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BEDROCK GEOLOGY OF THE NUNATARSSUAQ AREA, NORTHWEST GREENLAND

BY

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AND

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WITH 14 FIGURES IN THE TEXT
AND 1 MAP

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Abstract.

All the rocks of the Nunatarssuaq area of northwest Greenland are of Precambrian age. The basement complex, of early or middle Precambrian age, is composed of amphibolite, porphyroblastic gneiss, banded gneiss, and migmatite, cut by numerous pegmatite dikes and a single granitic stock. This complex is unconformably overlain by gently dipping conglomerate and sandstone of the Thule group, of late Precambrian age. Diabase dikes, probably also of late Precambrian age, cut both the basement complex and the Thule group.

The principal structural elements of the basement complex are northwest strikes and variable dips of the foliation, possibly two northwest trending anticlines and a northwest plunging syncline, and two sets of steeply dipping joints that trend northwest and northeast, along which the diabase dikes have been injected. All rocks were affected by block faulting and tilting, probably in Cretaceous or Tertiary time.

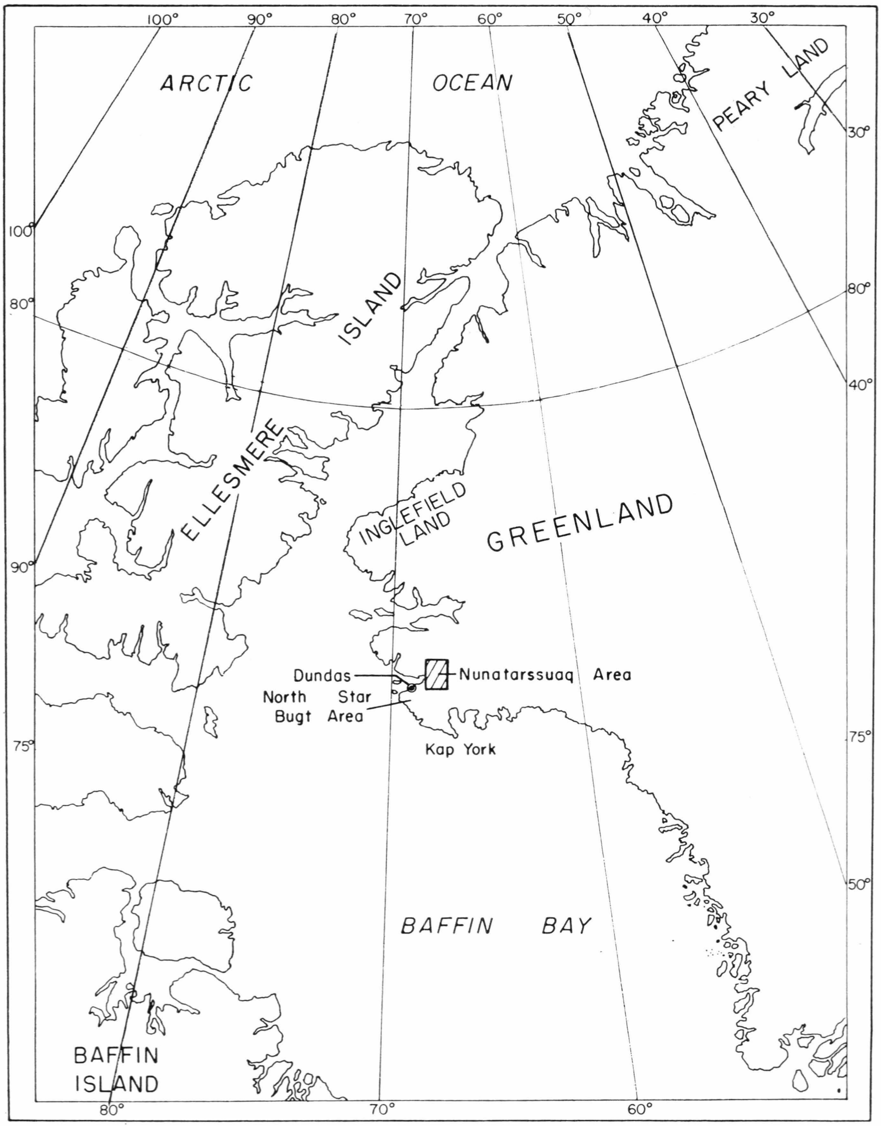

Fig. 1. Index map showing location of the Nunatarssuaq area, Greenland.

INTRODUCTION

Location of Area.

The triangular-shaped area that covers approximately one hundred seventy five square miles (450 square km.) at the head of Wolstenholme Fjord in northwest Greenland is known as the Nunatarssuaq area and lies between 76°30′ and 76°55′ north latitude and 66°45′ and 68°05′ west longitude (fig. 1.) It is completely surrounded by ice except for a few miles on the west along Wolstenholme Fjord. All of its eastern border abuts the Greenland Ice Cap and its southwest border is along Harald Moltke Bræ, an outlet of the Greenland Ice Cap. Another ice cap and its outlet, Knud Rasmussen Gletscher, form the northwest boundary of the area. For ease of reference the Nunatarssuaq area is herein referred to as "Nunatarssuaq".

Topography and Surficial Features.

Nunatarssuaq is part of the rolling plateau of northwest Greenland which is underlain by igneous, metamorphic, and sedimentary rocks of Precambrian age (Troelsen, 1950, p. 13). At Nunatarssuaq the plateau is generally between 600 and 750 m above sea level and reaches a maximum height of about 1,050 m.

The plateau has been greatly modified by glaciers, which at one or more times during the Quaternary period have covered all of Nunatarssuaq. In addition to the two valleys occupied by Harald Moltke Bræ and Knud Rasmussen Gletscher, a third U-shaped valley, still partly filled by glaciers, has been excavated along the eastern margin of the area. Skåret, which trends northeast parallel to the valley occupied by Knud Rasmussen Gletscher, also has been excavated predominantly by ice, as evidenced by its U-shaped profile.

Wasting of the glaciers against moderately steep slopes has produced many channeled hillsides that show good bedrock exposures. These are well displayed on the south side of Rasmussen Sø and along the north side of Harald Moltke Bræ west of Ohio Fjeld. Good exposures of bedrock are present on steep valley walls scoured by ice and on valley floors recently uncovered by retreating ice.

Many bedrock exposures have been reduced to rubble by active frost riving. Mountain tops, for instance, are characteristically covered with large blocks of rubble which are essentially in place (shown on plate 1 as frost-shattered bedrock outcrops). Rubble on the sides of mountains, by contrast, is undergoing slow movement downslope. Talus commonly accumulates at the base of steep cliffs.

Glacial deposits are irregularly distributed throughout the area, and moraines are well developed around retreating ice. Frost features, particularly sorted nets, sorted stripes, and large lobate terraces, are very common in the glacial and rubble deposits (HOLMES and COLTON, 1960).

Previous Work.

To the writers' knowledge there is no previous published description of the bedrock geology of Nunatarssuaq. The area was traversed by RASMUSSEN (1915, p. 340) in 1912 on his westward crossing of the Greenland Ice Cap. KOCH in 1923 (1927, pp. 226-227) made a rapid survey of the western part of the area and included the results in his geologic map of the Kap York district of northwestern Greenland (KOCH, 1926, p. 306).

Few observations have been made on the basement complex of northwest Greenland. KOCH (1933, pp. 8-12) gives a summary for Inglefield Land and nearby areas where gray gneiss, diorite, and quartz-diorite occur widely and coarse-grained red granite is present locally. Gneiss and syenite are dominant in the basement complex of the Kap York district (KOCH, 1926, p. 306). At Uvdle point in the Thule area, MUNCK (1941, p. 10) notes hornblende schist and dark biotite gneiss cut by numerous pegmatite veins. The basement rocks of the Thule area, which have recently been mapped at a scale of 1:100,000, are dominantly pink and gray gneiss, with subordinate amounts of chlorite, epidote, and mica schist, amphibolite, and quartz-feldspar pegmatite (DAVIES, KRINSLEY and NICOL, 1963).

Present Work.

Field work for this report was done from June 19 to August 19, 1953. A few additional observations were made between August 20 and August 31 while the writers were assisting in glaciological studies on the Rampen.

Most of the field work was done on foot, working from base camps located at the head of Wolstenholme Fjord, Landsø, Rampen, and

Lykkedal. Helicopters were used to get to some remote areas. Exposures and contacts were plotted on vertical and oblique photographs and transferred to a base map prepared by the U. S. Army Map Service, scale 1:100,000, enlarged to 1:50,000. Vertical aerial photographs for the entire area at a scale of 1:24,000 became available near the end of the field season. Later a new base map was made by the Army Map Service at a scale of 1:50,000, and the geology was replotted on this map (plate 1).

Strikes were taken with a Brunton compass but because of difficulties in determining directions by magnetic compass at high latitudes, the compass observations were always checked against estimated directions as determined from the base map oriented to prominent topographic features. Where obviously in error, the compass observations were discarded and the estimated directions used. In general the strikes are probably accurate to within ten degrees.

Studies on the geomorphology and the glaciology of Nunatarssuaq, made during the 1953 field season and in subsequent years, have been published (Holmes and Colton, 1960; Nobles, 1954; White, 1956) or are in preparation. In 1955 Gregory (1956) mapped the northeast tip of Nunatarssuaq in greater detail than was possible during our work in 1953.

Acknowledgments.

Field studies for this report were a part of the comprehensive scientific program of Operation Ice Cap, 1953, sponsored jointly by the Transportation Corps and the Corps of Engineers, U. S. Army. Dr. Richard P. Goldthwait of the Ohio State University was project chief for the Nunatarssuak Area.

Thirty-five thin sections of rock specimens were examined by Charles Milton and twenty-five by Beatriz Valenzuela, both of the U. S. Geological Survey. An additional forty-two thin sections were examined by the junior author, then at the Ohio State University, and described in his Master's thesis (Horowitz, 1954), which was supervised by Dr. Carl A. Lamey. The present report incorporates the results of the examinations of all thin sections. The three photographs of rock specimens, figures 6, 12, and 14, were taken at the Ohio State University by James Barkes.

Six rock specimens were analysed chemically in 1954 by H. F. Phillips, P. L. D. Elmore and K. E. White of the U. S. Geological Survey, using rapid methods (Shapiro and Brannock, 1956). An age

determination (Larsen method) on a rock sample containing zircon was made by H. W. JAFFEE of the U. S. Geological Survey in 1954.

The manuscript has been reviewed critically by C. A. LAMEY of Ohio State University, by C. H. HEWITT, P. W. CHOQUETTE, D. R. BAKER, D. B. MACKENZIE of the Marathon Oil Company, and by H. W. COULTER and R. G. SCHMIDT of the U. S. Geological Survey.

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PRINCIPAL GEOLOGIC FEATURES

All the rocks of Nunatarssuaq are of Precambrian age. Approximately ninety percent of the area is underlain by a complex of metamorphic and igneous rocks, part of the Greenland shield. The principal metamorphic rocks of the basement complex are, from north to south, banded gneiss, porphyroblastic gneiss, and amphibolite. Numerous granitic pegmatite dikes and a single granitic stock cut the metamorphic rocks.

Banded gneiss underlies the northern two-thirds of Nunatarssuaq and contains large and small bodies of migmatite, irregular bodies of altered gneiss, and small bodies of altered basic rocks. The banded gneiss is bordered on the south by a northwest trending belt of porphyroblastic gneiss, and amphibolite is exposed in the vicinity of Ohio Fjeld. Granitic pegmatite dikes are found throughout the basement complex but are more numerous in the banded gneiss. A granitic stock is located on a nunatak bordering the Rampen where it intrudes the banded gneiss and exhibits a sharp contact with the gneiss.

The basement complex is unconformably overlain by gently dipping sedimentary rocks of the Thule group, only the basal portion of which is exposed. A number of diabase dikes cut the basement complex and the Thule group. The sedimentary rocks, consisting predominantly of conglomerate and sandstone, as well as the dikes, are considered to be of late Precambrian age.

Northwest strikes and variable dips characterize the foliation within the Precambrian gneisses. Two northwest trending anticlines and a northwest plunging syncline are suggested by the available data and indicate a Precambrian orogeny. Two sets of regional joints in the basement complex trend northwest and northeast, respectively, and dip steeply; the diabase dikes follow this joint system. Block faulting accompanied by tilting affected the area during Cretaceous(?) or Tertiary(?) time.

BASEMENT COMPLEX

Metamorphic Rocks.

Banded gneiss.

Distribution and geologic relations.

Banded gneiss and associated rocks underlie the northern two-thirds of Nunatarssuaq. The gneiss is bordered on the south by porphyroblastic gneiss, into which it appears to grade. The associated rocks, which are irregularly distributed, include migmatite, altered gneiss, and altered basic rocks. The migmatite and altered gneiss show gradational contacts with the surrounding banded gneiss, but field relations suggest that the altered basic rocks were probably intrusive. These three types of rocks are discussed separately in the section on "Rocks associated with banded gneiss".

Stringers, layers, and lenses that differ compositionally or structurally from the typical gneiss are scattered throughout the banded gneiss. Granitic stringers and amphibolite lenses are especially common. Small amphibolite lenses are well exposed in the outcrops along the bottom of Skåret, and larger bodies of amphibolite are present on the faces of Østre and Vestre Klovbjerg. Prominent layers of rock composed of epidote and hornblende cross Savtakkerne in the southeastern part of the area. Quartzitic layers, some of which contain disseminated magnetite and cummingtonite, are present south of Magnetitbjerg.

Innumerable granitic pegmatites and a single granite stock intrude the banded gneiss. In most places the intrusive contacts are sharp but elsewhere the pegmatites exhibit indistinct borders. More than a dozen diabase dikes with chilled margins and sharp contacts follow one of two well-defined joint systems in the gneiss.

Petrographic character.

The banded gneiss is composed of alternative layers of light and dark minerals (fig. 2). The thickness of these layers ranges from a few millimeters to ten or twenty meters, but most layers are a few centimeters to a meter or so wide. In a number of exposures the layers are straight and regular for tens of meters and are interrupted only where cut by pegmatites and diabase dikes. Elsewhere the layering is slightly

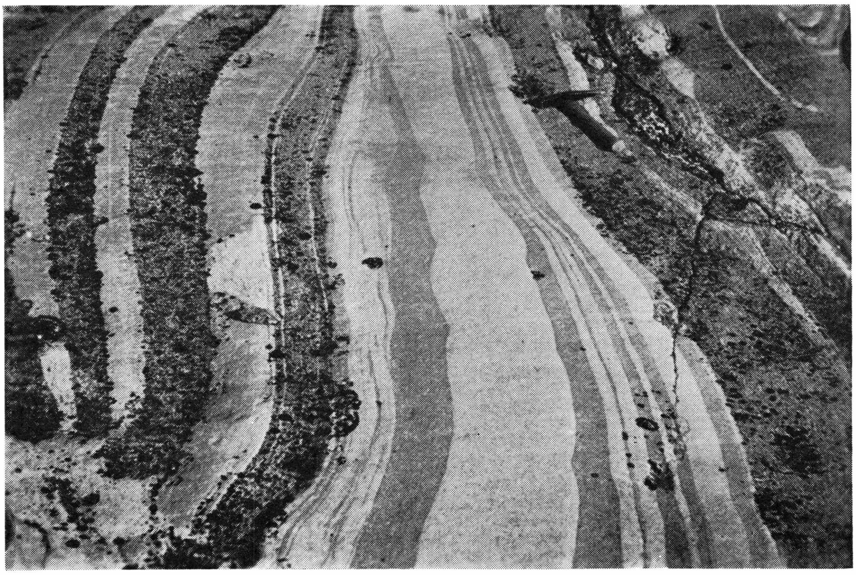

Fig. 2. Exposure of banded gneiss from upper Tvillinggletscher Dal, eastern Nunatarssuaq. Small dark patches are lichens.

to highly contorted. The bulk composition of the banded gneiss is modified by the presence of amphibolite lenses, small injected granitic stringers, and layers composed of epidote and hornblende.

Light layers of the gneiss consist predominantly of plagioclase (oligoclase-andesine) and quartz, smaller amounts of microcline, perthite, orthoclase, and albite, and a small percentage of mafic constituents. Garnet, pyrite, and zircon are the accessories. The plagioclase grains commonly show normal zoning but reversed zoning is also present. Most of the plagioclase is sericitized to some degree but the extent of this alteration varies considerably; the cores of normally zoned plagioclase crystals are commonly much sericitized. Myrmekitic texture is shown in some thin sections.

Dark layers consist predominantly of hornblende and a relatively iron-rich biotite, which point counts indicate form up to 85 per cent of some dark layers although 50 to 60 per cent is common. Considerable plagioclase feldspar (oligoclase) and quartz and minor amounts of epidote, sphene, allanite, zoisite, and magnetite are present. In some places chlorite and muscovite replace the biotite. A few layers show a rather high magnetite content, and in other layers hornblende is the only constituent. Some of the biotite and hornblende are replaced by epidote, which in places forms rims around allanite grains. Similarly, allanite forms rims around some zoisite grains.

Fig. 3. Amphibolite lenses in banded gneiss from the middle sector of Skåret, Nunatarssuaq.

Amphibolite lenses within the banded gneiss are exposed in numerous outcrops (fig. 3), and appear to be boudins. Each lens is a discrete body rather than one of a group of lenses along a single band. Most lenses are about one to four meters long and fifteen centimeters to one meter thick, but several larger ones are exposed in the walls of Skåret. The margins of the lenses are in places frayed where stringers of light minerals from the gneiss are mixed with amphibolite. The lenses are very similar mineralogically to the dark layers within the banded gneiss. Hornblende is the major constituent and it is accompanied by plagioclase (oligoclase-andesine) and quartz. Some hornblende is replaced by epidote and about half of the plagioclase is sericitized. Magnetite, sphene, and zircon are accessory minerals.

Granitic stringers, injected parallel to the gneissic banding, form only a very small percentage of the rock. They are generally under fifteen centimeters in exposed width and are characterized by a coarser grain size than the surrounding rock. They contain microcline, quartz, and hornblende in crystals up to a centimeter in length, with minor amounts of oligoclase, biotite, chlorite, and orthoclase.

Layers composed of epidote and hornblende form striking exposures in the southeastern part of the area. The epidote is finely granular and the hornblende forms crystals about a millimeter wide and up to a centimeter long. These minerals give an overall mottled green and black color to the rock. In thin section the hornblende appears as large poikiloblastic crystals that enclose crystals of epidote and sphene that are commonly only a few tenths of a millimeter in diameter. Small amounts of quartz, oligoclase, and other constituents are also present.

Layers of quartzitic rock crop out south of Magnetitbjerg. The quartzite has a mosaic texture and a grain size of 0.25 to 0.50 mm. Some of the layers contain considerable disseminated magnetite crystals less than 0.1 mm in diameter and cummingtonite crystals up to 1 mm long and 0.1 mm wide. Greenish-black layers that consist of pyroxene, zoisite or epidote or both, hornblende, plagioclase, quartz, and sphene are also present there.

Chemical composition.

Chemical analyses, by rapid methods (SHAPIRO and BRANNOCK, 1956), of a prominent dark layer (Field no. F-14) within the gneiss and a prominent light layer (Field no. F-224a) follow. The dark layer is located at a point north of Landsø about half way down the southeast wall of Skåret (76°46′ north latitude and 67°20′ west longitude). The light layer comes from a nunatak bordering the Rampen at 76°46′ north latitude and 66°54′ west longitude.

Chemical analyses of banded gneiss.

	light layer	dark layer
SiO_2	72.5	54.1
Al_2O_3	15.5	13.2
FeO	0.64	6.7
Fe_2O_3	0.2	2.4
MgO	0.43	8.0
CaO	2.8	8.9
Na_2O	4.7	2.6
K_2O	2.2	1.4
TiO_2	0.06	0.78
P_2O_5	0.02	0.27
MnO	9.01	0.20
CO_2	0.05—	0.05—
H_2O	0.2[illegible]	0.96
Total	99.37—	99.56—

H. PHILLIPS, P. ELMORE, K. WHITE, analysts.

Fig. 4. Migmatite from near summit of Vestre Klovbjerg, northwestern Nunatarssuaq.

Rocks Associated with Banded Gneiss.

Migmatite.

Distribution and geologic relations.

A large body of migmatite crops out at the summit of Vestre Klovbjerg in northwest Nunatarssuaq and extends to the edge of Knud Rasmussen Gletscher. It grades into the surrounding banded gneiss along a broad contact zone. Other bodies of migmatite, too small or too poorly defined to differentiate on the geologic map, are present on Gletscherknude, on slopes southeast of Nørresø, and elsewhere. The distribution of the migmatite within the banded gneiss follows no recognizable pattern.

Many pegmatitic veins and dikes and two northeast-trending diabase dikes cut the migmatite atop Vestre Klovbjerg. The migmatite disintegrates readily through frost action owing to its rather coarse texture.

Petrographic character.

The migmatite is a thoroughly mixed rock containing remnants of highly contorted gneiss and a large amount of siliceous material (fig. 4). Both indistinct and sharp contacts occur between its dark and light components. Locally, amphibolite lenses occur in the migmatite as they do in the banded gneiss (fig. 5).

Dark portions of the migmatite are mainly hornblende with microcline, biotite, and quartz, and accessory apatite. The light portions are chiefly quartz and microcline with cloudy albite-oligoclase and some brown biotite, in part chloritized; accessories are apatite, epidote, and altered allanite. Textures of both types of material are generally coarse.

Fig. 5. Amphibolite lens in migmatite from near summit of Vestre Klovbjerg, northwestern Nunatarssuaq.

Altered basic rocks.

Distribution and geologic relations.

Altered basic rocks crop out on a low hill at the northeast end of Landsø within the area of banded gneiss. The contact is obscured by glacial drift except at one place on the southwest side of the hill, where it parallels the banding of the gneiss. The outcrop pattern, however, appears to be elongate normal to the regional foliation of the gneiss and suggests an intrusive relationship. At one place the altered basic rock is cut sharply by a pegmatite dike 30 cm wide.

Two patches of rock that are probably altered basic rocks crop out at the bottom of lower Skåret. Both are lens shaped, with a maximum exposed width of about 5 m; they are too small to show on the geologic map (plate 1). The lenses are parallel to the gneissic banding, and each lens is cut by a pegmatite dike.

Petrographic character.

In the Landsø exposure the rocks are green, black, and brown and have a varied mineral content which includes large crystals of tremolite-actinolite, hypersthene, and, along the contact with the banded gneiss, hornblende. Crystals of hornblende and phlogopite line the borders of the pegmatite dike that intrudes the altered basic rocks. In thin section one sample of the altered rock consists mainly of actinolite with some phlogopite, minor amounts of chlorite, and veinlets of magnetite. A hypersthene-rich rock contains material resembling iddingsite, apparently formed from olivine, grains of magnetite, and possibly hedenbergite. A thin section of another sample consists of coarse tremolite with specks of chromite.

In the two patches in Skåret the rocks are green and black and contain well-developed crystals of actinolite. In thin section one sample consists mainly of actinolite (altered in part to calcite) and chlorite, with secondary quartz formed in the chlorite. About ninety percent of another sample is epidote and the remainder is sphene, chlorite, and grains of magnetite.

Altered gneiss.

Distribution and geologic relations.

Altered gneiss is irregularly distributed within the banded gneiss. The largest outcrop area is along the north wall of Modstrømmen but smaller patches are present along the walls of Skåret at a point west of Rampen and along the valley northwest of Nordre Tvillingsø. Because the outcrop areas in the three localities are small and their borders poorly defined, the altered gneiss is not differentiated from banded gneiss on the geologic map (plate 1). The bodies of altered gneiss are elongate parallel to the joint patterns which they appear to follow.

The altered gneiss grades laterally into ordinary banded gneiss, but the cores of the patches bear little or no resemblance to the gneiss and consist of irregularly fractured reddish rocks criss-crossed with numerous veins. Epidote veins that follow the local joint systems are particularly common, and some pegmatite dikes occur in and near the centers of the altered masses.

Petrographic character.

Hand specimens of rocks from the cores of the altered gneiss are intensely brecciated and generally contain irregular veins of quartz, epidote, and calcite. Away from the cores the gneissic banding is preserved and the mafic constituents of the gneiss are green. The characteristic color of the altered rocks is invariably red due to hematite staining.

The microscopic aspect of the altered gneiss varies considerably, probably with intensity of alteration. Slightly altered gneiss is mineralogically very similar to the banded gneiss, but contains highly sericitized plagioclase and shows some myrmekitic structure, partial replacement of mafic constituents by chlorite, and profuse hematite stains. Intensely altered gneiss is brecciated, contains fresh microcline and quartz replacing cloudy plagioclase, and some mylonitized layers.

Porphyroblastic gneiss.

Distribution and geologic relations.

Porphyroblastic gneiss occurs in a southeast-trending belt that crosses southern Nunatarssuaq from Wolstenholme Fjord to the southeast corner of the area. It is bordered on the north throughout its entire length by the banded gneiss, extends under the Thule group on the south throughout the western half of its length, then borders an amphibolite belt in the vicinity of Ohio Fjeld, and abuts Harald Moltke Bræ further eastward. Gneiss of similar texture occurs in the North Star Bugt area (Davies, Krinsley and Nicol, 1963).

As mentioned previously, the porphyroblastic gneiss appears to grade texturally into the banded gneiss. Its contact with the amphibolite was not observed and its nature is therefore unknown. It is believed, however, that the amphibolite was originally an igneous rock and the contact may be either concordant or discordant. The location of the contact is at best a rough approximation (plate 1). Numerous pegmatite dikes and a single diabase dike cut the gneiss with sharp contacts.

Petrographic character.

The porphyroblastic gneiss is typically a coarse-grained gray rock with well-developed slightly elongate porphyroblasts up to 3 cm in longest dimension (fig. 6). The porphyroblasts are aligned and, with biotite in parallel position, give the rock its conspicuous gneissic foliation (fig. 7). The texture is not everywhere uniform and the abundance of porphyroblasts varies considerably.

The porphyroblasts are chiefly oligoclase but some are albite and others are andesine. Many are poikiloblastic and enclose epidote, zoisite, and muscovite. The feldspars are generally zoned, and both normal and reversed zoning are present; their cores characteristically exhibit sericitization. A few porphyroblasts contain quartz and microcline.

The groundmass of the gneiss is a mosaic composed largely of quartz, oligoclase, biotite, epidote (with allanite cores), and considerable sphene; some microcline is also present. Accessory minerals are chlorite, muscovite, zircon, apatite, and magnetite. The mosaic texture is very similar to that of some well-cemented sandstones.

Some schistose rocks occur in scattered lenses and bands within the porphyroblastic gneiss. These bodies range in exposed width from 30 cm

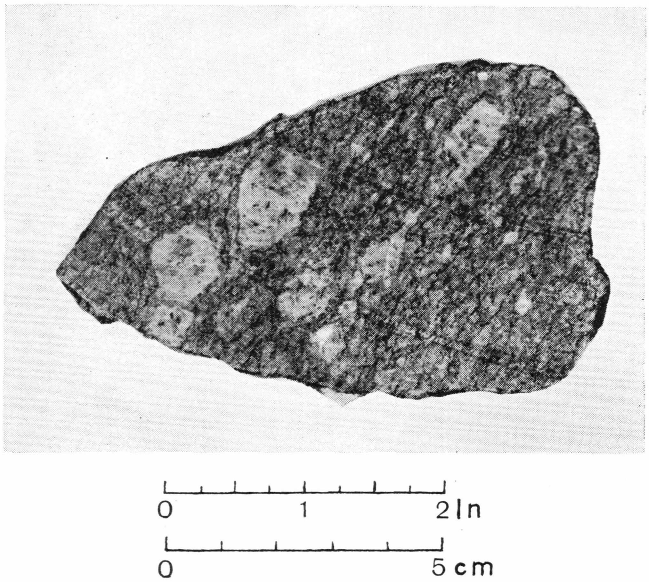

Fig. 6. Specimen of prophyroblastic gneiss from Lykkedal, southeastern corner of Nunatarssuaq.

to several tens of meters, are parallel to the gneissic foliation, and have sharp contacts. A schist band located at the foot of Knøsen along Knud Rasmussen Gletscher consists of biotite and hornblende with quartz, magnetite, apatite, and completely sericitized feldspar. A hornblende schist lens in Lykkedal contains considerable quartz and feldspar. Near the summit of Ohio Fjeld is a schistose outcrop made up of thin alternating bands of light and dark minerals that exhibit ptygmatic folding; the dark bands are composed of biotite, muscovite, and quartz, and the lighter bands, quartzose in composition, contain grains chiefly of quartz and some of plagioclase in a groundmass of zoisite.

Light and dark bands, of the order of 30 cm in thickness, occur parallel to the foliation of the gneiss in an exposure in Lykkedal. Thin sections show a fine, even-grained mosaic of quartz and biotite, with scattered epidote; one section shows an incipient growth of porphyroblasts. The rocks are less metamorphosed than the surrounding gneiss and are probably of sedimentary origin. The original rock may have been a low rank graywacke.

Fig. 7. Exposure of porphyroblastic gneiss from Lykkedal, southeastern corner of Nunatarssuaq.

Chemical composition.

A chemical analysis, by rapid methods, of typical porphyroblastic gneiss (Field no. F-200) from Lykkedal, in the southeast corner of Nunatarssuaq at about 76°35′ north latitude and 67°10′ west longitude, is given below. The composition of the porphyroblastic gneiss is the same as the median composition of the light and dark banded gneiss

Chemical analysis of porphyroblastic gneiss.

SiO_2	64.3
Al_2O_3	16.2
FeO	3.5
Fe_2O_3	2.0
MgO	1.9
CaO	3.9
Na_2O	4.0
K_2O	2.2
TiO_2	0.67
P_2O_5	0.19
MnO	0.08
CO_2	0.05
H_2O	0.97
Total	99.96

H. Phillips, P. Elmore, K. White, analysts.

(given previously), except for the higher content of alumina which is probably due to the abundance of feldspar porphyroblasts.

Amphibolite.

Distribution and geologic relations.

Amphibolite occurs south of the porphyroblastic gneiss in the vicinity of Ohio Fjeld in southern Nunatarssuaq. It crops out in a steep cliff that forms the west base of the mountain and also near the summit.

The contact of the amphibolite with the porphyroblastic gneiss was not observed, as mentioned previously, and its nature is therefore unknown. Further to the west the amphibolite is faulted against rocks of the Thule group. On the the south it abuts Harald Moltke Bræ, and its southern boundary is somewhere beneath this glacier, because amphibolite is not known to be present on the other side of the glacier in the North Star Bugt area (DAVIES, KRINSLEY and NICOL, 1963).

A few granitic pegmatites that are composed largely of quartz cut the amphibolite. Exposed surfaces of the amphibolite characteristically show a thick brownish coating formed by weathering.

Petrographic character.

The amphibolite is dark gray-green in hand specimens and occurs both as a massive and as a schistose rock. Some schistose rocks contain thin layers of quartz and minor amounts of feldspar that follow the foliation, but in others these layers cut across the foliation. Epidote veins occur along joints but are not common.

Chemical analysis of amphibolite.

SiO_2	48.8
Al_2O_3	14.5
FeO	10.5
Fe_2O_3	2.9
MgO	7.7
CaO	9.3
Na_2O	2.8
K_2O	0.31
TiO_2	1.0
P_2O_5	0.11
MnO	0.26
CO_2	0.28
H_2O	1.2
Total	99.66

H. PHILLIPS, P. ELMORE, K. WHITE, analysts.

Thin sections show actinolitic hornblende (altered in part to chlorite), with interstitial quartz and albite-oligoclase. Magnetite grains are disseminated through the rock, and veinlets of coarsely crystallized calcite are also present.

Chemical composition.

Chemical composition of a sample of amphibolite (Field no. F-135a) from the west base of Ohio Fjeld, at 76°37′ north latitude and 67°35′ west longitude, is given above. It is very nearly the same as that of a diabase sample from eastern Nunatarssuaq (discussed under "Diabase dikes").

Origin of the metamorphic rocks.

This discussion is necessarily brief and speculative, because specific information bearing on the original nature of the rocks is scanty and their evolution, which is obviously complex, is poorly understood. The suggestion is made that the grade of metamorphism decreases from north to south, from the banded gneiss and associated rocks, through the porphyroblastic gneiss, to the amphibolite. The evidence for this is threefold. First, the pegmatites and altered gneisses are much more common in the banded gneiss than in the porphyroblastic gneiss, and the migmatites occur only within the banded gneiss. Secondly, the textures of the gneisses as observed in thin sections and in the field become progressively coarser from south to north, from the porphyroblastic gneiss to the banded gneiss. Thirdly, the mineral assemblages in the banded gneiss (quartz, oligoclase-andesine, microcline, hornblende, biotite), the porphyroblastic gneiss (quartz, oligoclase, microcline, biotite, epidote), and the amphibolite (actinolite, albite-oligoclase, quartz) correspond to metamorphic facies of decreasing regional metamorphism. The assemblage in the banded gneiss is similar to that of the almandine-amphibolite facies of rocks with excess potassium and silica (Fyfe et al., 1958, p. 231; Turner and Verhoogen, 1951, pp. 455-6, 459), in the prophyroblastic gneiss to the quartz-albite-almandine subfacies of the greenschist facies of quartzofeldspathic rocks (Fyfe et al., 1958, pp. 223-4; Turner and Verhoogen, 1951, p. 463), and in the amphibolite to the quartz-albite-epidote-biotite subfacies of the greenschist facies of basic rocks (Fyfe et al., 1958, p. 223; Turner and Verhoogen, 1951, p. 469).

Within the banded gneiss complex, the original nature of the rocks is largely indeterminate. The grain size and mosaic texture of the quartzitic layers south of Magnetitbjerg indicate a sedimentary origin for these layers and favor the interpretation that the banded gneiss in general was originally a sedimentary, rather than an igneous, rock. If a sedimentary origin is postulated for the banded gneiss then the mineral assemblages and chemical composition indicate a series of quartzose and shaly rocks. On this basis the epidote-hornblende layers of the southeastern part of the area were probably derived from limy shales.

Origin of the layering in the banded gneiss is problematical. The layering may reflect compositional differences in the original rock, or it may have resulted from metamorphic differentiation processes, either diffusion or shearing during regional metamorphism. The great variation in the layering, ranging from regular, through wavy, to highly contorted, indicates at least a partially mobile mass. A combination of original compositional differences and metamorphic differentiation processes, primarily diffusion, would probably best explain the observed character of the layering.

The migmatites were originally banded gneisses, as suggested by the included remnants and their gradational contacts. They have developed either by differential melting of the original rock or through introduction of siliceous material. Because the small migmatite bodies are scattered haphazardly throughout the banded gneiss with no visible relation to any magmatic source, these bodies are perhaps better explained by differential melting. The origin of the large migmatite body atop Vestre Klovbjerg is problematical. It may be related to Precambrian orogenic movements, since the migmatite is apparently located along the axis of a plunging syncline within the metamorphic rocks (see section on "Structure").

Rocks mapped as altered basic rock are so classed because of their high content of mafic minerals and because the presence of chromite suggests an original ultramafic rock, possibly a peridotite. The rocks exposed at Landsø appear to be intrusive into the banded gneiss, but the rocks of the two patches in Skåret are conformable with the layering and either were introduced between the gneissic layers during regional metamorphism or were injected along pre-existing layers in these rocks and subsequently metamorphosed.

Development of altered gneiss from banded gneiss may be related to faulting, as suggested by the breccias, the mylonitized layers, and the irregular fractures. Some hydrothermal activity is indicated by the myrmekitic structures and the presence of pegmatites.

The porphyroblastic gneiss, which apparently grades into the banded gneiss, is believed to represent an original sedimentary rock, principally because of the mosaic texture within the groundmass, but of lower metamorphic grade than the banded gneiss. The gneiss was probably a series of sandstones and shaly sandstones, and the included schists were probably shales.

Mineral content of the amphibolite and similarity of its chemical composition to the diabase dikes that intrude the Nunatarssuaq area (see section on "Diabase dikes") suggest that the amphibolite was originally an igneous rock of basaltic composition. A similar mineral assemblage could also be derived from impure calcareous sediments, but in that case the amount of epidote and calcite would probably be greater. The metamorphism of the amphibolite was apparently accompanied by little metasomatism and the metamorphic grade of the amphibolite is considered to be the lowest within the basement complex.

Igneous Rocks.

Granitic pegmatite.

Distribution and geologic relations.

Granite pegmatites occur throughout the metamorphic basement complex of Nunatarssuaq but are much more numerous in the northern part of the area. Many granite pegmatite dikes intrude the banded gneiss and migmatite (fig. 8), and most of them are of normal composition, but highly quartzose ones are common in the porphyroblastic gneiss and the amphibolite of southern Nunatarssuaq. Narrow dikes of zoned pegmatite occur within the area of porphyroblastic gneiss near the terminus of Knud Rasmussen Gletscher (fig. 9). The pegmatites in the amphibolite around Ohio Fjeld are essentially quartz veins or esmeraldites.

Most pegmatites occur as dikes but some form irregularly shaped bodies (fig. 10). The dikes range in exposed width from about 2 cm to a maximum of 6 m. The maximum width was observed in an exposure 0.8 km south of Djævlekløft at 67°27′ west longitude. Most dikes cut the host rock cleanly along parallel walls but a few show indistinct borders and enclose fragments of the host rock.

Petrographic character.

Normal, quartzose, and zoned pegmatites are the most common types in Nunatarssuaq. A few consist almost wholly of graphic granite. Normal pegmatite, the most numerous type in the area, occurs in dikes that are rarely over 3 meters in exposed width. These dikes consist largely of feldspar (chiefly oligoclase and microcline), subordinate quartz, and small but variable amounts of biotite. In many cases a very thin shell of biotite lines the dike walls. Large crystals of magnetite occur in a few pegmatites. Orthoclase, muscovite, sphene, and apatite are accessories. In many dikes of this group the borders and cores are finer grained than the intervening areas, which are very coarsely crystalline. However, the mineralogy is essentially the same throughout the dikes. Quartzose pegmatites, usually less than 60 cm wide, consist almost

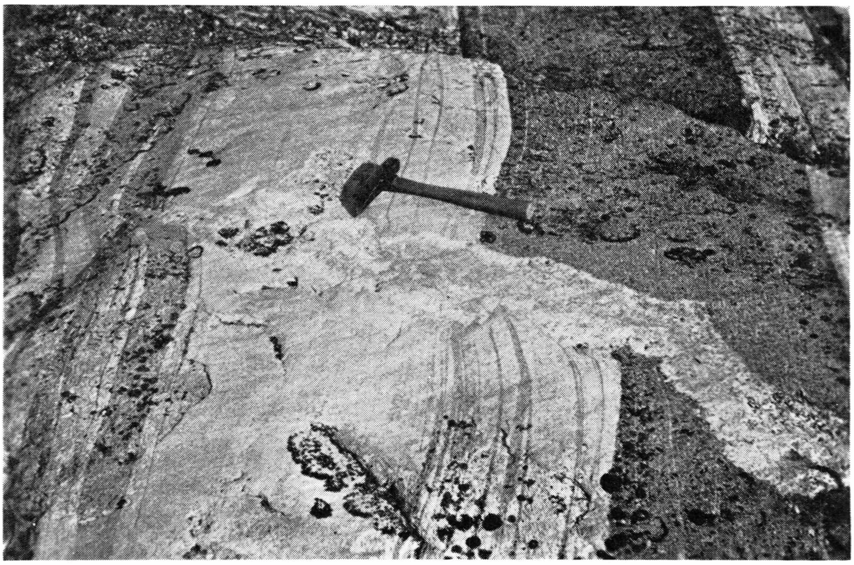

Fig. 8. Pegmatite dike cutting across off-set bands of gneiss, upper part of Tvillinggletscher Dal, eastern Nunatarssuaq.

Fig. 9. Zoned pegmatite dike, with feldspar walls (white) and quartz core (dark gray), in porphyroblastic gneiss, located near terminus of Knud Rasmussen Gletscher.

Fig. 10. Irregular body of pegmatite in banded gneiss, upper part of Tvillinggletscher Dal, eastern Nunatarssuaq.

totally of quartz with minor amounts of feldspar and muscovite. They are essentially esmeraldites. The zoned pegmatites contain a quartz core surrounded by green microcline and then by plagioclase. They are generally no wider than 30 cm, but a few, in which the zoning is not well developed, are 30 cm to 2 m wide.

Granite.

Distribution and geologic relations.

A granite stock covers approximately two-thirds of a square kilometer on a nunatak bordering the Rampen and is apparently surrounded by banded gneiss. It is the only stock that was observed in Nunatarssuaq, although other intrusive bodies probably occur nearby as indicated by large boulders of granite in drift deposits north of the Rampen.

The contact between the granite and the banded gneiss was observed on the south side of the nunatak in large frost-rived boulders that are essentially in place. It is sharp everywhere and the granite cuts the gneissic bands at various angles. Near the contact the granite contains conspicuous xenoliths of gneiss that have sharp borders, are essentially equidimensional, and are usually less than 30 cm in diameter.

The granite generally breaks up into large boulders that have rounded corners and contain numerous pits formed by weathering. Fresh specimens of the rock are light gray, but weathered surfaces are pink.

Petrographic character.

In hand specimen the granite is medium grained and consists chiefly of potash feldspar, quartz, and a little biotite. The potash feldspar exhibits conspicuous Carlsbad twinning of laths, which are 4 to 8 mm long. Other structures, such as orientation of individual minerals or variations in mineral distribution, were not observed in the granite.

In thin section the granite contains mostly microcline and quartz, minor amounts of oligoclase and biotite, and some large (0.6 mm) euhedral crystals of sphene. Apatite, zircon, muscovite, and magnetite are accessories. Acicular needles of either tourmaline or rutile form a sagenitic pattern in many quartz grains. Part of the plagioclase feldspar is sericitized, and most of the quartz shows strain shadows.

Age of Basement Complex.

Rocks of the basement complex are a part of the Greenland shield of Precambrian age. Because a profound unconformity separates these highly metamorphosed rocks from the overlying, unmetamorphosed sedimentary rocks of the Thule group, of probably latest Precambrian age, the basement rocks are considered to be early or middle Precambrian in age. The age of a specimen from a quartzo-feldspathic layer of gneiss (Field no. F-A230), collected in central Nunatarssuaq at 76°43.3′ north latitude and 67°28′ west longitude, is 1,090 million years as determined from its contained zircon (JAFFE et al., 1959). This age is well within the age limits of the Precambrian era, and may be the date of the original crystallization of the rock or of the last significant recrystallization (JAFFE, GOTTFRIED and WARING, 1955).

Among the rocks of the basement complex, the banded and porphyroblastic gneisses are believed to be gradational and therefore of approximately the same age. The amphibolite may be interlayered with the porphyroblastic gneiss and therefore of the same age, or it may be intrusive into, and younger than, the gneiss. All of the metamorphic and associated rocks are intruded by pegmatites, which are therefore younger in age. The granite stock is the youngest rock in the complex; the granite is inferred to be a part of the basement complex by analogy with other plutonic rocks of northwest Greenland that are associated with the basement complex but do not intrude the overlying Thule group. In Inglefield Land these rocks consist of granite, diorite, and quartz-diorite (KOCH, 1933, pp. 11-12), and in Prudhoe Land, south of Inglefield Land, syenite (KOCH, 1926, p. 307).

THULE GROUP

Name.

The Thule group (originally termed a "formation") was named by Koch (1929, p. 220) from the Danish trading post of that name in northwest Greenland, and the Wolstenholme Fjord area around Thule was designated as the type locality. Later, Troelsen (1950, pp. 35-37) recognized a sandstone formation and two dolomite formations within the Thule group on Inglefield Land in northwest Greenland and on Ellesmere Island in northeast Canada. A tripartite division of the group has recently been defined in the North Star Bugt area (Davies, Krinsley and Nicol, 1963): Wolstenholme formation (lower), 490 m thick, predominantly quartzite; Dundas formation (middle), 790 m thick, black shale; and Narssârssuk formation (upper), 1,040 m thick, predominantly a cyclical alternation of dolomite, sandstone, and siltstone.

Distribution and Character.

At Nunatarssuaq the basal portion of the Thule group is exposed in two distinct belts, one in the far northeastern corner and the other along the southwestern border. In the northeast the Thule group underlies the ice-free area that projects between the two ice caps. It also occurs on a nunatak which lies just within the margin of the Greenland Ice Cap. In the southwest part of Nunatarssuaq, the Thule group is present on the flanks of the mountains north of Harald Moltke Bræ and extends from Wolstenholme Fjord to the base of Ohio Fjeld; exposures occur up to a maximum height of about 580 m above sea-level. The Thule group is also present in three isolated patches, one at the summit of Ohio Fjeld at a maximum altitude of 790 m and the other two about one and one-half kilometers north of the summit.

Lithologically, the Thule group at Nunatarssuaq is divisible into two units, a lower unit characterized by conglomerate, and an upper unit of massive sandstone. In the southwest, the conglomerate is exposed in a narrow strip that averages three-fourths of a kilometer in width and extends from Wolstenholme Fiord to the base of Ohio Fjeld, and in the three outliers at and near the summit of Ohio Fjeld. In the northeast the conglomerate is exposed at one locality along Rødstenbæk and on a nunatak within the Greenland Ice Cap. At the base of the conglomerate unit is a thin zone of sandstone and some shale, both fairly friable and colored a deep reddish purple. This zone occurs along the contact west of Terasseløb, in the two outliers north of the summit of Ohio Fjeld, and on a nunatak within the Greenland Ice Cap. It is not present in the outlier atop Ohio Fjeld, where the conglomerate rests directly on the basement complex.

The massive sandstone comprises the bulk of the southwest and northeast sectors, and includes several beds of shale. Good exposures occur in a series of low hills between sucessive ice-marginal channels on the sides of the mountains along Harald Moltke Bræ.

Conglomerate.

Typically, the conglomerate consists of pebbles and cobbles in a reddish, sandy matrix. Beds containing numerous pebbles and cobbles alternate with beds in which the pebbles and cobbles are rarely in contact with one another (fig. 11). Lenses and beds of sandstone are fairly common within the unit. Fractures commonly cut across the pebbles and cobbles. The unit grades upward into the massive sandstone, as the number and size of pebbles decrease and the amount of sandy matrix increases.

Pebbles and cobbles range up to 15 cm in longest dimension and are almost everywhere well-rounded. Counts of 100 pebbles, all greater than one cm long, at three different localities yielded from 93 to 97 percent white quartz pebbles. The remaining pebbles were about equally divided between fine-grained black chert and red sandstone, except for a very few pebbles of gneiss with a high quartz content. In thin section the chert pebbles show vein quartz filling minute fractures, and contain a little hematite and manganese oxide (?). One sandstone pebble consists principally of well-rounded grains of quartz and chert in a matrix of quartz and chert, with minor amounts of kaolinite, illite, and sericite (?); a few grains of microcline, muscovite, and green hornblende are also present. Another sandstone pebble contains sub-rounded quartz grains, with a few grains of siltstone, in a very fine quartz-clay matrix. Hematite stains give the pebbles their reddish color.

Sandstone and shale at the base of the unit are deep reddish purple. In thin section the sandstone consists of well-rounded quartz grains in a matrix containing secondary quartz, sericite, and hematite. The chemical composition of a sample (Field no. F136d) collected close to the contact with the basement complex in a deep ravine on the western

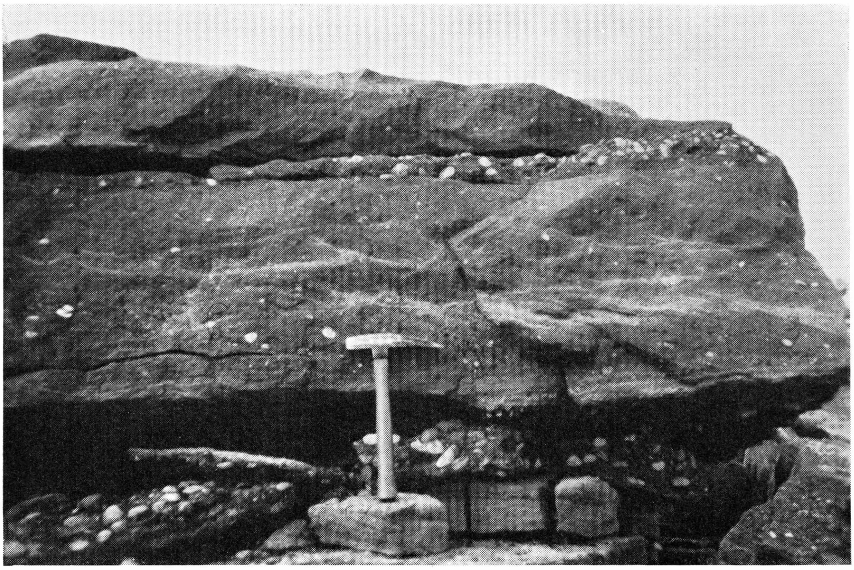

Fig. 11. Conglomerate from near base of the Thule group, located at summit of Ohio Fjeld, southern Nunatarssuaq.

slopes of Ohio Fjeld, at 76°37′ north latitude and 67°35′ west longitude, is given below. The ferric oxide content, which is just over 2.5 percent, gives the rock its color. The shale in thin section consists of kaolinite and halloysite with detrital and secondary quartz. Symmetrical ripple marks are present on the surface of several shaly beds observed west of

Chemical analysis of red sandstone.

SiO_2	90.0
Al_2O_3	4.1
FeO	0.22
Fe_2O_3	2.7
MgO	0.28
CaO	0.00
Na_2O	0.01
K_2O	1.0
TiO_2	0.36
P_2O_5	0.02
MnO	0.01
CO_2	0.05
H_2O	0.79
Total	99.54

M. Phillips, P. Elmore, K. White, analysts.

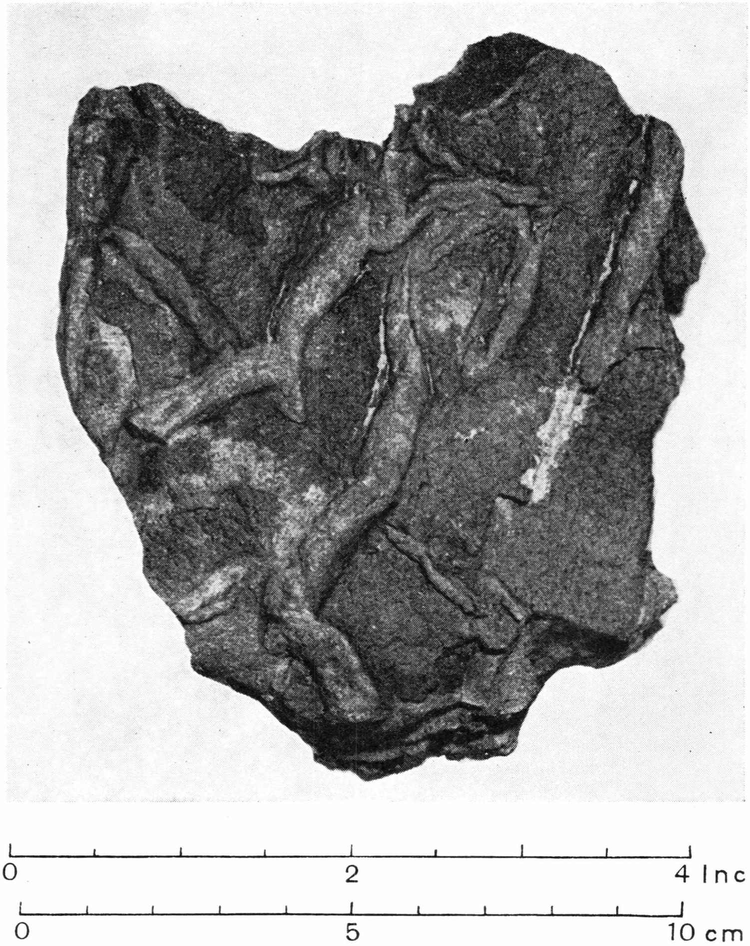

Fig. 12. Irregular, rope-like ridges (fucoidal markings) in shale from the Thule group.

Terasseløb. They have rounded crests and troughs, wave lengths of 4 cm, and amplitudes of 0.6 cm; they are probably modified oscillation ripples.

Sandstone.

Massive beds of sandstone overlie the basal conglomerate unit with no stratigraphic break. Their color is variegated, ranging from pink and red through yellow and greenish to white. Bedding planes are commonly indistinct, and some beds are apparently 3 or more meters thick; locally, however, beds are thin and some are cross-bedded. The texture of the rocks on fresh, broken surfaces is generally smooth, but in places is

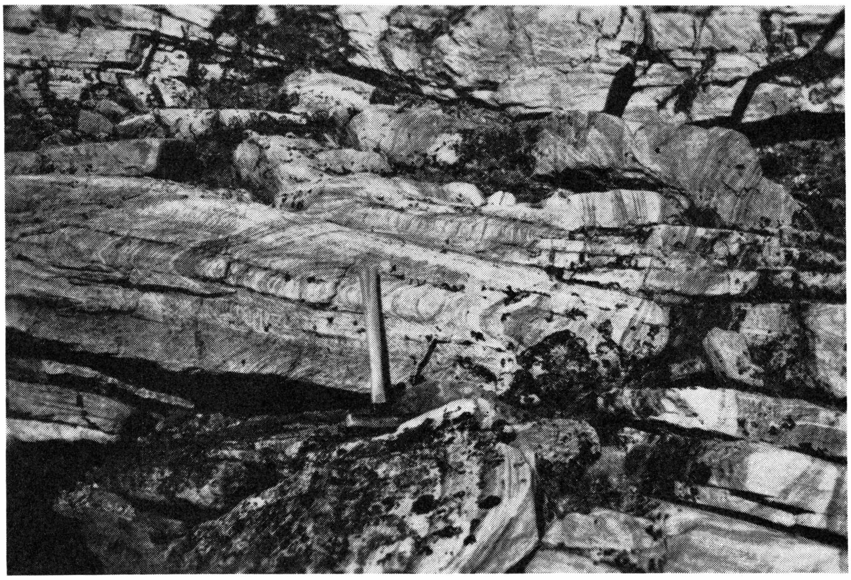

Fig. 13. Banding in an exposure of sandstone from the Thule group, northeast tip of Nunatarssuaq. Banding caused by variation in hematite staining.

sugary. In thin section the rocks consist of rounded grains of quartz and a few grains of feldspar, tourmaline, chert, zircon, and leucoxene. Secondary quartz forms an overgrowth on many grains and may fill all the interstices, giving a mosaic pattern. Hematite is also present interstitially, as is chlorite in the greenish rocks.

Thinly bedded, sandy shales occur within the sandstone unit and are exposed in an area of about three-tenths of a square kilometer in southwest Nunatarssuaq west of Trommebæk (plate 1) and in an area, too small to map, in northeast Núnatarssuaq. The beds are dark gray or dark reddish-gray, and some of their surfaces show irregular, rope-like ridges, about the diameter of a pencil (fig. 12). The ridges, which consist largely of sand grains, resemble fucoidal markings and are of indeterminate origin. In thin section about 50 percent of the shale is made up of grains of quartz and some feldspar, and the remainder consists of a considerable amount of calcite, some muscovite and hematite, and a clay mineral, probably illite.

A distinctive outcrop that forms a small knoll bordered by sandstone occurs on both sides of Rødstenbæk, west of Dryasbjerg in northeastern Nunatarssuaq. The rock, which appears brecciated, is mottled red and white, and is composed largely of chalcedony and dispersed hematite. Originally, it was probably a sandstone of the Thule group that later was altered hydrothermally, perhaps at the same time as the intrusion of the diabase dikes.

Color banding is a striking feature of sandy and some pebbly beds observed in two localities, one west of Terasseløb within the lower part of the sandstone unit, and the other at several places in northeast Nunatarssuaq. In one place, over 100 bands cover a sandy bed in an exposure that measures 1 m across the bedding and about 2 m along the bedding (fig. 13). The color of the bands is predominantly red; much of the banding is due to alternations in the shade of red but some is due to

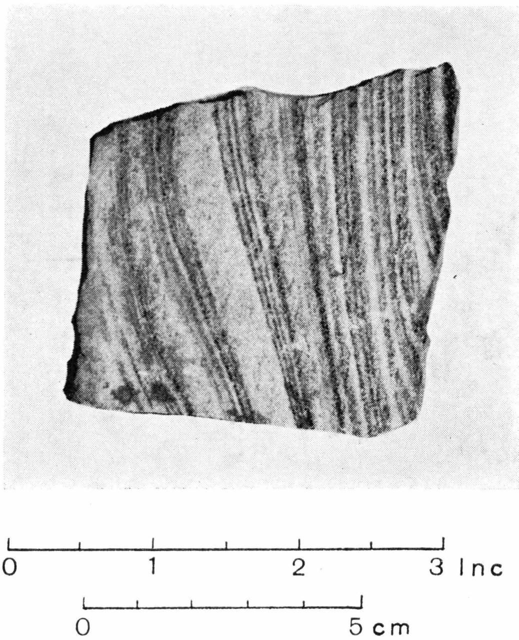

Fig. 14. Banding in sandstone from the Thule group caused by variation in hematite staining.

alternations between red and white. The bands in general are closely spaced, are commonly curved, and in many rock specimens are grouped together to form a "megaband" (fig. 14). In some specimens two sets of bands intersect. Thin sections show the bands to be concentrations of hematite between quartz grains, all of which show secondary quartz overgrowths. The source of the iron is apparently from within the basal sediments, and the bands are due to diffusion of the iron through the rocks. The fundamental cause, or causes, of the diffusion of the iron and its segregation into bands are unknown. The bands are apparently unrelated to the diabase dikes that intrude the Thule group, inasmuch as dikes are not present in the area west of Terrasseløb. A similar feature, termed liesegang banding, is common in rocks of comparable stratigraphic position in the western part of the United States.

Thickness and Stratigraphic Relations.

The Thule group at Nunatarssuaq, as in other parts of Greenland, unconformably overlies eroded Precambrian basement rocks. The unconformity was observed in a deep ravine on the western slopes of Ohio-Fjeld, where basal sandy and shaly beds of the Thule group dip 15 degrees to the southwest, parallel to the surface of the basement rocks. There, the surface is perfectly even for a distance of 7.5 m along its dip and 6 m across its strike. Elsewhere, the surface appears to be somewhat uneven. West of Terrasseløb, numerous gneissic boulders cover a small area within the sedimentary rocks and apparently represent a bedrock knoll, perhaps 6 m high, around which the Thule sediments were deposited. Structural contours drawn on the unconformity in southwest Nunatarssuaq show a gradient of 10 to 15 degrees to the south-southwest for the bulk of the group. Rather scanty data on the bedding (plate 1) indicate that the Thule beds are parallel to this surface.

Maximum calculated thickness of the Thule group is about 450 m and occurs at the western extremity along Wolstenholme Fjord. The red sandstone and shale developed locally at the base of the group has a maximum thickness of 7.5 m; the overlying conglomerate has an average thickness of 60 m; the sandstone at the top may attain a thickness as much as 380 m. A measured section within the shale beds of the sandstone unit in southwest Nunatarssuaq has a thickness of 6 m. The shale is underlain by about 275 m of conglomerate and sandstone, and is overlain by 100 m or so of sandstone. The thickness and character of the Thule group at Nunatarssuaq suggests that it is equivalent to the lower three-quarters of the Wolstenholme formation as defined in the North Star Bugt area (Davies, Krinsley and Nicol, 1963).

Origin and Conditions of Deposition.

Quartz pebbles in the conglomerate of the Thule group were derived from quartz-rich igneous rocks (quartz veins, granitic pegmatites, etc.), such as those in the basement complex, as evidenced by the character of the quartz. The kaolinitic material and the hematite present in the lowermost beds were probably derived from a soil rich in alumina and iron, perhaps a pedalfer soil, developed on the Precambrian rocks. The few sandstone pebbles present in the conglomerate suggest that a sedimentary series older than the Thule group was present in the Precambrian. Such a series may represent unmetamorphosed portions of sediments that formed the basement rocks or it may represent a separate sedimentary series younger than the basement rocks. Koch (1933, pp. 12-14) has described a sedimentary series in Inglefield Land that is younger than the basement rocks and older than the Thule group.

Apparently the Thule group was deposited in a sea that transgressed beveled Precambrian rocks and reworked coarse surficial material, as indicated by the widespread basal conglomerate. Locally lagoons probably existed, in which muds and sands accumulated. Gradually the water seems to have deepened and remained at approximately the same depth for a considerable length of time, thus permitting the accumulation of a great thickness of sand.

Age.

The Thule group, which is unfossiliferous except for non-diagnostic *Cryptozoon* (?) in the Thule area, is generally agreed to be of late Precambrian age. This age is based on relations in Inglefield Land where Thule sediments are disconformably overlain by fossiliferous Lower Cambrian rocks (KOCH, 1929, p. 222). Because of this discomformable relation, TROELSEN (1950, p. 37) prefers to call the group "eo-Cambrian".

DIABASE DIKES

Distribution and Geologic Relations.

Most of the twelve or more diabase dikes that occur in Nunatarssuaq are in the northern half of the area and none are in the southwest quarter of the area. Three of the dikes trend northeast, one along the bottom of Skåret and the other two northwest of Skåret. The remainder of the dikes trend northwest. The dikes are best exposed on steep valley walls, but where wide enough, frost-rived debris from the dikes can be readily traced across country. A number of dikes in the northeast corner cross the entire area, and one in central Nunatarssuaq crosses the area from Knud Rasmussen Gletscher to the Greenland Ice Cap, a distance of approximately 20 km. This dike, which averages 90 m in width, is the longest and widest one observed in Nunatarssuaq. The diabasic rocks weather to a characteristic reddish-brown debris that is easily recognized.

All but three of the dikes intrude the basement complex. The exceptions are two that cross the Thule group in the northeast sector and one that traverses the nunatak exposure of the Thule group east of Nørresø. This dike appears to be continuous with the one that cuts the basement complex and, if so, is the only one that crosses both groups of rocks. All dikes show sharp contacts and distinct chill zones that are more resistant to weathering than the cores. Some feldspar laths within the diabase are oriented parallel to the dike walls and probably indicate flowage during the emplacement of the diabase. The dikes follow one or the other of two prominent joint directions, and where observed, dip vertically or nearly vertically.

Diabase also occurs around the rim of a small oval-shaped area in Skåret, at the base of Østre Klovbjerg. This exposure, which has a core of breccia, is interpreted as a volcanic neck.

Petrographic Character.

All of the diabase dikes have fine-grained black chill borders, but the centers of large dikes are coarsely crystalline and speckled black and gray. In thin section the diabase is ophitic and is composed essentially of plagioclase and augite. The plagioclase is andesine or labradorite, is twinned, and shows both normal and oscillatory zoning. In some samples it is intensely sericitized, but the degree of sericitization varies from dike to dike. The augite is commonly twinned, and in some thin sections it is bleached and replaced by hornblende, brown biotite, and a little chlorite. The degree of uralization varies from dike to dike, and within the same dike. In fine-grained samples from small dikes and from borders of wide dikes, the augite is fresh and unaltered; in coarsely crystalline samples it may be completely bleached.

Secondary quartz replaces the feldspar in some specimens and comprises up to 5 percent of the rock. These particular rocks are similar to the quartz diabases described by MUNCK (1941, pp. 28-29) from the Thule area and by CALLISEN (1929, pp. 233-235, 238-239, 249-251) from north Greenland. MUNCK reports the occurrence of micropegmatite in the Thule area, but none was observed at Nunatarssuaq.

Other minerals present are talc (?), ilmenite, apatite, pyrite, epidote, and magnetite. A mineral showing high birefringence, possibly talc, is considered pseudomorphic after olivine. The amount of ilmenite varies from dike to dike and it occurs as large crystals of rhombic habit or as stringers of small crystals attached to one another. Much apatite appears as very elongate crystals embedded in the major consitiuents of the diabase. A few small epidote veins fill fractures in the dikes.

Diabase in the volcanic neck at the bottom of Skåret is fine-grained, and the breccia consists of small heterogeneous fragments of porphyritic diabase, quartz, and plagioclase. The cement is rich in chlorite and hematite dust.

Chemical Composition.

Chemical composition, determined by rapid methods, of a diabase (Field no. F-39b) from a northwest trending dike that crosses Skåret west of Rampen, at 76°48′ north latitude and 67°16′ west longitude, is given below.

Age.

In Inglefield Land diabase dikes intrude the Thule group, but none are known to intrude the overlying Cambrian strata, and diabase fragments occur in a conglomerate of Lower Cambrian age (KOCH, 1933, pp. 21-23; TROELSEN, 1950, p. 19). By analogy, the age of the diabase dikes elsewhere, including the Nunatarssuaq area, is believed to be late Precambrian.

Chemical analysis of diabase.

SiO_2	48.5
Al_2O_3	14.9
FeO	11.7
Fe_2O_3	2.7
MgO	4.6
CaO	6.6
Na_2O	3.2
K_2O	2.0
TiO_2	2.4
P_2O_5	0.51
MnO	0.20
CO_2	0.63
H_2O	1.5
Total	99.44

H. Phillips, P. Elmore, K. White, analysts.

STRUCTURE

Basement Complex.

Approximately 80 observations of foliation of the banded gneiss and porphyroblastic gneiss show a preponderance of northwest strikes and variable dips (plate 1). A plunging syncline between two anticlines is suggested. The axis of the more southerly anticline extends from the midpoint of Tvillinggletscher Dal west-northwest to Skaldepanden. The second anticlinal axis trends northwest and crosses the upper part of Skåret at a point west of Rampen. The syncline plunges northwest and encompasses the migmatite body atop Vestre Klovbjerg; its axis extends from a point just north of Østre Klovbjerg to Knud Rasmussen Gletscher. These folds probably record intense Precambrian orogenic movements that accompanied the regional metamorphism of the basement complex. The data suggest these movements were directed from the northeast and (or) the southwest.

Faulting.

Only minor faults, with displacements up to 1 m as measured along offset pegmatite dikes, are known to be confined solely to the basement complex (fig. 8). However, faulting may be associated with the altered gneiss within the banded gneiss complex, as mentioned in the section on "Origin of the metamorphic rocks", and some faulting probably was undetected because of the reconnaissance nature of the study and the character of the rocks.

Koch's map of the Kap York district (1926, p. 306) shows major faults extending along Knud Rasmussen Gletscher, Harald Moltke Bræ, and the eastern edge of Nunatarssuaq. We found no evidence for the fault along the eastern margin of Nunatarssuaq, and can offer no evidence for or against the fault along Knud Rasmussen Gletscher. Good evidence is present for the fault along Harald Moltkn Bræ, termed here the "Moltke Fault". Two other faults that also involved the Thule group are recognized and here named the "Ohio Fjeld Fault" and the "Rødstenbæk Fault".

Faulting of the Thule group is believed related to regional block faulting, which on Ellesmere Island involved beds that are dated as not older than Cretaceous and possibly as young as Miocene (Troelsen, 1950, pp. 32-33, 79). Thus, late Mesozoic or Tertiary is favored as the age of the faulting of the Thule group, although more than one period of faulting may be represented.

Moltke Fault.

The Moltke Fault separates the south-dipping Thule group in Nunatarssuaq from Precambrian basement rock on the opposite side of the glacier in the Thule area (Davies, Krinsley and Nicol, 1963). There, the basement rocks are exposed in steep cliffs that rise abruptly above the glacier and, because they are in fault contact with the Thule group further to the southwest, form a horst. Obviously, the location of the Moltke Fault is conjectural, but because of the asymmetry of the valley walls it is probably on the Thule side of the glacier.

Minimum stratigraphic displacement along the Moltke Fault is of the order of 450 m, the maximum thickness of the Thule group exposed at Nunatarssuaq. The downthrown, or north, side of the fault as a whole has been tilted from 10 to 15 degrees to the south-southwest, as measured from structural contours drawn on the unconformity between the Thule group and the basement complex.

Ohio Fjeld Fault.

The Ohio Fjeld Fault occurs on the western slopes of Ohio Fjeld where basal Thule sediments strike directly into a steep cliff of Precambrian amphibolite. The fault is rather accurately located at a point near the unnamed ravine cut into the west side of the mountain; the fault line has a general southwesterly trend (plate 1) but its exact location is not known with certainty, principally because of the paucity of exposures. It may trend more westerly along the unnamed ravine, separate the outlier atop Ohio Fjeld from the two outliers north of the summit, and become the easterly extension of the Moltke Fault or a branch of that fault. Because the amphibolite cliff is remarkably straight for a distance of about a mile and might be a fault scarp, the fault may trend more southerly along the base of the cliff.

Rødstenbæk Fault.

Field evidence indicates that a fault separates the Thule group and the basement complex in the northeast corner of Nunatarssuaq. The contact between these rocks was not observed, but its approximate location is known (Gregory, 1956). It extends eastward in a nearly straight line across fairly rugged terrain, having a minimum local relief of 90 to 120 m, along the lower part of Rødstenbæk. North of the contact, sandstone and a little shale are exposed for the most part, although conglomerate occurs in one locality in the middle sector of Rødstenbæk west of Dryasbjerg. Three observations show a southeasterly strike of the beds, which apparently intersect the contact obliquely, and an average dip of about 15 degrees to the northeast. This apparent fault has a minimum stratigraphic displacement of about 60 m.

Joints.

Jointing is very common in the rocks of the basement complex. Most joints trend either northwest or northeast, dip between 70 and 90 degrees, and form a prominent regional joint system. All of the diabase dikes are parallel to one or the other of the joint sets. Most of the major valleys are aligned with the joint directions (e. g,. Knud Rasmussen Gletscher valley, Moltke Bræ valley, Skåret, Djævlekløft). These valleys were probably cut initially by streams flowing along the strike of the joints, and some of the valleys were later accentuated by glacial scour.

Jointing is also common in the massive beds of sandstone and conglomerate of the Thule group. Observations at seven localities in southwest Nunatarssuaq show some northwest and northeast trends, similar to the regional pattern in the basement complex, but most show a northerly trend. All joints dip vertically, or nearly so.

Age of the jointing is unknown, but presumably the northeast and northwest sets were formed before the intrusion of the diabase dikes.

GEOLOGY HISTORY

At Nunatarssuaq the geologic history began in early or middle Precambrian time, probably with the deposition of arkoses, sandstones, and shales in a geosyncline. Rocks of basaltic composition were probably intruded into the sedimentary rocks or interbedded with them as flows or sills. Later, the sedimentary and associated igneous rocks were folded along axes that trend northwest, were moderately to intensely metamorphosed into gneisses and amphibolites, and were intruded by pegmatites. Zones within the banded gneiss were converted to migmatites, and in several places the gneiss was altered, possibly by faulting. At a later date, but probably continuous with the metamorphism, the granitic stock was intruded into the metamorphic complex. A sedimentary series older than the Thule group was possibly deposited on the basement complex.

An extensive erosion surface had been developed on the basement rocks by late Precambrian times. At Nunatarssuaq the surface probably had a pedalfer soil and, in one place, a local relief of about 6 m. In latest Precambrian times, the sea transgressed over the surface and the Thule sediments were deposited, chiefly quartzose beach gravels, but locally sand and silt in lagoons. As the depth of water increased, thick sand deposits were formed. Before the beginning of Cambrian time, diabase dikes were intruded into the basement rocks and the Thule group along two sets of prominent regional joints.

Whereas other areas of northern Greenland record sedimentation and orogeny during Paleozoic time, presumably the Nunatarssuaq area was fairly stable, above sea level, and subject to prolonged erosion. In late Mesozoic or Tertiary time, block faulting affected the area and produced the Moltke, Ohio Fjeld and Rødstenbæk Faults. The rocks of southwestern Nunatarssuaq were tilted from 10 to 15 degrees to the south-southwest, and those of northeastern Nunatarssuaq about 15 degrees to the northeast. Thereafter, the area was again subject to erosion and during Quaternary time was covered by glaciers at least once.

REFERENCES CITED

Callisen, Karen, 1929, Petrographische Untersuchung einiger Gesteine von Nordgrönland: Meddelelser om Grønland, Bd. 71, Nr. 6, pp. 217—255.

Davies, W. E., D. B. Krinsley, and A. H. Nicol, 1963, Geology of the North Star Bugt area, northwest Greenland: Meddelelser om Grønland, Bd. 162, Nr. 12.

Fyfe, W. S., F. J. Turner, and Jean, Verhoogen, 1958, Metamorphic reactions and metamorphic facies: Geol. Soc. America Mem. 73, 259 p.

Gregory, J. E., 1956, Geomorphology of the Red Rock Creek area, *in* R. P. Goldthwait, Study of ice cliff in Nunatarssuaq, Greenland: Ohio State Univ. Research Foundation, Project 636 (SIPRE Report 39), pp. 113—125 and map.

Holmes, C. D., and R. B. Colton, 1960, Patterned ground near Dundas (Thule Air Force Base), Greenland: Meddelelser om Grønland, Bd. 158, Nr. 6, 15 p.

Horowitz, Alan S., 1954, Petrography of the Nunatarssuaq area, northwest Greenland: M. Sc. Thesis, Dept. of Geology, Ohio State University, Columbus, Ohio.

Jaffe, H. W., D. Gottfried, and C. L. Waring, 1955, Larsen-method age determinations of 150 rocks ranging in age from Precambrian through Tertiary (Abstract): Geol. Soc. America Bull., v. 66, p. 1580.

— H. W., D. Gottfried, C. L. Waring, and H. W. Worthing, 1959, Lead-alpha age determinations of accessory minerals of igneous rocks (1953—1957): U. S. Geol. Survey Bull. 1097-B, pp. 65—148.

Koch, Lauge, 1926, A new fault zone in northwest Greenland: American Jour. Sci., v. 12, pp. 301—310.

— 1927, Report on the Danish Bicentenary Jubilee Expedition north of Greenland 1920—23: Meddelelser om Grønland, Bd. 70, pp. 1—232.

— 1929, Stratigraphy of Greenland: Meddelelser om Grönland, Bd. 73, Afd. 2, Nr. 2, pp. 205—320.

— 1933, The geology of Inglefield Land: Meddelelser om Grønland, Bd. 73, Afd. 1, Nr. 2, 38 p.

Munck, Sole, 1941, Geological observations from the Thule district in the summer of 1936: Meddelelser om Grønland, Bd. 124, Nr. 4, 36 p.

Nobles, L. H., 1954, Characteristics of high polar type glaciers in northwestern Greenland (Abstract): Geol. Soc. America Bull., v. 65, p. 1290.

Rasmussen, Knud, 1915, Report of the First Thule Expedition 1912: Meddelelser om Grønland, Bd. 51, Nr. 8, pp. 283—340.

Shapiro, Leonard and W. W. Brannock, 1956, Rapid analysis of silicate rocks: U. S. Geol. Survey Bull. 1036—C, pp. 19—56.

Troelsen, J. C., 1950, Contributions to the geology of northwest Greenland, Ellesmere Island and Axel Heiberg Island: Meddelelser om Grønland, Bd. 149, Nr. 7, 85 p.

Turner, F. J., and Jean Verhoogen, 1951, Igneous and metamorphic petrology: McGraw-Hill. New York, 602 p.

White, S. E., 1956, Glaciological studies of two outlet glaciers, northwest Greenland, 1953: Meddelelser om Grønland, Bd. 137, Nr. 8, 31 p.

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Pl. 1

Edition 1-AMS

Prepared by the Army Map Service (AM), Corps of Engineers, U. S. Army, Washington, D. C. Compiled in 1954 by photogrammetric methods. Aerial photography Aug. 1953. Horizontal control by Danish Geodetic Institute. Miscellaneous detail added from intelligence data. Map not field checked.

LEGEND

Loose surface, graded, all weather road
Track
Trail
Horizontal control point
Spot elevations in feet: Unchecked
Perennial lake
Moraine
Glacial outwash
Approximate Contour

GEOLOGIC MAP OF THE NUNATARSSUAQ AREA, NORTHWEST GREENLAND

By Arthur T. Fernald and Alan S. Horowitz.

Geology mapped in 1953.

Reproduceret ved Geodætisk Institut. København 1964

Scale 1:50,000

CONTOUR INTERVAL 25 FEET

THE ELEVATIONS ON THIS MAP ARE BASED ON A COMBINATION OF TRIGONOMETRIC AND ALTIMETER SURVEYS. IT IS ESTIMATED THAT 90% OF THE ELEVATIONS ON THE MAP ARE ACCURATE TO WITHIN 100 FEET AS REFERENCED TO SEA LEVEL.

TRANSVERSE MERCATOR PROJECTION

HORIZONTAL CONTROL IS TIED TO THE DANISH CONTROL NETWORK IN NORTHERN GREENLAND

APPROXIMATE MEAN DECLINATION 1950 FOR CENTER OF SHEET
ANNUAL MAGNETIC CHANGE 25' EASTERLY