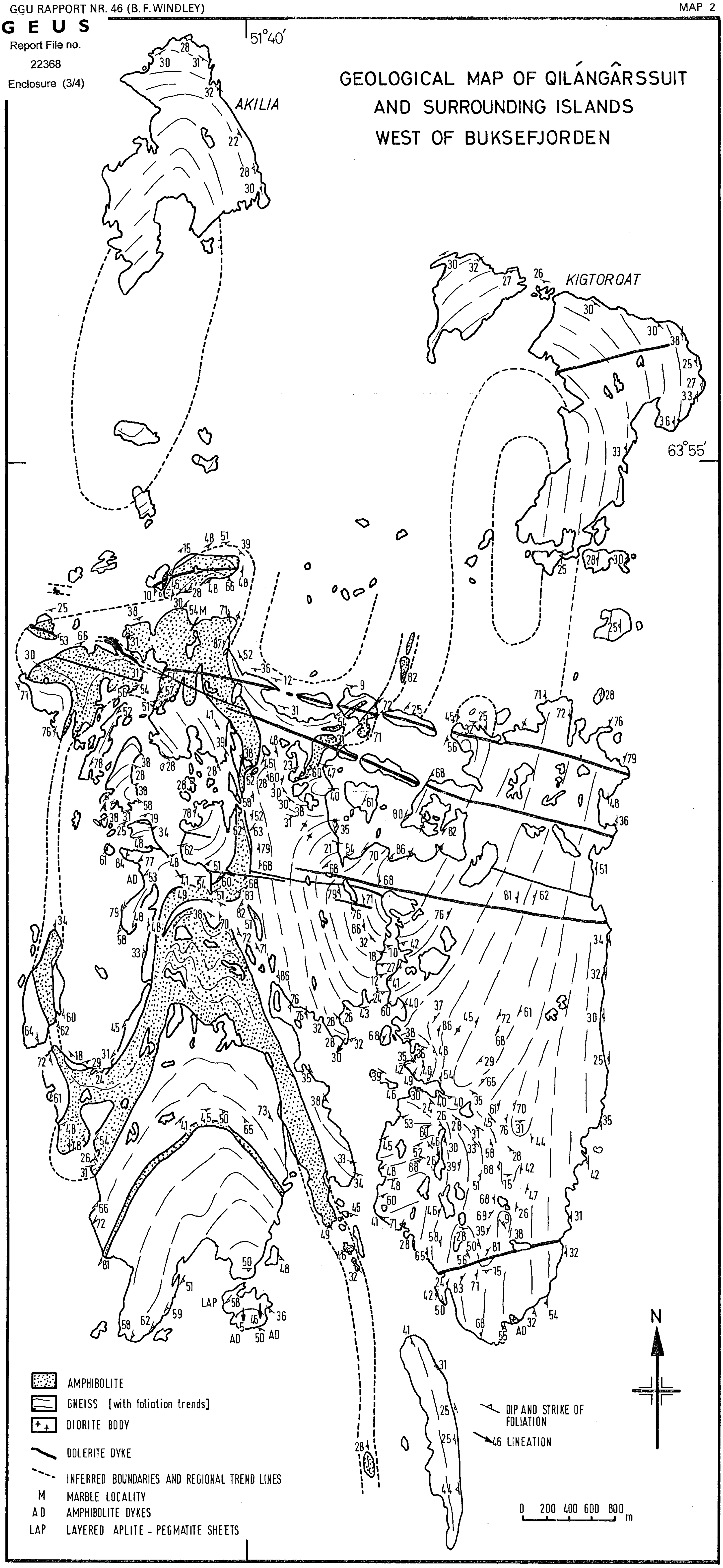
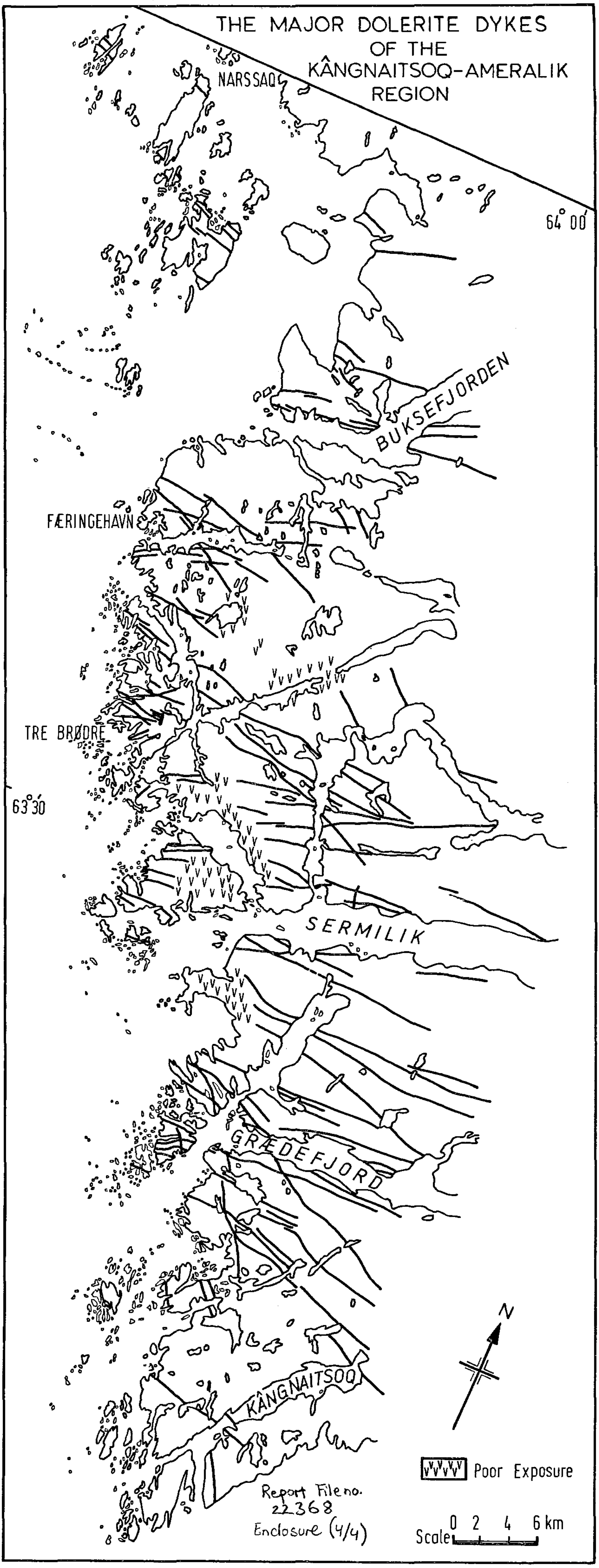
PRELIMINARY GEOLOGICAL MAP OF THE KÂNGNAITSOQ - AMERALIK REGION




63°30'
IKERASAGSSUAQ
SANERATA TIMÂ
AMITSUARSSUGSSUAQ
SERMILIK
63°30'
MARRAQ
AMITSUARSSUK
GRÆDEFJORD
AUVERFIGSSAT
KANGNAITSOQ
N
0 1 2 3 4 Km
Amphibolite
Anorthosite
Gneiss
Fault
Dip and strike of foliation
Inferred boundaries
Undifferentiated Superficial deposits
T = Talc locality
U = Ultrabasic body


GEOLOGICAL MAP OF QILÁNGÂRSSUIT
AND SURROUNDING ISLANDS
WEST OF BUKSEFJORDEN
51°40′
63°55′
AKILIA
KIGTORQAT
N
AMPHIBOLITE
GNEISS [with foliation trends]
DIORITE BODY
DOLERITE DYKE
INFERRED BOUNDARIES AND REGIONAL TREND LINES
M MARBLE LOCALITY
AD AMPHIBOLITE DYKES
LAP LAYERED APLITE - PEGMATITE SHEETS
DIP AND STRIKE OF FOLIATION
46 LINEATION
0 200 400 600 800 m


THE MAJOR DOLERITE DYKES
OF THE
KÂNGNAITSOQ-AMERALIK
REGION
NARSSAQ
64° 00'
BUKSEFJORDEN
FÆRINGEHAVN
TRE BRØDRE
63°30'
SERMILIK
GRÆDEFJORD
KÂNGNAITSOQ
N
Poor Exposure
Scale 0 2 4 6 km
Report File no.
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