GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 46

ON THE STRUCTURE AND PETROGRAPHY OF THE IPERNAT DOME, WESTERN GREENLAND

BY

RAIMO LAUERMA

WITH 36 FIGURES AND 7 TABLES IN TEXT
AND 6 PLATES

Academical dissertation
presented at the University of Helsinki

Reprinted from
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ABSTRACT

A well exposed area with a Precambrian gneiss dome was investigated. Photogeological methods were used to a great extent; the aerial photographs are reproduced and a geological map, scale 1:75 000, is presented.

The folding appears to be rather gentle. For the greatest part the rocks crystallized under the conditions of hornblende-granulite subfacies. Subsequently, a large proportion of them metamorphosed retrogressively.

Chemical analyses of three granodioritic and quartz dioritic rocks and one garnet are presented. Refraction indices and unit cell dimensions of three garnets, optical properties of some pyroxenes and triclinicity values of some potash feldspars are given. Twenty determinations of the sodium and potassium content of representative samples indicate that potassium is not concentrated in the gneiss core of the dome.

ACKNOWLEDGMENTS

My first information about the gneiss dome that is the subject of this paper came from Mr. K. Ellitsgaard-Rasmussen, who is at present Director of the Geological Survey of Greenland. It was while I was a member of an expedition that carried out geological investigations under his direction in the Precambrian area of West Greenland in the summer of 1952. I asked to be assigned the geological investigation of the dome and its surroundings, and I received the assignment the following year. The executive staff and other personnel of the Geological Survey of Greenland have also endeavored to arrange the best possible facilities for field work and follow-up research. I wish to extend particular thanks to Mr. K. Ellitsgaard-Rasmussen and Prof. A. Noe-Nygaard for their encouraging attitude toward this study.

The field investigations were carried out in the summers of 1953, 1954 and 1958. During the first two summers the work was done in conjunction with the reconnaissance mapping of the Precambrian area of West Greenland. In 1953 the expedition was headed by Mr. H. Sørensen and in 1954 by Mr. A. Berthelsen (both now professors). It pleases me to acknowledge their help in, for example, organizing my field investigations.

During the course of the field work, I was assisted by a number of people: in June 1953 by Mr. N. Henriksen and in July of the same year by Mr. E. Bondesen, who lent me a hand the following summer as well; then, for a short time, in August 1954 by Mr. Adam Dahl, a Greenlander from Itivleq. During the entire five-weeks' expedition in the summer of 1958, I had the assistance of a pair of Greenland seminar students, Ilanguaq Jensen from Thule and Samuel Kleinschmidt from Godthaab. To all the persons mentioned I wish to express my heartfelt gratitude for their valuable support and good companionship under conditions that were sometimes not quite enjoyable.

The laboratory work was done for the most part in 1955—56 at the Geological Institute of the University of Helsinki and in 1959—63 at the Geological Survey of Finland. For placing the facilities of these establishments at my disposal I wish to thank Professor M. Saksela, head of the former institute; Professor A. Laitakari, ex-director, and Professor V. Marmo, present director of the Geological Survey; Professor A. Kahma, chief of the Ore Department, and Professor A. Simonen, chief of the Petrological Department of the Survey.

When I presented a portion of my research results at the University of Helsinki for my degrees of Mag. Phil. and Lic. Phil. in 1955 and 1956, Professors M. Saksela and J. Seitsaari read my papers and offered valuable criticism. Dr. M. Härme read the manuscript of the present study and Dr. M. Okko scrutinized it, mainly from the formal point of view; both of them made valuable suggestions.

Dr. H. B. Wiik made the chemical analyses. Dr. K. Hytönen carried out many of the mineralogical determinations. Mr. L. Hyvärinen, Mag. Phil., made the ore-microscopical investigations. Mr. I. Rajala and Mr. A. Nurmi, Mag. Phil., prepared the mosaic of aerial photographs. Mr. E. Halme took the photomicrographs and Miss Karin Dahl drew the appended maps. Mr. Paul Sjöblom, M. A., translated the greatest part of the manuscript from the Finnish. Mr. T. C. R. Pulvertaft made some linguistic corrections. It gives me pleasure to acknowledge my appreciation to all these persons.

The Geodetic Institute, Copenhagen, kindly gave its permission to publish the appended aerial photographs.

At various stages of my work, I received financial aid from the University of Helsinki, the Outokumpu Foundation (Outokumpu Oy:n Säätiö) and the Cultural Foundation of Finland (Suomen Kulttuurirahasto), and for this I wish to express my gratitude.

Finally, I want to record my particular debt to Professor E. Wegmann, who during my visits — totalling three months — in 1957 and 1961 — to Neuchâtel, Switzerland, spared neither time nor effort in teaching me his methods of tectonic analysis.

Helsinki, April, 1964.

Raimo Lauerma

INTRODUCTION

When the Grønlands Geologiske Undersøgelse (Geological Survey of Greenland, abbr. GGU) started its investigations in western Greenland in 1946, one of its goals was to carry out in ten years a preliminary survey, mapping included, of the exposed coastal area situated between latitudes 61° and 69°N (Fig. 1). Roughly 1 000 km long and between 50 km and 150 km broad, this area is bare of ice and snow in the summertime. It is mountainous and very difficult to travel in, but it is broken up by scores of great fjords, which with their numerous branches and bays offer the investigator revealing geological profiles. The longest of the fjords are from 100 km to 150 km long. In view of the time reserved for the preliminary investigations, the limited possibilities of the expeditions, made up as they were of only a few geologists and students of geology, and the vast extent of the region as well as the difficult terrain, it was necessary to concentrate the investigations during the ten-year period almost wholly on the shores of the fjords and islands. It was only by photogeological methods in the main that data could be obtained from the areas, many of them stretching from 20 km to 40 km in breadth, which lie between the fjords. Any geological map drawn on the basis of such observation material can give at best only a very limited picture of the geology of such an area — predominantly comprising in this case migmatic rocks. Consequently, in addition to the reconnaissance mapping, a few suitable, smallish areas were investigated in fair detail in order to obtain a better view of the geology of the region as a whole. One sample area of this kind selected by GGU was the vicinity of the gneiss dome called Ipernat dome in the present paper.

This dome structure was first observed by H. Sørensen in 1950 while examining aerial photographs of the Godthaab district for geological reconnaissance mapping. These photographs, which are reproduced in Plates IV and V, clearly reveal a ring shaped structure. The area of the dome itself had most probably not been visited by any geologist before the present author started his investigations there in the spring of 1953. On the shore of Godthaabsfjord, near the dome, however, some geologists had done research work in connection with geological reconnaissance mapping.

The name »Ipernat dome» cropped up spontaneously during the field work carried out in the summer of 1953, when it was observed that it is situated in a boggy and sheltered tundra area, which breeds mosquitoes in extraordinary abundance (mosquito in Greenlandic = »ipernaq», plural »ipernat»). The name was originally intended only to serve temporarily in the field, but since not a single place name is known to exist in the area of the dome, it has remained in regular use. Ipernat dome refers only to the geological structure in question and thus does not represent any actual geographical place name.

The structure and genesis of different types of domes have long been the subject of numerous studies and discussions. The bedrock in large areas of Greenland is exceedingly well exposed. And when the present investigation was started, it was therefore known that this circumstance would make it possible to map and investigate the structure of this gneiss dome with considerable accuracy. Only in the light of detailed investigations of many examples can a reliable picture of the mode of origin of different kinds of domes be formed.

SITUATION AND OUTLINE OF GEOLOGY

Geographically, the situation of the area investigated is between Fiskefjord and the northernmost branch of the Godthaabsfjord, Qugssug, or between latitudes 64° 35′N and 64° 55′N and longitudes 51° 15′W and 51° 35′W. The site lies some 60 km northeast of the capital of Greenland, Godthaab, and roughly 80 km west of the western margin of the Inland ice. The area surveyed and mapped covers some 300 sq. km and its location is marked in Fig. 1.

When the GGU started its investigation in West Greenland in 1946, scarcely anything more was known about the geology of the region between the 61st and 69th parallels — where the Ipernat dome is situated — than that the rocks were principally migmatic, and probably belonged to the Precambrian. The southernmost part of Greenland — the part south of latitude 61°N — was geologically much better known. Wegmann (1938), for example, had published a masterly study on the geological structure of southern Greenland, with special attention given to the age relations of the rocks. To the Precambrian orogeny described in this work, he gave the name »Ketilidian».

During the early stages of the field explorations carried out by GGU in 1946—47, conclusive evidence was discovered in the vicinity of Søndre Strømfjord, situated between latitudes 66° and 67° N, of the existence of two Precambrian orogenies of different ages (Ramberg 1948a, Noe-Nygaard 1952). The younger orogeny, extending from around Søndre Strømfjord northwards at least as far as Jacobshavn (latitude 69°N), was named by Ramberg (1948a) the »Nagssugtoqidian».

The region between the 61st and 66th latitudes, or between the area of the Ketilides studied by Wegmann (1938) and the area of the Nagssugtoqides, is referred to by Noe-Nygaard and Ramberg (1960) simply as the pre-Nagssugtoqidian fold belt. The region is generally regarded as belonging to the Ketilides, but this view has not yet been proved.

The pre-Nagssugtoqidian rocks have been divided into several complexes, each showing specific structural characteristics. (Berthelsen, 1957, 1961; Noe-Nygaard and Ramberg, 1960). The area of the present study is situated in the eastern part of the Nordland Complex, near the boundary of the Godthaab Complex. Berthelsen (1957, p. 176) has drawn the Nordland Complex as covering an area of approximately 5 000 sq. km. However, the eastern and northern boundaries of the complex are very imperfectly known.

It is only in the last few years that reliable age determinations based on radioactive disintegration have been published from the Precambrian rocks of West Greenland. According to Moorbath, Webster and Morgan (1960) the Rb-Sr date for the biotite contained in the Julianehaab granite is 1590×10^6 years and the K-Ar date for the same biotite 1597×10^6 years. The emplacement of the Julianehaab granite occurred during the late stages of the Ketilidian orogeny (Wegmann, 1938), and these age determinations thus give a fairly reliable minimum age for the orogeny. On geological grounds Wegmann (op.cit. p. 132) expounded the conception that the Ketilides probably belong to a middle Precambrian cycle.

Recently, Armstrong (1963) has published K-Ar dates for two biotites and one feldspar from the Precambrian of West Greenland. Biotite from the granodioritic gneiss at the northeast end of Søndre Strømfjord gave 1650×10^6 years as a minimum age for the Nagssugtoqidian fold belt. A date of 2700×10^6 years was obtained for the biotite from a granodioritic gneiss at Godthaab in the pre-Nagssugtoqidian fold belt. The place where the latter sample was taken belongs to the Godthaab Complex and it is situated about 60 km southwest of the area of the present investigation.

According to the studies so far made, the part of the western coast of Greenland between the 61st and 69th parallels N lat. consists mainly of migmatic rocks. The most common rocks are granodioritic to quartz dioritic gneisses, hypersthene gneisses, various amphibolites and hornblende gneisses. To a considerably lesser extent there occur sillimanite-, garnet-, cordierite-, graphite- or pyrite-bearing gneisses and schists as well as skarn-bearing rocks. Ultrabasic rocks are not uncommon and generally there is quite an abundance of basic dikes. The intensity of the regional metamorphism varies from granulite facies to amphibolite and epidote-amphibolite facies, according to the mineral facies classification of Eskola (1939).

A geological reconnaissance map on a scale of 1: 500 000 of the region between the latitudes 69°N and 63° 45'N, or between Jacobshavn Isfjord in the north and Buksefjord in the south, was published by Noe-Nygaard and Ramberg (1960). This map covers the area of the Nagssugtoqidian fold belt studied so far and the northern part of the pre-Nagssugtoqidian fold belt. Together with its explanatory text this map gives a fairly good idea of what is nowadays known of the geology of this region, in which the area dealt with in the present study is situated.

The Ipernat dome consists of the central gneiss and several concentric rings. The two most conspicuous rings both in the field and in the aerial

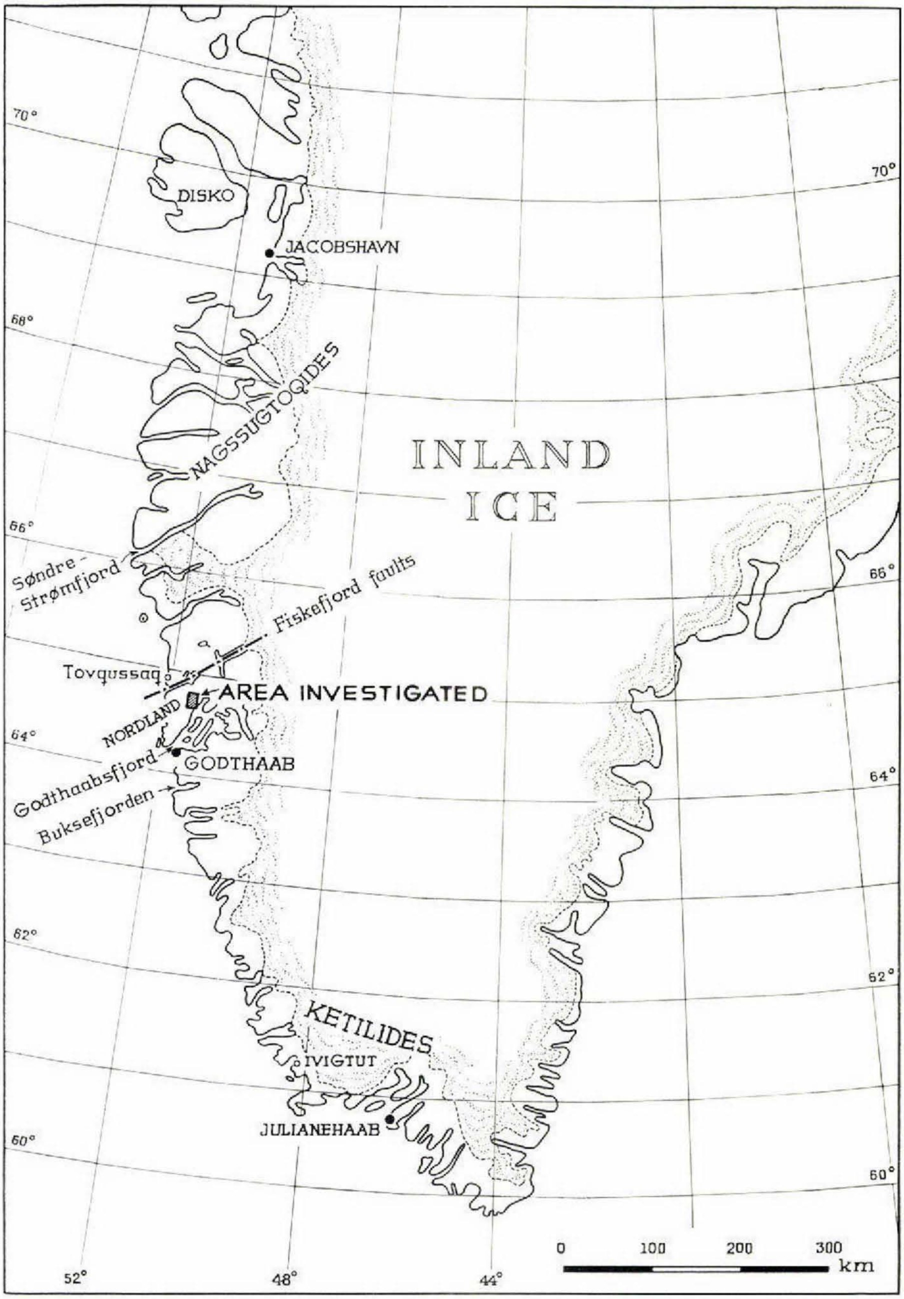

Fig. 1. Location of area investigated in western Greenland.

photographs consist in the main of amphibolite. The outer ring extends across a relatively broad area in the northern, western and southwestern parts of the dome, reaching a breadth of as much as a couple of kilometers, wheareas in the eastern part it is only between 200 and 400 meters wide. The inner amphibolite ring, which varies from 200 to 300 meters in width, conformably surrounds the homogeneous gneiss massif comprising the entire center of the dome. The area between these two amphibolite rings, measuring between one and two km in width, varies petrographically: it contains, for example, granodioritic and quartz dioritic gneisses, hypersthene gneisses and minor amphibolite zones. The area covered by the dome structure is some 9 km long and 6 km wide. The longest diameter runs approximately N—S. The shape of the outer amphibolite ring may be described as a deformed ellipse, the southeastern part of which has been flattened.

The center of the dome consists of a granodioritic to quartz dioritic gneiss massif, the length of which on the present erosion surface is about 2 km and the maximum width 1.2 km. The form of this central gneiss and the inner amphibolite ring enclosing it is a fairly regular ellipse.

The rocks of the surrounding country are largely the same as those of the area of the dome itself, namely, quartz dioritic and granodioritic gneisses, hypersthene gneisses, pyroxene amphibolites, amphibolites and hornblende gneisses. Present are also ultrabasic rocks as well as diabase and pegmatite dikes. In one place north of the dome, there occurs a layer of garnet-cordierite gneiss about 50 meters thick.

The surroundings of the dome, with the exception of the area to the east, are noticeably more complex in structure than the dome itself. Investigation has brought to light numerous large folds, some of which are between 0.5 km and 2 km in breadth. Many of them can be clearly distinguished in aerial photographs even without a stereoscope. Their situation, form and size are best observed from the geological map and the appended aerial photographs.

PHYSIOGRAPHY

Topographically, the area of the dome and its immediate extension eastward and northeastward is exceptionally level and low-lying compared to the surrounding country and to western Greenland as a whole. The highest points in the area of the dome are in its northeastern part, rising to altitudes of between 100 and 190 meters above sea level. Particularly the southern half of the dome, with the exception of the amphibolite zones, is very level (Fig. 2).

At distances of ten to twenty kilometers toward the southwest, west, north and northeast of the dome, the terrain generally rises to elevations of 300 to 700 meters; but even the highest summits are rounded. The tract situated to the southeast of the area of the investigation, on the southern and southeastern side of the northernmost branch of Godthaabsfjord, differs sharply from the topography just described. On the islands of Godthaabsfjord and to the southeast of them, there rise steep-walled, in many cases pinnacled mountains, which generally reach altitudes of between 1 000 and 1 600 meters; and the district is one of the most elevated in all of western Greenland. This sharp topographical difference between two neighboring tracts has long commanded the interest of researchers (Bøggild 1917, pp. 2 and 25).

The topography of the area investigated reflects amazingly faithfully the local geological structures and also changes in the composition of the rock. The resistance of different rocks to erosion has differed, and in many cases it has been nearly as selective as, for instance, the polishing hardness utilized in ore microscopy as a method of identification. The amphibolite zones occur as ridges, which rise distinctly higher than the granodioritic and quartz dioritic gneisses surrounding them. The height of these ridges above the surrounding terrain varies considerably and seems to depend on, among other things, the breadth of the amphibolite zone. In most cases it is in the order of one to twenty meters but rises in some cases to a height of about thirty meters in otherwise level stretches.

A good example of the foregoing is the eastern and southeastern portion of the dome's outer amphibolite ring. In the eastern part of the ring the

Fig. 2. View over southern part of dome towards south. Rounded hills in background are situated between dome and Godthaabsfjord and snow-covered mountains on islands of Godthaabsfjord.

rock consists of pyroxene amphibolite and in this area the zone forms a ridge about 250 meters wide which rises some 20 to 30 meters above the rather flat surroundings of migmatic rock. The slopes of the ridge follow the contact between the amphibolite and granodioritic or quartz dioritic gneiss mostly within 20 to 40 m. As the amphibolite zone proceeds southward, more siliceous portions appear in it in increasing measure. No sharp contacts between them and the amphibolite have been observed; in lieu of them there are gradual transitional zones. As the composition of the zone becomes more quartz dioritic, the height of the ridge also diminishes. In the southeastern part of the ring, where the composition of the zone and the surrounding rock is almost the same, the zone scarcely rises above the rest of the terrain.

In odd contrast, as it first seems, to the topographic mode of occurrence of the amphibolite zones is their very strong tendency to disintegrate under present conditions. In many places the amphibolites have disintegrated into debris to depths of 20 cm to 50 cm or perhaps more (Fig. 3), which makes the obtaining of fresh rock specimens at times troublesome. The granodioritic and quartz dioritic gneisses situated in the immediate proximity of the strongly weathered amphibolites have, on the other hand, scarcely undergone similar disintegration. However, in some instances, especially in low-lying and boggy places, these gneisses have broken up into large sharp-edged blocks.

The reasons for the varying mode of topographic occurrence of the rocks in the area just described have not been throughly clarified in connection with the present study. The observations with reference to it were made principally in an area where the elevation above sea level is less than 200 meters and where the relief usually amounts to only a few dozen meters.

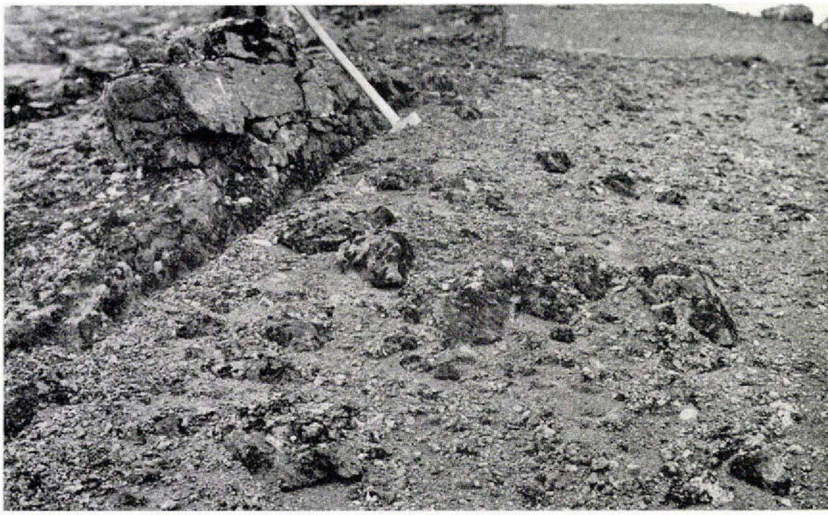

Fig. 3. Debris in situ, formed by disintegration of amphibolite layer. More resistant bed at hammer. Southern part of Quagssugtarssuaq. Altitude about 250 m.

The most plausible explanation is to be found in the difference between the amphibolites and the granodioritic and quartz dioritic gneisses with respect to their resistance to glacial erosion. The granodioritic and quartz dioritic rocks split and crack fairly easily into large, sharp-edged blocks, and these the glacier was able to break loose and carry away much easier than in the case of the tougher amphibolite.

The dome is situated in a fairly sheltered area in the interior and most of it and its surroundings are less than 100 meters above sea level. Accordingly, the local vegetation is rather abundant compared to the coast and higher regions. Lichen, moss and shrubs are a common occurrence in the area, while bushes between 0.5 m and 1 m in height also grow in the most protected places. Compared to the ideal conditions prevailing on the shores of the fjords and islands as well as in the regions situated at altitudes of more than 500 or 600 meters, the quality of the exposures is much inferior and less suitable for detailed petrological investigations.

On the other hand, the density of exposures in the area under investigation is quite sufficient for much more detailed geological mapping than it has until now been feasible to carry out. Large areas are wholly exposed and the distances between outcrops are at most a few dozen meters. There are hardly any glacial deposits in the area and the debris is also predominantly in situ. In applying photogeological methods one will observe that the local vegetation tends to clarify rather than conceal the lithological variations of the rocks. In aerial photographs taken during the summer

(Plate IV) the rock zones consisting of dark amphibolites appear distinctly paler than the light granodioritic and quartz dioritic gneisses surrounding them. This phenomenon is due to the various lichen and moss vegetation, following as it does with astonishing exactness the different rocks. The vegetation boundaries visible in the aerial photographs follow the contacts of the amphibolite zones in many cases within 5 to 10 meters.

Considering the local circumstances, it is not difficult to propose plausible explanations as to the reasons for this correlation between geology and vegetation. The amphibolites rise topographically higher, weather much more easily and afford plant life different moisture and pH conditions and chemically a different kind of ground to grow on than granodioritic and quartz dioritic gneisses.

The correlation between the rocks and the vegetation has been perceived and it has been utilized in the geological mapping only in the area of the dome itself and on its eastern and southeastern sides, or, in other words, where the vegetation is relatively rich and where aerial photographs have been taken during the summer.

MAPPING METHODS

The map material available for the present study has included the topographic map of the Danish Geodetic Institute on a scale of 1: 200 000, contact prints of aerial photographs on a scale of 1: 40 000, and a sketch map on a scale of 1: 40 000 drawn according to the aerial photographs. In 1954 topographic maps on a scale of 1: 50 000, which had just been completed, were also obtained.

In simplifying the latter maps for the geological map, over 200 smaller lakes and ponds have been left out of the map for sake of clarity. During field investigations they have been of great value in the precise location of observation sites.

The field work was conducted from camps located in different parts of the area in the summers of 1953, 1954, and 1958. The field observations in the largest part of the region were made by the present author. E. Bondesen in the summer of 1954 mapped a part of the area north of the dome. Some details of the geological map in the vicinity of the small inlet Kikiagdlit on the shore of Godthaabsfjord are drawn according to a sketch map made by H. Sørensen.

Two different methods have chiefly been used in investigating the geological structure of the dome and its surroundings. The one is the photogeological method and the other is based on tracing suitable rock zones in the field step by step.

The dome was discovered by examining aerial photographs, which have also greatly facilitated structural investigations. The geological structure of the region was analyzed in a preliminary manner before field investigations were undertaken by means of a stereoscopic study of the aerial photographs, and these pictures have been used at various subsequent stages of mapping. During the field work, moreover, they have proved exceedingly useful. Structural features, such as the strike of the bedding or foliation, the position of contacts, folds and faults, are often revealed by aerial photographs in considerable detail, even without a stereoscope, and it has been possible the whole time to compare them with the results obtained through field observations. It has thereby been possible to concentrate the field investigations directly on the structural keypoints.

The strike of the rock zones generally appears in aerial photographs as a banded pattern. The reason for this pattern can usually be traced to many factors of secondary character, the analysis of which is not always by any means easy.

One cause is the occurrence of two distinct joint sets in the stratified and foliated rocks. One joint set runs parallel to the bedding or foliation. The strike of the other joint set is parallel to the strike of the bedding or foliation, but its dip is roughly perpendicular to the dip of the bedding or foliation. The snow and moisture collecting in the stepped furrows produced by these two joint sets, the frequently richer vegetation in them, their tonal and textural relations, and other such factors enhance the banded pattern running parallel to the bedding or foliation of the rock. The joint sets cutting across the stratification perpendicularly or obliquely do not have the same effect in this respect because they are less regular and they lack the corresponding continuity.

The morphological features caused by selective erosion have been described already including the occurrence of amphibolite zones as ridges rising mostly from one to thirty meters above the surrounding terrain. Since it is possible with a stereoscope to distinguish without difficulty on the 1: 40 000-scale aerial photographs available altitude differences of about one meter between two adjacent spots, the differences in altitude dealt with in the foregoing have been more than sufficient to enable one to trace the zones.

The correlation between the rocks and the vegetation which has similarly been elucidated previously, greatly facilitated the geological mapping of the dome itself by photogeological means.

Faults, mylonitic zones and joints are to be seen best in aerial photographs taken early in the spring (Plate V). Erosion has usually worn such places deeper than the surrounding terrain, and in thus produced, commonly rectilinear depressions and ravines the snow lies longer and accentuates their appearance in the pictures. Otherwise, pictures taken at this season serve the purposes of photogeological research much less effectively than aerial photographs taken during the summer.

Four different series of aerial photographs taken of the mapped area have been available, all of them contact prints on a scale of approximately 1: 40 000. Only one series was taken in the summertime and it starts from the northern end of the dome, then extends over it toward the south. In the photogeological sense the first pictures in this series must be judged excellent (Plate IV).

Another method in the investigation of the geological structures has been that of following suitable rock zones in the field step by step as far as possible. Usually the same zone has been followed for several kilometers, sometimes for distances of as much as 10 km to 20 km. The majority of the rock zones followed have been amphibolites or related rocks, which occur as ridges rising above the surrounding ground. This procedure of tracing of a single zone furthermore makes it possible to study systematically any evidences of petrographic changes occurring along the strike of the zone. In most cases, the tracing of rock zones in the field has amounted to checking and verifying the results achieved by photogeological means.

The lack of suitable beds with sufficiently distinctive characteristics to serve as reliable marker beds has proved a major hindrance in carrying out structural investigations. Of the three chief rock types in the region, granodioritic and quartz dioritic gneisses, hypersthene gneisses and amphibolites, none suits this purpose, for they occur in extensive areas much in the same way and seem, in addition, to grade into each other along the strike of the layers. Garnet-cordierite gneisses, which probably would have proved suitable for the purpose, were met during the course of the investigations in only one place. Sporadically, there occur in the amphibolites narrow rusty layers. They might have been of considerable help in this respect except that far more detailed field work and topographic maps would have been required.

One difficulty, too, has been the fact that no primary features have been found that could be used for the determination of the top of beds, such as cross-bedding, graded bedding or pillow structures.

PETROGRAPHIC DESCRIPTION

The following laboratory methods were used in the petrographic study of the rock specimens.

The optical properties of the pyroxenes, the amphiboles, and some of the plagioclases reported were determined by means of the Leitz universal stage.

If not otherwise stated, the composition of the plagioclase was determined by comparing some refractive index of the plagioclase with that of Canada balsam and/or determining the maximum extinction angle of albite twins in sections normal to 010.

The triclinicity values of the potash feldspar were determined by X-ray methods, described by Goldschmith and Laves (1954). The potash feldspar was separated for this purpose by means of heavy liquids. The determinations were carried out by K. Hytönen.

In most cases the modal analysis was carried out by means of the Leitz integration stage, but in some cases the point counter method was used. Each analysis is based on a single thin section. Accordingly, the results must be regarded only as semi-quantitative, particularly with respect to the rocks of coarser grain.

The specific gravity of the rocks was determined by weighing the rock samples in the air and in the water with a balance constructed specially for this purpose.

PYROXENE AMPHIBOLITES, AMPHIBOLITES AND HORNBLENDE GNEISSES

This category of rocks includes numerous fairly different rocks that have been marked on the geological map with the same green color. These rocks often occur in the same zones and also grade into one another. In the structural descriptions they have simply been lumped together as amphibolites.

It has been difficult to find an accurate and generally approved term for the rocks here designated as pyroxene amphibolites. In the light of microscopic studies, their typical mineral assemblage in the mapped area is plagioclase, green hornblende, diopside and hypersthene in varying proportions. Rocks of more or less the same description have long been the object of active investigation in many countries and they have been given many different names, such as »basic division of the charnockite series», »basic charnockites», »basic granulites», »basic pyroxene granulites», »norite granulites», and »pyroxene amphibolites». Recently, Berthelsen (1960, pp. 20—21) suggested yet another nomenclature for these rocks, designating the pyroxene-hornblende-plagioclase rocks pyribolites and the pyroxene-plagioclase rocks pyriclasites.

The term pyroxene amphibolites has been used in the present study because they grade in the region investigated into normal amphibolites, and hornblende seems to belong as an essential part of the mineral assemblage, even in rocks mainly composed of pyroxenes and plagioclase. The term is, however, less appropriate when applied to rocks with very little hornblende.

In the field the pyroxene amphibolites, amphibolites and hornblende gneisses are more or less schistose. The pyroxene amphibolites, in particular, are generally distinctly layered, with dark and light layers alternating. The thickness of the layers varies from a few millimeters to some meters, and the impression is most often gained in the field that the layering is due to the original stratification. On the other hand, in some cases, at least, the possibility of segregation banding of metamorphic origin (Turner, 1941, pp. 1—16; Billings, 1954, pp. 344—345) has to be taken into consideration. This is true notably when the thickness of the layers is to be measured only in millimeters or centimeters.

The pyroxene amphibolites often occur in layers alternating with hypersthene gneisses, and in some places they appear to grade into each other along the strike of the layers.

Lenses of ultrabasic rocks generally occur in the pyroxene amphibolites, amphibolites and hornblende gneisses, and along their contacts, especially against granodioritic and quartz dioritic rocks. They are described more in detail on page 56. Furthermore, the pyroxene amphibolites and amphibolites sporadically contain narrow rusty intercalations, which vary in thickness from a few centimeters to several meters. The rustiness on the weathered surface seems generally to be due to the presence of very slight amounts of megascopically hardly perceptible disseminated sulphide minerals. On the other hand, the weathered hypersthene-bearing rocks are also generally rusty, and this circumstance reduces the value of rusty layers as marker beds, except when they are traced step by step.

In a few places, such as on the eastern shore of the small inlet of Kikiagdlit, small calcite lenses between five and thirty centimeters in diameter have been found in the amphibolite. Skarn lenses of the same size are a fairly common occurrence in the amphibolites.

Of the typical rock samples collected during the field investigations, some fifty were classified as various amphibolites and hornblende gneisses. Nearly forty thin sections were prepared from these samples, a few of which were seen under the microscope to be hypersthene gneiss. After a study of the thin sections, those specimens best representing the petrography of the amphibolites and hornblende gneisses of region as a whole were selected, and they are described in the following. The refractive indices, optic axial angles and extinction angles ($c \wedge \gamma$) reported here were determined by K. Hytönen and the ore microscopical investigations were carried out by L. Hyvärinen. The specimen numbers refer to the collection of the Geological Survey of Greenland.

Pyroxene amphibolite. Specimen No. 14 511. Locality 1 (Plate I), eastern part of the outer amphibolite ring.

The rock is distinctly layered. Dark and light layers a few dozen centimeters thick alternate in it. The specimen here described represents a dark layer. The color of the rock is a dark gray with a faint greenish tinge. Both megascopically and microscopically the rock is clearly schistose. The grain size varies from 0.5 mm to 2 mm. The texture is nematoblastic, almost granoblastic (Fig. 4). The specific gravity is 3.07.

The chief constituents are plagioclase, green hornblende, clinopyroxene and orthopyroxene. In addition, there is a small amount of opaque material, which appears to be for the greatest part limonite. Under the ore microscope a few very small grains of pyrite and pyrrhotite were discovered. The modal analysis is presented in Table I on p. 28.

The plagioclase is mostly polysynthetically twinned. It is clear and lacking in alteration products. It is somewhat zoned in that the centers of the grains are more basic than the marginal portions. Its α varies 1.563 — 1.567 and its β 1.568 — 1.571, which corresponds to An_{68}—An_{75} (Deer et al. Vol. 4, p. 131)

The hornblende is pleochroic from yellowish green to green. Its $2V\alpha = 76°$ and $c \wedge \gamma = 16°$.

The clinopyroxene is almost colorless, being faintly greenish. Its $2V\gamma = 58°$, $c \wedge \gamma = 45° — 47°$, $\alpha \sim 1.690$ and $\gamma \sim 1.720$. Refractive indices were not determined from the same grains as other optical properties. If a mineral of the pure diopside-hedenbergite series is involved, the refractive indices correspond to about 35—40 mol. % hedenbergite (Deer et al. Vol. 2, p. 62).

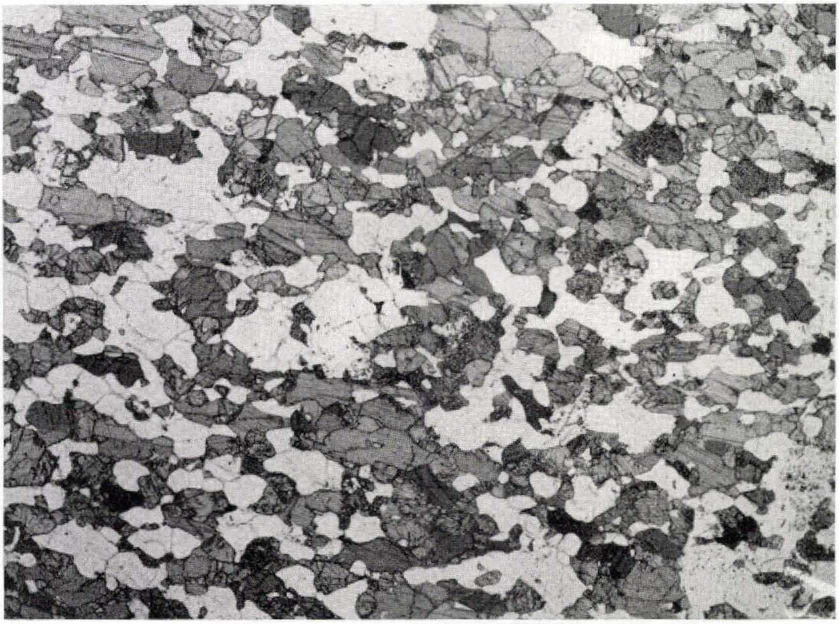

Fig. 4. Texture of pyroxene amphibolite. Specimen No. 14 511. One nicol. Magn. 9 x. White grains are plagioclase and darker grains are hornblende and pyroxenes. Photo: E. Halme.

The orthopyroxene is distinctly pleochroic, α red, β yellow and γ grayish green. Its $2V\alpha = 59°$, $\alpha \sim 1.705$ and $\gamma \sim 1.719$. Refractive indices were determined from other grains than the optic axial angle. The γ refractive index, which according to Deer et al. (Vol. 2, p. 29) is the most accurate optical method of determining the En:Fs ratio of an orthopyroxene, corresponds to about 40—45 mol. % ferrosilite, i.e., to hypersthene.

The thin section has a couple of spots where the hornblende at least seems to contain diopside as an inclusion, and several diopside grains possess a narrow green rim, i.e., evidence of alteration into hornblende. These are, however, exceptional instances. By far the greatest portion of mineral grains are wholly lacking in inclusions and alteration products. The mineral assemblage thus appears to be in a fairly steady state of equilibrium.

Pyroxene amphibolite. Specimen No. 14 512. Locality 1 (Plate I), eastern part of the outer amphibolite ring. About 0.5 m across the strike from the spot where the preceding specimen was taken.

This specimen represents a lighter, rusty layer. Megascopically the rock is conspicuously lighter than the previous specimen and brownish gray in color. Both megascopically and microscopically it is distinctly schistose.

The grain size is 1—2 mm. The texture is nematoblastic, almost granoblastic. The specific gravity is 3.04.

The principal constituents are plagioclase, clinopyroxene, orthopyroxene, titaniferous magnetite and green hornblende. In addition, the thin section contains a trace of biotite and apatite as well as, evidently on the surfaces of other mineral grains, limonite. Under the ore microscope there were detected, in addition to ilmenite and magnetite, a few very small grains of pyrrhotite. The modal analysis is presented in Table I on p. 28.

The plagioclase is generally polysynthetically twinned. It is clear and lacking in alteration products. Its $\alpha = 1.552$ and $\gamma = 1.561$, corresponding to An_{46}—An_{48} (Deer et al. Vol. 4, p. 131).

The clinopyroxene's $2V\gamma = 55° — 58°$, $c \wedge \gamma = 43°$, $\alpha \sim 1.695$ and $\gamma \sim 1.725$. Its color is a very pale green. The refractive indices were not determined from the same grains as other optical properties. If the mineral belongs to the pure diopside-hedenbergite series, the refractive indices correspond to about 45—50 mol. % hedenbergite (Deer et al., Vol. 2, p. 62).

The orthopyroxene's $2V\alpha = 52°$, $\alpha \sim 1.715$ and $\gamma \sim 1.730$. Refractive indices were determined from other grains than the optic axial angle. The γ refractive index corresponds to 50—55 mol. % ferrosilite i.e., to ferrohypersthene (Deer et al., Vol. 2, p. 28). It is distinctly pleochroic, α red, β yellowish green and γ greenish.

The hornblende is pleochroic from yellowish green to bluish green. Its $c \wedge \gamma = 12°$. Hornblende occurs in most cases as grains measuring 0.1—0.3 mm in diameter. Some of them occur as separate independent grains, some, again, as inclusions in hypersthene or diopside. In certain cases, the hornblende is clearly enclosed by a rim of diopside, which thus appears to be younger than the hornblende. In certain other grains, on the other hand, the diopside appears to alter into hornblende.

The very slight biotite content of the rock appears to be quite secondary and consequently younger than the other minerals. It occurs in many cases in the immediate proximity of oxide ore grains.

Pyroxene amphibolite. Specimen No. 14 515. Locality 2 (Plate I), northwestern part of the outer amphibolite ring.

The rock is megascopically distinctly schistose and its color is greenish dark gray. The mafic minerals, notably hornblende, can be distinguished as grains 1—6 mm long in a somewhat finer-grained matrix containing chiefly plagioclase. The diameter of the plagioclase grains is 0.5—1 mm. The texture is nematoblastic, almost granoblastic. The specific gravity is 3.12.

The chief constituents are plagioclase, green hornblende and hypersthene. Under the ore microscope only a few, quite tiny iron sulphide grains, evidently pyrite, were found. The modal analysis is presented in Table I on p. 28. On account of the coarse grain and broken character of the specimen, this analysis is not altogether reliable and the true proportion of plagioclase is likely to exceed the result obtained.

Polysynthetic twinning is to be seen in the plagioclase faintly or not at all. Weak zoning appears in some of the grains The refraction index $\beta =$ 1.573, corresponding to An_{80} (Deer et al., Vol. 4, p. 131).

The hornblende is pleochroic from pale green to dark green. Its $2V\gamma = 88° - 90°$ and $c \wedge \gamma = 23°$.

The orthopyroxene is markedly pleochroic, α red and γ grayish green. Its $2V\alpha = 78° - 81°$, $\alpha \sim 1.692$ and $\gamma \sim 1.702$. Refractive indices were determined from other grains than the optic axial angle. The γ refractive index corresponds to hypersthene containing about 30 mol. % ferrosilite (Deer et al., Vol. 2, p. 28).

Under the microscope, the plagioclase, hornblende and hypersthene are clear and nearly totally lacking in alteration products. Only in certain slightly broken grains is a weak alteration to be detected. The rock's mineral assemblage thus appears to be wholly in equilibrium.

Pyroxene amphibolite. Specimen No. 14 524. Locality 3 (Plate I), northwestern part of the outer amphibolite ring.

Megascopically the rock appears brownish dark gray. The weathered surface is rusty brown. The schistosity is weak, hardly detectable. The grain size is 0.5—1.5 mm. The texture is nematoblastic, almost granoblastic (Fig. 5) The specific gravity is 3.14.

The principal constituents are plagioclase, clinopyroxene, orthopyroxene, titaniferous magnetite and green hornblende. In addition, there is a small amount of apatite as well as, on the surfaces of the other mineral grains, limonite. Under the ore microscope a trifle of chalcopyrite and pyrrhotite were detected. The modal analysis is presented in Table I on p. 28.

The plagioclase is polysynthetically twinned. Its $\beta = 1.559$ and $\gamma =$ 1.563, corresponding to An_{52} (Deer et al., Vol. 4, p. 131).

The clinopyroxene is very slightly pleochroic from pale green to somewhat darker green. It is slightly zoned. $2V\gamma$ varies from 52° to 64°. Its $c \wedge \gamma =$ 42° and $\gamma \sim 1.720$. In the pure diopside-hedenbergite series this refractive index corresponds to about 40 mol. % hedenbergite (Deer et al., Vol. 2, p. 62).

The orthopyroxene is weakly pleochroic, α red and γ grayish green. Its $2V\alpha = 55°$, $\alpha \sim 1.715$ and $\gamma \sim 1.730$. The latter refractive index corresponds to ferrohypersthene with 50—55 mol. % ferrosilite (Deer et al., Vol. 2, p. 28). The optic axial angle was determined from other grains than the refractive indices.

Fig. 5. Texture of pyroxene amphibolite. Specimen No. 14 524. One nicol. Magn. 8 x. White grains are plagioclase, gray grains are mainly diopside and hypersthene and black grains are magnetite. Photo: E. Halme.

The opaque ore minerals generally occur as independant grains, of which the largest are the same size as the pyroxene grains, or 0.5 mm in diameter. According to the ore-microscopic examination, they consists for the most part of pure magnetite. Many of the magnetite grains contain ilmenite lamellae. Furthermore, there are ilmenite grains with magnetite and/or spinel lamellae. In addition to the oxide ore minerals, the polished section was observed to contain several tiny grains of sulphide minerals less than 0.1 mm in diameter. They are principally chalcopyrite, but there is a very slight amount of pyrrhotite, too.

Green hornblende occurs only sporadically as small grains. Its properties are by and large the same as in the three rock samples described in the foregoing. All the silicate minerals are clear and lacking in alteration products. The mineral assemblage thus seems to be quite in equilibrium.

Amphibolite. Specimen No. 14 505. Locality 4 (Plate I), eastern part of the dome, between the inner and outer amphibolite rings.

Megascopically the rock is distinctly banded and also under the microscope it is schistose. Dark and light bands a few millimeters thick alternate in it. The cause of the banding seems mainly to be the layered occurrence of hornblende. The grain size is 1—2 mm, but the hornblende occurs also as larger grains, which reach a length of as much as 1—2 cm. The texture is nematoblastic. The specific gravity is 2.96.

The principal constituents are green hornblende, plagioclase (ca. An_{35}) and biotite. In addition, there are small amounts of chlorite, apatite, quartz and sericite as well as, according to the ore microscopical examination, ilmenite and a few tiny grains of pyrite and chalcopyrite. The ilmenite occurs mainly along the fissures of hornblende. The modal analysis is presented in Table I on p. 28.

The green hornblende is clearly in a state of alteration and in many places it is bordered by biotite. A few large hornblende grains have evidently been crushed and in them the hornblende appears to be in a state of alteration into chlorite.

In some of the plagioclase grains, polysynthetic twinning is clearly to be seen, in others faintly or not at all. The plagioclase contains a trace of sericite, but otherwise it is clear and unaltered in appearance.

Hornblende gneiss. Specimen No. 14 550. Locality 5 (Plate I), southern part of the outer amphibolite ring.

Megascopically the rock is dark gray and its schistosity is rather weak. The grain size is 1—3 mm and the texture is nematoblastic. The specific gravity is 2.81.

The principal constituents are plagioclase (ca. An_{40}), hornblende, chlorite, biotite and quartz. Accessories are the opaque minerals, apatite, zircon, sericite and epidote. The modal analysis is presented in Table I on p. 28.

Polysynthetic twinning is clearly visible in majority of the plagioclase grains. The plagioclase contains a certain amount of sericite.

Quartz occurs as xenomorphic grains and it has a distinctly undulating extinction.

The hornblende is pleochroic from yellowish green to dark green. In addition to the green hornblende, there are also amphibole varieties with a bluish green tinge that usually occur in green hornblende grains. Their birefringence is in places conspicuously low and the variety presumably represents hornblende in process of chloritization. The hornblende is obviously in a state of alteration, and the alteration product is principally biotite, though chlorite also occurs.

The mineralogical compositions of pyroxene amphibolites, amphibolites and hornblende gneisses are best grasped from Table I. Their petrographic differences are due chiefly to the fact that great portions of them have undergone strong retrogressive metamorphism. Moreover, some of the amphibolites and, in particular, hornblende gneisses seem to have also

Table I. Modal analyses of pyroxene amphibolites, amphibolites and hornblende gneisses (vol. %).

	1.	2.	3.	4.	5.	6.
Plagioclase	42.2	61.3	23.9	56.5	32.4	60.8
Hornblende	34.4	1.2	49.5	0.1	52.1	23.5
Hypersthene	8.2	11.9	26.6	16.9	0.0	0.0
Diopside	15.0	19.4	0.0	15.9	9.7	0.0
Oxide ore	0.2	6.2	present	10.6	0.2	present
Biotite	0.0	present	0.0	0.0	1.7	6.1
Quartz	0.0	0.0	0.0	0.0	1.7	5.6
Chlorite	0.0	0.0	0.0	0.0	2.2	3.3
Others	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0

1. Pyroxene amphibolite. Specimen No. 14 511. Description on p. 22.
2. Pyroxene amphibolite. Specimen No. 14 512. Description on p. 23.
3. Pyroxene amphibolite. Specimen No. 14 515. Description on p. 24.
4. Pyroxene amphibolite. Specimen No. 14 524. Description on p. 25.
5. Amphibolite. Specimen No. 14 505. Description on p. 26.
6. Hornblende gneiss. Specimen No. 14 550. Description on p. 27.

changed metasomatically. The mineral facies conditions are discussed in more detail on pp. 59—62.

The data available do not suffice to draw reliable conclusions concerning the origin of these amphibolitic rocks. The most plausible explanation is that they are of volcanic origin. The calcite lenses and skarn occurrences described on p. 22 suggest, however, that at least part of the amphibolitic rocks in the region may originally have been calcareous sediments.

HYPERSTHENE GNEISSES

Hypersthene gneisses often occur in the region investigated as intercalations in pyroxene amphibolites, but to some extent they form rather large homogeneous areas. Their quantitative share of the rocks marked in the geological map as pyroxene amphibolites, amphibolites and hornblende gneisses is rather substantial and in more detailed mapping a part of them could be drawn separately. In places the hypersthene gneisses have been observed to grade into granodioritic gneisses and, according to some field observations, they appear to grade into pyroxene amphibolites along the strike of the layers.

The most extensive uniform hypersthene gneiss area met with in the region investigated is situated between the inner and the outer amphibolite ring in the western part of the dome, and it covers roughly ten square kilometers. In its typical occurrence the hypersthene gneiss is here very homogeneous. Its foliation is weak and can hardly be detected megascopically. The color of the weathered surface of the hypersthene gneisses is a pale reddish brown. This color has proved not only in the western Greenland but also in other countries, to be a reliable indication of hypersthene gneisses. In the vicinity of the dome this color has been observed to indicate the presence of hypersthene, especially in gneisses, very reliably. In a few localities it was surmised in the field, mainly on the basis of the color nuance of the weathered surface, that certain homogeneous gneisses represent a transitional type between hypersthene gneisses and granodioritic gneisses. Microscopic examinations supported this view.

In the western part of the dome near the inner amphibolite ring, the hypersthene gneiss grades into a dark gray gneiss (Specimen No. 14 516, p. 54) resembling the central gneiss. In the area northwest of the central gneiss, there appear in the hypersthene gneiss numerous inclusions and layers of amphibolite. The hypersthene gneiss area also contains smallish areas of garnet-bearing granodioritic rocks. The contacts between them and the hypersthene gneiss seem to be gradual rather than sharp.

In the following two typical hypersthene gneiss samples and one transitional type will be described.

Hypersthene gneiss, Specimen No. 14 514. Locality 6 (Plate I), western part of the dome between the inner and outer amphibolite rings.

Megascopically the rock is brownish gray and the color of its weathered surface is reddish brown. The rock is homogeneous and its foliation is very weak. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.63.

The principal constituents are plagioclase (ca. An_{25}), microcline, quartz, biotite, hypersthene, serpentine and opaque ore minerals. In addition, there are traces of chlorite, sericite and zircon. The modal analysis is presented in Table II on p. 31. According to the chemical analysis, the rock contains 4.38 % Na_2O and 2.86 % K_2O by weight.

Polysynthetic twinning is visible in the plagioclase only faintly or not at all. The plagioclase contains very small amounts of antiperthite and sericite as inclusions. The microcline is for the most part cross-hatched, and it occurs as xenomorphic grains 0.1—0.3 mm in diameter. It commonly contains tiny plagioclase inclusions. The triclinicity of the potash feldspar is 0.9. The quartz to a certain extent exhibits an undulating extinction.

The hypersthene occurs in the thin section as grains 0.2—0.8 mm long. No crystal forms are visible and the hyperstene is obviously in a state of alteration. The principal alteration product is a brownish, fibrous substance, which for the most part appears to be serpentine. In addition, there frequently occur oxide ore, biotite and a slight amount of chlorite in the proximity of the hypersthene grains.

Hypersthene gneiss. Specimen No. 14 548. Locality 7 (Plate I), southwestern part of the dome between the inner and outer amphibolite rings.

The color of the rock is a dark, brownish gray. The weathered surface is reddish brown. The rock is megascopically even-grained and homogeneous. The foliation is very weak, hardly perceptible. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.66.

The principal constituents are plagioclase (ca. An_{25}), quartz, biotite, hypersthene, potash feldspar and oxide ore. In addition, serpentine and zircon are present in slight amounts. The modal analysis is presented in Table II.

Polysynthetic twinning is clearly visible in the plagioclase. The slight amount of potash feldspar in the rock occurs wholly as antiperthite in the plagioclase. The diameter of the hypersthene grains is 0.3—1 mm, and the hypersthene is in a state of alteration in the way described in the foregoing.

Transitional type between hypersthene gneiss and granodioritic gneiss. Specimen No. 14 549. Locality 8 (Plate I), southern part of the dome between the inner and outer amphibolite rings.

In the locality where the sample was taken, the extensive hypersthene gneiss area marked on the geological map grades according to field observations, into granodioritic and quartz dioritic gneiss. In the field this grading is to be seen by the gradual change in the color of the rock's weathered surface from reddish brown into light gray.

On the site where the sample was taken, the rock is light gray with a faint brownish tinge. The color of the weathered surface has a faint suggestion of reddish brown. The rock is very slightly foliated, even-grained and homogeneous. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.61.

The constituents of the rock are plagioclase (ca. An_{20}), microcline, quartz, biotite, oxide ore, sericite and zircon. In addition, the thin section shows a slight amount of a mineral resembling serpentine and extremely tiny particles of hypersthene 0.01—0.02 mm long. The modal analysis is presented in Table II.

Polysynthetic twinning is plainly to be seen in the plagioclase. The plagioclase contains a slight amount of potash feldspar as antiperthite. The microcline occurs for the most part as xenomorphic grains 0.3—1 mm in diameter, which in most cases are clearly cross-hatched and contain plagioclase as perthite. The triclinicity of the potash feldspar is 0.9—1.0.

Table II. Modal analyses of hypersthene gneisses (vol. %).

	1.	2.	3.
Plagioclase	51.8	79.6	54.7
Potash feldspar	17.0	1.1	20.4
Quartz	28.5	15.3	23.0
Biotite	0.9	1.8	1.0
Hypersthene	0.8	1.4	trace
Ore	0.3	0.8	0.3
Others	0.7	< 0.1	0.6
Total	100.0	100.0	100.0

1. Hypersthene gneiss. Specimen No. 14 514. Description on p. 29.
2. Hypersthene gneiss. Specimen No. 14 548. Description on p. 30.
3. Transitional type between hypersthene gneiss and granodioritic gneiss. Specimen No. 14 549. Description on p. 30.

The quartz has a faintly undulating extinction. The biotite is pleochroic from light brown to dark brown. In addition, the thin section reveals the presence of a slight amount of green biotite, which appears to represent a variety at the incipient stage of chloritization. Under the microscope it is green in color, but its birefringence is almost the same than that of the brown biotite.

In several spots in the thin section between the grains and as small aggregates, there occurs a brownish, fibrous mineral, which appears to be serpentine. Sericite also often occurs in association with it. In the middle of one such aggregate, which probably contains serpentine and sericite, tiny grains 0.01—0.02 mm long could be observed. Their refraction indices, birefringence and straight extinction correspond to those of hypersthene. All these grains have a simultaneous extinction. The evidence indicates that they are the remains of an almost totally altered hypersthene grain.

As the foregoing descriptions and Table II make clear, these hypersthene gneisses are very poor in dark minerals. In composition they vary from quartz dioritic to granodioritic. In all the cases investigated the hypersthene is more or less in a state of alteration owing to retrogressive metamorphism.

GARNET-CORDIERITE GNEISS

Garnet-cordierite gneisses have been met with in the mapped region in only one spot, which is situated at the northern edge of the geological map. Here the garnet-cordierite gneiss forms a continuous layer, the visible portion of which is approximately 1 km long. At both ends it terminates in a lake, so the true length of the layer could not be determined.

Fig. 6. View towards south over western part of inner amphibolite ring and central gneiss. Amphibolite in foreground and right of lake, central gneiss at left.

The layer is a few dozen meters thick, being about 50 m at its thickest. It has a vertical dip and on both sides there occurs amphibolite. In color the rock is brownish gray and the weathered surface is a pale rusty brown. The southern end of the layer contains very little or no garnet, whereas the northern end has an abundance of it. The occurrence of cordierite was not detected until the microscopic examination was carried out, and the few specimens do not suffice for the drawing of any significant conclusions concerning its distribution or abundance throughout the layer.

In the following a sample is described which was taken from a spot containing considerable garnet.

Garnet-cordierite gneiss. Specimen No. 14 559. From the northern part of the layer described above. Locality 9 (Plate I).

Megascopically the rock is pale rusty brown and distinctly foliated. The grain size is generally 1—2 mm. The diameter of the garnet grains varies between 1 mm and 5 mm. The texture is granoblastic. The specific gravity of the rock is 2.94.

The principal constituents are quartz, garnet, biotite, plagioclase (ca. An_{40}), cordierite and oxide ore. In addition, there is a slight amount of zircon and some micaceous mineral as an alteration product of cordierite and garnet.

Polysynthetic twinning is clearly visible in the plagioclase. The quartz has a weakly undulating extinction. The biotite is pleochroic from very

Fig. 7. View towards southeast over southwestern part of central gneiss and inner amphibolite ring. Amphibolite in foreground forming ridge about 5 m high; central gneiss at left behind lake.

pale brown to reddish brown, and there are distinct pleochroic haloes around the zircon grains contained in it.

The garnet forms xenoblasts with quartz and oxide ore inclusions. Under high magnifications it is also possible to distinguish a micaceous mineral, which is evidently a product of an incipient alteration of garnet.

The garnet's refraction index $n = 1.778$, the cell edge $a_0 = 11.518$ Å and the specific gravity 3.99 (Determinations by K. Hytönen).

Calculated according to the chemical analysis (Table IV, p. 42) the garnet contains about 40—45 mol. % pyrope, 49—54.5 mol. % almandine, 0—3 mol. % grossular, 1.5—5 mol. % andradite and 1—1.5 mol. % spessartite. This calculation of the percentages of the garnet's end-members is, however, somewhat uncertain, because the chemical analysis does not closely agree with the theoretical ratio of 3:2:3 for the $Si:R^{+3}:R^{+2}$ of the garnet group. The FeO seems to be low and the Fe_2O_3 correspondingly too high. The determination of FeO was for this reason repeated several times, but without significant differences. The Pratt method was used in all these determinations. The garnet's incipient stage of alteration described above is one possible explanation for this discrepancy.

The cordierite similarly exhibits incipient alteration, with a micaceous mineral as a product. Around the tiny zircon grains contained in the cordierite there are distinct pleochroic haloes.

This garnet-cordierite gneiss is the only rock found in the mapped region which might be interpreted as an argillaceous sediment by origin.

Fig. 8. Northernmost part of central gneiss. Contact of central gneiss and amphibolite is situated on upper slope. View towards northwest.

THE CENTRAL GNEISS

The center of the dome structure as a whole comprises a homogeneous granodioritic and quartz dioritic gneiss massif. It is approximately 2 km long and 1.2 km broad, and its shape is a fairly regular ellipse. The foliation even in the marginal parts of the central gneiss is so weak that its strike and dip are difficult to determine in places. With the exception of the jointing, no reliable tectonic observations have been obtained of the center of the gneiss. This weakness of the foliation is due, at least in part, to the paucity of mafic minerals. The structure of the central gneiss and its surroundings will be described in more detail on pp. 76—78. Figures 6 and 7 on pp. 32—33 show general views from the central gneiss.

There are relatively few exposures in the area of the central gneiss and their quality is not the best possible, either. The middle parts of the central gneiss, especially, are largely covered with vegetation and shallow lakes. The best exposed is the northernmost part of the central gneiss, which is practically a single outcrop (Fig. 8).

No inclusion or schlieren have been found in the central gneiss any more than granitic, pegmatitic or other such veins. The field observations have brought to light very little variety in the central gneiss.

In the following, typical samples taken from different parts of the central gneiss will be described.

Granodioritic rock. Specimen No. 14 501. Locality 10 (Plate I), middle of the central gneiss.

Fig. 9. Texture of granodioritic variety of central gneiss. Specimen No. 14 501. Nicols +. Magn. 11 x. Photo: E. Halme.

In the field the rock is rather homogeneous. No distinct foliation is to be seen. The rock is dark gray with a tinge of blue. The grain size is 1—2 mm. The biotite forms larger flakes and flake aggregates, the diameter of which rises in some cases as high as 5—10 mm. The texture is granoblastic, though in spots there are features that could, perhaps, be interpreted as blastohypidiomorphic (Fig. 9). The specific gravity is 2.64.

The constituents are plagioclase (ca. An_{20}), microcline, quartz, biotite and chlorite as well as oxide ore and small amounts of sericite and zircon. The modal analysis is presented in Table III on p. 40.

According to the chemical analysis, the rock contains 4.83 % Na_2O and 2.41 % K_2O by weight.

Polysynthetic twinning is clearly visible in the majority of the plagioclase grains. Many plagioclase grains contain microcline up to as much as 50 %, forming stripes. In other plagioclase grains, on the other hand, no potash feldspar is in evidence.

For the most part the microcline is cross-hatched. Partly it occurs as stripes in the plagioclase and partly as interstitial grains 0.2—0.4 mm in diameter. The interstitial microcline grains also contain tiny plagioclase inclusions. The triclinicity of the potash feldspar is 0.9.

The quartz has a distinct undulating extinction. Some of the biotite is clearly pleochroic from light brown to dark brown. A number of the biotite flakes are greenish or green and are evidently in a state of alteration into clorite.

A certain mineral aggregate appearing in the thin section is composed chiefly of chlorite and ore. Judging by the form of the aggregate, what is involved is a chloritized amphibole grain.

Quartz dioritic rock. Specimen No. 14 502. Locality 11 (Plate I), middle of the central gneiss.

According to field observations, the rock is fairly homogeneous. Its foliation is extremely weak or none is apparent. The rock is light gray with a faint violet tinge. The grain size is 1—2 mm and the texture is granoblastic (Fig. 10). The specific gravity is 2.62.

The principal constituents are plagioclase (ca. An_{20}), quartz, microline, biotite and sericite. The accessories are apatite, ore, chlorite, zircon and epidote. The modal analysis is presented in Table III on p. 40, and the chemical analysis in Table IV on p. 42.

Polysynthetic twinning is visible faintly or not at all in the plagioclase, which contains conspicuous amounts of sericite and some microcline as antiperthite.

The microcline is cross-hatched and occurs partly as antiperthite in plagioclase and partly as interstitial grains measuring 0.1—0.4 mm in diameter. The triclinicity of the potash feldspar is 0.95.

The biotite is pleochroic from light brown to dark brown. Neither greenish nor green biotite varieties are present in the thin section.

The thin section has one spot in which there is an epidote grain in the middle and chlorite around it. Possibly a chloritized amphibole grain is in question.

A number of the plagioclase grains and biotite flakes are clearly bent, suggesting movements that took place after the crystallization of these minerals.

Quartz dioritic gneiss. Specimen No. 14 506. Locality 12 (Plate I), northern part of central gneiss, about 100 m from the contact.

The color of the rock is dark gray. The foliation is so weak that its strike and dip are difficult to measure in the field. The grain size is 1—3 mm. The biotite in places forms larger flakes and flake aggregates measuring some 4—5 mm. The texture is granoblastic. The specific gravity is 2.64.

The principal constituents are plagioclase (ca. An_{20}), quartz, biotite, potash feldspar and sericite. The accessories are sphene, apatite, epidote, ore and zircon. The modal analysis is presented in Table III on p. 40.

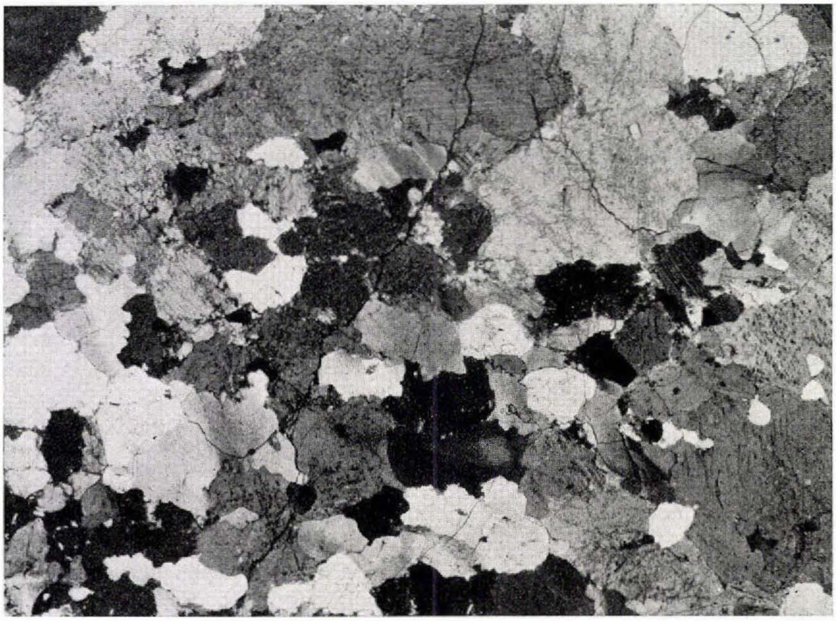

Fig. 10. Texture of quartz dioritic variety of central gneiss. Specimen No. 14 502. Nicols +. Magn. 11 x. Photo: E. Halme.

According to the chemical analysis, the rock contains 5.50 % Na_2O and 1.15 % K_2O by weight.

For the most part, polysynthetic twinning is only faintly visible in the plagioclase or not at all. The plagioclase is conspicuously sericitized and it contains a certain amount of antiperthite.

The potash feldspar occurs partly as antiperthite in the plagioclase, partly as xenomorphic grains around 0.3—0.5 mm in diameter.

Most of the biotite is pleochroic from light brown to dark brown. Some of the biotite is greenish and evidently in a state of alteration into chlorite. The quartz exhibits distinct undulating extinction.

Quartz dioritic gneiss. Specimen No. 14 507. Locality 13 (Plate I), western part of central gneiss, about 100 m from contact.

Megascopically, the rock is dark gray, and its foliation is rather weak. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.64.

The principal constituents are plagioclase (ca. An_{20}), quartz, biotite, chlorite and potash feldspar. The accessory constituents are sericite, apatite, ore, sphene and epidote. The modal analysis is given in Table III on p. 40.

According to the chemical analysis, the rock contains 5.52 % Na_2O and 0.90 % K_2O by weight.

Polysynthetic twinning is visible in the plagioclase only faintly or not at all. The plagioclase is conspicuously sericitized.

The potash feldspar occurs partly as antiperthite in the plagioclase, partly as interstitial grains 0.1—0.2 mm in diameter.

The quartz exhibits a strong undulating extinction. The biotite occurs in the thin section mostly in small aggregates. Furthermore, it is present around the ore grains. A portion of the biotite is brown and another portion greenish.

Quartz dioritic gneiss. Specimen No. 14 508. Locality 14 (Plate I), eastern part of central gneiss, about 20 m from contact.

Megascopically the rock is dark gray. Its foliation is rather weak. The grain size is 1—2 mm. The biotite occurs as slightly larger flakes and flake aggregates 4—5 mm in diameter. The texture is granoblastic. The specific gravity is 2.63.

The principal constituents are plagioclase (ca. An_{20}), quartz, potash feldspar, biotite, sericite and green hornblende. The accessories are ore, sphene, apatite and epidote. The modal analysis is given in Table III on p. 40.

According to the chemical analysis, the rock contains 5.83 % Na_2O and 0.85 % K_2O by weight.

Polysynthetic twinning is visible in the plagioclase only faintly or not at all. The plagioclase is conspicuously sericitized.

The potash feldspar occurs for the most part as antiperthite in the plagioclase. In the entire thin section there are only a few interstitial potash feldspar grains and they are 0.1—0.2 mm in diameter. The triclinicity of the potash feldspar is 0.75.

The hornblende seems to be in a state of alteration and around it there occur biotite and some epidote.

Part of the biotite is brown and part greenish. Around a few ore grains there occur leucoxene and biotite.

Granodioritic gneiss. Specimen No. 14 510. Locality 15 (Plate I), southern part of central gneiss, about 50 m from contact.

Megascopically this rock differs from the other varieties of rock included in the central gneiss and described in the foregoing in that, for instance, light, slightly reddish layers containing chiefly quartz and feldspar alternate with darker layers richer in biotite. For this reason the foliation of the rock is more distinct than in the specimens from the central gneiss described previously. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.62.

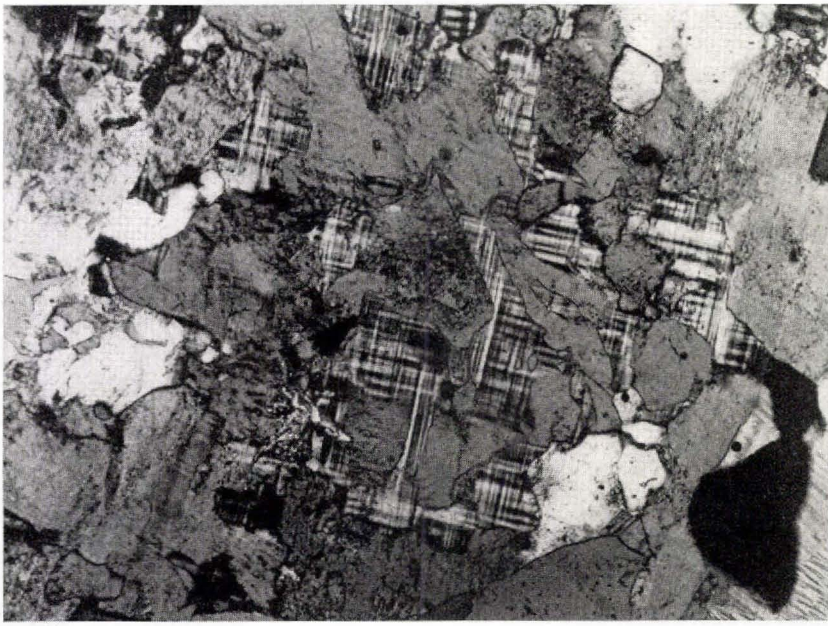

Fig. 11. Textural mode of occurrence of plagioclase and potash feldspar in granodioritic variety of central gneiss. Specimen No. 14 510. Nicols +. Magn. 55 x. Photo: E. Halme.

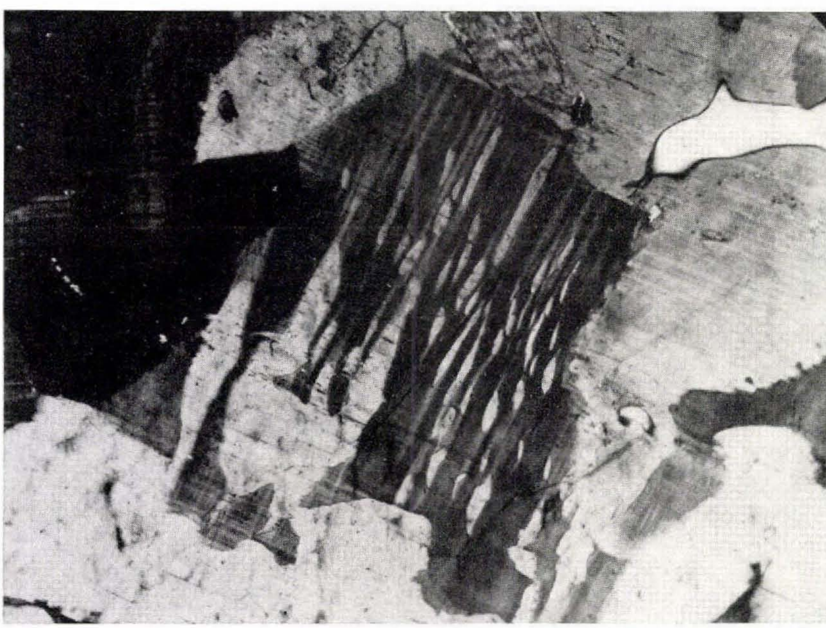

Fig. 12. Textural mode of occurence of plagioclase and potash feldspar. Same thin section as in Fig. 11. Nicols +. Magn. 130 x. Photo: E. Halme.

Table III. Modal analyses of specimens from central gneiss (vol. %).

	1.	2.	3.	4.	5.	6.
Plagioclase	61.6	65.2	63.9	77.0	67.3	43.6
Potash feldspar	19.7	4.9	3.9	1.3	3.1	17.5
Quartz	16.8	25.0	23.8	18.3	24.4	31.5
Biotite and Chlorite	1.7	3.3	5.8	2.1	2.7	6.3
Hornblende	0.0	0.0	0.0	0.0	0.9	0.0
Sericite	present	1.4	2.6	1.1	1.5	1.1
Others	0.2	0.2	< 0.1	0.2	0.1	< 0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0

1. Granodioritic rock. Specimen No. 14 501. Center of central gneiss. Description on p. 35.
2. Quartz dioritic rock. Specimen No. 14 502. Center of central gneiss. Description on p. 36. Chemical analysis in Table IV.
3. Quartz dioritic gneiss. Specimen No. 14 506. Northern part of central gneiss. Description on p. 36.
4. Quartz dioritic gneiss. Specimen No. 14 507. Western part of central gneiss. Description on p. 37.
5. Quartz dioritic gneiss. Specimen No. 14 508. Eastern part of central gneiss. Description on p. 38.
6. Granodioritic gneiss. Specimen No. 14 510. Southern part of central gneiss. Description on p. 38. Chemical analysis in Table IV.

The principal constituents are plagioclase (ca. An_{20}), quartz, potash feldspar, biotite and sericite. Accessory constituents are ore, zircon and sphene. The modal analysis is presented in Table III and the chemical analysis in Table IV.

Polysynthetic twinning is clearly visible in some of the plagioclase grains, while in others it is faint or not apparent at all. Part of the plagioclase is sericitized.

The mode of occurrence of the potash feldspar and the relations between the potash feldspar and the plagioclase vary a good deal. There occurs very little potash feldspar in plagioclase as antiperthite. A large part of the potash feldspar appears as xenomorphic grains 0.1—0.3 mm in diameter and often containing small plagioclase inclusions. In a few cases the plagioclase is present as separate »islets», the interstices of which are filled with cross-hatched microline (Figs. 11 and 12 on p. 39). The parts of each mineral, which seems to be situated separately, have a simultaneous extinction.

The triclinicity of the potash feldspar varies from 0.4 to 0.8. The greatest portion of it seems to have the latter value.

In the light of the foregoing descriptions and Table III, the composition of the central gneiss varies from quartz dioritic to granodioritic. The amount of dark minerals is only about two to six vol. %. The triclinicity of the potash feldspar varies from 0.4 to 0.95. According to these determinations, it is microcline. The content of potassium and sodium in quartz dioritic and granodioritic rocks of the mapped region as a whole will be discussed on pp. 63—66.

OTHER AREAS OF HOMOGENEOUS GNEISSES

In addition to the central gneiss there occur in the mapped region several other areas of homogeneous granodioritic and quartz dioritic rocks. In other places these rocks form migmatites in association with other varieties of rocks.

Immediately north and northeast of the dome, there is situated a homogeneous gneiss area. In shape it is an elongated triangle, the sides of which are concave. Its length is some 3.5 km and greatest breadth about 2 km. Megascopically the rock closely resembles the central gneiss. Its foliation is very weak even in the marginal parts, though it conforms to the amphibolite layers bordering the gneiss. Megascopically apparent foliation is almost totally missing from the middle portions of the gneiss.

In the following are descriptions of one typical sample from the middle of this gneiss and several other samples from other homogeneous gneiss areas in the region investigated.

Quartz dioritic rock. Specimen No. 14 554. Locality 16 (Plate I), north of the dome.

Megascopically the rock is generally light gray, but portions richer in biotite form darker splotches in places. Foliation can scarcely be detected. The grain size tends to be 1—2 mm. The diameter of some of the quartz grains is as much as 3 mm and the biotite also forms larger flakes and flake aggregates measuring some 3—5 mm in diameter. The texture is granoblastic. The specific gravity is 2.65.

The principal constituents are plagioclase (ca. An_{20}), quartz, biotite and sericite. Accessory constituents are epidote, ore, apatite, zircon, potash feldspar and sphene. The modal analysis is presented in Table V on p. 49.

According to the chemical analysis, the rock contains 5.46 % Na_2O and 1.00 % K_2O by weight.

Polysynthetic twinning is visible in the plagioclase only faintly or not at all. The plagioclase contains an abundance of sericite and some epidote. The very small amount of potash feldspar contained in the rock (less than 0.1 vol. %) is situated almost wholly in the plagioclase as antiperthite.

The quartz has a strong undulating extinction. The biotite is pleochroic from nearly colorless or very light brown to dark brown. In the middle and around many of the biotite flakes there are epidote grains and in places the biotite is bordered by muscovite. Around the ore grains leucoxene often occurs.

Granodioritic rock. Specimen No. 14 561. Locality 17 (Plate I), northwest of the dome.

Table IV. Chemical analyses of granodioritic and quartz dioritic rocks and of garnet. (weight %). Analyst, H. B. Wiik.

	1.	2.	3.	4.
SiO_2	73.73	73.38	70.68	37.18
TiO_2	0.06	0.25	0.11	0.10
Al_2O_3	15.03	14.43	17.68	23.50
Fe_2O_3	0.89	0.67	0.60	6.62
FeO	0.28	0.93	0.36	20.04
MnO	0.01	0.02	0.00	0.59
MgO	0.34	0.93	0.54	10.41
CaO	2.15	1.31	3.38	1.64
Na_2O	4.86	4.50	5.05	—
K_2O	1.50	3.38	1.11	—
P_2O_5	0.05	0.01	0.04	—
H_2O+	0.29	0.43	0.27	0.22
H_2O-	0.07	0.06	0.03	0.02
CO_2	0.00	0.00	0.00	—
Total	99.26	100.30	99.85	100.32

1. Quartz dioritic rock. Specimen No. 14 502. Center of central gneiss. Description on p. 36. Modal analysis in Table III, p. 40.
2. Granodioritic gneiss. Specimen No. 14 510. Southern part of central gneiss. Description on p. 38. Modal analysis in Table III, p. 40.
3. Quartz dioritic gneiss layer. Specimen No. 14 536. Northwestern part of dome. Description on p. 46. Modal analysis in Table V, p. 49.
4. Garnet from garnet-cordierite gneiss. Rock specimen No. 14 559. Description on p. 32.

Megascopically, the rock is light gray with a tinge of yellowish brown. The biotite content is quite small. The foliation is weak, scarcely perceptible. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.61.

According to the chemical analysis, the rock contains 5.77 % Na_2O and 1.29 % K_2O by weight.

The principal constituents are plagioclase (ca. An_{20}), quartz, biotite and cross-hatched microcline. In addition, there are small amounts of oxide ore, sericite, apatite, sphene and zircon.

The plagioclase contains some potash feldspar as antiperthite.

Granodioritic gneiss. Specimen No. 14 568. Locality 18 (Plate I), northwestern shore of the lake Quagssup Taserssua, southwest of the dome.

Megascopically, the rock is dark gray and contains biotite in relative abundance. The foliation is fairly distinct. The grain size is 1—3 mm and the texture is granoblastic. The specific gravity is 2.63.

According to the chemical analysis, the rock contains 4.57 % Na_2O and 2.50 % K_2O by weight.

The principal constituents of the rock are quartz, plagioclase (ca. An_{20}), biotite and cross-hatched microcline. The accessories are oxide ore, apatite, sericite and zircon.

The plagioclase is on the whole noticeably sericitized.

Granodioritic gneiss. Specimen No. 14 576. Locality 19 (Plate I), northwestern shore of Godthaabsfjord, about 500 m northeast of Nûa.

Megascopically, the rock is light gray and contains biotite in relative abundance. The foliation is fairly distinct. The grain size is 1—3 mm and the specific gravity is 2.66.

According to the chemical analysis, the rock contains 3.43 % Na_2O and 4.29 % K_2O by weight.

The principal constituents of the rock are plagioclase (ca. An_{20}), quartz, cross-hatched microcline and biotite. In addition, small amounts of sphene, oxide ore, muscovite, apatite, zircon and epidote are found.

The plagioclase contains some potash feldspar as antiperthite and the microcline some plagioclase as perthite. The plagioclase is somewhat sericitized.

Granodioritic rocks. Specimen No. 14 587. Locality 20 (Plate I), northeast of the northeastern corner of the dome.

Megascopically, the rock is light gray with a pale reddish tinge. The biotite content is rather slight. The foliation is weak, scarcely perceptible. The grain size is 1—2 mm and the specific gravity is 2.62.

According to the chemical analysis, the rock contains 5.09 % Na_2O and 3.21 % K_2O by weight.

The principal constituents of the rock are plagioclase (ca. An_{20}), quartz, cross-hatched microcline and biotite. The accessory constituents are sericite, sphene, apatite and zircon.

The plagioclase exhibits distinct polysynthetic twinning. It contains a very small amount of potash feldspar as antiperthite and a bit of sericite. The microcline contains a noticeable quantity of plagioclase as perthite.

Quartz dioritic gneiss. Specimen No. 14 597. Locality 21 (Plate I), between the southeastern part of the dome and Niaqornatsiaq.

Megascopically, the rock is light gray. The biotite content is rather slight. The foliation is only faintly in evidence. The grain size is 1—2 mm and the specific gravity 2.66.

According to the chemical analysis, the rock contains 5.63 % Na_2O and 0.76 % K_2O by weight.

The principal constituents of the rock are quartz, plagioclase (ca. An_{20}), biotite and sericite. The accessory constituents are epidote, potash feldspar, sphene, oxide ore and zircon.

Fig. 13. Nearly horizontal bedding in northwestern part of dome. View towards northeast. Quartz dioritic gneiss layer in lowest part of wall in right margin of figure. Upper part of wall is mainly amphibolite. Height of wall is about 15 m.

The slight amount of potash feldspar in the rock is wholly situated in the plagioclase as antiperthite. The plagioclase is noticeably sericitized.

Granodioritic gneiss. Specimen No. 14 613. Locality 22 (Plate I), about 1 km east of the northeastern corner of the dome.

Mecascopically, the rock is light gray. Its biotite content is rather small. The foliation is distinctly perceptible. The grain size is 1—2 mm and the specific gravity is 2.67.

According to the chemical analysis, the rock contains 5.08 % Na_2O and 2.41 % K_2O by weight.

The principal constituents of the rock are plagioclase (ca. An_{20}), quartz, cross-hatched microcline, biotite and sericite. The accessory constituents are epidote, apatite, sphene, oxide ore and zircon.

The plagioclase exhibits distinct polysynthetic twinning. In places it contains some sericite but scarcely any potash feldspar as antiperthite. The microcline contains a bit of plagioclase as perthite.

Granodioritic gneiss. Specimen No. 14 573. Locality 23 (Plate I), southeastern part of the dome between the inner and outer amphibolite rings.

Megascopically, the rock is light gray. Its biotite content is rather small. The foliation is weak but none the less distinguishable. The grains size is 1—2 mm and the specific gravity is 2.63.

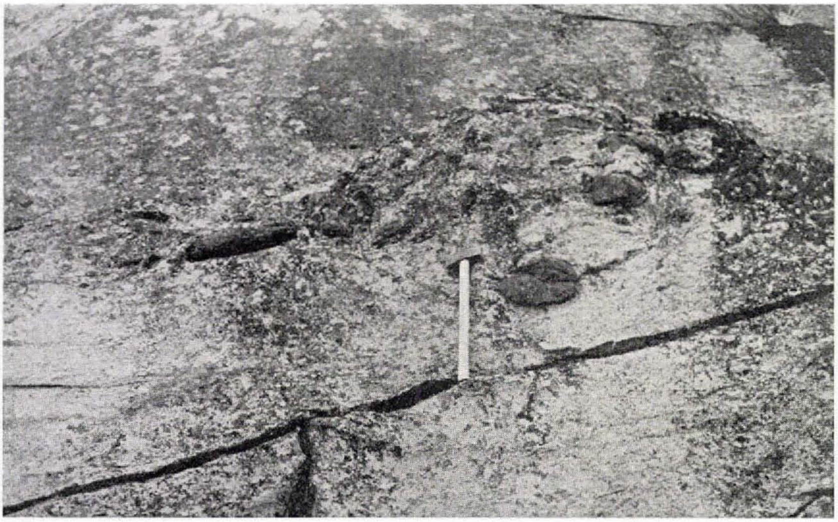

Fig. 14. Skarn lenses, mainly diopside, in quartz dioritic gneiss layer. Same layer as in Fig. 13.

According to the chemical analysis, the rock contains 4.90 % Na_2O and contains 3.36 % K_2O by weight.

The principal constituents of the rock are plagioclase (ca. An_{20}), quartz, cross-hatched microcline and biotite. The accessory constituents are sphene, muscovite, apatite and zircon.

In the light of the descriptions in the foregoing, these homogeneous gneisses vary in composition from quartz dioritic to granodioritic. No essential petrographic difference between these rocks and the central gneiss has been noticed.

QUARTZ DIORITIC INTERCALATIONS IN AMPHIBOLITES

At various places in the region investigated, the amphibolites contain intercalations of quartz dioritic gneisses. The contacts between the gneiss layers and the amphibolites are usually sharp and in many cases the contact is a shear surface. No apophyses intruding from the gneiss layers into the surrounding amphibolites have been found. The thickness of the gneiss layers is generally about 5—15 meters. Fig. 13 represents the mode of occurrence of such a gneiss layer.

In the gneiss layer shown in this figure, a horizon has been found which includes an abundance of skarn lenses containing chiefly diopside (Fig. 14).

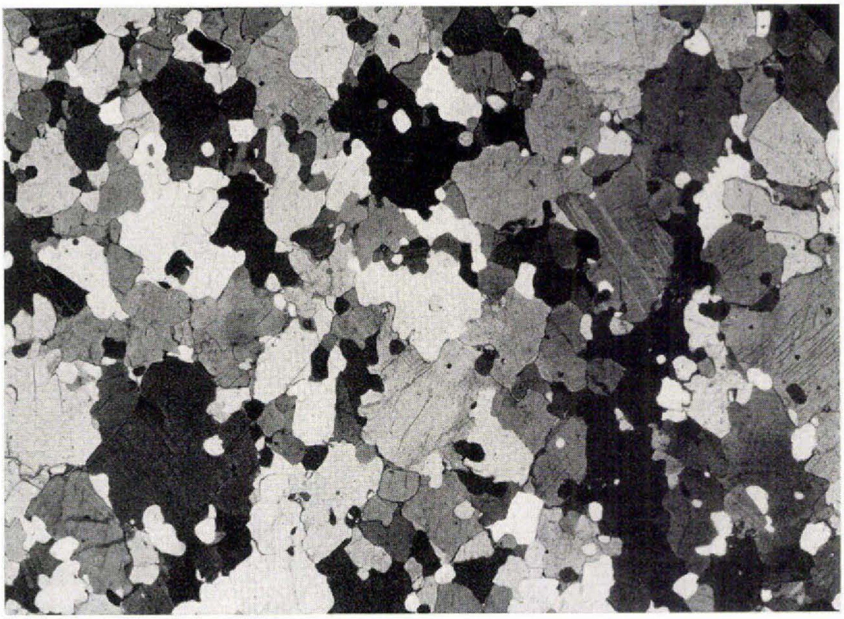

Fig. 15. Texture of quartz dioritic gneiss layer. Specimen No. 14 536. Same gneiss layer as in Figs. 13 and 14. Nicols +. Magn. 11 x. Photo: E. Halme.

This horizon of skarn lenses is exposed for a distance of more than 50 meters.

The quartz dioritic intercalations in the amphibolites occur most plainly in the western and northern parts of the dome, where the layers dip very gently or lie almost horizontal. A couple of these gneiss layers have been followed partly in the field and partly by means of aerial photographs, for a distance of some 5 km.

In the following a description will be given of two of typical specimens taken from such a gneiss layer.

Quartz dioritic gneiss layer. Specimen No. 14 536. Locality 24 (Plate I), northwestern part of the dome. The layer is the same as that shown in Fig. 14.

Megascopically the rock is dark gray. Its foliation is weak, scarcely perceptible. The grain size is 1—2 mm and the texture is granoblastic (Fig. 15). The specific gravity is 2.64.

The principal constituents are plagioclase (ca. An_{20}), quartz and potash feldspar. In addition, there is a small amount of biotite and the accessory constituents are sericite, ore, chlorite and zircon. The modal analysis is presented in Table V on p. 49 and the chemical analysis in Table IV on p. 42.

Polysynthetic twinning is clearly to be seen in most of the plagioclase grains. In places the plagioclase contains considerably potash feldspar as antiperthite. Moreover, the potash feldspar occurs as interstitial grains 0.1—0.2 mm in diameter. The quartz has a weak undulating extinction.

The biotite is pleochroic from light brown to dark brown. Sporadically the thin section reveals the presence of a very fine-grained material, which seems to consist principally of chlorite and sericite.

Quartz dioritic gneiss layer. Specimen No. 14 569. Locality 25 (Plate I), southwestern part of the dome.

Megascopically the rock is very much like the specimen No. 14 536, just described, except that it is a trifle lighter in shade. The grain size is 1—2 mm and the specific gravity is 2.62.

Also microscopically the rock is very much the same in appearance as the preceding sample, except that its plagioclase reveals a substantial content of sericite.

According to the chemical analysis, the rock contains 5.31 % Na_2O and 0.55 % K_2O by weight.

According to the descriptions in the foregoing, these gneiss intercalations in the amphibolites are quartz dioritic in composition and very poor in mafic minerals. Under the microscope they are rather similar to quartz dioritic rocks forming larger homogeneous areas.

GARNET-BEARING GRANODIORITIC ROCKS

Garnet-bearing rocks are rather rare in the mapped region. With the exception of the garnet-cordierite gneiss layer described on pp. 31—33, they have been met with in noteworthy amounts only in the area of the dome itself, between the inner and outer amphibolite rings, especially to the west, north and northeast of the central gneiss. Here garnets occur in the granodioritic rocks in smallish areas, which are mostly a few dozen meters in diameter. According to the field observations, the garnet-bearing granodioritic varieties of rocks grade without any sharp boundaries into garnet-free rocks. The garnet content is rather small, generally around one vol. % or less.

In the following, descriptions are given of four samples of garnet-bearing granodioritic rocks.

Garnet-bearing granodioritic gneiss. Specimen No. 14 518. Locality 26 (Plate I), north of the central gneiss, between the inner and outer amphibolite rings.

Megascopically, the rock is light gray, slightly reddish. The foliation is rather weak. The rock contains red garnet grains 0.5—1 mm in diameter. The garnet grains are partly arranged in bands and generally occur in the same bands together with biotite. This banded mode of occurrence is, however, very weak and noticeable only in some places. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.63.

The constituents of the rock are plagioclase (ca. An_{20}), potash feldspar, quartz, biotite, garnet and oxide ore. The modal analysis is presented in Table V on p. 49. With regard to the amount of garnet reported (0.3 vol. %), it should be remarked that the thin section revealed the presence of only one garnet grain, and it is on this basis that the garnet content was determined. According to the megascopic estimation made of the sample, the true garnet content of the rock would seem to be somewhat greater, or around 0.5—1 vol. %.

The plagioclase exhibits distinct polysynthetic twinning. It contains hardly any potash feldspar as antiperthite. The potash feldspar occurs as xenomorphic grains 0.2—0.6 mm in diameter. The majority of the grains are clearly cross-hatched and have a noteworthy content of plagioclase as perthite. In an X-ray examination, potash feldspar separated from the specimen with heavy liquid was found to have two values of triclinicity, namely, 0.0 and 0.9. In this light, the rock contains both orthoclase and microcline.

The biotite is pleochroic from light brown to dark brown. The quartz exhibits very weak undulating extinction. The garnet is xenoblastic and contains quartz and also a bit of oxide ore as inclusions.

The garnet's refraction index $n = 1.796$ and the cell edge $a_0 = 11.528$ Å. (Determined by K. Hytönen).

From a sample weighing several kilograms, some 500 mg of fairly pure garnet was separated by means of heavy liquids, and it was subjected to a silicate analysis (analyst, H. B. Wiik) in spite of the difficulties attendant upon the scant amount of the material.

This analysis gave the following semiquantitative results: $SiO_2 = 38$ %, $TiO_2 = 0.05$ %, $Al_2O_3 = 23$ %, $Fe_2O_3 = 4$ %, $FeO = 27$ %, $MnO = 1.6$ %, $MgO = 6.6$ %, $CaO = 1.2$ %, $H_2O + = 0.2$ % and $H_2O - = 0.1$ % by weight. (Total = 101.75 % by weight).

Calculated according to this analysis, the garnet contains approximately 64—67 mol. % almandine, 26—28 mol. % pyrope, 3.5 mol % grossular and 3.5—4 mol. % spessartite. The analysis is not closely in agreement with the theoretical composition of the garnet group. (cf. p. 33).

Garnet-bearing granodioritic rock. Specimen No. 14 572. Locality 27 (Plate I), west of the central gneiss between the inner and outer amphibolite rings.

Table V. Modal analyses of quartz dioritic and garnet-bearing granodioritic rocks (vol. %).

	1.	2.	3.	4.
Plagioclase	61.9	70.8	42.3	44.4
Potash feldspar	< 0.1	3.3	19.0	22.4
Quartz	29.1	25.2	36.7	27.6
Biotite	2.3	0.5	1.5	4.2
Garnet	0.0	0.0	0.3	1.0
Sericite	6.3	< 0.1	0.0	< 0.1
Others	0.4	0.2	0.2	0.4
Total	100.0	100.0	100.0	100.0

1. Quartz dioritic rock. Specimen No. 14 554. Description on p. 41.
2. Quartz dioritic gneiss layer in amphibolite. Specimen No. 14 536. Description on p. 46. Chemical analysis in Table IV, p. 42.
3. Garnet-bearing granodioritic gneiss. Specimen No. 14 518. Description on p. 47.
4. Garnet-bearing granodioritic rock. Specimen No. 14 528. Description on p. 49.

Both megascopically and microscopically the rock closely corresponds to the preceding sample. However, the garnet is clearly in a state of alteration into, e.g., biotite. The specific gravity of the rock is 2.63.

According to the chemical analysis, the rock contains 4.60 % Na_2O and 3.12 % K_2O by weight.

Garnet-bearing granodioritic gneiss. Specimen No. 14 528. Locality 28 (Plate I), northeast of the central gneiss between the inner and outer amphibolite rings.

Megascopically, the rock is reddish gray. Its foliation is generally weak and in places can hardly be distinguished. The rock is rather homogeneous, except that to a varying degree it contains roundish knobs about 1—6 mm in diameter composed mainly of garnet and mica. The grain size varies from 0.5 mm to 4 mm, but generally it is 1—2 mm. The texture is granoblastic (Fig. 16 on p. 50). The specific gravity is 2.59.

The principal constituents are plagioclase (ca. An_{20}), quartz, potash feldspar, biotite and garnet. The accessory constituents are sericite, chlorite, ore, sphene and zircon. The modal analysis is presented in Table V. The thin section contains only one garnet-bearing knob and the garnet content reported is based on this fact. It is hard to make accurate estimates of the actual garnet content of the rock.

According to the chemical analysis, the rock contains 4.14 % Na_2O and 5.78 % K_2O by weight.

The potash feldspar contains a considerable abundance of plagioclase as perthite and the plagioclase contains considerable potash feldspar as antiperthite. The mixture of potash feldspar and plagioclase is often so fine-

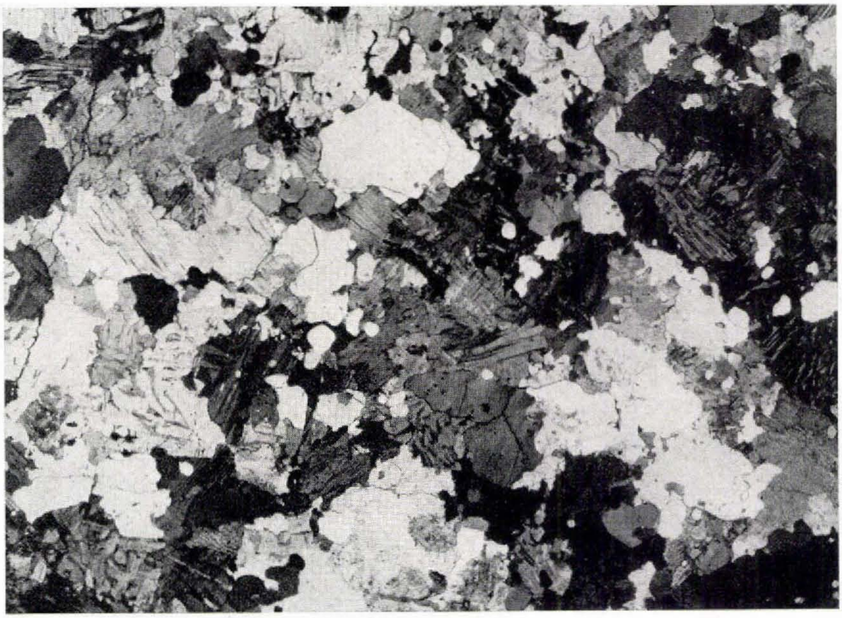

Fig. 16. Texture of garnet-bearing granodioritic rock. Specimen No. 14 528. Nicols +. Magn. 11 x. Photo: E. Halme.

grained that study of the minerals is difficult even under high magnifications. For this reason, also in modal analysis their ratio is apt to be erraneous. The plagioclase has undergone advanced sericitization.

The garnet, ore and main portion of the biotite and and chlorite all occur together in the thin section in an accumulation roughly 5 mm in diameter. Apparently, a garnet grain in a state of alteration is involved.

The garnet's refraction index $n = 1.805$ and the cell edge $a_0 = 11.567$ Å (determined by K. Hytönen).

Garnet-bearing granodioritic rock. Specimen No. 14 525. Locality 29 (Plate I), south of the central gneiss between the inner and outer amphibolite rings.

Megascopically the rock is light gray. The foliation is very distinct. The grain size is 1—2 mm and the specific gravity is 2.62.

The principal constituents are quartz, plagioclase (ca. An_{20}), and microcline. In addition, the rock contains green biotite, garnet, oxide ore, sericite and a trifle epidote and zircon.

The garnet and the main part of the biotite and the oxide ore occur together in an aggregate about 2 mm in diameter. Apparently, what is involved is a garnet grain that has for the greatest part altered.

Fig. 17. Migmatic rocks. Niaqornatsiaq, western shore of Godthaabsfjord. Wiew towards north.

According to the chemical analysis, the rock contains 4.40 % Na_2O and 3.20 % K_2O by weight.

The plagioclase contains a fair abundance of sericite, but, on the other hand, scarcely any potash feldspar as antiperthite. The microcline is cross-hatched and in many cases contains abundant plagioclase as perthite. The quartz has a marked undulating extinction.

In the light of the examples described in the foregoing, these garnet-bearing rocks are granodioritic in composition. In three of the four specimens studied, the garnet is obviously in a state of alteration caused by retrogressive metamorphism.

MIGMATITES

The granodioritic and quartz dioritic rocks in the mapped region generally form migmatites with other rocks, especially amphibolites. Often, within a rather limited area, all transitional stages are to be found from amphibolites with only few granodioritic or quartz dioritic veins or schlieren to fairly pure granodioritic or quartz dioritic rocks with only few more or less altered inclusions or schlieren of amphibolite or related rocks. In many places the granodioritic and quartz dioritic rocks also compose more extensive homogeneous areas.

The strike and dip of amphibolitic and other inclusions in the granodioritic and quartz dioritic rocks are generally parallel to the strike and dip of the larger amphibolite layers situated in their proximity.

Fig. 18. Migmatic rocks. Western shore of Godthaabsfjord near Niaqornatsiaq. View towards north.

The structure and mode of occurrence of the migmatites in detail are best to be seen and photographed on the sea coast, where the exposures, polished by ice and wholly free of vegetation, are almost ideal for geological study (Figs. 17—19) or then in higher terrain, as, for example, north of the dome. (Fig 20). These figures, 17—20, show migmatite types quite characteristic of the mapped region.

In the following a few typical rock specimens from the migmatite areas will be described.

Migmatic gneiss. Specimen No. 14 574. Locality 30 (Plate I), eastern part of the dome, between the inner and outer amphibolite rings.

The rock is distinctly banded. In it there alternate light and dark bands, the thickness of which varies from a few centimeters to several dozen centimeters. The thin section has been made of the contact between a light and a dark band. The grain size is 1—2 mm and the texture is lepidoblastic, almost granoblastic. The specific gravity is 2.67.

The principal constituents are plagioclase (ca. An_{20}), quartz, biotite and potash feldspar. The accessory contituents are sericite, apatite, ore, sphene and zircon.

Modal analyses have been made of the light and the dark band separately, being presented in Table VI on p. 56. The dark band is seen to contain more biotite but less quartz and potash feldspar than the light band.

Fig. 19. Migmatic rocks. Western shore of Godthaabsfjord near Utsoqiuse. View towards north.

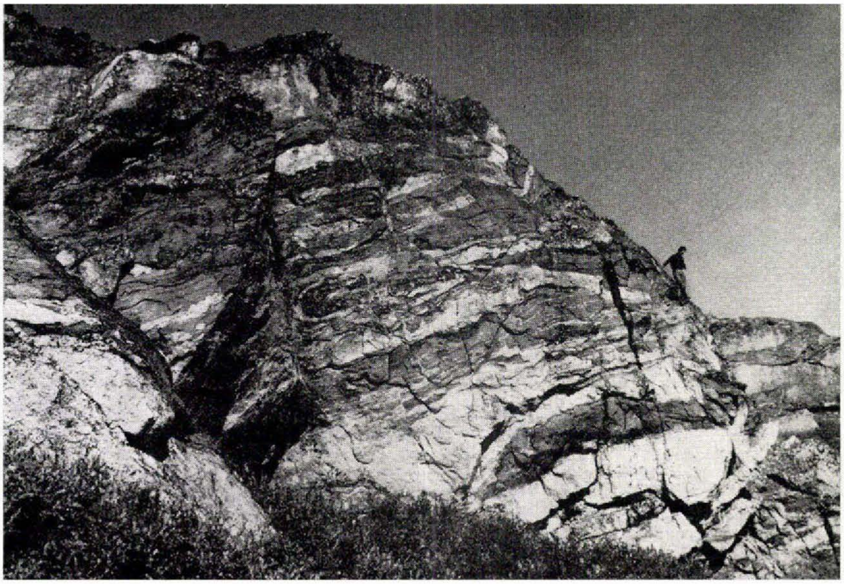

Fig. 20. Migmatic rocks. 4 km north of northwestern corner of dome. View towards northeast.

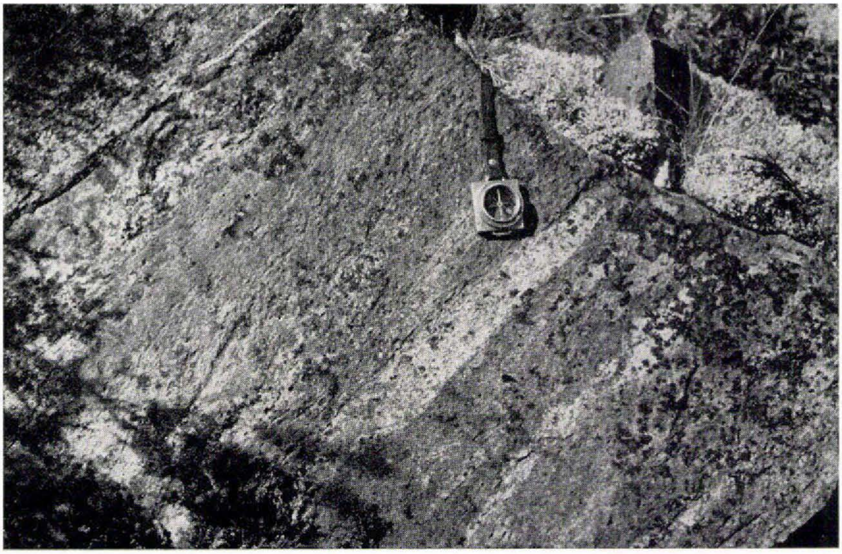

Fig. 21. Light bands in dark gray gneiss. West of inner amphibolite ring. View towards north.

Polysynthetic twinning is visible in the plagioclase only faintly or not at all. The plagioclase contains sericite and a small amount of potash feldspar as antiperthite.

The potash feldspar occurs partly in the plagioclase as antiperthite and partly as interstitial grains 0.1—0.3 mm in diameter. The biotite is pleochroic from light brown to dark brown. The quartz exhibits a marked undulating extinction.

Dark gray portion of migmatic gneiss. Specimen No. 14 516. Locality 31 (Plate I), about 50 m west of the inner amphibolite ring.

In the spot here mentioned there occurs dark gray gneiss, which megascopically resembles the marginal portions of the central gneiss. Deviating from the central gneiss, it has in places light bands a few centimeters broad (Fig. 21). The specimen here described consists of dark gray gneiss while the sample to follow, No. 14 517, represents the light band.

The dark gray gneiss is rather weakly foliated. Its grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.68.

The principal constituents of the rock are plagioclase (ca. An_{25}), quartz and biotite. In addition, it contains small amounts of potash feldspar, apatite, sphene, sericite, ore and zircon. The modal analysis is presented in Table VI on p. 56.

Some of the plagioclase grains exhibit a distinct polysynthetic twinning, in others the twinning is only faintly visible or not at all. The entire potash feldspar content of the rock occurs in the plagioclase as antiperthite.

The biotite is pleochroic from light brown to very dark brown. The ore and sphene generally occur as inclusions in the biotite or in the immediate vicinity of biotite. In a few spots the ore grain is in the middle with a rim of sphene around it and biotite situated outermost.

Light band in dark gray gneiss. Specimen No. 14 517. From the same spot as the preceding sample.

The rock is light gray with dark, biotite-rich bands, the thickness of which varies from about 1 mm to 5 cm. The thin section was made from a piece of the sample that contained no biotite-rich bands. The grain size is 1—3 mm and the texture is granoblastic. The specific gravity is 2.65.

The principal constituents are plagioclase (ca. An_{20}), quartz, biotite, feldspar and sericite (muscovite). Accessory constituents are sphene, ore and epidote. The modal analysis is presented in Table VI on p. 56.

Polysynthetic twinning is visible in the plagioclase only faintly or not at all. The potash feldspar of the rock is present partly in the plagioclase as antiperthite, partly as interstitial grains 0.1—0.2 mm in diameter.

The quartz exhibits a marked undulating extinction. The biotite is pleochroic from light brown to dark brown. The sphene occurs mainly in the biotite.

Quartz dioritic gneiss. Specimen No. 14 513. Locality 32 (Plate I), eastern part of the outer amphibolite ring.

This sample has been taken from the same, roughly 200 m broad amphibolite layer as the pyroxene amphibolite specimens No. 14 511 and 14 512 described on pp. 22—24 as well as the hornblende gneiss specimen described on p. 27. According to the field observations, these rocks grade into each other. No sharp boundaries between these varieties of rock have been noticed.

In color this quartz dioritic gneiss is dark gray. It is fairly homogeneous and distinctly foliated. The grain size is 1—2 mm and the texture is granoblastic. The specific gravity is 2.72.

The principal constituents are plagioclase (ca. An_{35}), quartz, biotite and hornblende. In addition, there are small amounts of sericite, clorite, oxide ore, potash feldspar, apatite, epidote, sphene and zircon. The modal analysis is given in Table VI on p. 56.

Polysynthetic twinning is plainly visible in most of the plagioclase grains. Some of the plagioclase grains contain substantial amounts of sericite. The slight potash feldspar content of the rock (0.2 vol. %) occurs as tiny particles in the plagioclase.

Table VI. Modal analyses of migmatic gneisses (vol. %).

	1.	2.	3.	4.	5.
Plagioclase	65.1	64.1	60.4	51.1	50.3
Potash feldspar	0.7	3.5	0.3	3.4	0.2
Quartz	15.1	28.9	21.8	40.9	35.2
Biotite	18.7	3.3	16.4	2.8	11.4
Hornblende	0.0	0.0	0.0	0.0	1.3
Sericite	0.2	0.1	0.3	1.2	0.9
Others	0.2	0.1	0.8	0.6	0.7
Total	100.0	100.0	100.0	100.0	100.0

1. Dark band in migmatic gneiss. Specimen No. 14 574. Description on p. 52.
2. Light band in migmatic gneiss. Same specimen as above.
3. Dark gray part in migmatic gneiss. Specimen No. 14 516. Description on p. 54.
4. Light band in dark gray migmatic gneiss. Specimen No. 14 517. Description on p. 55.
5. Quartz dioritic gneiss. Specimen No. 14 513. Description on p. 55.

The biotite is pleochroic from light brown to dark brown or greenish brown. A portion of the biotite contains ore, sphene and zircon. Around the ore grains there commonly occurs a leucoxene rim and also biotite. The hornblende appears to be in a state of alteration into greenish biotite and chlorite. The quartz has a strong undulating extinction.

The samples of migmatic rocks described in the foregoing are mainly quartz dioritic in composition. The essential petrographic difference between the darker and lighter bands appears to be the fact that the dark bands contain much more biotite but appreciably less potash feldspar and quartz than the light bands do (Table VI).

ULTRABASIC ROCKS

Occurrences of ultrabasic rocks have been met with in considerable abundance in various parts of the mapped region, especially south, east and north of the dome. They are found in other varieties of rocks as conformable lenses. They vary greatly in size; some are only a few square meters or even less in area whereas the largest are over 500 m long and about 200 m wide. Some are situated in amphibolites or hornblende gneisses, some at or near the contact of the amphibolite layers and the granodioritic or quartz dioritic gneisses, while some are situated in the granodioritic or quartz dioritic gneisses. The situation of the largest ultrabasic lenses is shown on the geological map. Fig. 22 shows the mode of occurrence of the ultrabasic rocks in the field north of the dome.

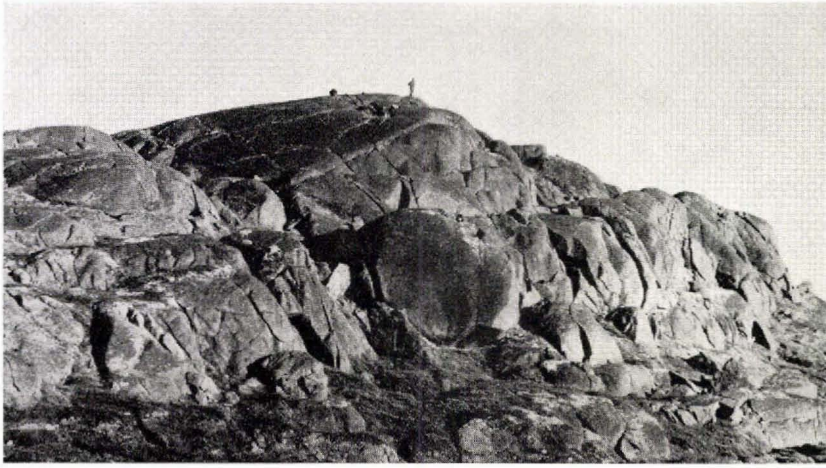

Fig. 22. Part of great ens of ultrabasic rock. 2.5 km north of northern border of dome. View towards southeast.

According to the field observations, some of the ultrabasic rocks contain mainly olivine and serpentine, and the principal constituents of others are hypersthene, hornblende and diopside.

The mode of occurrence, petrography, mineralogy and chemical composition of ultrabasic rocks similar to those of the Ipernat dome region are described in fair detail by Sørensen (1952, 1953, 1954) and Berthelsen (1960).

PEGMATITES AND APLITES

In the region investigated, pegmatites are comparatively rare, and none at all have been found in the area of the dome itself. On the northwestern shore of Godthaabsfjord, especially south of the Niaqornatsiaq peninsula, a few pegmatite dikes cutting across the foliation of the other rocks have been observed (Fig. 23). They vary in breadth from about 10 cm to about 5 m. Their strike varies, too, but mostly it is roughly E—W. The dip is steep or vertical. In addition to feldspars and quartz, the minerals met with in these dikes include muscovite, biotite, garnet and magnetite as well as a few small beryl crystals.

In different parts of the mapped region, some cross-cutting aplite dikes have been found. In general, these dikes are 10 to 50 cm wide but in some cases reach a width of a couple of meters. Their strike varies from N 70°E to E—W and their dip is steep or vertical. Besides feldspars and quartz, some biotite has been found in them. In one aplite dike some 20 cm broad

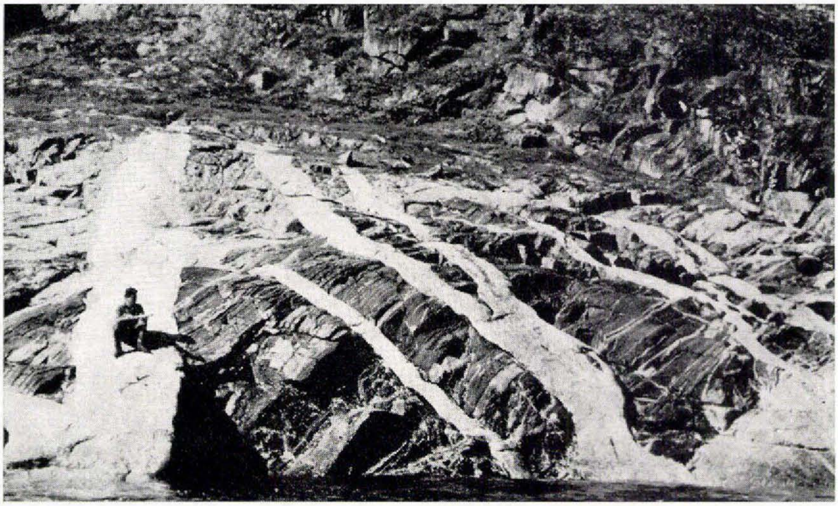

Fig. 23. Cross-cutting pegmatite dikes. Western shore of Godthaabsfjord near Niaqornatsiaq. View towards west.

near the northern edge of the dome there have been found numerous magnetite crystals measuring as much as 1—2 cm in diameter.

Ramberg (1956) has described in some detail the pegmatites on the shores of Godthaabsfjord as well as in other parts of West Greenland.

DIABASE DIKES

Only a few of the diabase dikes commonly occurring in western Greenland have been found in the mapped region. Their situation and strike are best to be seen on the geological map. Their dip is invariably steep or vertical. The dikes vary in breadth from about 20 cm to about 30 m, but their most usual breadth is 10 to 20 m.

In narrow dikes and near the contacts of broader dikes the grain size of the rock is 0.1—0.5 mm or even less, whereas in the middle portions of broader dikes the grain size is about 1—5 mm.

Recently, Berthelsen and Bridgwater (1960) have published a fairly thorough study on the field occurrence and petrography of similar basic dikes in the region immediately north and northwest of the area of the present investigation.

MINERAL FACIES CONDITIONS

As the foregoing petrographic descriptions have made clear, the majority of the rocks in the region investigated crystallized under PT-conditions approaching or corresponding to the granulite facies of Eskola (1939, pp. 360—363). The typical mineral assemblage of the basic rocks, represented here by pyroxene amphibolites, is hypersthene-diopside-hornblende-plagioclase in varying proportions. This mineral assemblage occurs in numerous thin sections in complete equilibrium and devoid of alteration products. In many cases, titaniferous magnetite appears to be associated with this mineral assemblage as an essential member.

The mineral assemblage plagioclase-diopside-hypersthene-hornblende conforms strictly to the hornblende-granulite subfacies of Turner (1958, pp. 232—235). The role of the titaniferous magnetite, which is present in the amount of as much as 10 vol. % (Table I, p. 28), is somewhat uncertain. According to Ramberg (1948 b, p. 553), the stability relationships of some silicates (hornblende, biotite, sphene and titanic augite) require a liberation of Ti and usually Fe from silicate lattices under granulite facies conditions and these elements can form titaniferous iron ore. According to Parras (1958, p. 102), the orthorombic pyroxene seems to remain stable to a certain Fe-content only (65 mol.% ferrosilite), whereupon the excess iron of the bulk composition of the rock becomes distributed between other phases, not least in anhydrous biotite — or it occurs outright as magnetite.

In the region here described, two of the samples dealt with (Nos. 14 512 and 14 524, pp. 23 and 25) reveal the presence of orthopyroxene in apparent equilibrium with titaniferous magnetite, and in both cases the orthopyroxene contains about 52 mol.% ferrosilite. In two other mineral assemblages apparently in equilibrium and including orthopyroxene (Spec. Nos. 14 511 and 14 515, pp. 22 and 24), no magnetite or ilmenite has been observed. The orthopyroxenes in these specimens contain about 45 mol.% and 30 mol.% ferrosilite, respectively.

In the majority of the pyroxene amphibolite samples examined microscopically, however, evidence of the effects of diminishing temperature and/or pressure can be noted. The hypersthene appears to undergo alteration into diopside and the diopside into hornblende. Around or near oxide ore grains, leucoxene often occurs and also in certain cases biotite. In places hornblende also appears to undergo alteration into biotite and/or chlorite.

In one thin section (Spec. No. 14 512, p. 23) sporadic signs of the effects of rising temperature and/or pressure have been noticed.

In rocks of granodioritic composition either hypersthene or garnet occur in many cases, particularly between the inner and outer amphibolite rings. No rocks have been encountered in the region in which these minerals occur together. In the hypersthene gneisses (pp. 28—31) the hypersthene has always been found to be more or less in a state of alteration. In garnet-bearing granodioritic rocks the garnet in some instances at least seems to occur together with biotite in a state of equilibrium without textural evidence of the biotite's having altered into garnet or vice versa (Spec. No. 14 518, p. 47). In other specimens (e.g., Spec. No. 14 528, p. 49) the garnet is clearly in a state of alteration apparently into various kinds of mica and oxide ore.

The occurrence of hypersthene and garnet in granodioritic and quartz-dioritic rocks indicate PT-conditions at or near those of granulite facies. According to Turner (1958, p. 232), who has divided the granulite facies into two subfacies, the pyroxene-granulite and hornblende-granulite subfacies, biotite does not occur in rocks conforming strictly to the specifications of the pyroxene-granulite facies. Accordingly, these hypersthene gneisses and garnet-bearing granodioritic rocks more correctly belong to the hornblende-granulite subfacies. It should be borne in mind, however, that in many instances, though not invariably, at least part of the biotite is distinctly diaphthoretic. Its occurrence in a mineral assemblage does not, therefore, provide evidence against the possibility that these rocks might have crystallized earlier under pyroxene-granulite facies PT-conditions.

According to Eskola (1939, p. 360), a characteristic of granulite facies varieties of rock is the high pyrope content of (Fe, Mg) Al-garnets, a content that in the granulites of Finnish Lapland varies between 47 and 55 mol. %, whereas the pyrope content of rocks belonging to the amphibolite facies rises to no more than 30 mol. %. The garnet of the garnet-bearing granodioritic rock (p. 48) contains, according to chemical analysis, approximately 26—28 mol. % pyrope; the rock would therefore more properly belong, after Eskola's (1939) facies classification, to the amphibolite rather than to the granulite facies. It nevertheless remains questionable to what extent the relatively low pyrope content of the (Fe, Mg) Al-garnet can be used as proof of the lack of PT-conditions of the granulite facies unless the chemical bulk composition of the rock is known. If the rock's MgO:FeO ratio is low, it would be unlikely that the garnet's pyrope content would be high, even where the PT-conditions might allow it.

In the sole garnet-cordierite gneiss occurrence of the region investigated (pp. 31—33) the garnet contains, according to the chemical analysis, approximately 40—45 mol. % pyrope, or nearly as high a content as in the typical granulites of Finnish Lapland, (Eskola, 1939, p. 360). This variety of rock also contains cordierite and biotite. The latter mineral appears to be at least partially diaphthoretic and perhaps does not belong to the assemblage during the crystallization of which the garnet achieved its present chemical composition. On the other hand, it is not known whether at the stage of incipient alteration the chemical composition of the garnet might have changed somewhat from what it was originally. Judging by the rock's mineral composition, its Mg content is fairly high.

In different parts of the region, but especially in the southeastern part of the dome, evidence has been found of rather strong regional retrogressive metamorphism. In such places the amphibolitic rocks no longer contain hypersthene and diopside occurs only as an unstable relict. The hornblende turns unstable, too, and alters partly into biotite and/or chlorite. The oxide ore minerals are in some instances surrounded by leucoxene and/or biotite. The plagioclase is in many cases more or less sericitized. The hypersthene of the hypersthene gneisses is in a state of alteration into serpentine, biotite and oxide ore minerals. The garnet of the granodioritic rocks is in a state of alteration into various micas and oxide ore minerals (pp. 49—50).

Nowhere has this retrogressive metamorphism been observed to have led to the creation of a new mineral assemblage completely in equilibrium. The boundaries of the granulite facies and other facies corresponding to lower PT-conditions are not sharp but represent zones of gradual transition. The most distinct transitional zone is found in the eastern part of the dome, where the hypersthene gneiss area marked on the geological map in yellow gradually passes over into an area of granodioritic and quartz dioritic gneiss. The breadth of this transitional zone is, according to field observations, several hundred meters. In the same area, the outer amphibolite ring reveals plain evidence of a strong retrogressive metamorphism.

The retrogressive metamorphosis has probably been strongly promoted by metasomatic changes, above all, by an increase in water and also at least SiO_2. No quartz-free amphibolites that had crystallized in complete equilibrium under PT-conditions of the amphibolite facies (after the facies classification of Eskola, 1939) whatsoever have been found in the region, but the alteration of pyroxene amphibolites into amphibolite invariably seems to be associated with the occurrence of quartz and also chlorite in the mineral assemblage — at least as minor constituents (Table I, p. 28).

In the great fault zones of the region there are frequent occurrences of epidote and chlorite. In some cases, again, the rocks of the fault zones have been mylonitized and turned into completely aphanitic varieties. The appearance of epidote and chlorite in these zones indicates that, at some stage, at least, during the faulting the regional PT-conditions had permitted the crystallization of such minerals. Faulting of this kind, of course, causes facies changes only of a local character.

CONTENT OF POTASSIUM AND SODIUM IN QUARTZ DIORITIC AND GRANODIORITIC ROCKS

In studies dealing with gneiss domes, the possible roles of potash metasomatism, granitization, granitic magma and other such factors in the formation of the domes have sometimes been the subject of lively discussion. For this reason, efforts have been made in the present investigation to determine the Na_2O and K_2O content of granodioritic and quartz dioritic varieties of rock. For this purpose samples were collected that, according to field observations, represented the average composition of such rocks as closely as possible. By means of megascopic and microscopic comparison, the most representative samples taken from different parts of the region investigated were selected for analyses. In considering the reliability of the results from the standpoint of the representativeness of the samples, it should be noted that all the ones analyzed were taken from places which, in the light of field observations, are free of inclusions, schlieren and veins and are fairly homogeneous. The sample crushed and homogenized for analysis generally weighed about one kilogram. The Na_2O and K_2O contents were determined gravimetrically. The results of the analyses are presented in Table VII as well as in figures 24 and 25, which also show the sampling sites. On the basis of these results, it would appear that K_2O was slightly concentrated in the area between the inner and outer amphibolite rings, but not, considered on the average, in the central gneiss. In the central gneiss the K_2O content is distributed so unevenly that, judging by the six analyses available, no reliable conclusions can be drawn with respect to the distribution of K_2O in the different portions of this gneiss.

The textural mode of occurrence of the potash feldspar varies and appears to depend considerably on the content of this mineral in the rock. The potash feldspar content of certain quartz dioritic rocks is only a fraction of one vol. %. In such cases, the potash feldspar usually occurs as antiperthite in the plagioclase. As the amount of potash feldspar increases, it generally occurs as both antiperthite in the plagioclase and as small interstitial grains. At its maximum, the potash feldspar content of granodioritic rocks rises to roughly 20 vol. %. In these varieties of rock, the

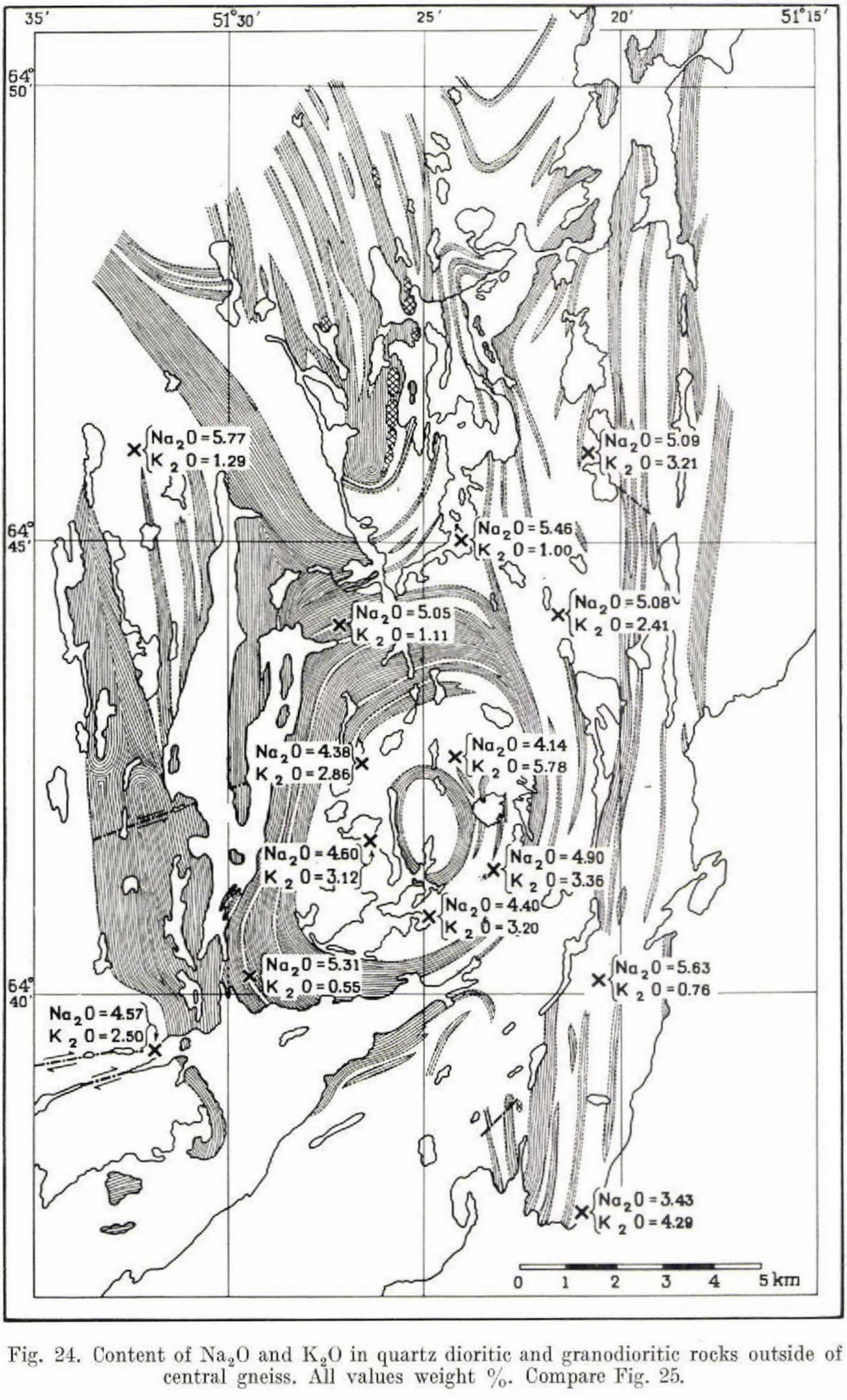

Fig. 24. Content of Na_2O and K_2O in quartz dioritic and granodioritic rocks outside of central gneiss. All values weight %. Compare Fig. 25.

Table VII. Gravimetric determinations of sodium and potassium content of quartz dioritic and granodioritic rocks (weight %). Analyst, H. B. Wiik.

Specimen Nos	Na_2O	K_2O	Na_2O + K_2O	Petrographic description on page
Central gneiss				
14 501	4.83	2.41	7.24	34
14 502	4.86	1.50	6.36	36
14 506	5.50	1.15	6.65	36
14 507	5.52	0.90	6.42	37
14 508	5.83	0.85	6.68	38
14 510	4.50	3.38	7.88	38
Average values	5.17	1.70	6.87	
Area between the inner and outer amphibolite rings				
14 514	4.38	2.86	7.24	29
14 525	4.40	3.20	7.60	50
14 528	4.14	5.78	9.92	49
14 572	4.60	3.12	7.72	48
14 573	4.90	3.36	8.26	44
Average values	4.48	3.66	8.14	
Quartz dioritic gneiss layers in amphibolites				
14 536	5.05	1.11	6.16	46
14 569	5.31	0.55	5.86	47
Average values	5.18	0.83	6.01	
Surroundings on the dome				
14 554	5.46	1.00	6.46	41
14 561	5.77	1.29	7.06	41
14 568	4.57	2.50	7.07	42
14 576	3.43	4.29	7.72	43
14 587	5.09	3.21	8.30	43
14 597	5.63	0.76	6.39	43
14 613	5.08	2.41	7.49	44
Average values	5.00	2.21	7.21	
Average values of all areas	4.96	2.10	7.06	
Average values of all 20 analyses	4.94	2.28	7.22	

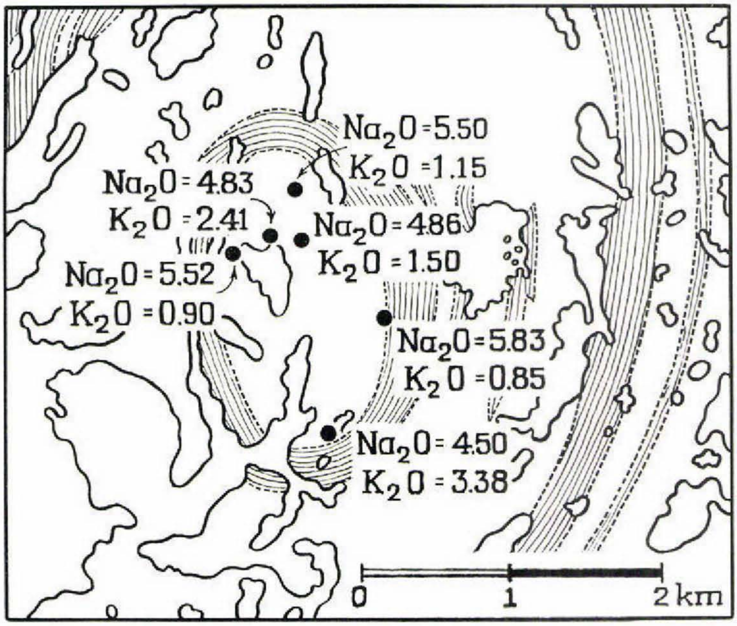

Fig. 25. Content of Na_2O and K_2O in samples from central gneiss. All values weight %. Compare Fig. 24.

textural relations of the potash feldspar and the plagioclase appear to vary greatly. The plagioclase contains potash feldspar and the potash feldspar contains plagioclase in varying amounts. The greatly varying K_2O content of granodioritic and quartz dioritic rocks indicates that the potassium may be, at least in part, of metasomatic origin.

TECTONIC DESCRIPTION

BEDDING AND FOLIATION

In mapping and studying geological structures, it is extremely important to ascertain whether an S-surface appearing in the field runs parallel to the bedding or not. Discriminating reliably between original bedding and foliation of metamorphic origin is perhaps one of the most difficult problems in the analysis of structures of highly metamorphic areas, and erring in this respect is easily apt to lead to a completely wrong conception of the structure of an area (cf. Billings 1954, pp. 344—345, Noe-Nygaard and Berthelsen 1952, pp. 258—262). Also in the region here under consideration, this discrimination has proved to be a highly difficult matter in many places, and in some cases no solution could be reached.

In many places, but mainly in the western and northern parts of the dome, the mode of occurrence of the rocks resembles closely the stratification of younger and far more weakly metamorphosed formations, especially when viewed from some distance (Fig. 13 on p. 44). The mode of occurrence of the amphibolites and hypersthene gneisses — which in places extend as gently dipping or nearly horizontal layers of practically unvarying thickness and petrographic character for several kilometers — gives the distinct impression of original bedding.

The pyroxene amphibolites and amphibolites are seen, upon close examination, to be usually more or less distinctly layered. Dark and light layers alternate and the thickness of the layers varies between a few meters and a few millimeters. The most significant difference between the dark and the light layers appears to be that the darker ones contain a greater abundance of mafic minerals, primarily hornblende (Table I, p. 28). It is, however, hard to determine to what extent this alternation of light and dark layers is due to changes of material occurring during the sedimentation and to what extent to segregation of the rock components in various layers or bands during metamorphism (cf. Turner 1941, pp. 1—16, and Billings 1954, p. 345).

In a large part of the mapped area, particularly in the vicinity of the dome itself, with the exception of its eastern portion, the dip of the layering is 45° or less and in many places only between 5° and 20°. In these areas there was not observed foliation whose plane intersects the bedding plane. The only S-surface to be observed in the field is that of the primary bedding, which is likely to be further accentuated by concordant foliation and/or segregation banding of metamorphic origin, This type of foliation is designated by Mead (1940, p. 1009) »bedding foliation» and by Billings (1954, pp. 340, 343) »bedding cleavage» or »bedding schistosity».

In a few places evidence has been observed of the occurrence of two different S-surfaces in the same exposure. In such cases one S-surface appears to be that of the original bedding and the other one that of foliation of metamorphic origin, which intersects the former.

One such place is situated northeast of the central gneiss approximately half way between the inner and the outer amphibolite ring (Locality 33, Plate I). In addition to a gently dipping, in spots nearly horizontal S-surface, there occurs at this locality steeply dipping or vertical foliation. According to the field observations, two intersecting S-surfaces are involved.

A similar place has been found on the northern shore of the lake Quagssup Taserssua, on a curved peninsula, southwest of the dome (Locality 34, Plate I) The curved form of the peninsula indicates a large fold and the same impression has been obtained through stereoscopic examination of aerial photographs. Field observations made at the western end of the peninsula indicated, however, that a steeply dipping foliation ran straight N 15°E across it, intersecting the plane of the probable bedding. In the same place, another, much weaker and gently dipping S-surface was observed, its attitude conforming quite well to the shape of the probable fold. The rock in which these two intersecting S-surfaces have been noted is a rather fine-grained, pale gneiss. Owing to the scantiness of mafic minerals, these S-surfaces are rather faintly in evidence. In the eastern part of the peninsula, where the rock is amphibolite, two intersecting S-surfaces have not been found.

Similar observations of the existence of two intersecting S-surfaces have been made also elsewhere in the region investigated, particularly to the west and to the north of the dome. In these, as in the foregoing cases, one of the S-surfaces is probably parallel to the original bedding. The other, intersecting S-surface probably represents foliation of metamorphic origin. The relation of the latter to major structures could not be determined with certainty on account of the scantiness of the observations. The probability is, however, that it developed parallel to the axial plane. What we have, therefore, is probably an axial plane cleavage, according to Mead (1940, p. 1010).

During the field work some suitable amphibolitic layers were followed step by step for several kilometers and the attitude of the S-surface to be seen in the amphibolite was measured at regular intervals. In certain places it was observed, however, that the strike of the only S-surface, foliation and/or banding apparent in the amphibolite did not conform to the strike of the amphibolitic layer but deviated from it in many instances by 10° to 20°. In other words, this S-surface does not run parallel to the original bedding.

These observations have been made in areas that are wholly exposed and where the amphibolitic layer is completely visible both in the field and in aerial photographs. Accordingly, the strike of the amphibolitic layer could be examined and mapped quite reliably. The observations have been made chiefly on the northeastern and northern sides of the dome, where the dips of the foliation, layering and probably also the bedding are steep or vertical.

The reasons for this behaviour of the S-surfaces of the amphibolites may be many and differ with each separate case. In some cases the effect of local magnetic anomalies was suspected — this would have meant that the whole phenomenon was illusory, but this could not be demonstrated. It is also possible that the amphibolite is in some places folded, although the layer itself does run rather rectilinearly and the field observations are not sufficiently detailed to verify the folding. Locally the foliation and/or banding is likely to turn more or less parallel with a fault, etc. In some localities the observations were too numerous and consistent, however, to be explained in these ways. A far more plausible explanation is that in the field only foliation and, perhaps, segregation banding of metamorphic origin can be observed and that the original bedding has been nearly or totally obliterated. Detailed study is greatly hampered, however, by the fact that in many places the amphibolites are strongly weathered and the poor quality of the exposures is apt to prevent detection of two intersecting S-surfaces of different ages.

The S-surfaces measured in the field have been marked on the geological map with the same symbol irrespective of wheather they appear, in the light of field observations, to represent original bedding, foliation of metamorphic origin or, perhaps, segregation banding.

FOLDING AND LINEATION

The large folds, which are presented on the geological map, can invariably be recognized in the aerial photographs either directly or under stereoscopic examination. Their existence has then been verified by following

Fig. 26. Gentle anticlines in northern part of dome. Crests of folds are situated at highest tops of ridges, or 20—30 m above level of lake. Site is 1 km north of northern contact of central gneiss. View towards N 60°E.

in the field step by step some suitable layer of rock; almost without exception amphibolites or related rocks have served this purpose. The folds identified in this way have generally been so wide that their observation *in toto* from a single spot on the ground is in most cases impossible. They commonly measure from a few hundred meters to several kilometers across.

In the northern part of the dome, folding has been observed on a slightly smaller scale than that described in the foregoing. This folding is very gentle. Its wave length is a few hundred meters and the crests of the anticlines are at most 10 to 30 meters higher than the troughs of the synclines (Fig. 26). In connection with such folds, there often occurs jointing developed perpedicular to the fold axis (Fig. 27).

The small-scale folding, which varies in width from a few dozen centimeters to several meters, is mostly very gentle, just as are the large folds. In the area of the dome no exceptions to this have been met with, but a few do occur in the surrounding terrain. In some instances the small-scale folding has been so gentle that it has been advisable to apply to it a special tectonic symbol of its own. The axes of these very gentle small folds deviate in some cases distinctly from the attitude of the regional fold axis (Plate II), and the elucidation of the mode of origin of such very gentle small-scale folding is difficult. One possible explanation is that it originated in connection with boudinage.

Some of the small folds are typical drag folds in shape. One of them is situated on the eastern flank of an anticline several hundred meters wide,

Fig. 27. Ridges running parallel to fold axis and jointing approximately perpendicular to latter. Fold axis plunges 5°—10° north, or to left in picture. View toward N 70° E. Tops of ridges are about 20—30 m higher than foreground.

Fig. 28. Drag folds in migmatic rock. Eastern flank of almost isoclinal anticline several hundred meters wide plunging 15° north. View towards north. Locality 36 in Plate I.

Fig. 29. Great drag fold situated on western flank of anticline about 2 km wide. Height of wall in picture is about 25 m. Northwest of dome. Locality 35 in Plate I.

west of the dome. (Fig. 28, p. 71). Its locality is marked on the Plate I with the number 36.

An exceptionally large and clear-cut drag fold (Fig. 29) is situated northwest of the dome (Locality 35, Plate I). The height of this fold is roughly 20 meters. It rests on the western flank of an anticline about 2 km wide.

Especially in the study of the structures of high-metamorphic complexes, the term »lineation» has been very much used and misused. The term itself has fallen into considerable disrepute because it has been applied to a great variety of linear structures without any clear definition of its signification in each separate case. In the present study the lineation has been measured on the bedding or foliation planes, where it is due to parallel alignment of mineral grains, mainly hornblende prisms or biotite flakes. It has been endeavored to make observations of this type of lineation, but the results achieved have remained slight. It has proved difficult to measure reliable lineations from the principal rock types of the region, namely, granodioritic and quartz dioritic gneisses, hypersthene gneisses and amphibolites.

The few lineation observations that seem reliable are presented in Plate II. In the light of these observations, this kind of lineation agrees most often but by no means invariably with the conception of the attitude of the regional fold axes arrived at by other means.

On the other hand, observations of the lineations have not been appreciably needed in the elucidation and mapping of larger geological structures, for other procedures have proved far more reliable. The trend and plunge of the fold axis of large folds has generally been determined from those points where the crest of the anticline or the trough of the syncline »rises into the air», i.e., intersects the surface of the ground, and where beds of the opposite limbs converge and the beds show a maximum curvature. By means of a stereographic projection, the attitude of the fold axis can be constructed from a few measurements of the strike and dip of a bed in such a place much more reliably than is possible on the basis of any observations of small folds or lineations (cf. Wegmann, 1929 a, b; Phillips, 1954).

JOINTING AND FAULTING

During the field work, the jointing of the region investigated proved so complicated and difficult to study that no systematic field observations or measurements were made of it. A far clearer and more unified picture was observed to be obtainable by photogeological means (Plate III).

The relation of a few joint sets to other geological structures appears rather plain. One joint set is always parallel to the bedding or foliation. Another joint set has a strike parallel to the bedding or foliation, but the dip of the joints is approximately perpendicular to the dip of the bedding or the foliation. These two joint sets appear very clearly in, e.g., the marginal parts of the central gneiss, especially close to its northern contact (Fig. 8 on p. 34) and in association with gently dipping amphibolite and other layers. In certain cases the jointing perpendicular to the fold axis of major folds is also highly developed (Fig. 27 on p. 71).

Numerous large fault zones have been observed in the mapped region, being clearly visible in aerial photographs and topographic maps as well as in the field. Cutting across high ridges and mountains, they frequently form deep gorges. According to photogeological investigations and field observations, there are at least several dozen smaller fault zones. In most of the cases studied, the fault plane appears to have a steep or vertical dip.

Insofar as possible, efforts were made both in the field and by photogeological means to obtain data on the nature of the movement along the faults and on their age relations.

In the southwestern corner of the region covered by the geological map, two fault zones intersect two nearly parallel diabase dikes with a N—S trend. The trend of the more southern fault zone is N 70°E and that of the one farther north N 80° E. Each of them appears to be approximately vertical. These dikes have enabled determining the direction and magnitude of the strike-slip component in each of the fault zones. In both cases the more northern block has moved eastward compared to the more southern block. In other words, according to Anderson's terminology (1951, p. 59), they both are dextral wrench faults. The strike-slip in the more southern fault zone is about 70 to 80 meters and in the more northern one about 10 to 20 meters. These strike-slip components are fairly definitely established and not merely apparent, for both diabase dikes are just about vertical. No reliable data exist on the magnitude of the possible dip-slip component, but it seems to be small or negligible. The magnitude and direction of the given displacements naturally apply only to the time after the intrusion of the diabase dikes. No other reliable marker layers besides these dikes have been found. In the light of photogeological studies, however, other morphological features yield the same result as the diabase dikes. Accordingly, at least the greatest part of the movement along the fault zone took place after the intrusion of the diabase dikes. In the morphology both fault zones occur as gorges the depth of which is mostly from 5 to 20 meters. The breadth of the gorges is mostly 10 to 30 meters.

Some 5 km north of these fault zones there is located a third, which runs fairly parallel to the other two across the end of the Usuk peninsula. It trends N 70°E and seems to be nearly vertical. In the topography it occurs as a slightly shallower and narrower ravine. No point has been found in the mapped area where this fault intersects a diabase dike or some other dependable marker layer. Consequently, it has not been possible to determine the direction and magnitude of the relative movement as readily as in the cases described earlier. Some field observations indicate, however, that the more northern block has moved westward, in comparison with the more southern one, roughly 10 to 20 meters. According to photogeological investigations, the direction of the displacement is the same and the magnitude of the strike-slip about 20 to 40 meters. In contrast to the previously described faults, this one thus appears to be sinistral. The magnitude of the possible dip-slip component is unknown.

Between Godthaabsfjord and the southeastern part of the dome, there are two large fault zones, which have been followed for a distance of about 10 km by means of aerial photographs and in the field. The trend of the more northern fault zone is N 60°E and that of the more southern one N 45°E. The dip appears to be vertical. No reliable observations have been obtained of the direction and magnitude of the displacement along these faults. One somewhat unreliable observation has been made at a point where the more northern fault zone runs across Niaqornaq peninsula. In the southern part of the peninsula there is a diabase dike which appears to be cut off at the point of intersection with the fault. No extension of the dike, properly speaking, has been found. In an area of a few square meters on the northwestern wall of the gorge formed by the fault zone, over 200 m from the northern end of the dike toward the northeast, the remains of a strongly crushed and mylonitized diabase dike have been found. If these remains derive from the same dike, the northern block has moved northeast in comparison with the more southern one and the magnitude of the strike-slip is over 200 m. No other data supporting this view are available.

In the region investigated a few other faults as well have been found, the direction of displacement and the magnitude of the strike-slip component of which could be determined principally by photogeological means. They are also shown on the geological map. In all these cases the magnitude of the strike-slip appears to be 10 to 30 meters.

As the appended aerial photographs and the Plate III show, the entire region under investigation is morphologically exceedingly broken up. In most cases, however, it is difficult to determine whether a zone or line observed in aerial photographs or in the field intersecting other geological structures, is a fault with a remarkable displacement, a fault in which the total displacement is so small — a few meters or less — that it is hard to recognize either in the field or by photogeological means, or just a joint possibly enlarged by erosion. One is apt to walk across the smallest zones in the field without noticing them, although they can be clearly distinguished in aerial photographs under stereoscopic examination. The larger fault zones usually occur in the topography as quite clear-cut gorges.

The central parts of the larger fault zones are very seldom exposed. Ordinarily they are covered by boulders, water or vegetation. For this reason, the reliable elucidation of petrographic and mineralogical changes that possibly occurred in connection with faulting is difficult. Usually observations relating to it have to be made from the walls of the fault zone, where the rocks have probably not undergone such far-reaching alterations as in the middle of the zone.

In the three fault zones described in the foregoing — the ones situated to the west and southwest of the dome — the rocks appear to have broken only mechanically in connection with the faulting. Furthermore, weak epidotization has been observed in places in the walls of the fault zones. In none of these three fault zones, however, is the middle of the zone exposed.

In many places in the great fault zones situated to the southeast of the dome, marked mylonitization (Fig. 30) and, in addition, some epidotization have been observed. In certain places the rocks have altered completely aphanitic. The middle portions of the fault zones are seldom exposed here, either.

Fig. 30. Southeastern border of great fault zone. Niaqornaq. View towards northeast.

The trend of the great fault zones discussed in the foregoing is approximately the same as that of the Fiskefjord faults (Berthelsen and Bridgwater, 1960, pp. 14—15; Berthelsen, 1962). With but a single exception, they show dextral displacement, they cut up the diabase dikes and the rocks in them have undergone by and large the same kind of petrographic alterations as in the Fiskefjord faults. Accordingly, it seems probable that the great fault zones of the region investigated are approximately of the same age as the Fiskefjord faults.

ON THE STRUCTURE OF THE DOME

The main features of the structure of the dome and its surroundings are best to be seen from the geological map and Plate II, which includes various data on the fold axes together with related observations. Matters concerning the structure of the dome have also been discussed in the previous chapters.

As previously the middle of the dome can be described as a homogeneous quartz dioritic and granodioritic gneiss area. This central gneiss is conformable overlain by an amphibolitic layer, which dips radially outwards from the center of the gneiss at 20°—45°. The thickness of the amphibolitic layer varies, according to estimates made on the basis of its outcrop breadth

Fig. 31. Northern contact of central gneiss. Central gneiss in foreground and amphibolite on upper slope. Person at right is standing at contact. View towards northeast.

and dip, from approximately 100 m in the western part of the layer to slightly over 200 m in the eastern part of the layer. The form of the central gneiss and the amphibolitic layer surrounding it is a dome or doubly plunging anticline, which is slightly tilted eastward. Figs. 6—8 on pp. 32—34 offer a general view of the vicinity of the central gneiss.

The foliation to be seen in the marginal portions of the central gneiss, the contact between the gneiss and the amphibolite and the S-surfaces noticeable in the amphibolite — probably bedding — are all conformable The foliation of the central gneiss is weak in its marginal portions and in the center of the gneiss it is scarcely detectable. The reason for this may be only or mainly the fact that the gneiss does not contain more than very small amounts of mafic minerals.

Apophyses possibly penetrating the amphibolite from the central gneiss have been sought but not found. At all the points investigated where the contact of the amphibolite and the central gneiss is exposed, it appears to be a shear surface or a shear zone. The thickness of this shear zone reaches 10 to 50 cm. In many spots it contains abundant biotite, whereas in other places it tends to be cataclastic.

In certain places near the northern and northeastern contact of the central gneiss, cataclastic zones and biotite-rich shear surfaces have been found in the gneiss parallel to the contact. Their distance from the contact

Fig. 32. View towards northeast over northermost part of dome while sun is setting in northwest. Bedding dips very gently north and northwest or is nearly horizontal.

is as much as 10 to 20 meters, measured over the ground. The amphibolite layer thus appears to have slipped along the contact between the amphibolite and the central gneiss, and shearing and cataclastic movements have taken place to a smaller extent in the gneiss itself as well. Fig. 31 shows the mode of occurrence of the northern contact of the central gneiss and the amphibolite in the field.

Evidence of possible diapiric movements has been sought in the central gneiss and its surroundings but with scanty results. The dip of the contacts of the central gneiss is not appreciably steeper than the dip of the bedding and/or the foliation in its surroundings.

Boudinage has been met with at a number of places in the lower part of the inner amphibolite layer near the western contact. It usually occurs in the immediate vicinity of the contact, i.e., 20 to 50 cm away. The length of the boudins along the strike of the amphibolitic layer is generally in the range of 10 to 20 cm, but the direction of their longest axis seems to be radially outward from the central gneiss. This boudinage is of too local development and insufficiently clear, however, to be regarded as reliable evidence of the diapiric rise of the central gneiss.

The structure of the outer portions of the dome is also fairly simple, and it can best be seen on the appended maps and on the Figures 32—33. The tilting of the dome toward the east is far more conspicuous, however, in its outer parts than in the central gneiss and its surroundings. The outer amphibolite layer is slightly overturned in the eastern part of the dome.

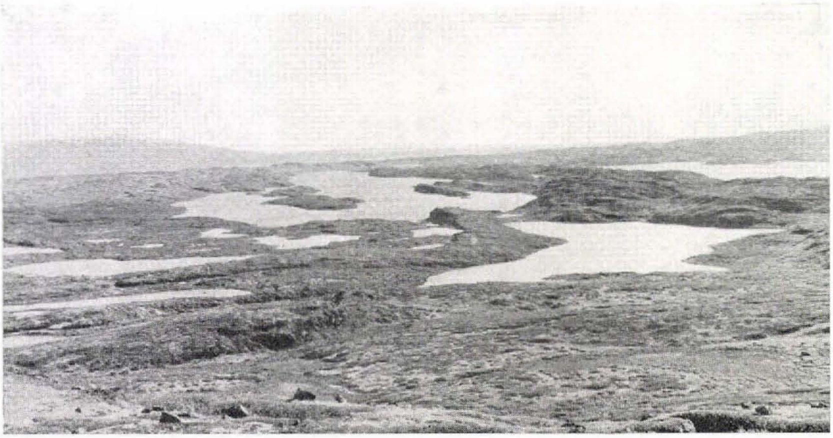

Fig. 33. View towards S 15° W over western part of dome (at left) and great lake west of it. Northwesternmost corner of dome is situated on eastern shore of nearest lake in right foreground.

ON THE STRUCTURE OF THE SURROUNDINGS OF THE DOME

The area north of the dome is structurally perhaps the most complicated part of the entire mapped region. The main structural features are clearly evident on the geological map and on the Plate II, i.e., a syncline, or, perhaps, synclinorium several kilometers wide opening toward the north. West of this syncline there is an anticline, likewise several kilometers wide, which plunges gently southeast. On the eastern side of the syncline the folding is more complicated. Inside the nose of the syncline, a couple of kilometers north of the northern border of the dome, the axis of the syncline appears to plunge roughly 40° toward the NW; but 1 to 2 km northwest the axes of small folds plunge gently SE. Some 5 to 10 km northward from the northern border of the dome, ridges formed mainly by amphibolite layers rise at an angle of about 5°—10° toward the north to altitudes of between 450 and 550 meters (Fig. 35). The morphology of the area and tectonic observations indicate here a fold axis plunging gently toward the south or southeast.

In the northwestern corner of the geological map (Locality 37, Plate I), three parallel arching amphibolite layers may be observed. They are situated on a fairly steep slope and a two-dimensional map is apt to give a misleading conception of their true form. The true mode of occurrence of these layers is best revealed by Fig. 34 where the northernmost layer is to be seen. The layers form part of the eastern flank of a great anticline plunging gently southeastward.

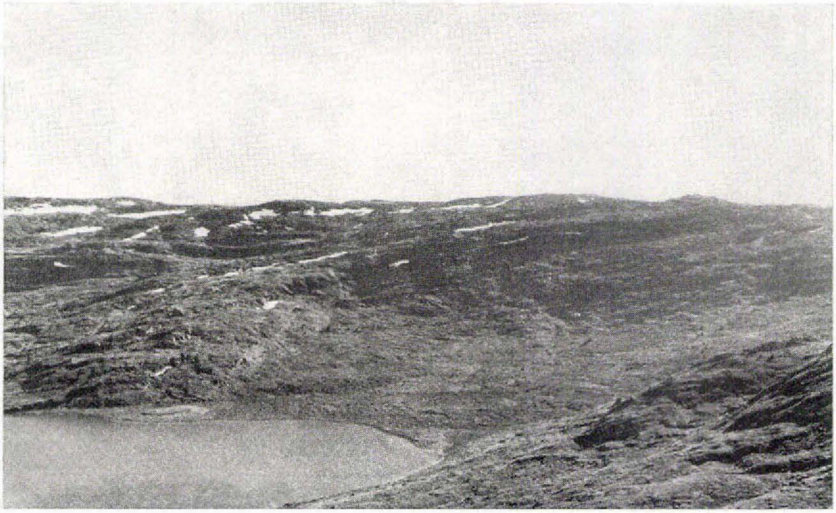

Fig. 34. Portion of eastern flank of anticline about 2 km wide. Northwest of dome. Locality 37 in Plate I. Fold axis plunges 20° to left or S 20° E. View towards west. Top of ridge is about 200 m higher than level of lake.

West of the southwestern part of the dome there is a gentle syncline, the width of which probably reaches a few hundred meters. It appears to be largely situated underneath the lake, and the reliability of the tectonic observations is not entirely free of doubts. In certain places it seems possible that the S-plane appearing in the field represents a foliation that does not run parallel to the bedding.

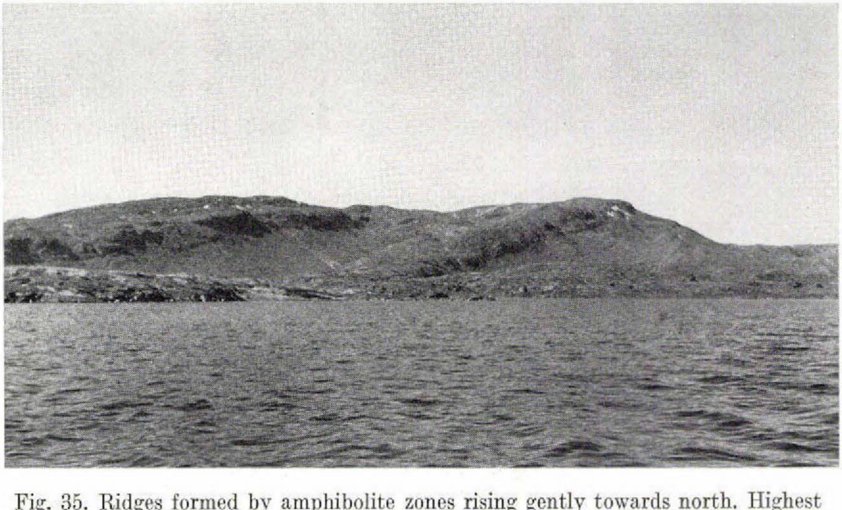

Fig. 35. Ridges formed by amphibolite zones rising gently towards north. Highest tops are situated about 8—10 km north of northern border of dome and rise 400—500 m above level of lake. View towards northwest.

Fig. 36. View towards south over area west of dome.

Two kilometers west of the southern end of Usuk peninsula, an anticline several hundred meters wide has been recognized. Its locations is marked on the Plate I with the number 36. The fold axis plunges about 15°—20° north. The fold is almost isoclinal and its axial plane dips about 70°W. In addition, a few other probable folds have been found west of the dome. The field observations do not, however, suffice to draw reliable conclusions concerning their size, attitude of the fold axes and the axial planes, etc. The rocks are fairly homogeneous and the bedding and/or foliation generally hard to detect, in addition to which suitable marker beds are lacking. Furthermore, in certain places, fracture cleavage tends to hamper the investigation of these folds. The total structure of the area is best grasped from appended maps and Fig. 36.

The area southeast, east, and northeast of the dome appears to be rather simple in structure. It is characterized by numerous fairly parallel amphibolite layers with N—S strike and, for the most part, a 70°—85° W or vertical dip. These layers generally vary in thickness from 20 to 200 meters. Several of these layers run very nearly or quite parallel for a distance of as much as 20 km. In spite of the fact that they have been usually followed step by step along the strike of the layers, they have not been observed to converge anywhere; thus, at no place does the crest of the anticline or the trough of the syncline appear to intersect the surface of the ground. Accordingly, the regional fold axis ought to be nearly horizontal and to trend N—S. No evidence is available to show whether the amphibolite layers are stratigraphic beds situated on top of each other or whether isoclinal folding causes certain layers to recur at least in some cases.

SUMMARY AND DISCUSSION

The area of the Ipernat dome with its surroundings, which is described in this paper, belongs to the extensive Precambrian bedrock region of western Greenland. Geologically it belongs to a pre-Nagssugtoqidian orogeny, which is probably the same as the Ketilidian orogeny in southern Greenland described by Wegmann (1938). The pre-Nagssugtoqidian rocks have been divided into several complexes. The area described here belongs to the Nordland complex.

By far the greatest part of the area not covered by lakes and ponds is exposed. This circumstance has made it possible to map the structure of the dome and its surroundings with unusual reliability, mainly by photogeological methods and by tracing suitable rock layers in the field step by step.

The main rock types of the mapped area are pyroxene amphibolites, amphibolites, hornblende gneisses and quartz dioritic to granodioritic rocks. In addition, there are occurrences of garnet-cordierite gneisses and ultrabasic rocks as well as pegmatite, aplite and diabase dikes.

At least for the greatest part, the rocks, excluding the dikes, crystallized under PT-conditions corresponding to the hornblende-granulite subfacies of Turner (1958). Subsequently, a large proportion of the rocks retrogressively metamorphosed under PT-conditions corresponding to amphibolite and/or epidote-amphibolite facies according to the facies classification of Eskola (1939). Nowhere has this retrogressive metamorphism been observed to have led to the creation of a new mineral assemblage completely in equilibrium.

The main rock types of the area all show a conformable mode of occurrence. Saksela (1953), who has described the tectonic occurrence of plutonic rocks in Finland, divides them into two classes: synorogenic and late-orogenic. The tectonic mode of occurrende of quartz dioritic and granodioritic rocks of the mapped area corresponds closely to the synorogenic group described by Saksela. Only the pegmatite, aplite and diabase dikes are discordant in their mode of occurrence.

The folding in the whole mapped area appears to be rather gentle. The breadth of a few of the anticlines and synclines is several kilometers. Noe-Nygaard and Berthelsen (1952) regard a gentle mode of folding to be a typical feature of rocks of the granulite facies. Similar observations have been made with respect to the area of highly metamorphic pyroxene-gneisses in southwestern Finland (Härme, 1954, p. 48; 1960, pp. 42—45 and 62). Wegmann (e.g., 1953, 1956) has greatly emphasized the different structural styles in the different structural levels (Stockwerke).

The Ipernat dome is some nine kilometers long and six wide. It consists of a quartz dioritic to granodioritic central gneiss and several concentric rings. The two most conspicuous rings consist in the main of amphibolite. The central gneiss is two kilometers long and 1.2 kilometers wide. The foliation to be seen in its marginal portions, the contact between the gneiss and inner amphibolite ring and the S-surface noticeable in the amphibolite — probably bedding — are all conformable. No apophyses intruding from the central gneiss into the surrounding amphibolite have been detected. The contact between the central gneiss and the amphibolite is, at least in most places, a shear surface. The bedding and/or foliation dip outward from the center of the dome, in most cases at angles of 10° to 45°. In the eastern part of the dome the dips vary from 45° to 90°. The dome is slightly tilted to the east. Evidence of the diapiric rise of the central gneiss has been sought but with very scanty results.

In the light of field observations, microscopical investigations and chemical analyses of twenty representative samples of quartz dioritic and granodioritic rocks taken from different parts of the area, the potassium seems to be slightly concentrated into the area between the inner and outer amphibolite ring, but not into the central gneiss.

Gneiss domes and their mode of origin have been described and discussed by numerous geologists from different countries. Some well-known examples of domes are the Vredefort dome in South Africa (e.g., Hall and Molengraaff, 1925) and the domes in Maryland and New Hampshire, U.S.A. (e.g., Cloos and Broedel 1940; Chapman 1939; Billings 1945). Wegmann (1930) has elucidated the problems of diapirism, which are closely related to the mode of origin of gneiss domes. Attention in the following will be mainly given the studies on the Precambrian domes in Finland and Greenland with which the present author is more familiar.

Very well known is Eskola's (1949) conception of so-called mantled gneiss domes, the origin of which he attributes to two successive orogenies. In his view, these domes apparently represent earlier synkinematic intrusions related to an orogenic period. The plutonic mass is later eroded and levelled, and thereafter follows a period of sedimentation. The domes are heaved up in connection with the granitization of the old pluton during a second orogenesis. Eskola has also made later contributions (1951, 1952) to the problem of mantled gneiss domes.

Saksela (1951, 1952, 1953) emphasizes that the Karelidic gneiss domes are situated at axial culminations and it is to this circumstance that he principally attributes their origin.

Preston (1954) has studied in detail the Karelidic gneiss domes of the Kuopio district in eastern Finland. His description fits well with the examples of the type at Pitkäranta that had been described and discussed by Trüstedt (1907), Eskola (op.cit.) and Saksela (op.cit.). Preston's conception of the origin of mantled gneiss domes comes quite close to that of Eskola's, except that the gneiss of the Kuopio domes is not wholly orthogneiss in origin, and he concludes that also other rocks than the old pluton have been mobilized and swollen by this same geological process. The chief reason for the swelling of the domes is, in his view, an expansion of volume brought on by a potash metasomatism.

A comparison between the Karelidic domes and the Ipernat dome brings out many differences. According to Eskola (1949, 1951) the lowest horizon of the mantle of Karelidic domes consists in some cases of basal conglomerates with boulders of the same gneiss that forms the dome; in others the basement stratum is a layer of quartzite, overlain by dolomite and mica schists; and in still others the dolomite or amphibolite forms the basement stratum. In the Ipernat dome the layer conformably lying on the central gneiss consists of amphibolite overlain by rocks of quartz dioritic to granodioritic composition and amphibolite layers. Furthermore, investigations so far made have brought to light no marked petrographic difference between the central gneiss and other homogeneous granodioritic and quartz dioritic rocks in the area of the Ipernat dome and its surroundings.

Härme (1954) has studied the Mustio cupola in southwestern Finland. No gneiss core similar to that which in Karelidic domes is supposed to be the basement of sedimentation is to be seen here. The lowest member detected in the stratigraphic sequence is a leptite interbedded with limestone and penetrated by microcline granite. Above this follow subsilicic volcanic rocks and mica schists. According to Härme the updoming of this cupola was caused by the upheaval of the microcline granite in a liquid state, the overlying strata having been pushed up.

The closest object of comparison to the Ipernat dome is the Tovqussaq dome described by Berthelsen (1950, 1960). It is situated roughly forty kilometers northwest of the area mapped in connection with the present study. The size, structure and petrography of these two domes are in broad outline rather similar, but the structure of the surroundings of the Tovqussaq dome seems to be more complicated. According to Berthelsen's descriptions

(1960, pp. 58—60) and my own observations, made one day in the summer of 1954, there are also rather marked petrographical differences between the core rocks (or central gneisses) of the two domes. The core rocks of the Tovqussaq dome contain nebulitic bands, schlieren and veins in noteworthy amounts. None at all have been found in the central gneiss of the Ipernat dome, which as a whole is highly homogeneous.

According to Berthelsen (1960, pp. 214—215), the formation of dome structures in gneissic terrains depends on three factors designated by him physico-chemical disharmony, tectonic disharmony, and true double folding.

The Ipernat dome forms a natural and well-fitting part of a rather gently folded complex of highly metamorphic rocks. In this view it could simply be described as a gentle doubly plunging anticline. Even in cases like the Jura mountains, however, the folding is a very complicated process, where many factors and mechanisms act simultaneously and in succession (e.g., Wegmann, 1962). A still more intricate process is the folding in connection with high-metamorphic complexes, where also intrusions as well as metamorphic and metasomatic reactions take place. In this light it is also difficult to estimate to what extent incipient diapiric movements, metasomatic processes and other such possible factors have contributed to the origin of this dome.

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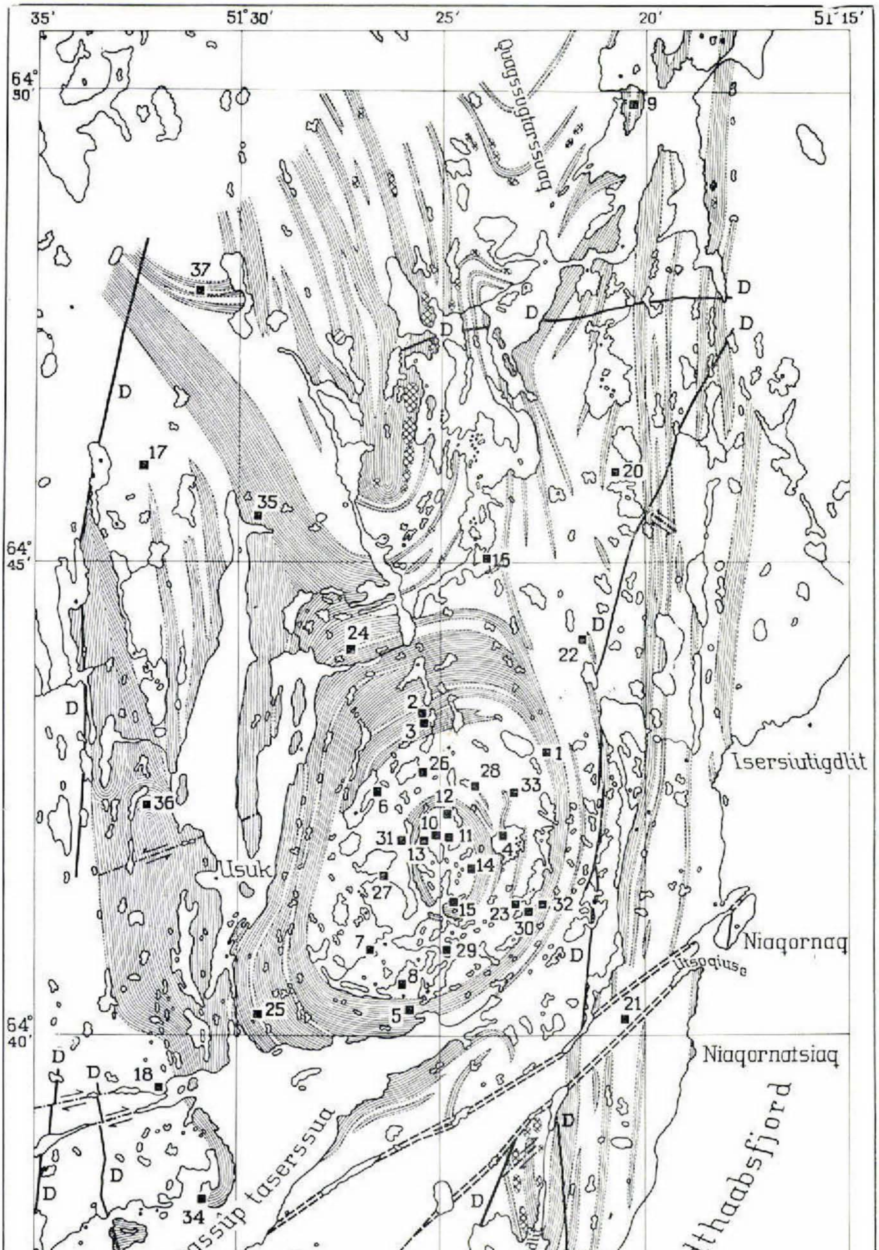
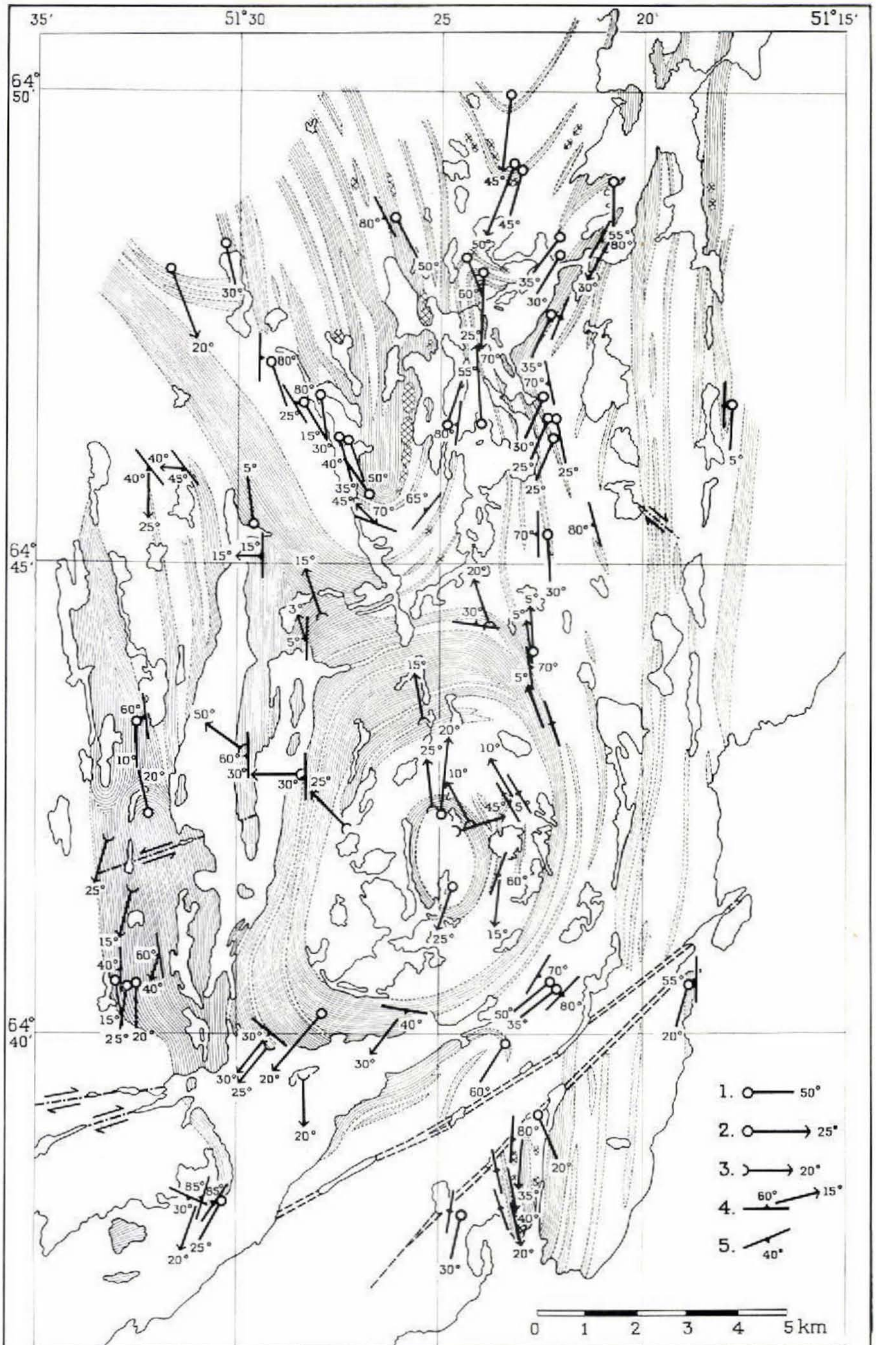
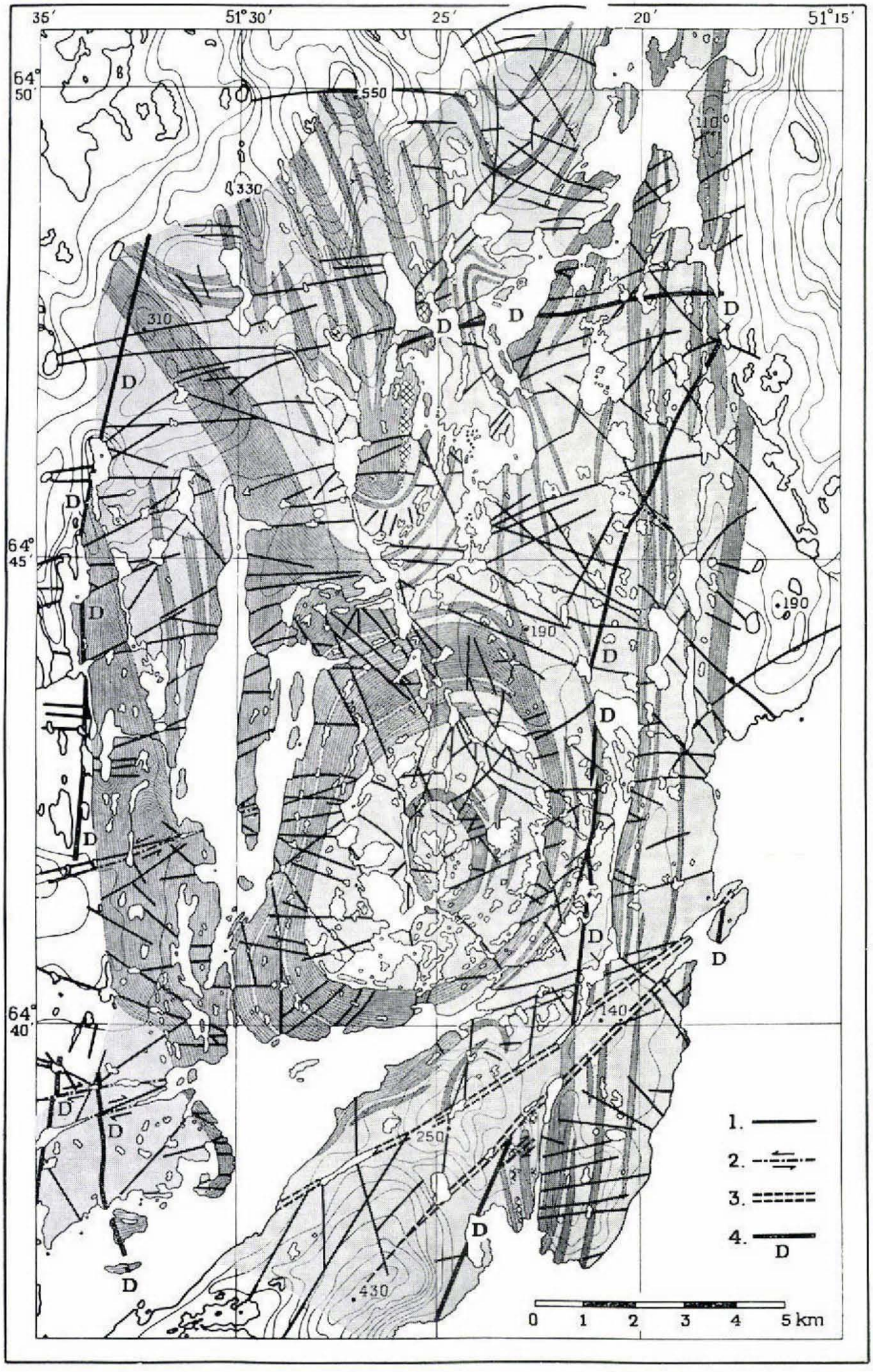


Index map of localities referred to in text.



Fold axes and related observations.

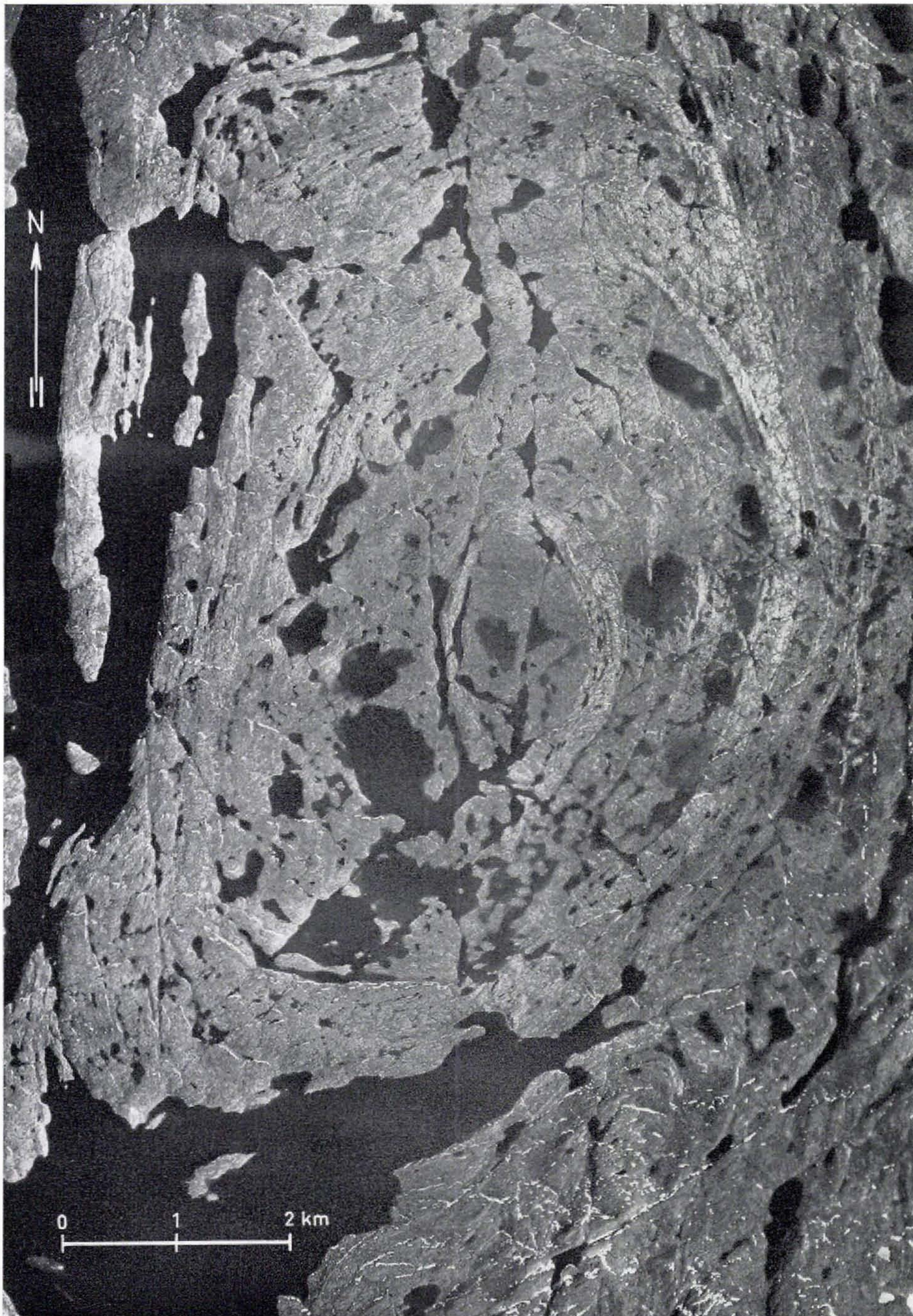
1. Fold axis measured on small fold.
2. Fold axis of large fold constructed by means of stereographic projection.
3. Fold axis measured on very gentle small fold.
4. Lineation and foliation. See text p. 72.
5. Bedding and/or foliation.



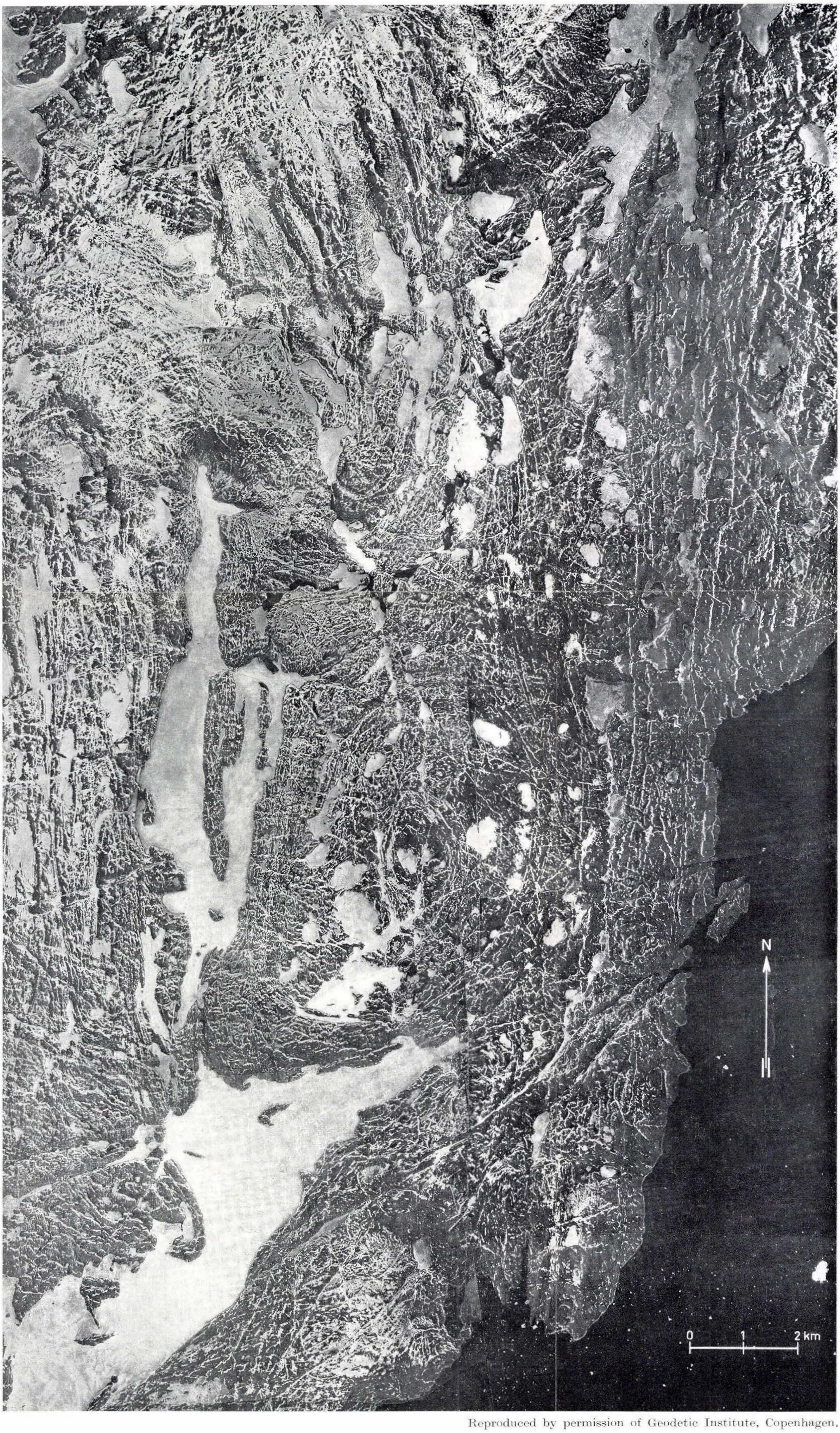
Joints, fractures and faults according to photogeological investigations. Joints parallel to strike of bedding and/or foliation are omitted.

1. Joint, fracture, or fault with very small displacement.
2. Fault with remarkable displacement.
3. Large fault zone.
4. Diabase dike.

Heights in meters. Contour interval 50 m. Base map reproduced by permission of Geodetic Institute, Copenhagen.



Aerial photographs A 31 B/69 and A 31 B/71 showing Ipernat dome in summer.



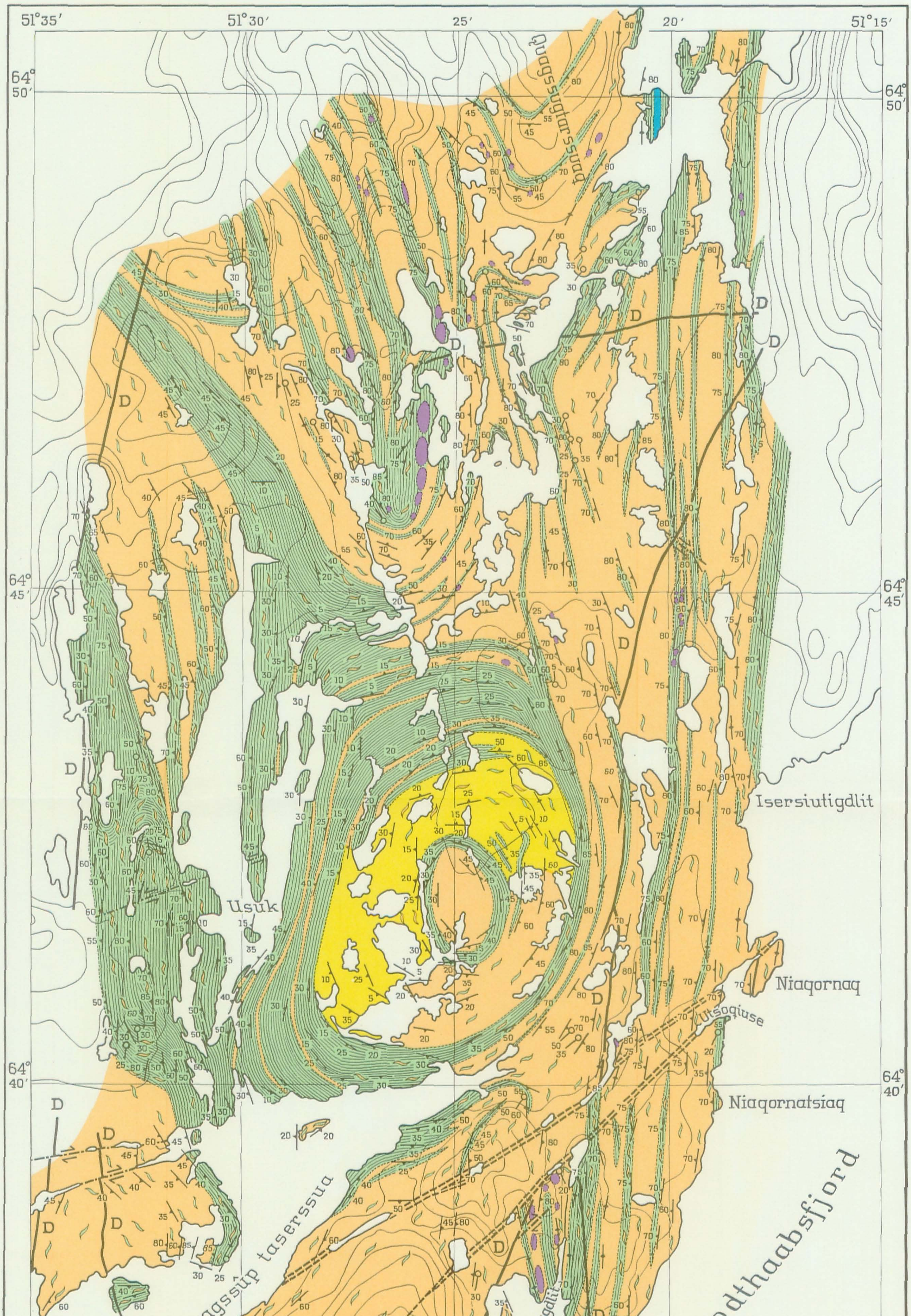
Uncontrolled mosaic of aerial photographs taken in spring. Same area as in geological map (Plate VI). Tones of some ice-covered lakes are slightly retouched.

GEOLOGICAL MAP OF IPERNAT DOME

by

RAIMO LAUERMA

1964



LEGEND

- Pyroxene amphibolites, amphibolites, and hornblende gneisses
- Hypersthene gneiss
- Quartz dioritic and granodioritic rocks
- Garnet-cordierite gneiss
- Ultrabasic rocks
- Quartz dioritic and granodioritic veins and schlieren
- Amphibolitic inclusions and schlieren
- Diabase dike
- Strike and dip of foliation, banding, and/or bedding,
- Fold axis
- Fault
- Large fault zone

Scale 1: 75 000

0 1 2 3 4 5 km

Contour interval 50 meters

Based on topographic map, scale 1: 50 000
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