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OUTLINE OF THE PRECAMBRIAN GEOLOGY OF SOUTHERN WEST GREENLAND

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ABSTRACT

The Archaean gneiss block of West Greenland is made up of gneisses, amphibolites and anorthositic rocks and contains the oldest crustal rocks yet known on earth. The Archaean block is bordered to the south by the Ketilidian mobile belt, largely consisting of younger granitic intrusions and to the north by the Naggsugtoqidian mobile belt which mainly consists of reworked Archaean rocks.

INTRODUCTION

In 1955 Gronlands Geologiske Undersogelse (The Geological Survey of Greenland, GGU) started the systematic mapping of the west coast of Greenland. Up to 1963 the work was concentrated in the southernmost part of Greenland, from 1964 to 1968 the region around Frederikshåb was mapped, and, after an interruption of the systematic mapping for one year, mapping in the Fiskenaesset region started in 1970 and will continue until 1975.

The mapping is performed by 10–25 geologists each summer. Transport in the otherwise almost inaccessible terrain is supplied by two Bell 47 J helicopters and by several GGU cutters. The final results of the mapping are being presented in a series of 1 : 100 000 map sheets, but the field mapping is mainly done on enlarged aerial photographs and 1 : 20 000 field maps, which permit detailed mapping of the generally well exposed terrain.

Apart from 1 : 100 000 maps, GGU publishes geological maps at 1 : 500 000 and in 1969 a special mapping operation was undertaken in the region around Sondre Stromfjord to collect information for the compilation of one of the 500 000 sheets.

Minor mapping operations are going on continuously along most of the west coast, for example in the Godthåb region, with the help of GGU cutters but with very little helicopter support. The most inportant investigations prior to the Survey mapping were those of Kornerup in 1878, Ussing in 1900 and Wegmann in 1936.

In the following sections an outline of the Precambrian geology of southern West Greenland is presented. The first section, by F. Kalsbeek, deals with the Archaean gneiss block (fig. 1). In the second section, by J.H. Allaart, the Ketilidian mobile belt south of the Archaean block is described, and in the third section, by A. Escher, an account is given of the Nagssugtoqidian mobile belt to the North.

The contents of this paper are based on 20 years of cooperation between numerous geologists. This paper is published with the permission of the director of GGU, K. Ellitsgaard-Rasmussen.

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THE ARCHAEAN GNEISS BLOCK

The Archaean gneiss block is exposed over a coastal stretch of c. 600 km between Ivigtut and Sondre Stromfjord. Due to detailed mapping done in parts of the block and the excellent exposure in most of the terrain, many details of the geology of the Archaean block are now fairly well known. The main rock types are variably migmatised gneisses, amphibolites and anorthositic rocks of which gneisses are by far the most abundant. In the following discussion the area around Godthåb and Fiskenaesset (fig. 1) will be described in some detail as mapping activity is at present concentrated here.

In the terrain around Godthåb McGregor (1973) has been able to differentiate between an older group of gneisses, the Amitsoq gneisses, and a younger group of gneisses, the Nuk gneisses, which, due to intense deformation, in many localities occur side by side. The older gneisses contain a swarm of metamorphosed basic dykes, generally strongly deformed but locally well preserved and clearly discordant (fig. 2). Such dykes never occur in the younger gneisses. The Nuk (younger) gneisses frequently show cross cutting relationships with a series of metavolcanic rocks and metasediments, the Malene supracrustals. The Amitsoq (older) gneisses do not cut the Malene supracrustals; they may have formed a basement to the supracrustals, in which case they would be older, or the contacts between the two rock types may be purely tectonic, in which case the age relationships would be uncertain.

An extensive programme of isotopic investigations has been undertaken by the Oxford Isotope Geology Laboratory, and is being published in a series of very informative papers. The older (Amitsoq) gneisses have been dated at 3700–3750 m.y. by Rb-Sr and Pb-Pb whole rock isochron dating (Black et al., 1971, Moorbath et al., 1972) and by U-Th-Pb dating of zircons (Baadsgaard, 1973). They are among the oldest rocks as yet found on the earth. The younger (Nuk) gneisses have been dated at about 3000 m.y.

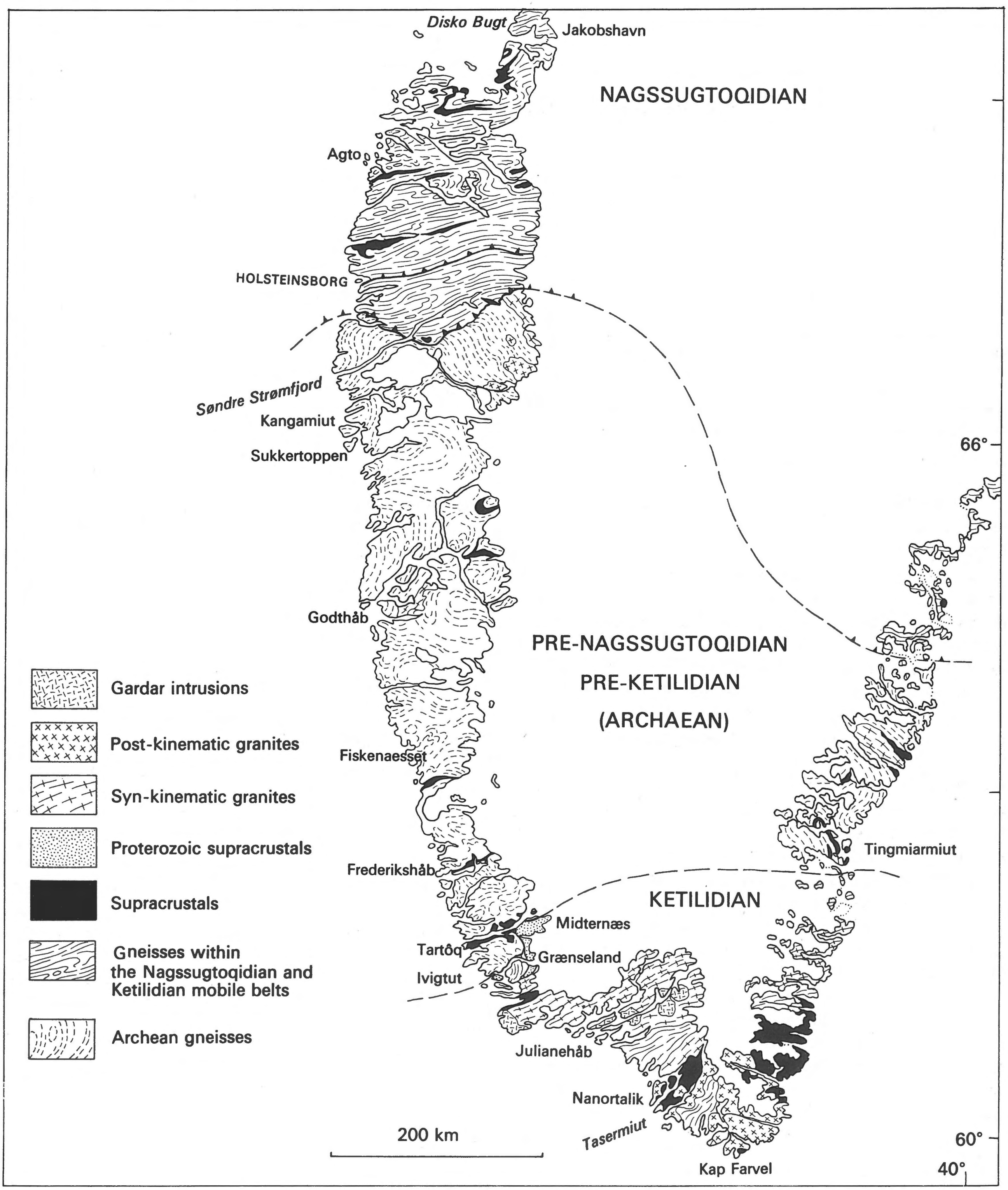


Fig. 1
The main geological divisions in southern West Greenland.

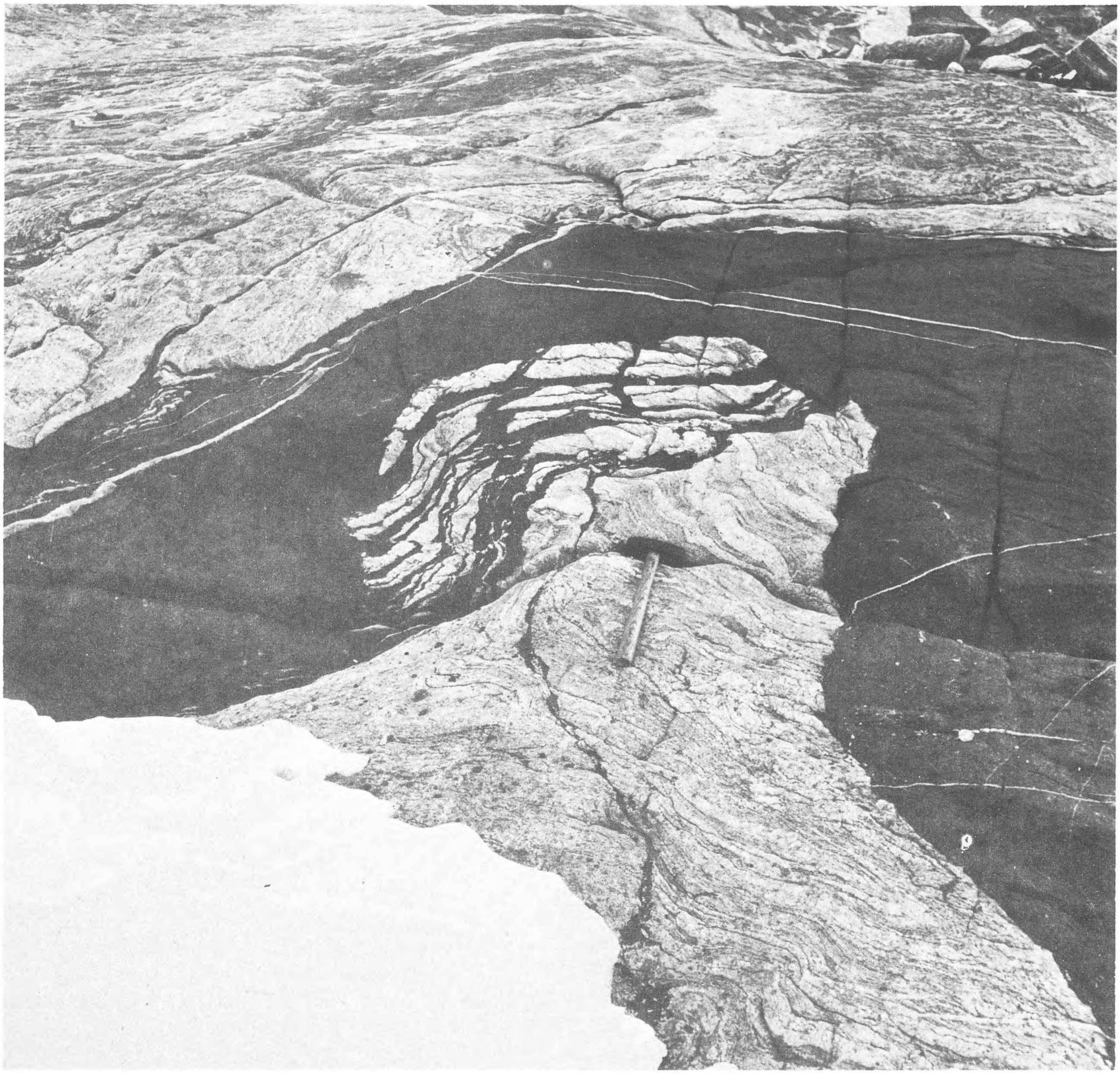
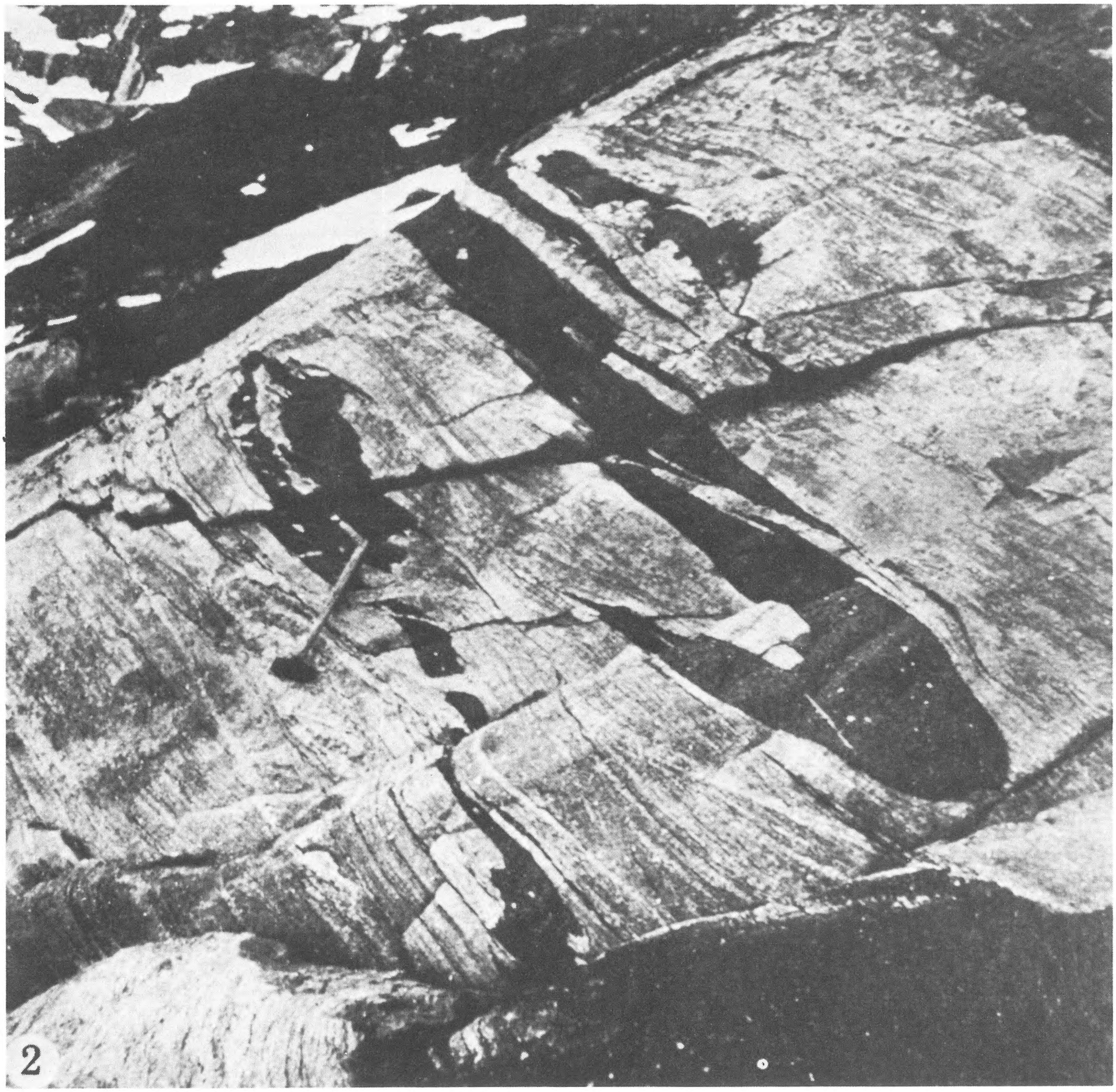


Fig. 2
Metamorphosed basic dykes in the early Precambrian Amitsoq gneisses; A: little deformed dyke, B: folded and broken dyke. (After McGregor, 1973).

(Pankhurst et al., 1973). The age of the Malene supracrustals is not yet known.

Enclosed within the older gneisses of the Godthåb region a sequence of supracrustal rocks is found in the Isua area, c. 150 km north-east of Godthåb. This sequence consists of quartzites, meta-greywackes and banded iron formation together with metamorphic basic and ultrabasic igneous rocks. The analytical age of these rocks, 3760±70 m.y. (Moorbath et al., 1973), is not significantly different from that of the surrounding gneisses, but recent field work has shown that the gneisses have cross cutting relationships with the metasediments (Bridgwater, personal communication). It is of interest to note that among the oldest rocks recognised in the Earth's crust clearly water lain sediments already play an important role.

The Fiskenaesset region (Kalsbeek & Myers, 1973) is at present being mapped systematically at a scale of 1 : 20 000. It has not been possible in this region to differentiate between older and younger gneisses, since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discordant amphibolites are generally lacking.

Amphibolitic rocks form c. 15% of the terrain and for part of these a supracrustal origin has been established. The best preserved amphibolites occur in the Ravns Storo amphibolite belt in the southern part of the region near Frederikshåbs Isblink (A n d e r s e n & F r i e n d, 1973). Here, pillow structures are locally well preserved and bear witness to a supracrustal origin of the rocks. Elsewhere, thin mica schist layers locally occur within the amphibolites. In the Ravns Storo belt, however, metagabbros have also been recognised and it is possible that in other areas part of the amphibolites may also derive from originally intrusive rocks.

In other parts of the Archaean block well preserved supracrustal sequences of basic volcanic rocks, sometimes associated with metasediments, have also locally been found. The relationship with the surrounding gneisses is not always well understood, and it is not known which of these supracrustal rocks are contemporaneous and which are not. One of the best preserved is the Tartoq Group, in the southern extremity of the Archaean block, which is less complexly deformed than the surrounding gneisses. The latter are therefore interpreted as the gneissified and deformed basement on which the Tartoq Group was deposited (H i g g i n s, 1968). For the Ravns Storo

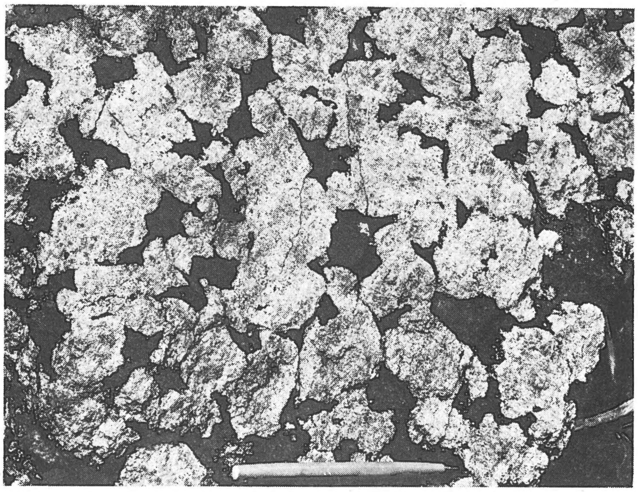

Fig. 3
Meta-leucogabbro with undeformed igneous cumulus texture. The plagioclase primocrysts have been replaced by finer grained metamorphic plagioclase. The interstitial mineral is mainly green hornblende. (After Myers, 1973).

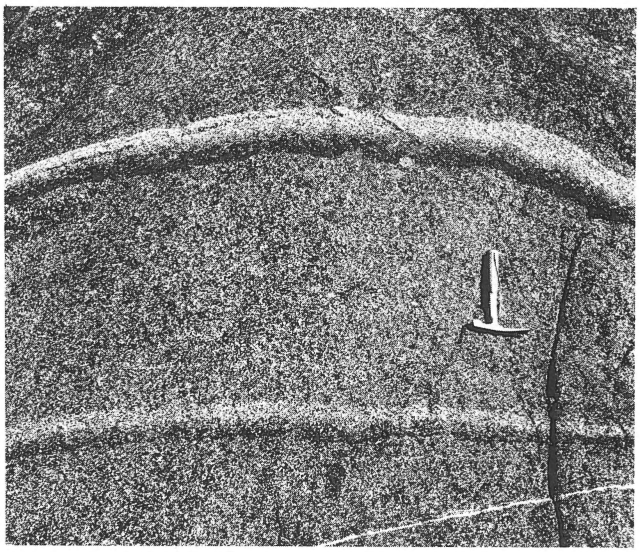

Fig. 4
Gravity-stratified layers between uniform layers of meta-gabbro. (After Myers, 1973).

amphibolite belt in the Fiskenaesset terrain such evidence has not been found.

Some of the amphibolite sequences in the Archaean block have been interpreted as root zones of "greenstone belts", which, together with the structural style of the area, would be characteristic for deep-level Archaean terrains (Windley & Bridgwater, 1971). As yet, such speculations are open to discussion.

Anorthositic rocks, occurring both as persistent bands up to several km wide and as swarms of inclusions in the gneisses, form about 5% of the terrain. These rocks grade from ultramafics and gabbroic rocks through leucogabbros to anorthositic rocks. Although generally they are strongly deformed and recrystallised, they are locally surprisingly well preserved so that original igneous features can often be studied in detail. The anorthositic and associated rocks are thought to represent original stratified igneous complexes, intruded into a sequence of supracrustal volcanics and minor sediments. The latter are now found as amphibolites and rare mica-schists which commonly fringe the anorthosite complexes.

During the field work in 1970 it was found that in part of the area the anorthosite complexes show a more or less constant stratigraphy (Windley, 1971). Much simplified, the complexes show the following sequence of layers from (what later proved to be) the bottom upward: (1) minor ultramafic rocks, (2) layered anorthositic and (leuco-)gabbroic rocks, ranging upward into (3) leucogabbroic rocks, often with well preserved coarse cumulus textures (fig. 3), which finally give away to (4) anorthositic rocks which locally are garnetiferous. Hornblende chromitite layers occur near the top of the sequence and not, as in most other stratified complexes, mainly near the bottom. The average content of mafic minerals (mainly hornblende) for the complexes as a whole generally varies from 20-30%. Chemical analyses of sample traverses through the complex have left no doubt that the sequence as described above is the correct way up, and this can locally be confirmed by field evidence such as well preserved igneous layering (fig. 4).

The anorthositic and associated rocks are by far the best investigated rocks in the Fiskenaesset region. A wealth of petrological, geochemical and mineral chemical information has been collected (Windley, 1973, Windley et al., 1973, Windley & Smith, in press). It has been concluded that the anorthosite complexes formed from a water-rich highalumina basic magma, which would explain, for example, why the chromitite layers occur near the top of the intrusion, and why the plagioclase is so calcic (compositions between An 80 and An 95 are most common).

Associated with the anorthosite complexes exotic rock types occur, containing such rare minerals as sapphirine, kornerupine and ruby corundum. These rocks almost invariably occur at the contact between the top of the anorthosites and ultramafic rocks or metasediments in the bordering amphibolites and apparently resulted from metasomatic processes between the intruding anorthosites and the adjoining rocks (Herd, 1972 and 1973).

Anorthositic rocks have been recognised over most of the Archaean block, but rarely so well preserved as in the Fiskenaesset region. They occur for example within the Malene supracrustals of the Godthåb region. Often they are only found as minor lenses within the gneisses. It has been suggested (see e.g. Pulvertaft, 1973) that the presence

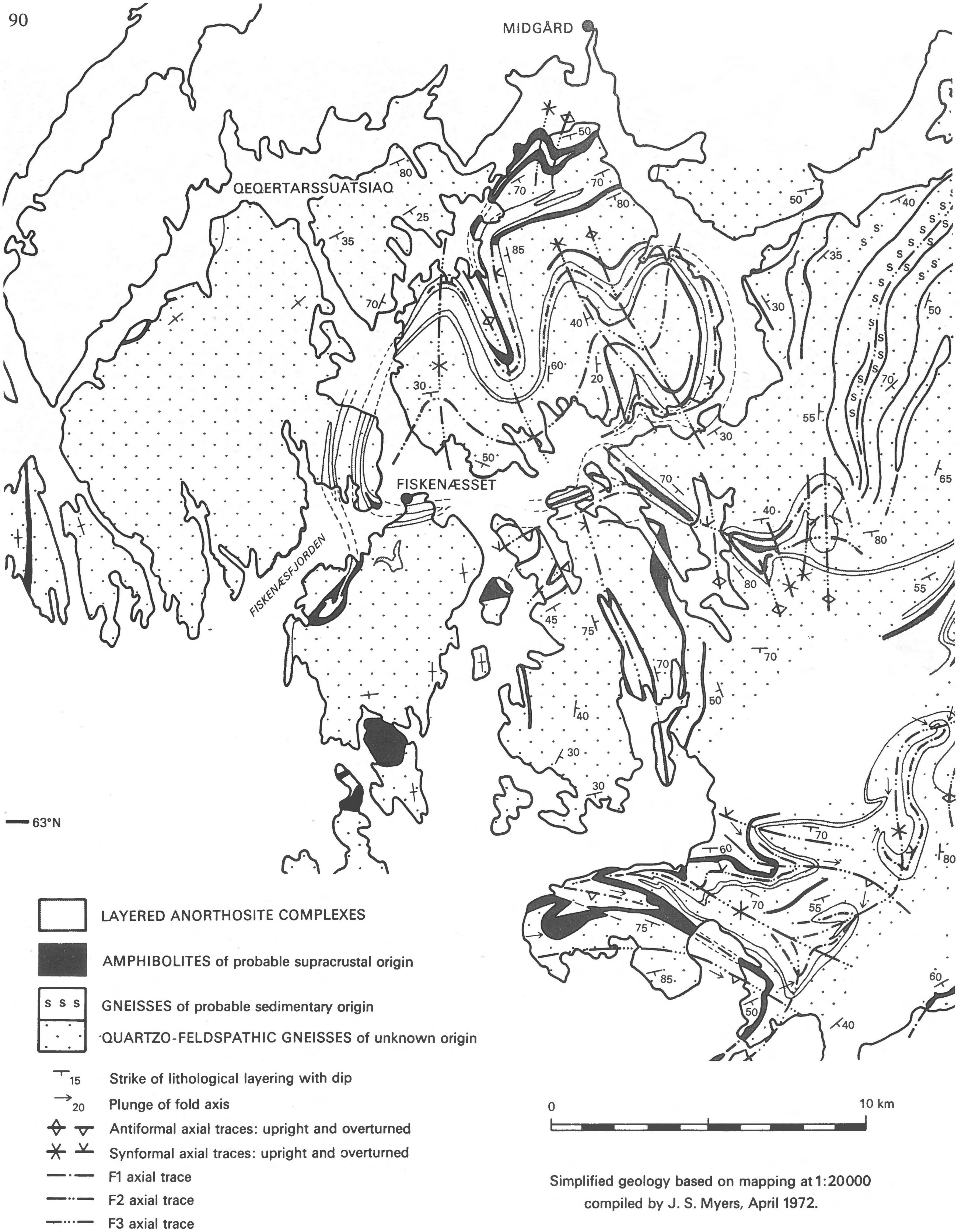

Fig. 5
Interference fold pattern outlined by anorthosites and amphibolites in the area around Fiskenaesset. (Section of Plate 1, Kalsbeek and Myers, 1973).

of such anorthosites outside the Archaean block indicates that the gneisses in which they occur are reworked Archaean rocks.

As mentioned earlier, it is supposed that part of the amphibolites in the Fiskenaesset region are of supracrustal origin. It is possible that some of the gneisses in the area represent the basement upon which these supracrustals were laid down, but in spite of intensive search no direct evidence of such a basement has been discovered. On the contrary, sheets of granitic gneiss commonly intrude amphibolites and anorthositic rocks, and both the amphibolites and the anorthosites are often strongly migmatised by quartzo-feldspathic gneiss.

The origin of the gneisses poses a very difficult problem, which is essentially due to the fact that it is almost impossible in the field to subdivide the gneisses into different mappable genetic types. Strong deformation and migmatisation have almost everywhere obliterated the contacts between originally separate gneiss units. Only locally, in low deformation areas, can such units be differentiated. Generally, the gneisses grade imperceptably from clearly banded types to homogeneous types, and from very leucocratic types to melanocratic types. It has also proved to be difficult to subdivide the gneisses into distinct groups by petrographical and geochemical means. Most gneisses have tonalitic compositions: 30-40% quartz, 50-60% plagioclase (An 20-30), 0-10% microcline and 5-15% biotite. These rocks grade into gneisses with a granitic composition.

Locally, the presence of remnants of garnet-sillimanite gneisses, quartzites and rarely marble, point to a possible sedimentary origin for some of the gneisses; elsewhere, clearly cross-cutting relationships point to an intrusive origin for other gneisses. We tend to the belief that most of the gneisses are of igneous origin and younger than the amphibolites, anorthosites and metasediments which are provisionally considered to be the oldest rocks in the area. The banding in the gneisses, often a thin pegmatite banding, is thought to be mainly due to migmatitic and deformational effects.

The deformational history of the Archaean rocks is very complex. This is not surprising since the rocks represent a vast time span of plutonic activity in the earth's history – in the order of perhaps 1000 million years or more.

Amphibolite and anorthosite horizons have been extensively used as markers to define the large scale fold pattern. In the Fiskenaesset region three major fold phases, with axial surfaces perpendicular to each other, produced intricate interference patterns (fig. 5). What originally appeared to be simple anorthosite layers often proved to be tightly compressed isoclines. This can be shown in the field by careful mapping, and is also demonstrated by geochemical work which shows geochemical trends that are symmetrical about the centre of the anorthosite outcrop. Since it is possible to define the way up in a number of the anorthosite complexes, one has a unique possibility to recognise synclines and anticlines (and not as in many complexly folded terrains only synforms and antiforms).

The age of the rocks in the Fiskenaesset area is as yet largely unknown, and the same is true for most of the Archaean block outside the Gothåb district. This is partly due to the fact that large parts of the Archaean block have undergone a late phase of granulite facies metamorphism which recently has been dated at 2850±100 m.y. (Black et al., 1973). In these areas, dating of events older than 2850 m.y. is virtually impossible, and difficulties have also been encountered outside the areas of granulite facies rocks; and it is possible that part of the amphibolite facies terrain consists of retrograded granulite facies rocks.

According to Heier (1973) granulite facies rocks generally have lost much of their U and Th contents, and retrograded granulite facies rocks retain their abnormally low U concentrations and their abnormal Th/U ratios. A study of U, Th and K contents of rocks from the Archaean gneiss block (Kalsbeek, in press) has shown that the granulite facies rocks of the Nordland area, north of Godthåb contain six times less U than the amphibolite facies rocks of the Frederikshåb area (fig. 6). Th/U ratios in the Frederikshåb area approach normal values, and it appears that the rocks here did not loose their U, and therefore probably did not take part in the granulite facies event. In the Fiskenaesset terrain, however, the amphibolite facies rocks generally also have abnormally low U contents, and this may be due to the metamorphic event at 2800 m.y. which makes dating of older rocks so difficult. It is possible that isotopic age determinations in the Frederikshåb terrain will be more fruitful than those in the Fiskenaesset terrain.

Provisionally it is considered that most of the Fiskenaesset gneisses compare most closely with the younger (Nuk) gneisses in the Godthåb district. However, the possibility cannot yet be excluded that they correlate with the older (Amitsoq) gneisses, in which case the amphibolites and anorthosites would be older than 3700 m.y.

Several sets of younger dolerite dykes dissect the Archaean basement. The age of these rocks is not yet known. These dykes are generally undeformed in most of the Archaean block but locally they are displaced by transcurrent faults.

THE KETILIDIAN MOBILE BELT

Development during the Early Proterozoic

The Ketilidian mobile belt (fig. 7) comprises all the basement rocks between Ivigtut in the north-west and Kap Farvel, the southern tip of Greenland. The belt is characterised by low – to medium-pressure high-grade regional metamorphism and deformation, and by the development of large quantities of granitic rocks part of which show field

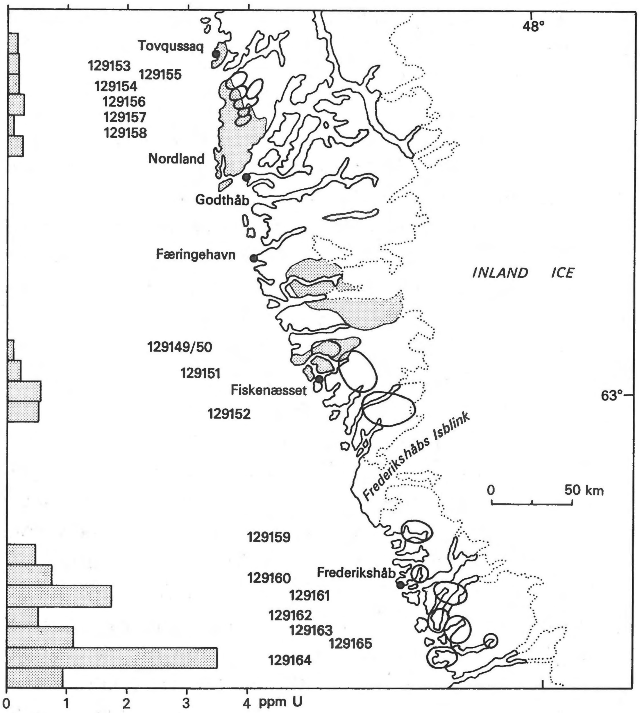

Fig. 6
U contents in composite sand samples from granulite facies (shaded) and amphibolite facies terrains in the Archaean block. (After Kalsbeek, in press).

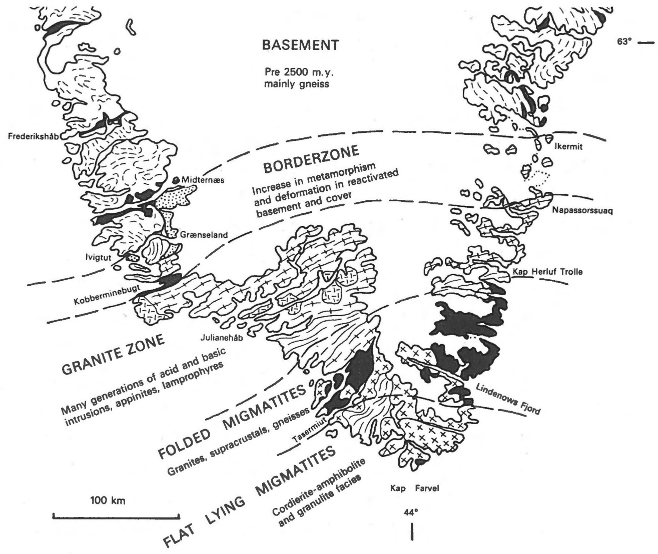

Fig. 7
The main geological divisions of the Ketilidian mobile belt. (After Bridgwater et al., 1973). For the legend see fig. 1.

evidence of derivation from older (Archaean: > 2480 m.y.) basement. Early Ketilidian granites and late-Ketilidian granites yield Rb-Sr whole rock and U-Pb zircon ages of 1830 and 1780 m.y. respectively (Gulson & Krogh, 1972; van Breemen et al., in press), while K-Ar ages of various rocks throughout the belt cluster around 1600 m.y.

The mobile belt can be subdivided into several zones from the north-western margin towards the south-east.

1) The northern border zone, in the northern part of which in Midternaes (Higgins, 1970) and Graenseland (Bondesen, 1970) sediments and volcanic rocks overlie Archaean gneisses and supracrustal rocks unconformably. A three-fold succession of sedimentary-volcanic-sedimentary rocks can be recognised. The lowest part of the succession is preserved at the northern end of the supracrustal belt where the Vallen Group of sedimentary rocks and the Sortis Group of volcanic rocks total several thousand metres. The Vallen Group is represented by conglomerate and dolomite, quartzite, a thick succession of pelitic shale and greywacke, and an upper, thinner succession of alternating dolomite and shale. This group is of particular interest because it contains considerable evidence for the presence of life at the beginning of the Ketilidian period. Near the top of the Vallen Group for instance a thin dolomite unit contains abundant globular organic bodies interpreted as algal-like organisms and named Vallenia (Bondesen et al., 1967). The Sortis Group is composed of tholeiitic pillow lavas with sills, overlain by pyroclastic rocks, sedimentary rocks with thick intrusive sills and a thick upper pillow-lava unit. Towards the south the two groups thin rapidly and near Kobberminebugt they are succeeded by the Qipisargo Group (Berthelsen & Noe-Nygaard, 1965) consisting of 100-200 m conglomerate and more than 1000 m of pelite and semipelite. The conglomerate at the base of this group indicates that there was a marked change in conditions after the extrusion of the upper pillow lavas of the Sortis Group.

In the southern part of the border zone the Ketilidian volcanic and sedimentary rocks and their underlying basement are progressively affected by Ketilidian deformation and metamorphism (Henriksen, 1969) so that south and east of the border zone it is no longer possible in the field to distinguish with certainty between Ketilidian rocks and their pre-Ketilidian basement. In the Kobberminebugt region where deformation has been extreme the supracrustal rocks and reworked basement were metamorphosed under medium to high amphibolite facies conditions with the formation of andalusite, sillimanite, staurolite and garnet.

2) A complex zone of granites, diorites and gneissose granites (Julianehåb granite) in which a central zone of late granites can be distinguished. The Julianehåb granite contains evidence of several phases of homogenisation, deformation and remobilisation. These processes were closely connected with basic and intermediate igneous activity (Allaart et al., 1969).

3) An intricately folded zone of gneiss, granite and migmatised Proterozoic (> 1780 m.y.) or older sedimentary and volcanic rocks a few thousand metres thick and with

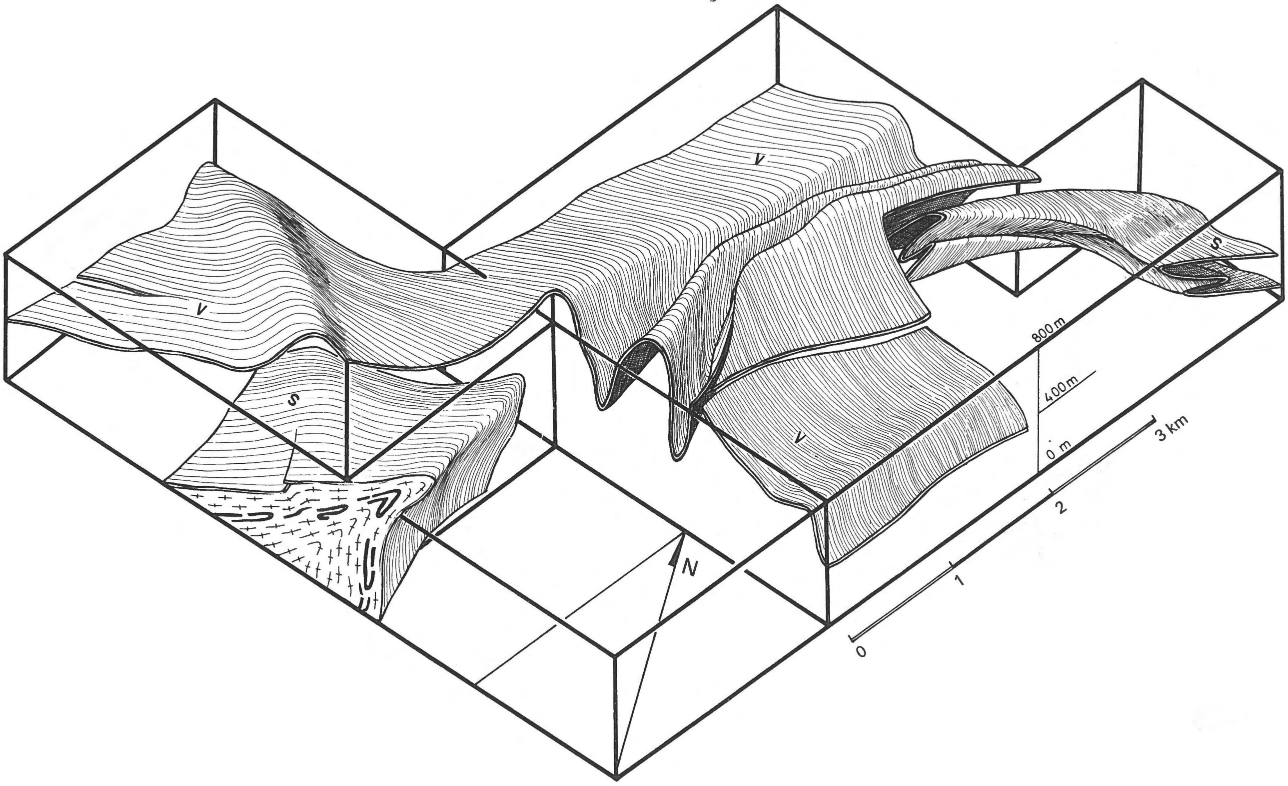

Fig.8
Structural stereogram representing the surface between the lower metavolcanic unit and the pelitic to semipelitic gneisses (V), and two pyritic horizons (S) within the pelitic to semipelitic gneisses.

amphibolite facies mineralogy. In the Tasermiut area the succession from bottom to top is probably as follows: pelitic to semipelitic gneisses, basic metavolcanic rocks, arkosic quartzites, basic metavolcanic rocks.

An impression of the fold structures in this part of the belt is given in fig. 8 of an area mapped by Escher (1966). Here an earlier episode of NE-folding producing tight folds was succeeded by generally open NW-folding. The core of the anticline defined by the pyritic schist horizon in the left front side of the stereogram (fig. 8) is filled by a conformable body of early granodiorite (U-Pb zircon age 1830 m.y., van Breemen et al., in press). In this granodiorite a large number of straight-edged amphibolite bodies occur. These are isoclinally folded (fig. 9), and these isoclines can be shown to be earlier than the earliest NE-folding in the area. The amphibolites are thought to be pre-orogenic basic dykes intruded into crust already consisting of gneiss or granodiorite which was partially or wholly remelted during Ketilidian plutonism without destroying all the original relations between the rocks of different composition. The anticlinal granodiorite is thus interpreted as being the remobilised (Archaean?) basement beneath the original sedimentary basin in the Tasermiut area.

Fig. 9
Double-folded discordant amphibolite in early Ketilidian granodiorite on the northern shore of Tasermiut fjord.

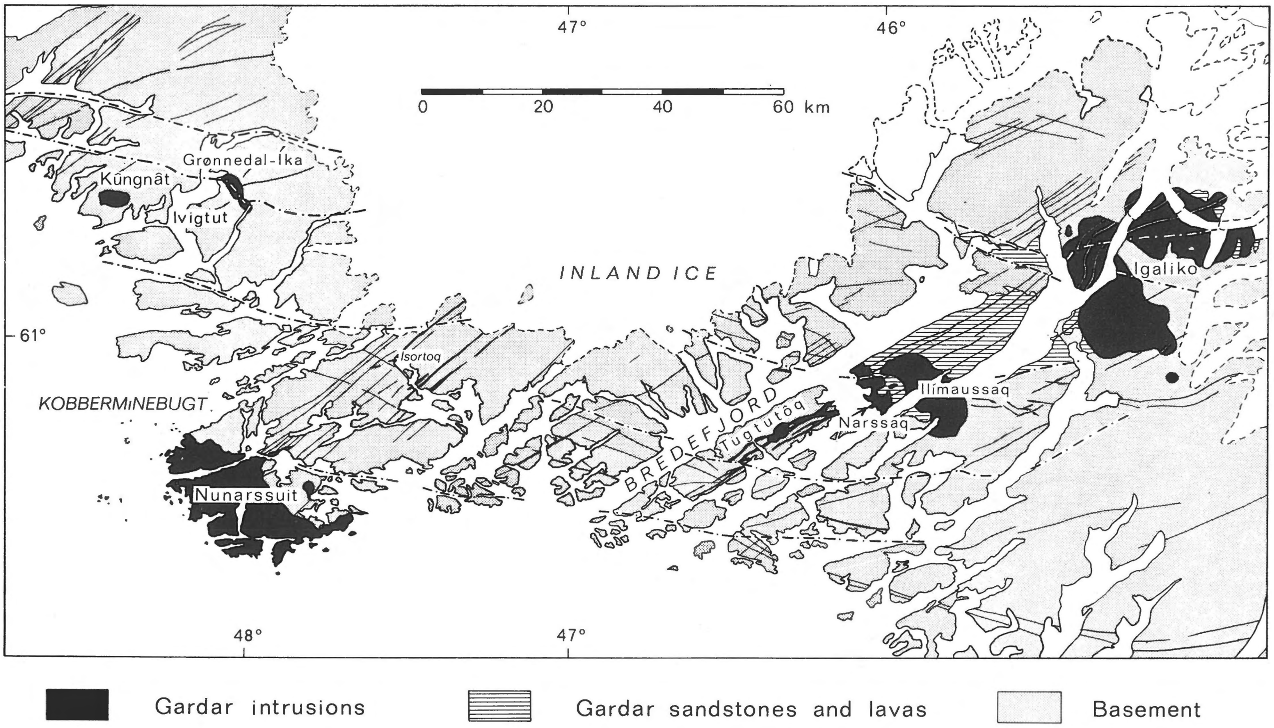

Fig. 10
Sketch map of South Greenland showing the main intrusions and dyke swarms in the Gardar igneous province. The Puklen intrusion occurs just north-east of the 't' of Nunarssuit. Klokken is situated just SSE of the southernmost member of the Igaliko complex. (Slightly modified after Watt, 1966).

4) The southern tip of Greenland consists of a flat-lying dome-shaped migmatite complex of high-grade (cordierite-amphibolite to cordierite-granulite facies) metasediments and metavolcanic rocks and early granite sheets (U-Pb zircon date 1832 m.y.; Gulson & Krogh, 1972). This structure is in many places disrupted by post-tectonic intrusions of norites, monzonites and adamellites belonging to the rapakivi suite. These are elongate mushroom-shaped bodies with tops forming approximately flat-lying sheets subconcordant with the regional foliation and with subvertical stems commonly elongated in a NNW direction (Bridgwater et al., in press). The rapakivi intrusions occupy more than 50% of the surface of the area.

Gardar supracrustals, igneous activity (Middle Proterozoic) and post-Gardar events

After the cessation of the late early Proterozoic plutonic activity South Greenland was subjected to denudation, faulting, deposition of red-beds and lavas accompanied and followed by the emplacement of regional dyke swarms and alkaline intrusive centres (fig. 10) (Sorensen, 1966; Watt, 1966). The continental sandstones and overlying lavas, called the Eriksfjord Formation (Poulsen, 1964), are mainly confined to a NE-trending down faulted block between Narssaq and the Inland Ice, although isolated outcrops and stoped blocks in younger intrusions suggest that they originally covered a much larger area.

ESE-trending transcurrent faults are the dominant structural features in the Gardar province. These were initiated before the end of the Ketilidian plutonism and remained active throughout the Gardar period. It has been suggested (Wegmann, 1939; Poulsen, 1964) that the Gardar province is part of a rift system mainly controlled by ESE-faulting. Intrusion of dyke swarms alternated with repeated fault movements. The earliest dyke generations are olivine dolerites which trend ESE. Their age relations to the sandstones and lavas are not known, but they may be older. Most of the dyke swarms trend ENE and consist of several generations of olivine dolerite, trachydolerite, microsyenite and giant composite syeno-gabbro dykes (Isortoq and Tugtutoq). The swarms are not all contemporaneous. Field evidence suggests (Berthelsen & Henriksen, in press) that the oldest dyke swarms occur in the west and that dyke activity migrated eastwards with time.

There are approximately 10 intrusive centres in the Gardar province. These can be subdivided into: 1) those with undersaturated foyaitic rocks (Igaliko, Gronnedal, Hviddal giant dyke of Tugtutoq), and 2) those with satured to slightly oversaturated syenites (Kungnat, Nunarssuit, Puklen, Tugtutoq central complex, Klokken). To the second group also belongs the smallest intrusion, the Ivigtut granite. This is a 300 m wide stock in the top of which a cryolite-bearing pegmatite was developed. The cryolite has now been removed by mining. The most famous Gardar intrusion of Ilimaussaq (Ferguson, 1964) does not fit into this classification as it consists of both peralkaline granites and quartz syenites and peralkaline nepheline syenites and sodalite syenites (agpaites). It contains mineralisations of uranium, thorium, zirconium, beryllium, niobium and associated rare earths (Nielsen, 1973).

The age of the younger intrusions ranges from 1250 to 1000 m.y. (van Breemen & Upton, 1972). It is not yet known how much older the Gronnedal intrusion, the early dolerites and the rocks of the Eriksfjord Formation are.

Late Phanerozoic dykes of olivine tholeiite and local dykes of lamprophyre and carbonatite occur in coast-parallel swarms near the coast between Frederikshåb Isblink (62°30') and Kap Farvel. These mark the time of rupture of Greenland from the Canadian Shield.

THE NAGSSUGTOQIDIAN MOBILE BELT

The gneisses forming the northern part of the Archaean block in East and West Greenland are cut by dense swarms of dolerite dykes. Towards the north the dykes, together with their country rocks, are progressively deformed and metamorphosed resulting in a reorientation and parallelisation of both dykes and country rock structures. These changes were the basis on which Ramberg (1949) distinguished a Nagssugtoqidian complex from a pre-Nagssugtoqidian (Archaean) complex in West Greenland. Similar observations by Bridgwater & Gormsen (1968) in South-East Greenland made it possible to correlate the Nagssugtoqidian mobile belt from West to East Greenland. It forms a ca. 300 km wide belt characterised by a pronounced regional fabric oriented parallel to its boundary with the Archaean block (fig. 1). Although K/Ar dating of Nagssugtoqidian rocks gives ages within the range 1790 to 1650 m.y., preliminary U/Pb dating of zircons by R. Chessex (personal communication, 1972) suggests that the main phase of Nagssugtoqidian deformation and metamorphism is much older and probably took place between 2600 and 2200 m.y. ago.

Stratigraphy and lithology

The Nagssugtoqidian rocks consist mainly of reworked Archaean basement gneisses, locally with interlayered and folded relics of Archaean and early Proterozoic supracrustals. The reworked gneisses are mostly granodioritic to quartz-dioritic containing biotite, hornblende and garnet. Hypersthene is often present in the central part of the belt. Basic layers, lenses and agmatites are common. In the southern part of the Nagssugtoqidian belt these basic fragments are believed mainly to represent reoriented and metamorphosed remnants of dolerite dykes belonging to the same dense swarms which intruded the Archaean gneisses south of the boundary.

Supracurstal rocks, largely represented by metasediments, occur mostly in the central and northern part of the Nagssugtoqidian belt, north of the Holsteinsborg thrust fault. They form thin belts interlayered and deformed together with the basement gneisses. Two main groups of supracrustal rocks can be distinguished:

(a) An older Archaean group, showing evidence of having been metamorphosed and strongly deformed in pre-Nagssugtoqidian times. It is composed mainly of sillimanite-bearing garnet-biotite gneisses.

(b) A younger group, formed in the time interval separating the last main Archaean period of metamorphism from the first Nagssugtoqidian metamorphic event. It is composed mostly of marbles, quartzites and calc-silicate rocks associated with graphite-schists containing sillimanite, garnet and muscovite. In the southern part of the belt, south of the Holsteinsborg thrust zone only a few occurrences of younger supracrustals were found. They consist mainly of anthophyllite schists, phyllites, amphibolites and marbles. Relict pillow structures have been recognised locally in these southern rocks.

No large granite areas occur within the Nagssugtoqidian in West Greenland, although a few small isolated granites associated with migmatites have been observed. These appear to be synkinematic with the main Nagssugtoqidian deformation. A large folded quartz diorite body is found in the central part of the belt (Henderson, 1969).

Structure and metamorphism

The Nagssugtoqidian complex is characterised in West Greenland by a predominant ENE trend of the main structural elements. In a general way it is possible to subdivide the complex into linear or straight belts where this regional fabric is well developed, and areas where a preferred direction is not so obvious (fig. 11). This typical alternating pattern resembles a large-scale augen structure. The augen are represented by the lens-shaped lacunae in which the original Archaean structures and the dykes intruding them are best preserved. In contrast the Archaean structures and dykes in the linear belts are generally completely deformed and reoriented by the later Nagssugtoqidian movements. The Archaean "lacunae" possess intricate basin and dome structures formed by superimposed similiar-type folding (Bondesen, 1970b). This structural pattern, lacking any dominant strain direction (fig. 12), is very similar to that found in the main Archaean block south if the Nagssugtoqidian boundary (cf. fig. 5). In the linear belts, the pronounced ENE trend is probably due to a dominant Nagssugtoqidian simple shear strain. This rotational strain acted partly in a horizontal direction parallel to the linear belt (Sorensen, 1970), and partly upward and at right

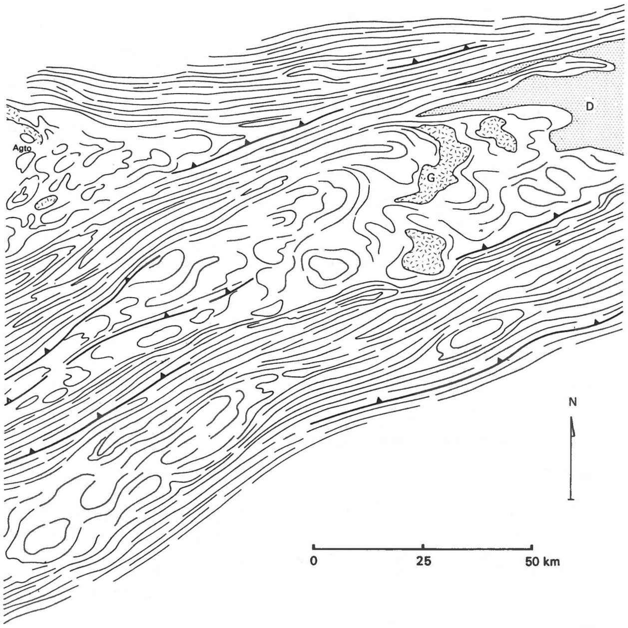

Fig. 11
Structural pattern of alternating linear belts and less deformed areas in the central part of the Nagssugtoqidian mobile belt in West Greenland.
G = granite, D = quartz diorite.

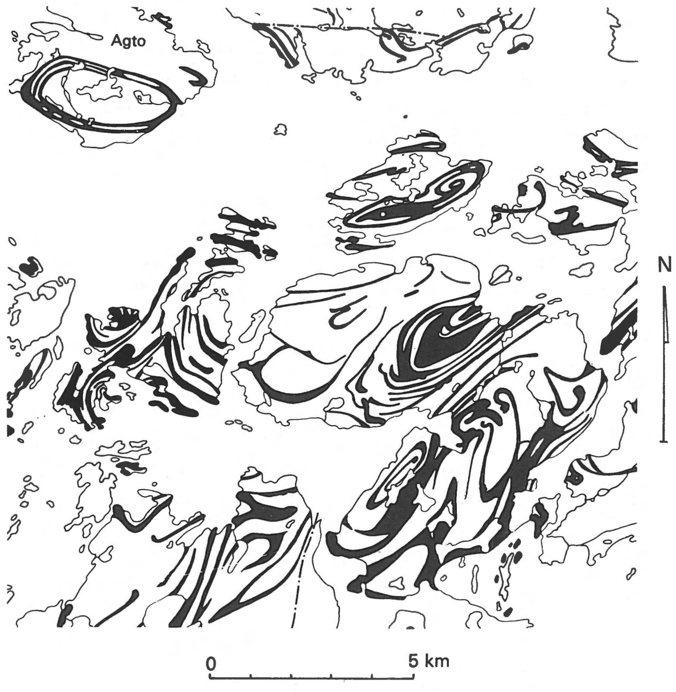

Fig. 12
Intricate basin and dome structures formed by superimposed similar-type folding in the Agto region. (From E. Bondesen, 1970b). Black: Amphibolite; white: Gneiss.

Fig. 13
Map of the deformed (in the NW part) and undeformed (in the SE part) dykes in the Sondre Stromfjord area.

angles to the belt, along shear planes dipping to the NNW. The contact between linear belts and Archaean lacunae can be progressive, due to ductile shear, or discordant due to brittle thrusting. In many places, and particularly in the northern part of the Nagssugtoqidian mobile belt, the linear belts are deformed by a weak late-nagssugtoqidian deformation, resulting in large open folds and flexures with northwest striking axial surfaces.

In the southern part of the mobile belt the Nagssugtoqidian deformation was accompanied by a retrogression of the Archaean granulite facies gneisses to amphibolite facies. In the central part of the belt granulite facies and amphibolite facies rocks co-existed during the Nagssugtoqidian deformation.

The southern Nagssugtoqidian boundary

The southern Nagssugtoqidian boundary in West Greenland cuts across Sondre Stromfjord near the Sukkertoppen ice cap, following roughly an ENE direction. South of this boundary, granulite facies gneisses are cut by two undeformed basic dyke swarms, with a dominant ENE striking swarm (the Kangamiut dyke swarm) post-dating an east-west swarm. The Nagssugtoqidian boundary is in this area a transition zone approximately 20 km wide in which retrogression of the granulite facies gneisses takes place

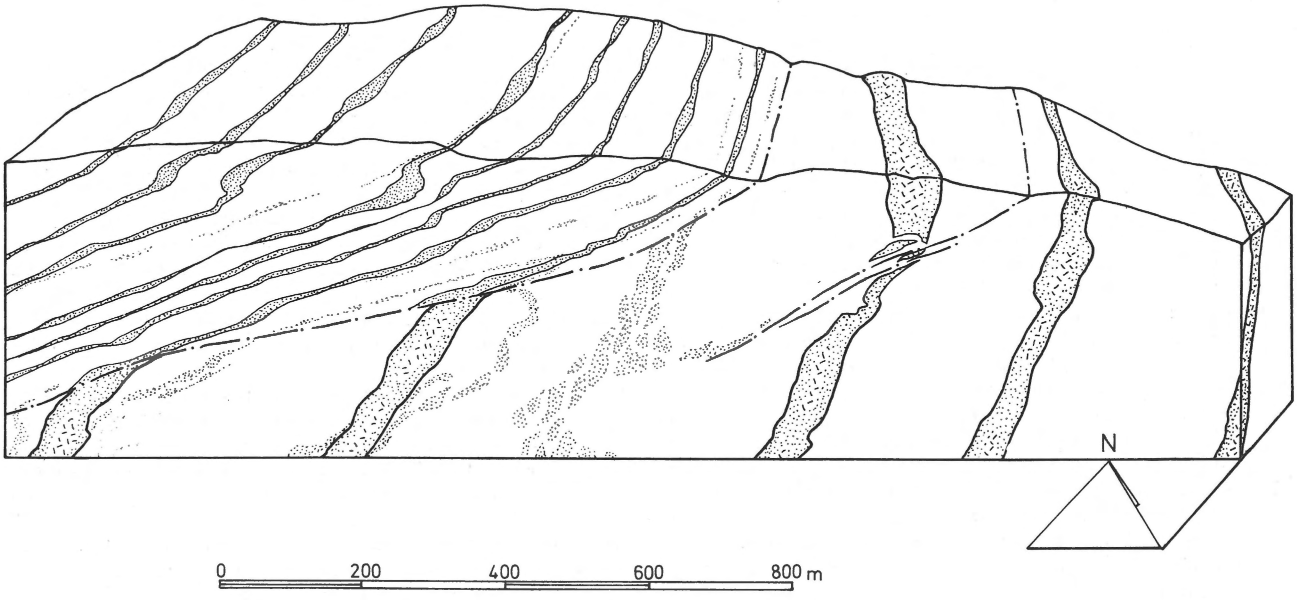

Fig. 14
The main Nagssugtoqidian deformation boundary in the region north-east of the Sukkertoppen ice cap: both dykes and gneiss structures are deformed and reoriented by a ductile overthrusting (rotational or simple shear strain) from the NNW.

progressively. The mineralogical changes are closely correlated with structural changes, the most dramatic of which is a change in strike and dip of both dyke swarms (fig. 13 & 14). This change can either be abrupt, or more gradual and brought about by a series of parallel shear belts.

The deformation of two dyke swarms, which were originally at a high angle to one another, affords an ideal circumstance for measuring the post-dyke deformation of the area lying to the north of the boundary. Results so far obtained (E s c h e r, E s c h e r & W a t t e r s o n, in press) show that the boundary represents the southern limit of rocks which have undergone intense rotational homogeneous strain, or simple shear strain. The plane of simple shear to which the boundary is parallel dips NNW at 10 to 20°, with the direction of simple shear within this plane being SSE. The type of movement can be regarded as effecting an overthrusting of the northern amphibolite facies block onto the southern granulite facies block with a horizontal shortening of at least 65%. Although horizontal shortening by this mechanism cannot take place without some relative vertical displacement of the rocks on either side of the boundary, the vertical movement is insignificant relative to the horizontal displacement. The displacement at this boundary can be described as ductile overthrusting of the Nagssugtoqidian rocks over a stable Archaean foreland. The total amount of shortening must exceed, probably greatly, 100 km.

There seems to be in principle no difference between the southern Nagssugtoqidian boundary and the boundaries within the mobile belt between less reworked Archaean lacunae and strongly reworked linear belts. Both probably reflect a considerable shortening of the crust, brought about by a succession of imbricate shear zones and thrusts dipping to the NNW. This overthrusting was partly ductile and partly brittle depending on the state of the material or on the rate of deformation. The less reworked lacunae of Archaean rocks within the mobile belt possibly represent originally more competent zones. The difference in type of supracrustal rocks between the areas north and south of the Holsteinsborg thrust may imply a fundamental difference between these areas prior to Nagssugtoqidian events.

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