# Anorthosite from Buksefjorden; West Greenland

by

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## Abstract

A thick layer of anorthosite folded with para-gneisses in a syncline has been found in Buksefjorden, West Greenland. It is made up of bytownite, hornblende, biotite and small interstitial grains of clinozoisite. There are inclusions of hornblendite which are found in a stage of dissolution in the anorthosite and amphibolitic rocks are also found within the anorthosite. The rocks in this region are metamorphosed under amphibolite facies conditions, but small areas of granulite facies gneisses are found in such a way that it is reasonable to assume that the whole complex (including the anorthosite) has formerly been exposed to granulite facies conditions. There are younger zones of mylonites which may be recrystallized. The anorthosite is interlayered between para-gneisses and it may be of sedimentary origin. The extension of the layer has not yet been studied.

## Introduction

In 1954 K. ELLITSGAARD-RASMUSSEN and ME MOURITZEN (2) described an anorthosite from Søndre Strømfjord in West Greenland and that was the first mention of this type of rock from West Greenland.

As mentioned in the quoted paper anorthosite had previously been found in other places in West Greenland and they were first of all studied by Dr. HANS RAMBERG in the Godthaab- and the Ameralik Fiords in the summer of 1951. In 1952 anorthositic rocks were observed at Færingehavn and still further south at Fiskernæsset by the geologists of the Geological Survey of Greenland (G.G.U.). In the summer of 1953 Mr. H. MICHEELSEN and the writer found near the mouth of Buksefiorden the southern continuation of the rocks studied by RAMBERG in Ameralik. The same locality had been briefly visited by Mr. J. BONDAM in 1952. Later in 1953 Mr. A. BERTHELSEN found anorthositic rocks at Tovqussaq north of the Godthaab Fiord.

The anorthosite of Buksefiorden was visited on a reconnaissance trip and time did not suffice for a closer study of the occurrence. The field relations noted were however found to be of some interest and since there may furthermore pass several years before the anorthosites of this region can be thoroughly studied the observations made are laid forth in this brief note.

## General Geology

The geology of the area north of Buksefiorden has been dealt with by the writer (6, page 67) and by A. BERTHELSEN (1). The rock complex of the region between Godthaab and Færingehavn is made up of various gneissic and granitic rocks together with amphibolites, mica-schists, anorthosites and ultrabasites to mention the most important constituents. The general pattern of folding is fairly simple with very large and broad, often slightly overturned folds which again are composed of many minor folds. The metamorphic grade corresponds to the amphibolite facies. Granulite facies is found in the north-western part of the Godthaab Fiord.

The same complex is found in Buksefiorden, but conditions are here made rather complicated by the presence of a great number of zones of dislocation and crushing which in places have destroyed all primary features. The displacement along the zones was in part plastic since the strike of the gneiss may change direction when approaching the mylonites

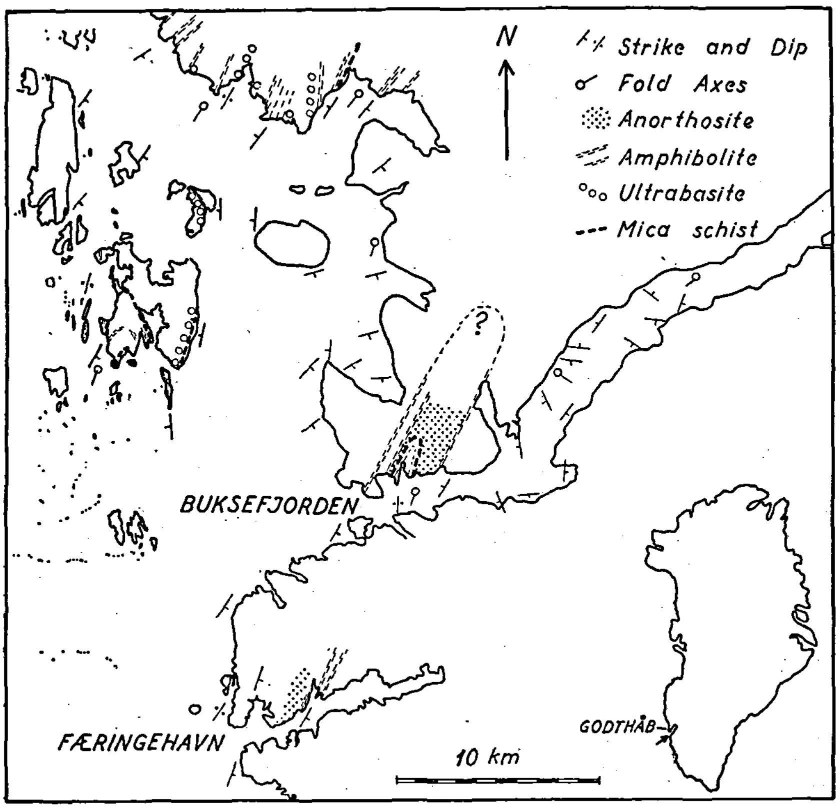


Fig. 1. Geological map of the region. Dolerites and mylonites have been omitted. The southern continuation of the anorthosite has not been examined.

so that it is parallel to the latter in their immediate vicinity. Recrystallization (granitization) of later date than the crushing has been noted. The crushing and displacement is at least partly younger than the intrusion of a swarm of doleritic dykes.

A characteristic feature of the Buksefiord is the presence of small areas made up of rusty-coloured, hypersthene-bearing rocks of typical granulite facies habit. They are enclosed in hornblende gneisses in places in an agmatitic way. It is apparently a situation where a granulite facies complex has been exposed to metamorphism corresponding to the amphibolite facies and is found in a process of adjustment to the new conditions. In this connection reference should be made to the presence of gneisses with a faintly blue quartz and with green spots. The latter are analogous with similar rocks in other areas interpreted as transformed hypersthene gneisses.

The granulite facies areas may also be cut by mylonites (with epidote) so that there is within a few metres rocks formed at granulite facies, amphibolite facies, and epidote-amphibolite facies conditions.

In the outer part of the fiord anorthosite has been found on the north coast (fig. 2). It forms a thick layer folded in a syncline with amphibolite and mica-schist above and a banded series with amphibolite (in part garnetiferous) below the anorthosite. Towards the east a thick conformable zone of displacement forms the border of the anorthositic complex. While there are a great number of zones of crushing to the east of the anorthosite, very few are found to the west where, on the contrary, a great multitude of pegmatites are found.

*The Anorthosite.* The anorthosite is medium- to coarse-grained with grains of plagioclase as large as 1 centimetre. It may be a pure white plagioclase rock, but a black hornblende (with greenish tinge) is normally an important constituent making the rock dioritic in places. The hornblende is arranged in streaks or in layers giving the rock a gneissic appearance. The amount of hornblende increases towards small bodies of hornblendite which are conformably enclosed in the anorthosite. There seems to be a gradual transition from hornblendite (with prismae of hornblende attaining a length of about 1 centimetre) to anorthosite, the first-named being digested by the latter. Biotite may be abundant in the outer parts of the hornblendites and also in some parts of the anorthosite. The size of the individual bodies of hornblendite is a few metres.

There are two additional types of hornblende-bearing rocks in the anorthosite, namely: 1) fragments of amphibolite which may indicate a possible relationship between anorthosite and amphibolite, and 2) layers of medium-grained amphibolite, often with a pronounced lineation. The second type may represent metamorphosed basic dykes.

The anorthosite has hornblende-bearing pegmatites.

Finally it should be mentioned that there are conformable, strongly banded zones of dislocation with about five centimetres large grains of microcline in some bands.

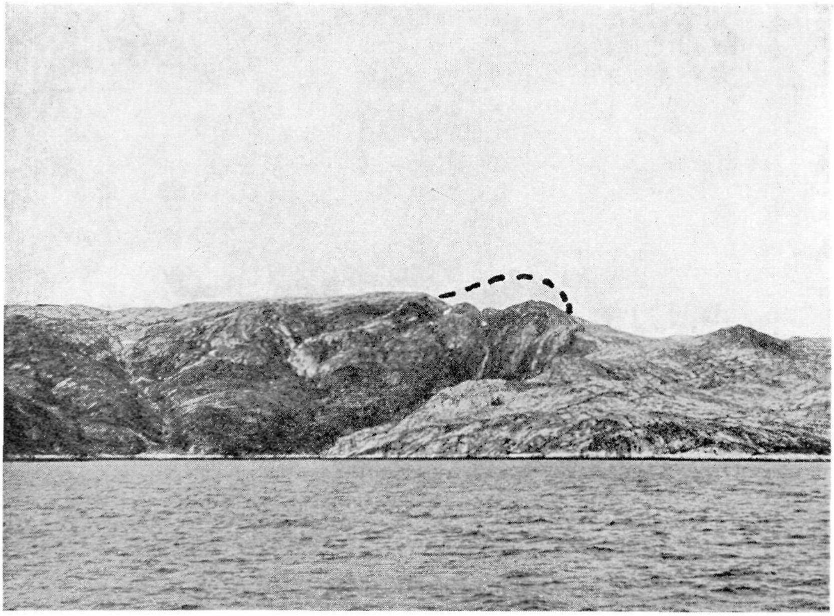

Fig. 2. The anorthosite seen from the south. Towards the right and towards the left: anorthosite folded in a syncline with the axis of folding plunging towards the fiord. The central part of the syncline is occupied by mica schist and amphibolite.

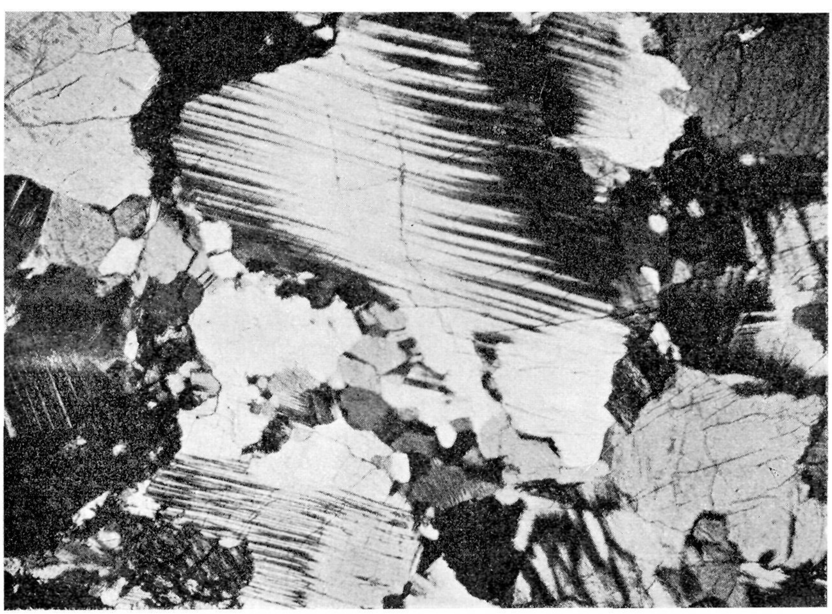

Fig. 3. The anorthosite (no. 18192a). 30 ×, +nic. Mechanically deformed grains of plagioclase and smaller grains of hornblende. (CHR. HALKIER phot.).

## Petrography

*The Anorthosite* (nos. 18192a, b and c). The anorthosite is medium- to coarse-grained with granoblastic texture. The components are: plagioclase, hornblende, biotite, clinozoisite, chlorite, and quartz.

The plagioclase is present in irregular grains with polysynthetic twinning (many thin twin lamellae). The anorthite contents were determined by the universal stage method of REINHARD (4) and it was found, when plotting the measurements, that the poles of the composition planes and the twin axes hit the curves of REINHARD's plates 2 and 5 at both 70 and 80 % anorthite. 70 % gives twinning according to the manebach and to the complex albite-ala laws; 80 % gives albite and pericline twinning. $(\div)2V$ = about 78° and $n\beta = 1{,}573$ confirm the latter percentage, i.e. 80 %. Normal zoning is present, the lowest content of anorthite observed in the marginal zone is 70 %. The plagioclase of this anorthosite is thus more basic than normally found in large masses of anorthosite. A similar composition was found in the plagioclase of the rock described by K. ELLITSGAARD-RASMUSSEN and ME MOURITZEN (2).

The hornblende is faintly green in thin section and is present as grains with a corroded appearance in the interstices between the grains of plagioclase. It is apparently being replaced by the plagioclase and also by a brown biotite which is present in varying quantities in association with hornblende in different parts of the rock. Biotite is also found as independent, interstitial small flakes.

Clinozoisite occurs in small irregular grains very often on the borders between plagioclase and hornblende but also between the grains of plagioclase and more rarely on fractures in the plagioclase.

Small grains of quartz (with wavy extinction) and of a colourless chlorite are present in a very subordinate amount.

Ore minerals are not present.

The rock has been exposed to cataclastic deformation. The twin lamellae of the plagioclase are often bent and the plagioclase may have undulatory extinction (fig. 3). The borders of the grains may be crushed and thin cataclastic zones are present. It appears as if clinozoisite is especially formed where the margins of the plagioclases are crushed, the mineral is formed at the expense of the pulverized plagioclase (and where on the borders between plagioclase and hornblende most probably also at the expense of hornblende).

The rock is very fresh, there may be a slight clouding and an incipient formation of sericite (and possibly of scapolite) in the plagioclase.

*The Hornblendite.* The most prominent type (no. 18195a) is a coarse-grained rock made up of prismae of hornblende (which is faintly green in thin section). There is a slightly developed parallelism of the hornblende which has well-developed prismae faces.

The hornblende is intergrown by small flakes of biotite and chlorite.

In the "triangles of error" between the hornblende plagioclase occurs in somewhat turbid grains. Pericline twinning has been noted and the anorthite content is about 90 %. As secondary products clinozoisite and sericite are found (fig. 4).

Outwards this inclusion of hornblendite, which is a few metres across, becomes more and more rich in plagioclase (no. 18195b). This rock has still well-developed prismae of hornblende penetrated by biotite and corroded by plagioclase. The plagioclase is turbid and has repeated twinning (albite and pericline). An anorthite content of about 90 % was found in larger grains. Smaller grains had 55 % and inverse zonal structure with about 65 % marginally.

Small grains of clinozoisite are present especially on the borders between plagioclase and hornblende.

The rock in the diffuse zone between hornblendite and anorthosite (no. 18195c) is of the same appearance as the anorthosite described above only differing from the latter in its higher content of hornblende. Its plagioclase has an anorthite content of about 80 % (fig. 5).

Specimen no. 18194a is of a somewhat different type. When examined in the handspecimen it is a fine-grained greenish-black rock cut by surfaces of dislocation. The examination under the microscope shows that the rock has been exposed to severe cataclasis. Only a few larger grains of hornblende (of the same appearance as in no. 18195a) are preserved and they are embedded in a matrix of very small grains of hornblende. The hornblende may have irregular extinction and may be cut by crush zones made up of tiny grains of hornblende. The larger grains may in some cases show a peculiar disintegration into columns made up of numerous small grains of hornblende. In extreme cases the larger grains of hornblende are entirely crushed, but their original outlines may still be seen.

Chlorite is a rare constituent and so are a few tiny grains of ore.

No. 18194b from the same small mass of hornblendite is of a quite different appearance. It has green spots half a centimetre across in a matrix of a greenish black hornblende.

Seen under the microscope it resembles no. 18194a in being mechanically deformed, but the deformation is here more pronounced. Embedded in a matrix of small, fairly polygonal grains of hornblende, larger grains (or rather: well-defined areas made up of numerous small grains) are found. They are at high magnification seen to consist of a colourless mineral (possibly hornblende) and of ore pigmentation arranged in parallel lines (resembling the columns mentioned from 18194a). Green hornblende may be associated with these aggregates, it is especially seen in their marginal parts and it may have colourless spots and show a decrease in intensity of colour towards the aggregates.

Grains of diopside occur scattered in this rock and locally small aggregates of elongated grains of clinozoisite are seen.

A considerable amount of an almost colourless (lengthfast) chlorite is present.

As to the origin of the aggregates of colourless hornblende(?) and ore pigmentation they may be a further development of the columnar hornblende in 18194a or they may represent highly altered grains of pyroxene, diopside or, if the hornblendites are transformed ultrabasic rocks, hypersthene.

*"Metabasites"*. Nos. 18196 and 18197 are examples of the zones of amphibolite in the anorthosite.

No. 18196 has a pronounced elongation in the handspecimen. The prismae of hornblende are, as it is seen under the microscope, arranged in two directions approximately at right angles. The hornblende is strongly green. Plagioclase is found in mechanically deformed grains, it has about 45 % anorthite and has normal zonal structure with 35 % marginally. Biotite, ore, chlorite and clinozoisite are rare constituents.

No. 18197 is of a more massive appearance. Its hornblende is corroded and clinozoisite is prominent between hornblende and plagioclase. There is a good deal of biotite; and sphene is also present.

These rocks may be metamorphosed dolerites, but the question cannot be settled until more observations are available.

*The Mylonites*. The anorthosite has conformable narrow zones of a banded appearance with elongated grains of quartz and in some layers more than five centimetre large porphyroblasts of a grey perthitic microcline. These large grains alternate with fine-grained zones with thin layers of biotite. The field study leaves no doubt as to the origin of these rocks. They are recrystallized mylonites.

The rock (no. 18193) is fine-grained when seen under the microscope, but the cataclasis is less pronounced than expected from the field evidence. Recrystallization has obliterated the crushing.

The fine-grained layers consist of plagioclase (40–45 % anorthite, albite twins), quartz, microcline, and tiny flakes of biotite arranged in thin layers (together with a subordinate amount of a colourless mica). The quartz has undulatory extinction, the grains extinguish in a columnar way, the columns being parallel to the crystallographical c-axis. The microcline has small blebs of plagioclase and quartz along its margins (cf. PERRIN and ROUBAULT (e.g. 3)).

Clinozoisite is scarce, so is ore pigmentation.

There has thus been an introduction of potassium feldspar into these zones, the microcline and the quartz are the last formed minerals and the plagioclase has here a composition which corresponds better with the amphibolite facies conditions than the bytownite of the anorthosite. This granitization has healed the crushed zones.

*The Hypersthene Gneiss* (no. 18171). This sample was collected about one kilometre to the east of the anorthosite in one of the small areas of granulite facies gneiss.

The rock is coarse-grained, rusty-coloured and of a very massive appearance in the handspecimen. It has plagioclase, hypersthene and hornblende as main constituents.

Fig. 4. The central part of hornblendite (no. 18195a). 30 ×, 1 nic. Plagioclase between prismae of hornblende. Small grains of clinozoisite along the boundary of the plagioclase. A few flakes of biotite. (Chr. Halkier phot.).

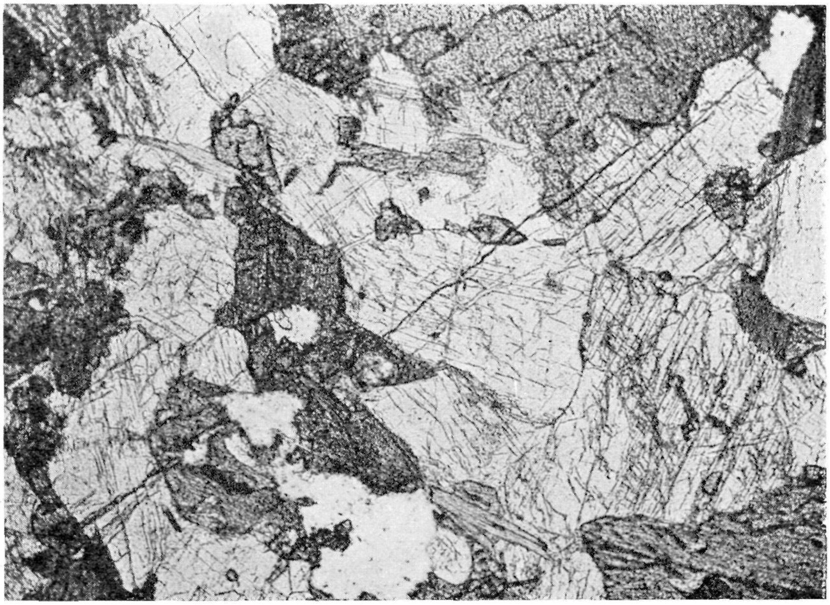

Fig. 5. Marginal part of hornblendite (no. 18195c). 30 ×, 1 nic. Corroded grains of hornblende in a matrix of plagioclase. In centre: small grains of clinozoisite between grains of plagioclase. A few flakes of biotite. (Chr. Halkier phot.).

Under the microscope it is seen that the hypersthene is uralitized and also transformed into chlorite. Hornblende is present in prismatic grains which may have inclusions of hypersthene. The remaining dark minerals are biotite and a few grains of diopside.

The plagioclase is slightly antiperthitic and it is the most prominent salic mineral. Quartz is present in a subordinate amount.

The rock is a dioritic enderbite.

## Discussion

No lengthy discussion can be based on the cursory field work in Buksefiorden, but this paper has been written in the hope that the information obtained there, summarized in the following 8 points, nevertheless may prove to be of some use for future work on the anorthosite problem.

1) The anorthosite is found in an area metamorphosed under amphibolite facies conditions, but with relics of rocks formed under granulite facies conditions, thus, there appears to be a relationship between hypersthene-carrying gneisses and anorthosite also at this place (cf. for instance the South Norwegian anorthosites). The anorthosite described by K. Ellitsgaard-Rasmussen and Me Mouritzen (2) is situated in an amphibolite facies complex on the border between the southern Kangamiut complex (composed of granulite facies gneisses which are cut by dykes of dolerite) and the northern Nagssugtoqidian complex which was formed in a younger orogenesis than the Kangamiut complex. The northern complex is composed of amphibolite facies gneisses, but since the dykes from the southern complex also are present there (strongly metamorphosed), it is reasonable to assume that there may well have been an association between the granulite facies rocks and the anorthosite and that the latter has survived the Nagssugtoqidian orogenesis.

At Tovqussaq and at Fiskernæsset there is also an association between granulite facies and anorthosite, but no such relationship has been seen in the Godthaab Fiord or in Ameralik. To this it should be added that the Buksefiorden area tectonically belongs to the same complex as the Godthaab-Ameralik region and that only modest remnants of granulite facies rocks are preserved in Buksefiorden; all such remnants may have disappeared from the first-named region.

2) The plagioclase of the anorthosite at Buksefiorden is more basic than is normal for large pre-Cambrian masses of anorthosite (cf. Turner and Verhoogen, 7, page 252).

3) The anorthosites of the region in question are folded in conformity with the gneisses and they are associated with para-gneisses: amphibolite (with skarn) and mica-schists. They may thus be of sedimentary (calcareous?) origin and may have been formed in a period where these sediments were exposed to granulite facies conditions.

4) The mylonites in the anorthosite recrystallized (were granitized) with the formation of quartz, microcline and andesine. The composition of the plagioclase, in connection with the limited amount of epidote minerals in the mylonite, show that this recrystallization took place under amphibolite facies conditions. (At other places in the area there is a good

deal of epidote on the zones of crushing, but there are no doubt several periods of crushing and recrystallization).

5) The presence of clinozoisite in the anorthosite should be seen in the light of the above-mentioned points. The anorthosite was formed at such a high pressure and temperature that a bytownitic plagioclase was formed. This feldspar was no longer stable when exposed to metamorphism of lower grade. A more sodic plagioclase was formed with the simultaneous appearance of clinozoisite and quartz. In this connection it should be emphasized that the plagioclase of the anorthosite has normal zonal structure and that the stable plagioclase of the mylonite has 45 % anorthite. That the bytownitic plagioclase has been able to survive is most probably due to the fact that an insufficent amount of "dissolved ions" has been available in the examined interior parts of the anorthosite (cf. ROSENQVIST, 5, page 59). The transformation has most probably progressed further along the borders of the layer which were not examined.

As to the presence of epidote in an amphibolite facies rock it is worth noting α) that it is especially developed on the borders between plagioclase and hornblende (cf. ROSENQVIST, op.cit, page 60: the stability region of epidote depends not only on pressure and temperature, but also upon the $Al/Fe^{\cdots}$ ratio); β) the epidote mineral is only found along the boundaries of the plagioclase in places where cataclasis has pulverized the latter, and more rarely on the cleavages of the plagioclase. This shows that the transport of material is most pronounced in the "intergranular film" and it may further indicate that the formation of epidote took place in a late stage of the metamorphism.

6) The origin of the hornblendites is still uncertain. They may represent altered masses (or layers) of skarn or ultrabasic rocks. These rocks (or possibly also the hornblendites) may have been formed through metamorphic differentiation when the anorthosite came into existence (cf. point 3) above). The hornblendites are in any case subject to dissolution in the anorthosite during the formation of dioritic rocks.

7) As mentioned in point 3) the anorthosite is folded with the surrounding gneisses forming a syncline in the latter. The same is the case for the anorthosites to the north in the Godthaab and Ameralik Fiords and to the south at Færingehavn and Fiskernæsset. The field work is not yet so advanced that it can be decided whether there is one continuous layer or not.

8) Anorthosite has so far only been noted in a few regions in West Greenland and the known occurrences are of the type described in this paper. Another rock, the white "granulite" is very common in the granulite facies areas. It is made up of antiperthite, elongated grains of quartz, mesoperthite (or microcline), garnet and often biotite. Mr. KNUT S. HEIER has in Southern Norway demonstrated that rocks resembling the Greenlandish granulites may be interpreted as having been formed at the expense of anorthosites (personal communication). A similar relationship may be the case in Greenland.

## ACKNOWLEDGEMENTS

The anorthosite described in this paper was visited during the G.G.U. expedition to West Greenland in 1953. I wish to express my gratitude to Mr. A. BERTHELSEN, mag. scient. and to Mr. H. MICHEELSEN for good companionship in the field and for the discussions in the laboratory.

Thanks are also due to Professor A. NOE-NYGAARD for the excellent working facilities in the Mineralogical Museum of Copenhagen, to Mr. K. HEIER, cand. real., Oslo, for valuable discussions, to Mr. C. HALKIER, Konservator at the Mineralogical Museum for preparing the photographs for the publication, to Miss RAGNA HANSEN for drawing the map and to Mr. P. PADGET, M.Sc. for kindly correcting the English of the manuscript.

*The map. (fig. 1) is based on the topographical maps of the Geodetic Institute, Copenhagen.*

## DANSK RESUME

*I sommeren 1953 blev en ny forekomst af anorthosit fundet i Vestgrønland, nemlig* i Buksefjorden. Denne forekomst hører sikkert til det anorthositførende komplex, som Dr. H. RAMBERG i 1951 undersøgte i Godthaab Fjord og i Ameralik, der jo ligger umiddelbart nord for Buksefjorden. Bjergarten består af bytownit, hornblende, biotit og lidt clinozoisit og ligner den bjergart, som tidligere er blevet beskrevet af K. ELLITSGAARD-RASMUSSEN og ME MOURITZEN (2).

Anorthositen har delvis opløste indeslutninger af hornblendit og har desuden lag og fragmenter af amfibolit. Den er foldet i en synklinal sammen med de over- og underliggende paragnejser (amfibolit og glimmerskifer).

Området er metamorfoseret under amfibolit facies betingelser; men i begrænsede *små områder findes hist og her granulitfacies gnejser, der forekommer på en sådan* måde, at man må gå ud fra, at hele området tidligere har været metamorfoseret under granulitfacies betingelser.

Alle bjergarter gennemskæres af mylonitzoner.

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