GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 31

STRUCTURAL STUDIES IN THE PRE-CAMBRIAN OF WESTERN GREENLAND

III

SOUTHERN SUKKERTOPPEN DISTRICT

BY

ASGER BERTHELSEN

WITH 16 FIGURES IN THE TEXT AND 1 PLATE

Reprinted from
Meddelelser om Grønland, Bd. 123, Nr. 2

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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CONTENTS

Abstract.

This paper summarises several summers field work within the southern Sukkertoppen district. Since detailed mapping has only been carried out within smaller areas within the region, the remainder being covered by reconnaissance mapping along the coasts, the results should be considered as preliminary.

The southern Sukkertoppen district can be divided into three tectonic units, the Nordland, the Finnefjeld, and the Alángua complexes, which, most probably, were formed during the Ketilidian cycle (E. Wegmann, 1938). The metamorphic complexes are traversed by postorogenic dykes and faults (Berthelsen and Bridgwater, 1960). The dykes and faults were seemingly formed before the Nagssugtôqidian revolution which affected the country further to the north (Ramberg, 1948).

The northern Nordland complex is shown to have passed through a metamorphic and structural evolution very similar to that which recently has been described from a small area within the complex (see table 2). An original granulite facies rock assemblage has been exposed to two successive imprints of retrograde metamorphism: first an amphibolite facies metamorphism; next a postorogenic epidote-amphibolite to greenschist facies metamorphism in connection with the formation of the younger faults. Evidence is brought forward that the tectonic phases established from Tovqussap nunâ may also be traced within the remaining parts of the Nordland complex. In one case (see fig. 3) an analysis of the basement structures reveals that the post-orogenic faulting is of the wrench fault type.

The Finnefjeld complex which is build up of homogeneous hornblende-biotite-bearing quartz-dioritic gneisses is believed to have been originally composed of granulite facies rocks. Subsequent strong penetrative movements accompanied by low grade amphibolite facies metamorphism were responsible for the formation of the present Finnefjeld gneisses. This idea is strongly supported by the facts that relic patches of hypersthene gneiss and transgressive, but deformed, more or less uralitised diorite bodies occur within the Finnefjeld gneiss.

The Alángua complex comprises abundant pelitic and semipelitic schists, amphibolites, ultrabasics and skarn rocks in addition to gneisses which are considered to be of metasomatic origin. The ultrabasic rocks have been described by H. Sørensen (1952, 1953, 1954, and 1955). The rocks of this complex can also be shown to have passed through two periods of metamorphism (see also H. Sørensen, 1952); an original medium to high grade amphibolite facies metamorphism was succeeded by a later low grade amphibolite facies metamorphism accompanied by granitisation, pegmatisation etc., indicating the presence of a volatile-rich dispersed phase.

Although not studied in detail, the structures of the Alángua complex are sufficiently well-known to establish the kinematic evolution of this complex. The first amphibolite facies metamorphism seems to correspond to the Smalledal-Pâkitsoq phases of the Nordland complex, while the subsequent period of low grade amphibo-

lite metamorphism can be matched with the posthumous phase. During this latter, the northern part of the Nordland complex, which locally was thrust over the Alángua rocks (thereby causing their refolding) was converted into the present Finnefjeld gneisses. This interpretation explains the present differences between the three complexes as being due to Stockwerk tectonics, fig. 16. An alternative theory which holds that the Alángua rocks are younger than those of the southern complexes does not seem to concur with the field relation known so far. No mineral deposits of economic interest were found during the survey, but traces of sulfides (see tables 1 and 3), magnetite, molybdenite, corundum, monazite, zircon, talc and soapstone have been met with at various localities.

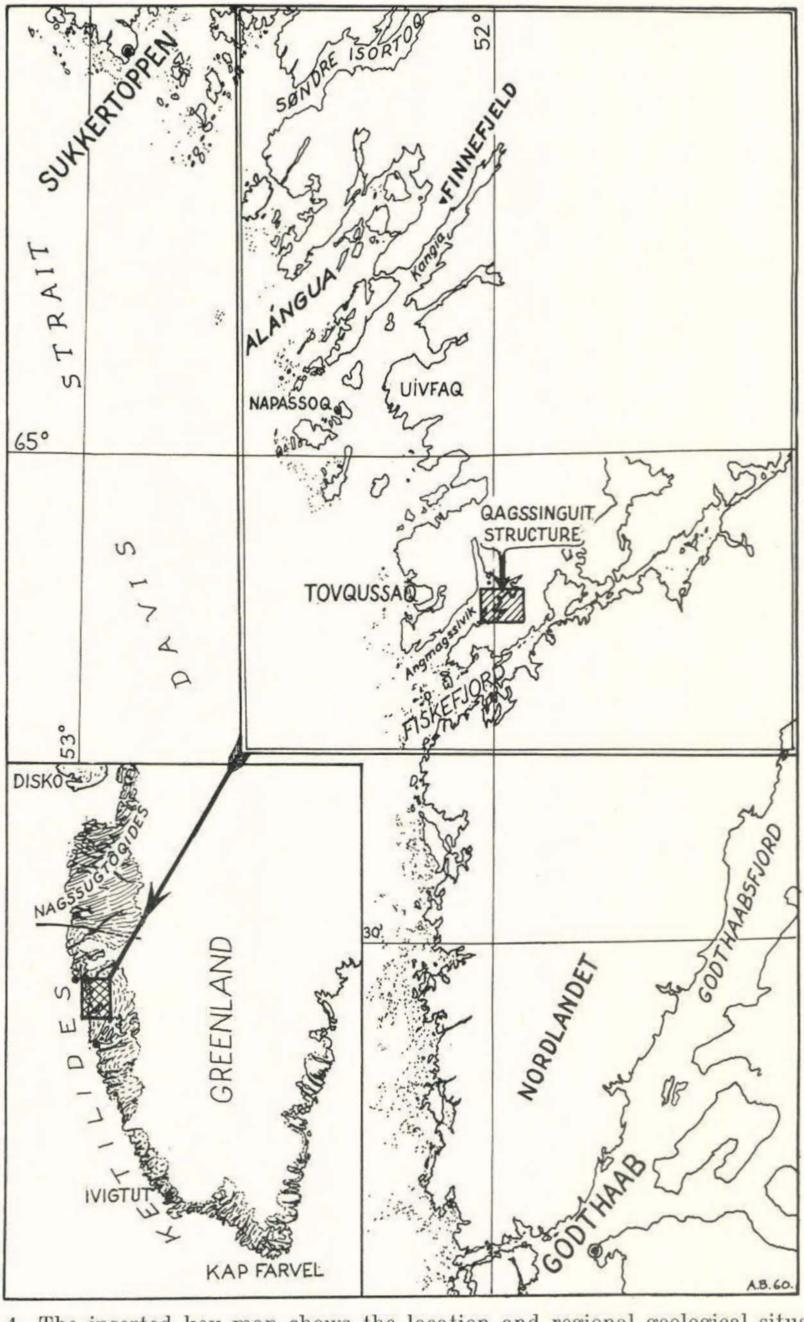

Fig. 1. The inserted key map shows the location and regional geological situation of the area discussed. On the main map of the area between Sukkertoppen and Godthaab the location of the Qagssínguit structure (fig. 3) is shown by the small shaded square.

I. INTRODUCTION

This paper represents an attempt to summarise the results of several summer's geological and structural field work carried out under the auspicies of the Geological Survey of Greenland (GGU) within the Southern Sukkertoppen district. The author has to a large extent drawn from his own experience but observations made by Dr. HANS RAMBERG, Messrs. H. SØRENSEN, mag. scient., R. LAUERMA, fil. lic., H. MICHEELSEN, mag. scient., and E. BONDESEN, mag. scient., have been of great importance. The author is indebted to these for having placed their results at his disposal.

The region discussed in this paper embraces the seaboard country between Sdr. Isortoq and the northern extremity of Nordlandet (fig. 1). It is about 75 km from north to south and from 20 to more than 50 km in an east-west direction. The region forms part of the geological reconnaissance map recently published by A. NOE-NYGAARD and H. RAMBERG (1960).

Systematic mapping has only been carried out within smaller parts of the southern Sukkertoppen district. For the remainder, the mapping has been limited to reconnaissance along the coast and a few traverses inland. To these field observations, photogeological interpretations have been added. Much more field work is needed if an exhaustive account should be given. Detailed investigations within smaller, selected areas of the region have clearly shown its extreme complexity. Therefore, as said at the beginning, this paper only represents an attempt to summarise the results obtained so far. In its very nature, it is incomplete and conjectural. It is hoped, however, that it may do some good in establishing a regional background permitting a deeper understanding of already published and forthcoming contributions of less regional scope.

The preparation of the maps has been made possible through the courtesy of the Geodetic Institute, Copenhagen.

Previous work.

Apart from K. L. GIESECKE'S (1878) and J. A. D. JENSEN'S (1889) studies during the last century, no geological field work was undertaken within the southern Sukkertoppen district until 1949, when Dr. H. RAM-

BERG took up reconnaissance mapping on the behalf of the Geological Survey of Greenland (GGU). This mapping was continued in 1953 and 1954 by H. SØRENSEN and the author. For short intervals in the seasons of 1956 and 1957, the author worked again in the district.

Part of Dr. RAMBERG's material has been incorporated in his modern textbook on metamorphic and metasomatic rocks (H. RAMBERG, 1952) and in his paper on pegmatites in West Greenland (H. RAMBERG, 1956). The ultrabasic rocks of southern Sukkertoppen district have been described in several papers by H. SØRENSEN (1952, 1953, 1954, and 1955). Contributions to the structural geology have been published by the author (A. BERTHELSEN, 1950, 1954, 1957, 1960a, and 1960b; see also A. NOE-NYGAARD, 1955). The field work carried out in 1953, 1954 and 1957 by R. LAUERMA within the extreme south-east part of the district will be reported on separately by Mr. LAUERMA in the near future.

The structural sketch map accompanying this paper (Pl. 1) is largely based on Dr. Ramberg's 1954 compilation of all available results (see A. NOE-NYGAARD and H. RAMBERG, 1960), but the sketch map also includes results from subsequent field work and from photogeological studies.

II. STRUCTURAL DIVISION OF THE REGION

The southern Sukkertoppen district is made up of pre-Cambrian gneisses and schists and other highly metamorphosed rocks. This crystalline basement is traversed by basic dykes and numerous faults. Glacial deposits are seldom of any great extension or thickness, and, in consequence, the basement rocks are usually well exposed and provide good material for field and photogeological studies.

The metamorphic terrain can be divided into several complexes, each of which shows its particular metamorphic and structural evolution (see Pl. 1). The southernmost complex of the region discussed here has been called the Nordland complex, from the name of the large peninsula between Fiskefjord and Godthaabsfjord (BERTHELSEN, 1957). Apart from Nordlandet, this complex includes the Fiskefjord area, the Tovqussaq area and the country north as far as the Uivfaq peninsula. To the south, the Nordland complex borders on the Godthaab complex, while to the north it joins the Finnefjeld complex. The latter complex abuts on the Alángua complex still further to the north. The northern part of the Sukkertoppen district is made up of the Kangâmiut complex (H. RAMBERG, 1948).

The structural setting of these complexes suggests that they all form part of a deeply eroded mountain chain, the Ketilides, which was first recognised in South Greenland by E. Wegmann (1938). Many facts speak in favour of this theory which, however, still awaits confirmation with the aid of absolute age determinations.

The postorogenic basic dykes of the southern Sukkertoppen district have recently been dealt with by A. Berthelsen and D. Bridgwater (1960). According to these authors the dykes were intruded in two separate periods. Between these two episodes of volcanic activity, the formation of an important system of wrench faults, the Fiskefjord faults, took place. The dykes as well as the Fiskefjord faults are considered to be of pre-Cambrian age (pre-Nagssugtôqidian).

III. LITHOLOGY AND PETROGRAPHY OF THE NORTHERN PART OF THE NORDLAND COMPLEX

While the geology of the interior part of the Nordland peninsula is largely unknown (except in the north-east where the Ipernat area has been mapped by R. Lauerma), we have a fair amount of data from the northern part of the complex which is deeply cut by the branching Fiskefjord. The best known part of the northern Nordland complex, however, is the Tovqussaq peninsula, which recently has been described in great detail in part II of this series (Berthelsen, 1960b). This paper also contains the definitions of several otherwise new petrographic terms used in the following.

The Tovqussaq area is made up of various gneisses, basic and ultrabasic rocks, pelitic schists, siliceous rocks and calc-silicates which form an apparently conformable succession originally some 1000 metres thick. This succession is believed to be of supracrustal origin. In addition to these rocks, metasomatic diorites and anorthosites are found.

The predominant gneisses are more or less composite quartz-dioritic hypersthene gneisses which have been uralitised or biotitised to varying degrees whereby so called 'purple gneisses' were formed. The purple gneisses may grade into light coloured granodioritic to granitic biotite gneisses. True granulite (in the German sense) occurs as well. Some gneisses are rich in enclaves, boudins or layers of 'gabbro-anorthosite' (i. e. a plagioclase-diopside-hornblende-biotite ± scapolite rock). The basic rocks, which form thick marker horizons, are represented by pyribolite (a plagioclase-bearing rock, in which orthorhombic and clinopyroxenes about equal or exceed hornblende in amount). The ultrabasic rocks range from olivinitic to hornblenditic types. The pyroxenitic to hornblenditic rocks have previously been described by H. SØRENSEN (1953). Garnet-sillimanite-bearing biotite schists, siliceous and calc-silicate rocks are quantitatively less important than the basic rocks. The dioritic and anorthositic rocks have all once carried hypersthene.

In many respects the rocks of the Fiskefjord area show a great resemblance to the Tovqussaq rocks. The predominant gneisses are also quartz-dioritic (to granodioritic) and carry biotite, occasionally hornblende and in several places hypersthene, diopside and garnet. However, in the Fiskefjord area purple gneisses are far less common than at Tovqussaq, while light coloured to white types, which owe their colour to a diaphthoritic bleaching imposed on them during the formation of the postorogenic Fiskefjord faults, are widespread. In many of these bleached gneisses, the quartz has retained its original blue colour. North of Tovqussaq, where the diaphthoritic influence of the faulting is less important, purple gneisses are typically developed.

The Tovqussaq rocks have been interpreted as original granulite facies rocks which have been partially adjusted to amphibolite facies conditions during a later period of metamorphism. The Fiskefjord rocks have evidently passed through a similar evolution, but have suffered in addition from a post-orogenic diaphthoritic metamorphism which has reached deep into the fault blocks. The grade of this youngest metamorphism corresponds to epidote-amphibolite facies or greenschists facies.

The gneisses of the Fiskefjord area contain conformable layers of pyribolite, pyroxene-amphibolite and diopside-amphibolite. Intercalations of garnet-biotite schists are less common and siliceous rocks (ore-bearing quartzites) have only been found at a few localities.

Gabbro-anorthositic rocks have not been encountered within the Fiskefjord area, nor within the part of the complex north of Tovqussaq.

Within the Fiskefjord area the ultrabasic rocks are common and form bodies which may be more than 1 km in length. The larger masses have a dunitic to peridotitic composition. Within their central parts 10–30 cms wide diopside nodules may be found. The ultrabasic masses are usually arranged as elongated boudin-like bodies but may also occur as plug-like massifs in the centre of synclines or basin structures. They are surrounded by either pyribolite, amphibolite or gneisses. Where enclosed in gneiss, they have developed what seems to be a metosomatic reaction zone of medium grained noritic rocks. In the proximity of the later faults, the ultrabasic rocks are often serpentinised.

Dioritic and anorthositic (strictly speaking plagioclasitic) rocks have also been recorded from the Fiskefjord region, where the plagioclasitic types in particular seem to have a wide distribution. Where studied in detail, they have turned out to be of replacive origin (BERTHELSEN, 1957, fig. 15).

As mentioned above, the field work has brought forward evidence which proves the triple-metamorphic nature of the Fiskefjord rocks. In order to illustrate some of the mineralogical changes caused by this complex metamorphic evolution, some selected samples are described below. The location of the samples described can be found in fig. 2.

Petrography of some rocks from the northern Nordland complex.

Gneisses and other quartzo-feldspathic rocks.

4090 A. Quartz-dioritic garnet-bearing gneiss.

A rather light, brown to greenish, medium grained rock with a crystalloblastic texture. The dark red garnets are from 1 to 3 mm large. A faint banding may be noticed in the hand specimen. The minerals are plagioclase (28–30 $^0/_0$ An), quartz, garnet, yellow green to olive biotite and green hornblende besides a little hypersthene and accessory apatite and ore.

4090 B. Hypersthene-bearing gneiss of almost dioritic composition.

A coarse to medium grained brownish green rock with heteroblastic texture. The minerals are andesine, hypersthene, biotite, garnet, quartz and accessory zircon and ore. The granoblastic plagioclase forms a base in which the more or less orientated biotite flakes and the porphyroblasts of hypersthene and garnet are set. Hypersthene also forms smaller xenoblastic grains. It is strongly pleochroic. The yellowish to deep orange brown biotite forms tiny flakes, some of which are orientated at right angles to the foliation. Quartz is only found in association with biotite.

14932. Finely banded pyroxene gneiss.

A fine grained cinnamon coloured rock containing medium grained bands of white quartz, dark grey plagioclase and a little pyroxene. Apart from occasional thin bands of calcsilicates and quartz, the minerals are plagioclase, quartz, hypersthene, diopside, biotite and small quantities of hornblende, plus accessory apatite and ore. The fine grained cinnamon coloured parts are almost free of quartz and shows a grano- to nematoblastic texture due to preferred orientation of the pyroxenes (especially the hypersthene). Biotite in slender flakes of yellow to brown colour, seems to have formed later than hypersthene. The green hornblende is only found in a few very small idioblasts within the somewhat antiperthitic plagioclase, which is an andesine (40 $^0/_0$ An).

19380. Quartz-dioritic hypersthene-bearing gneiss.

A dark, greenish grey, almost fine grained rock with a rather well developed foliation. The dominant texture is granoblastic. The minerals are plagioclase, quartz, hypersthene with uralitic borders in places, yellow brown biotite and accessory apatite and ore.

14930 and **14932.** Banded amphibolitic gneiss.

Greenish grey rocks containing thin light coloured quartz-feldspathic bands. The texture is gneissic with lobate granoblastic bands. The minerals are plagioclase, hornblende, quartz, biotite and some epidote, apatite, sphene and ore. The somewhat antiperthitic plagioclase shows an An $^0/_0$ of 30–35, and is slightly saussuritised. The hornblende is faint bluish green with more strongly coloured edges. It seems to have formed by uralitisation of diopside. Epidote occurs especially along the grain borders of hornblende. Where noticed, sphene occurs as leucoxene rims on ore.

19344. Quartz-dioritic biotite hornblende gneiss.

A light coloured, medium grained rock composed of plagioclase quartz, biotite, hornblende, epidote, apatite, sphene and ore. The texture is incipient cataclastic, and plagioclase shows bent twin lamellae while the quartz shows undulating extinction. The plagioclase (23 $^0/_0$ An) is faintly antiperthitic and strongly saussuritised with needle-shaped inclusions of epidote, some sericite and calcite. The biotite occurs in irregular olive-green grains associated with hornblende, epidote and ore. It also forms diablastic intergrowths with quartz. The uralitic green hornblende is usually associated with vermicular quartz.

19328. Quartz-dioritic biotite gneiss.

A rather light coloured, faintly yellowish gneiss with a cataclastic texture. The minerals are plagioclase, quartz (milky blue in hand specimen), biotite, light mica, epidote and apatite, sphene and ore. The plagioclase (20–22 $^0/_0$ An) is strongly saussuritised. It is weakly antiperthitic and may show bent twin lamellae. The biotite is olive green to brownish and contains in places small orientated grains of quartz. The sphene forms a leucoxenic rim on the ore grains.

19361. Quartz-dioritic biotite gneiss.

A rather dark, greenish grey rock of medium to fine grain. The texture is somewhat cataclastic, but primarily granoblastic. The minerals are plagioclase, quartz, brown biotite, and ore. Seritication of the plagioclase is prominent and the biotite may be partly chloritised.

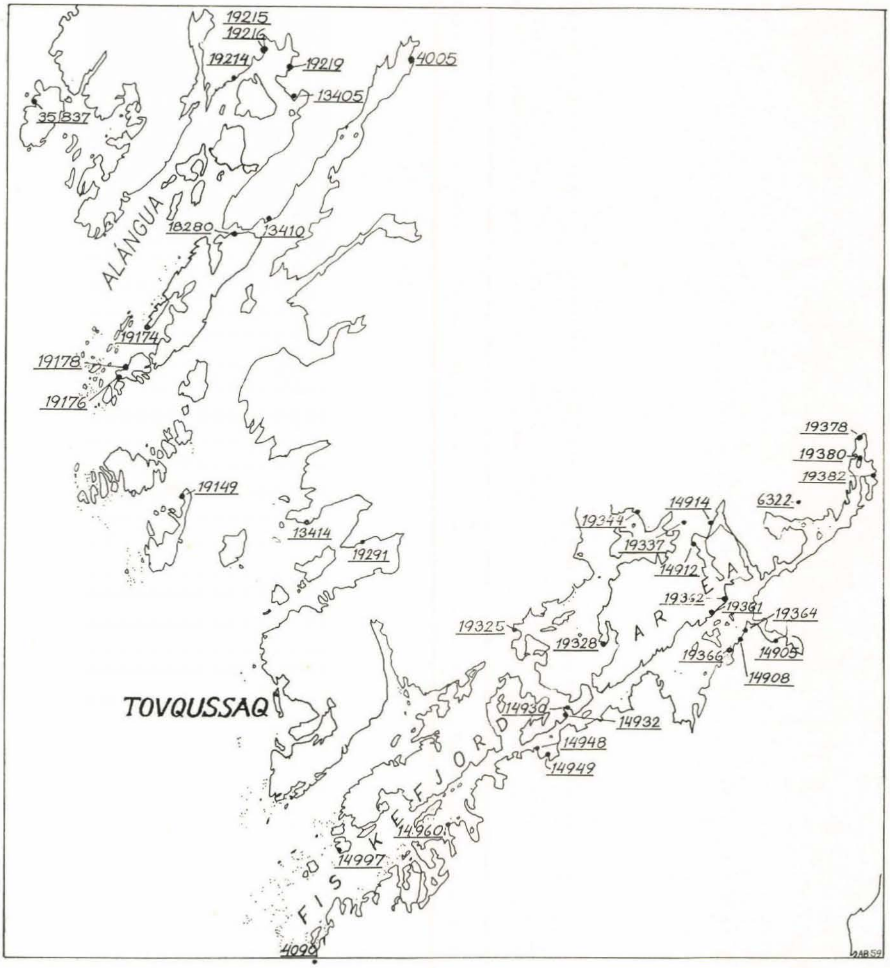

Fig. 2. Map showing the location of the described samples.

19366. Quartz-dioritic biotite gneiss.

A bluish grey, medium grained, foliated rock of rather leucocratic composition. The texture is hemi-granoblastic with lobate grain contours except within the sparse and thin lepidoblastic mafic foliae. The minerals are plagioclase (28 $^0/_0$ An), which is antiperthitic, quartz, yellowish to brown biotite and uralite, together with a few interstitial grains of microcline and accessory apatite, ore and zircon.

14905. Quartz-dioritic biotite gneiss.

A light coloured, faintly violet rock of medium grain. The minerals are plagioclase, quartz, biotite, sericite, hornblende, a little microcline, epidote, leuxocene, apatite and zircon. The texture is cataclastic and mortar seams are common. The contorted plagioclase is a faintly antiperthitic oligoclase, which is rather strongly saussuritised. Biotite is olive green to brown and is intergrown with vermicular quartz. The biotite flakes may be bent and are partly replaced by light mica. Green hornblende is only found as a few irregular grains. Epidote occurs sparingly around the dark minerals.

19325. Mylonitic gneiss of quartz-dioritic composition.

A light coloured, strongly schistose rock with plagioclase, quartz, sericite, biotite, epidote, apatite, sphene and ore. The slightly antiperthitic calcic oligoclase is strongly seriticised and shows bent twin lamellae. The quartz is strongly cataclastic. Light mica is also found in lepidoblastic development. Epidote is abundant as small irregular grains. Sphene occurs as leucoxene rims on ore.

14948. Granodioritic biotite gneiss.

A light coloured, medium to fine grained rock with an indistinct foliation. The quartz is milky blue. The minerals are plagioclase, quartz, microcline, biotite and muscovite, epidote and some sphene, apatite and ore. The texture is cataclastic and mortar seams surround some grains. The plagioclase (22–23 $^0/_0$ An) is somewhat saussuritised and is corroded by microcline. Where bordering on microcline, it shows a clear zone against the latter mineral. Mesoperthite is found locally. The green biotite seems secondary to hornblende, since it contains vermicular quartz and sphene. (This rock was collected close to the proper Fiskefjord fault).

14960 B. Syenodioritic granofels.

A purple to rose, fine grained rock of leucocratic syenodioritic composition, with an indistinct foliation marked by the scarce dark minerals. The texture is lobate, hemi-granoblastic. The minerals are antiperthite plagioclase (20–22 $^0/_0$ An), small amounts of quartz, interstitial microperthitic untwinned potash feldspar and biotite.

The syenodioritic granofels just described encloses an up to two metre thick layer of ore-bearing quartzite. Siliceous rocks from other localities within the Fiskefjord area have also been found to be ore-bearing, but the quartzite described here is the most ore-rich type so far found.

14960 A. Ore-bearing quartzite.

The fresh unweathered rock is dark brownish green, medium to fine grained and shows a hemi-granoblastic texture. The non-opaque minerals are quartz and some plagioclase (28 $^0/_0$ An), hypersthene and biotite. The hypersthene is partly replaced by biotite. The opaque minerals are pyrite, pyrrhotite, chalcopyrite and magnetite.

The result of a semi-quantitative spectographic analysis of this rock is given in Table 1 below. For comparison, an analysis of a finely banded pyrite-bearing quartzite (from another locality) has been added.

Table 1. Semi-quantitative spectrographic analysis of ore-bearing quartzites from the Fiskefjord area. (Analyst IB SØRENSEN, cand. polyt. et lic. techn.).

ppm	Sn	Pb	Ag	Cu	Zn	Co	Ni	Cr	Mo	V	Ba	Sr	Ti	La	Y
14960 A	÷	÷	÷	1%	÷	100	300	100	10	50	100	50	3000	÷	÷
14922	÷	÷	÷	200	÷	30	300	10	÷	20	10	10	3000	÷	÷

The following two samples come from the region north of Tovqussap nunâ.

19291. Quartz-dioritic biotite gneiss.

A faint greenish brown, medium to fine grained rock with a faint foliation. The texture is hemi-granoblastic to almost heteroblastic. The minerals are plagioclase, quartz, yellow brown biotite in stumpy flakes and forming diablastic intergrowth with quartz, a pale green uralitic hornblende with a few relics of hypersthene, apatite in large grains, a little zircon and ore.

13414. (Collected by H. SØRENSEN). Violet granofels ("purple gneiss").

A light violet, fine grained rock with an interlobate hemigranoblastic texture. The minerals are slightly antiperthitic plagioclase, quartz, microperthitic potash feldspar (mostly interstitial), yellow-brown biotite, a little hornblende and apatite and ore.

Basic and ultrabasic rocks.

Three types of intercalated basic layers have been studied. Their description may illustrate the variation displayed by rocks which during reconnaissance work were simply called 'amphibolites'.

19378. Diopside-amphibolite.

An almost fine grained, dark greenish rock with a faint lineation. When seen in section at right angles to this preferred orientation, the texture appears wholly granoblastic. The minerals are plagioclase, green hornblende, greenish diopside, small quantities of brown biotite, and accessory ore and apatite. The plagioclase shows normal zoning (30–

35 % An in some grains, while others reach almost 40 % in their cores). The hornblende which is pleochroic from yellow green to dark olive green, seems to replace the diopside.

14914. Pyribolite.

An almost fine grained dark greenish rock with a faint foliation and a better developed lineation. The texture is almost nematoblastic. The minerals are plagioclase (37–40 % An), transparent diopside, brownish green hornblende, some pink hypersthene and a little biotite and ore. The hypersthene is found as corroded grains surrounded by diopside, which latter mineral shows a strong preferred orientation.

14908. Plagioclase-diopside rock.

This rock is somewhat foliated and lineated and has a dark greenish colour. It is fine grained but contains abundant porphyroblasts of diallage up to half a centimetre across. Under the microscope the texture appears hemi-granoblastic. The plagioclase (41–48 % An) predominates slightly over the dark minerals among which a greenish diopside is far the most common. The other mafics are a dark green hornblende and relatively much ore. Accessory apatite may also be seen. The diopside shows exolution lamellae and schiller inclusions.

The noritic rocks which surround some of the larger ultrabasic masses are represented by the following sample.

19364. Noritic granofels.

A grey, medium grained rock with a saccharoidal to slightly lobate hemi-granoblastic texture. The minerals are plagioclase (70–72 % An), bronzite (ca. 20 % Fs), a pale green hornblende and a little ore. Diopside may also be found as small grains enclosed by bronzite. The dark minerals are traversed by ore pigmented cracks, which are less common in the surrounding feldspar. The bronzite is corroded by the pale amphibole and may be included by this as smaller rounded grains.

According to observations made by Mr. H. MICHEELSEN, the noritic rocks have been formed at the expense of original ultrabasic rocks (dunites and peridotites) through metasomatic reaction with the surrounding rocks, which are usually gneisses. The transformation is initiated with a growth of orthopyroxene poikiloblasts within the ultrabasic rock. At a later stage, plagioclase appears between the bronzite grains. The first formed noritic rocks are granular. Where they have been exposed to later shear movements, foliated to schistose types have been formed. Similar 'hybrid' noritic rocks have been described from the Alángua complex by H. SØRENSEN (1955).

The ultrabasic rocks are represented by the two samples described in the following. Specimen 6322 was collected within an ultrabasic mass occurring close to a late fault.

19337. Dunite.

A medium to fine grained rock of greenish colour due to a high content of olivine (> 75 %). The minerals are olivine (ca. 10–15 % Fa), enstatite, phlogopite, colourless to pale brownish amphibole, ore, and spinel (picotite) in addition to small amounts of serpentine (as fillings in fissures and cracks).

6322. Somewhat serpentinised olivinite.

A dull grey, medium grained rock composed of olivine (> 50 %) and orthopyroxene with poikiloblastic insets of 1) small idioblastic grains of pale greenish amphibole, 2) small lobate grains of reverse-zoned calcic labradorite, and 3) lobate to lepidoblastic grains of yellow-brown mica. A grey to pink spinel, ore and serpentine occur as well. The small ore grains are mostly concentrated in the numerous thin serpentine veins which are nearly parallel.

Plagioclasitic and dioritic rocks.

The anorthositic (plagioclasitic) rocks from the Fiskefjord area are represented by two samples. Specimen 14997 comes from a smaller body of anorthosite, the metasomatic origin of which has previously been emphasised (Berthelsen, 1957).

14997. Andesinitic granofels.

A medium grained granofelsic rock with a dark bluish grey colour. Plagioclase forms the bulk (about 94 %) of the rock, and the other minerals are hypersthene, uralitic hornblende, ore and a little quartz. The texture is saccharoidal granoblastic. The green hornblende forms narrow coronas on the pink hypersthene (40 % Fs) and contains small vermicular inclusions of quartz, which only occurs in this way. The main mineral, the plagioclase, is dusty and shows an An content from 40–43 %.

15912. Oligoclasitic granofels.

A dark bluish grey rock of medium grain and with an almost saccharoidal granoblastic texture. The specimen contains only about 5 % dark minerals. In addition to the main light mineral, a slightly seritised and dusty oligoclase (24 % An) which is somewhat antiperthitic, small quantities of interstitial potash feldspar and quartz are found. The dark minerals comprise diopside, hypersthene and hornblende, very little biotite, apatite and ore. The hypersthene grains are surrounded by an uralitic corona with an inner zone of colourless amphibole enclosing small ore grains and an outer narrow rim of green hornblende. The diopside is only slightly uralitised.

The dioritic rocks found in the Fiskefjord area seem to have suffered from retrograde alteration similar to that in the surrounding gneisses, but may also have been metasomatically altered. One of the occurrences seems to have been exposed to a potash metasomatism, which has transformed the original diorite into a rock of monzonitic composition. A few (highly altered) diorite aplites have also been encountered.

19382. Biotite-hornblende diorite.

The carmine-red rock is medium grained and shows a crystalloblastic texture. The minerals are plagioclase, biotite, quartz, microcline, hornblende and accessory ore and apatite. The plagioclase (21–24 $^0/_0$ An) is dusty and somewhat sericitised. It may show undulating extinction just like the quartz, which latter mineral forms interstitial to strongly amoeboid grains. The biotite is brown and is commonly fringed by ore grains. In places it is seen to be secondary to hornblende. Since the hornblende encloses small quartz grains, it may in its turn be secondary to pyroxene. Microcline is found as antiperthite and interstitially. Quartz, as well as the interstitial microcline, were seemingly formed during the retrograde changes shown by the transition pyroxene→hornblende→biotite.

14949. Metasomatically altered diorite.

This rock is a medium grained, flesh coloured granofels with scattered dark greenish minerals. A weak lineation may be noticed in the hand specimen. The minerals are feldspar, hornblende with sieve texture, a little interstitial quartz, epidote and accessory apatite, ore and sphene (partly as leucoxene). The feldspar consists of an original plagioclase, which has been extensively replaced by microcline to form mesoperthite. The sieve texture of the hornblende indicates its uralitic origin. The formation of the epidote may be explained by the proximity of the important Fiskefjord fault.

The following sample represents the yellow-green types met with in the immediate neighbourhood of the big wrench faults. The rock described was cut by undeformed pink pegmatites containing decimetre large crystals of albite and some quartz.

19362. Albite-epidote granofels.

A medium to coarse grained yellow-green rock with heteroblastic to granoblastic texture. The minerals are albite, epidote, quartz, chlorite, sphene, apatite and very scarce ore. The well-twinned albite contains aggregates and idioblastic grains of a yellowish green epidote, which forms an important constituent of the rock. Only a few grains of quartz are found. A pale green chlorite, which is associated with sphene, forms pseudomorphs after the original dark minerals. The mineral association albite (ca. 4 $^0/_0$ An), epidote and chlorite indicates that this rock has recrystallised under greenschist facies conditions. The original composition seems to have been dioritic.

Summary.

Judging from the descriptions given above, the Nordland rocks have all been granulite facies rocks once. This is indicated by the widespread occurrence of typical granulite facies minerals such as blue quartz and orthopyroxene. More or less complete uralitisation or biotitisation of the pyroxenes and the appearance of sphene indicate a subsequent partial or complete adjustment to amphibolite facies conditions. Cataclasis, saussuritisation of the plagioclase, formation of epidote, chlorite or light mica at the expense of former dark minerals are all features which are related to the Fiskefjord faulting.

IV. STRUCTURAL GEOLOGY OF THE NORTHERN NORDLAND COMPLEX

A careful structural analysis of the Tovqussaq peninsula has shown that this area has passed through an extremely complex structural evolution. The results of this study are shown in table 2.

The structures which were developed during the different orogenic phases, and which were superimposed on each other, are believed to represent the successive imprints of the different structural levels (Stockwerke) through which the Tovqussaq rock passed on their way 'down' and 'up' during one single orogenic cycle.

In spite of the much more sketchy character of the mapping in the surrounding area, much information indicating that this chronology is valid for whole the northern part of the complex has been collected.

In the Fiskefjord area, the structural analysis of the basement rocks is difficult on account of the later faulting. The older group of the post-orogenic basic dykes are here an important key for the structural work. From the displacement of the vertical or near-vertical dykes, the horizontal component of the fault movements can be ascertained, but the vertical component can only be determined by using the basement

Table 2. Structural and metamorphic evolution of Tovqussap nunâ (slightly revised from A. BERTHELSEN, 1960 b, Table 1).

	Division	Structural characteristics	Metamorphism
Cratogenic period	Younger group of basic dykes	Dyking along E–W, NE and NW directions	
	Fiskefjord-faulting	Dextral movements along NE to ENE trending wrench faults	Diaphthoritic alterations corresponding to a PT level of greenschist facies
	Older group of basic dykes	Dyking along N–S and ENE directions (extrusion?)	Local palingenetic remelting of dyke walls
Orogenic cycle	Tovqussaq mylonites	Shearing, mylonitisation and faulting (para- to postcrystalline)	Amphibolite facies
	Posthumous phase	Shearfolding and largely paracrystalline penetrative movements	
	Intermediate phase	Dioritisation along tension-conditioned fractures	Granulite facies
	Langø sub-phase	Repeated deformation. Latekinematic dioritisation	
	Pâkitsoq phase	Open to closed or squeezed folds generally with SE to S plunging axes. Synkinematic dioritisation	
	Doming	Diapiric movements in the 'dome'	Mobile migmatitic stage, (amphibolite facies?)
	Smalledal phase	Recumbent folding (ENE axes)	
	Midterhøj phase	Development of isoclines with NW to N–S trending axes	'Schist facies'
	Supracrustal period	Sedimentation and extrusion (intrusion?)	

structures as a control. This means that photogeological extrapolations to complete the imperfect reconnaissance cannot be made across faults.

Only in one case is the basement structure sufficiently well-known to allow a thorough analysis of the faulting. This is in an 'apparent dome' structure occurring around Qagssínguit on the south-east coast of the Angmagssivik fjord, fig. 3. In this figure, the fault blocks have been placed in their 'original' position prior to the horizontal movements which displaced the Feeder dyke, so that this dyke appears in its original straight course. The displacement of the coast line shows the horizontal

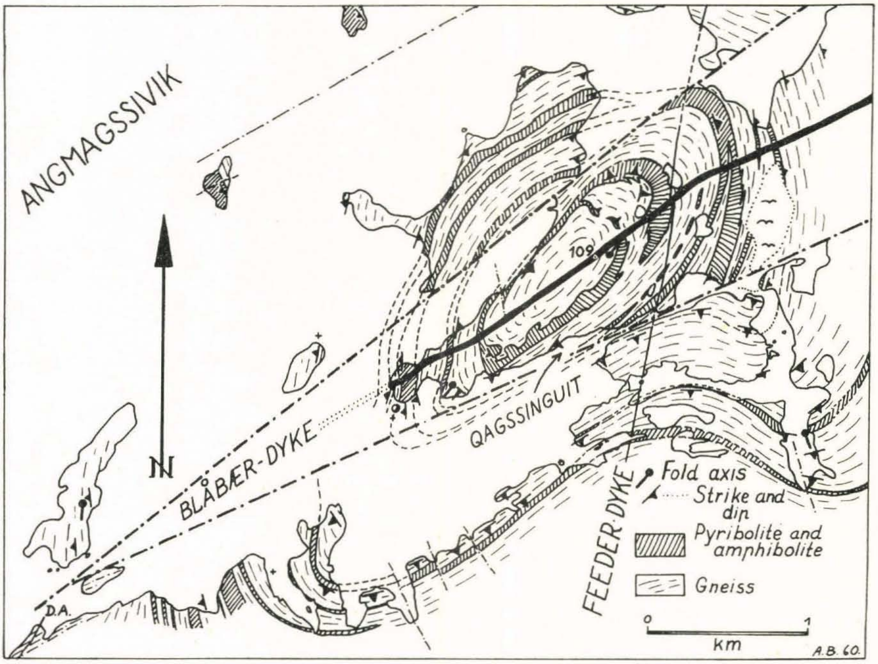

Fig. 3. Sketch map of the Qagssínguit structure (for location see fig. 1). Note that the positions of the fault blocks have been restored so that the Feeder dyke is restored to its original straight course. The horizontal displacement can be read from the displacement of the coast line. No corrections for vertical fault movements have been made. The Blåbær dyke is younger than the faulting since an apophysis belonging to this dyke cuts the fault zone in the extreme south-west of the map (D.A.).

component corrected for in this reconstruction. Although a fair coincidence between the basement structures in the adjacent fault blocks is obtained, it is nevertheless apparent, particularly around the southern fault, that there must be a vertical component. At this locality it is, however, far less important than the horizontal component, and we are still able to analyse the basement structures.

The Qagssínguit structure is elongated in a NE direction. It becomes overturned to the north, while a secondary antiform is developed in its southern flank. Two axes are found, a NE one, which culminates, and one which plunges to SSE. The expression 'apparent dome' has been applied in the above because this structure is not a true dome, but has been formed from the hinge zone of an overturned to recumbent fold with a NE-trending axis by gentle refolding on a SSE-plunging axis.

A comparison between the Qagssínguit 'dome' and the structures shown by similar basic marker horizons in Tovqussap nunâ allows one to conclude that the overturned to recumbent structure originated during the Smalledal phase, while the refolding took place during the Pâkitsoq phase. In both areas, the overturned to recumbent folds indicate a large scale tectonic transport towards NW or NNW during the Smalledal phase.

The Qagssínguit structure, in other words, supplies us with a model of the initial Tovqussaq 'dome' before the onset of the diapiric movements (A. BERTHELSEN 1960b, fig. 70). It may also viewed as a less tightly refolded equivalent to the Smalledal antiform of northwestern Tovqussaq (op. cit., fig. 66).

The 'splitting up' of the basic marker horizons of the Qagssínguit structure south-east of Angmagssivik is highly reminiscent of the outcrop pattern caused by isoclines developed during the earliest phase of folding at Tovqussaq (the Midterhøj phase), but the region mapped south of Angmagssivik is too small to permit a more thorough analysis of these features to be carried out here.

The structures in the remaining parts of the Fiskefjord area are only imperfectly known, but we have sufficient evidence to state that they are comparable to those described from Tovqussap nunâ. It would not be correct to describe the area as characterised simply by dome and basin structures, although some larger basins and some fault-cut domes have been mapped out (see Pl. 1). Various local structures show clearly that important folding occurred earlier as well as after the formation of the domes and basins. (Some structures, which now appear to be domes, may also turn out to be 'apparent domes' when studied in greater detail). The vertically directed movements which lead to the formation of the domes and basins seem to be contemporaneous with the diapiric movements at Tovqussaq, i.e. they took place during the shift from the stress pattern of the Smalledal phase to that of the Pâkitsoq phase.

In the interior parts of Fiskefjord, NNW–SSE trending axes are commonly observed in smallfolds developed during the Pâkitsoq phase. Due to culminations and depressions the plunge is varying, but in general SSE plunges predominate.

The country south of the entrance to the Fiskefjord is built up of granulite facies rocks which have suffered only slightly from retrograde alteration. They form large SSE-plunging open anticlines (see Pl. 1 and fig. 4). One cannot conclude, however, that in these structures the rocks are younging towards south. There may exist hidden or unobserved repetitions due to older recumbent folds. Had the Krebsesø antiform in eastern Tovqussaq been studied as superficially as this area, the existence of older refolded isoclines and big recumbent folds would hardly have been recognised. From a structural point of view, the northwestern extremities of the Nordland peninsula undoubtedly constitute most rewarding ground for detailed studies.

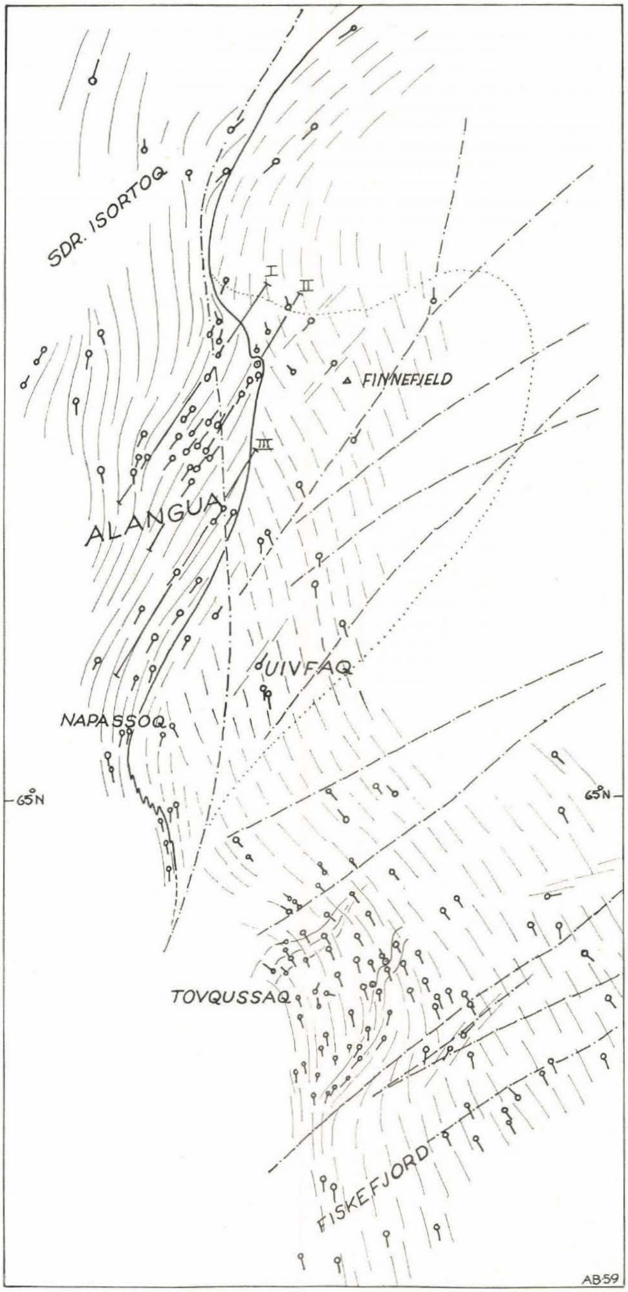

Fig. 4. Tectonic map of the southern Sukkertoppen district. The symbols indicate the trend and plunge of observed fold axes. The thin broken lines show generalised axial trends.

The structures north of the Tovqussaq area are difficult to reconstruct because a large part of the area is sea-covered. A general northeasterly depression zone in the NNW-trending axes can, however, be discerned within the fault block north of Eqaluk. Due to this depression, the axes steepen into an almost vertical position on the Terqarnat island due south of Uivfaq (fig. 4).

To summarise this description in a few lines, we may state that:

1. Possible traces of the Midterhøj phase have been found in the Qagssínguit structure.
2. Where traced, the folds developed during the Smalledal phase indicate large scale tectonic transport towards NW or NNW.
3. Throughout the complex, dome and basin structures bear witness of vertically directed movements having taken place during the span of time separating the Smalledal and the Pâkitsoq phase.
4. Structures formed during the Pâkitsoq phase are widespread and generally control the pattern of small scale structures (NW- to N–S trending axes).
5. The intermediate period is only represented by a few occurrences of dioritic aplites.
6. Outside Tovqussap nunâ, the posthumous phase can—with a few exceptions—only be recognised by the effect of its amphibolite facies metamorphism because the dioritic aplites and dykes, which help to separate this phase out, could not be given much attention during the survey.
7. The Fiskefjord faulting was principally characterised by horizontal displacements, although the fault movements included minor vertical components. Hence, this fault system may correctly be described as one of dextral wrench faults.

In order to arrive at a more coherent description of the genetic relations between the different northern complexes, we will now consider the Alángua complex.

V. LITHOLOGY AND PETROGRAPHY OF THE ALÁNGUA COMPLEX

The Alángua complex, which was recognised as a major geological unit for the first time in 1949 during the reconnaissance mapping conducted by Dr. RAMBERG, has been described briefly already by A. BERTHELSEN (1950 and 1957) and H. SØRENSEN (1953). In 1953, H. SØRENSEN and the author re-examined the southern part of this complex.

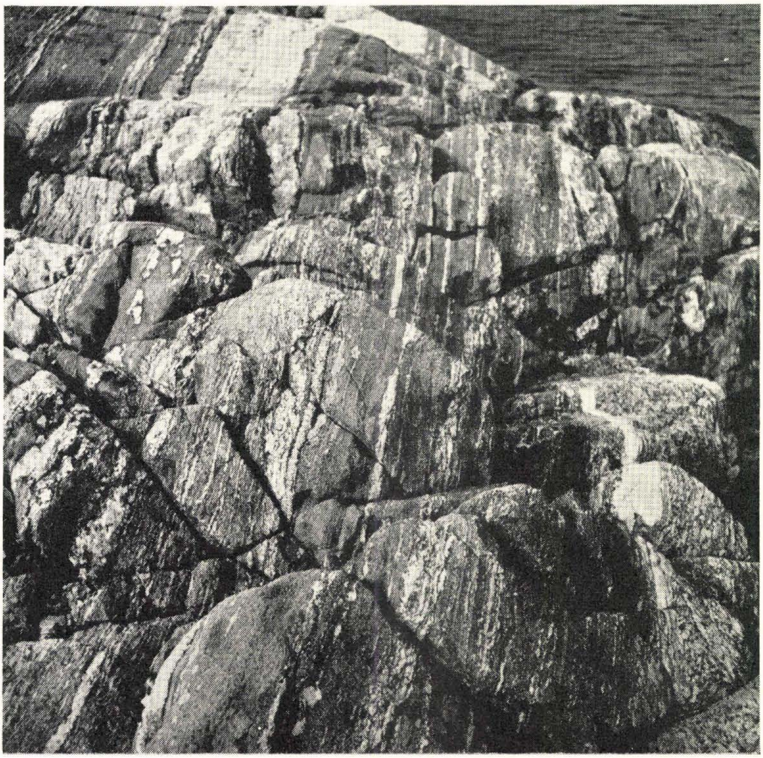

Fig. 5. Feldspathised biotite schists on a large island south of the entrance to the Alángua fjord. Photo GGU, A.B.

During this survey special attention was paid to the structures within the complex and to its border relations with the Finnefjeld complex to the south. The border between the two complexes was mapped from the Alángua fjord in the north to Talerulik south of Napassoq. H. Sørensen, furthermore, continued his studies of the ultrabasic rocks of this region.

The Alángua complex embraces a series of intensively folded schists and gneisses. Biotite schists with garnet and sillimanite, various types of diopside-rich amphibolites, garnet amphibolite and amphibolitic schists form quantitatively important intercalations in more gneissic rocks. The biotite schists often carry small amounts of sulfides, in which case they weather to a strong rust colour. Epidote-rich calc-silicate rocks in the form of small lenticular enclaves are also common within the schists and gneisses of the Alángua fjord region.

From the narrow inlet south of Sdr. Isortoq, boudins of diopside skarn, originally forming metre-thick layers, have been described by H. Ramberg (1956, p. 205, fig. 15). Pegmatites carrying diopside, scapolite, hornblende, sphene, calcic plagioclase and quartz separate the

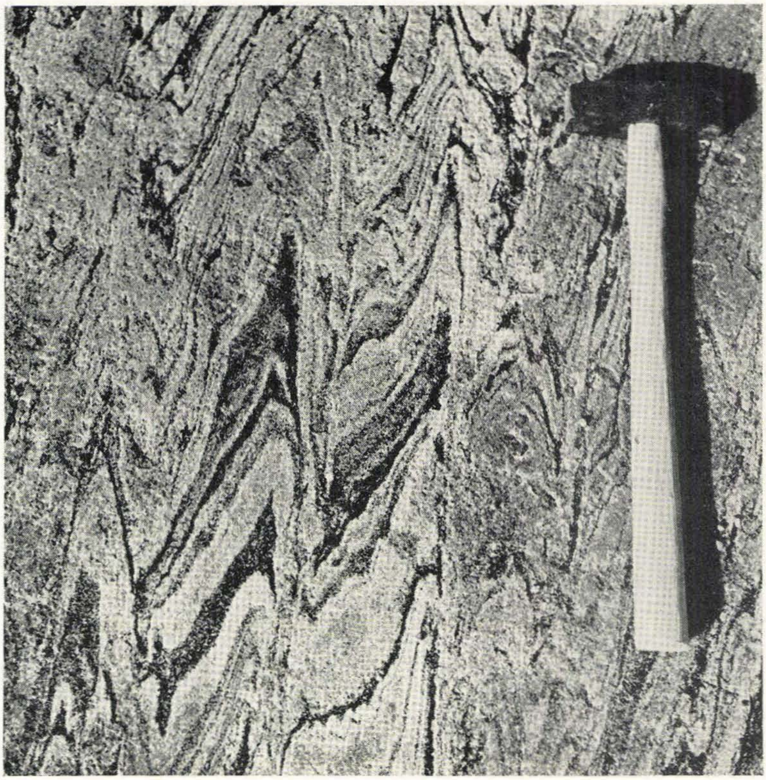

Fig. 6. Nebulitic smallfolding in gneissified schists close to the locality pictured in fig. 5. Photo GGU, A.B.

boudins. The competent skarn rocks are enclosed in a grey biotite-bearing bytownite-quartz gneiss which is interpreted as an altered lime-rich-sediment.

Ultrabasic rocks of varying composition occur as boudins, lenticular bodies or form breccias within both schists and gneisses (H. Sørensen, 1952, 1953).

It should also be mentioned that a leucocratic fine grained gneiss probably of quartzitic origin has been found at the head of the Alángua fjord close to the border of the complex.

Most, if not all, gneisses can be proved to have been formed at the expense of some type of schist. Grey quartz-dioritic hornblende-biotite gneisses, which in places are rich in amphibolitic inclusions, seem to represent transformed amphibolitic rocks (H. Sørensen, 1953). Other types of gneisses have obviously originated by incomplete granitisation of mica schists. This is especially well seen between Napassoq and South Alángua, where all transitional stages are met with (fig. 5 and 6). The gneisses thus formed are generally of quartz-dioritic composition and

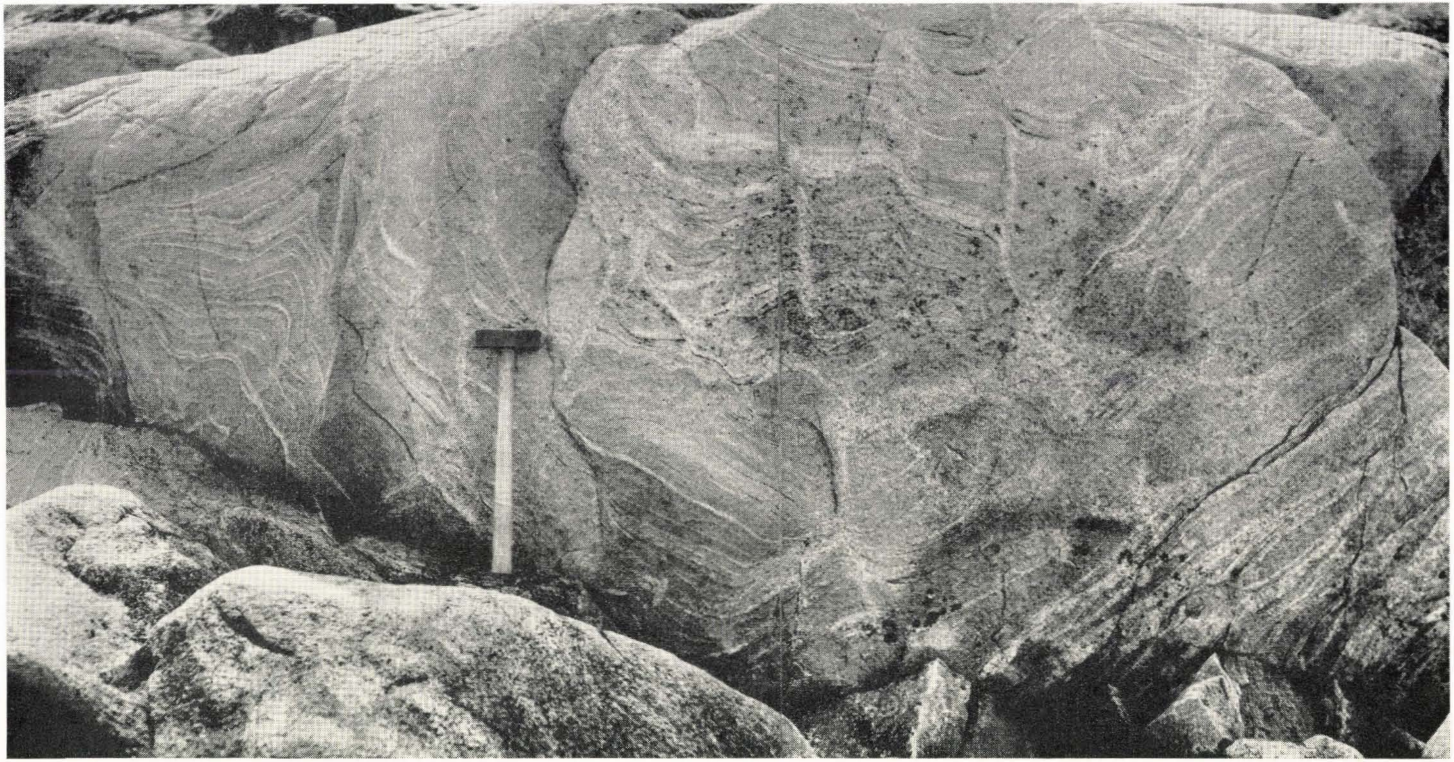

Fig. 7. Nebulitic small scale structures showing an open synform in light coloured gneisses on the elongated island south-southwest of Igdlutsiait. Photo GGU, A.B.

carry biotite as the mafic mineral. There occur also some distinct gneiss layers the origin of which is less apparent. After a closer study, however, they revealed several features which prove their metasomatic origin. These are first of all ghostly (or nebulitic) structures which can be studied on the washed outcrops along the shore (fig. 7). In addition, calc-silicate inclusions and lenses have survived the gneissification of the primary schists in several places.

The granodioritic to granitic members of the complex and also the granitic pegmatites seem to have been formed by a granitisation or migmatisation of later date than the gneissification. Studying the ultrabasic rocks, H. SØRENSEN has also demonstrated two successive periods of amphibolite facies metamorphism, the younger of which was characterised by strong migration in the dispersed phase (H. SØRENSEN, 1952).

Prior to any metamorphism or transformation, the Alángua complex seems, thus to have comprised psamitic, semi-pelitic and pelitic sediments besides marls and calcareous rocks. To what extent old volcanic rocks such as tuffs, basic lavas or intrusive sills, are represented is difficult to decide now, because of the strong metamorphic and kinetic "rolling out" of all primary structures (such as pillows or intrusive contacts). We can only say that the majority of the rocks found within this complex have originated from supracrustal rocks, most probably once forming part of a geosynclinal sequence. The origin of the ultrabasic rocks poses a separate problem, which has been dealt with by H. SØRENSEN (1952, 1953).

In order to give an impression of the petrography of some of the rocks discussed above, some descriptions have been added below. The ultrabasic rocks, some amphibolitic rocks and a few gneisses have already been described by H. SØRENSEN (1953).

Two samples (**19174** and **19178**) of garnet-biotite-bearing schists collected in the archipelago south of the entrance to Alángua have been studied. Both rocks are fine to medium grained. The garnets vary in size from 1 mm to half a cm. Biotite and garnet constitute about one third of the rocks; the remaining minerals are acid andesine, quartz and accessory ore, apatite and zircon. The biotite is yellow to brown or red-brown. The pink garnet is hypidioblastic and often contains small rounded grains of quartz.

A quartz-dioritic gneiss from the same region (**19176**) is dark grey, medium to fine grained and has a well developed foliation and lineation. The minerals are oligoclase, quartz biotite, a little potash feldspar, a few scattered garnets and accessory apatite, zircon and ore. Two grains of a slightly radioactive, yellow epidote mineral with a faint pleochroism were also found. The texture is typical gneissic with lepidoblastic brown biotite and elongated quartz grains. The plagioclase is somewhat antiperthitic. Potash feldspar is also found interstitially. The only grain of garnet found in two slides shows poikiloblastic outlines.

A quartz-dioritic hornblende-biotite gneiss (**35837, 2**) from the north coast of the largest island between Sdr. Isortoq and Alángua, is a medium to fine grained dark grey, well foliated rock. The minerals are plagioclase quartz, hornblende, biotite, a little potash feldspar and accessory apatite, ore, sphene and allanite. The plagioclase is a calcic oligoclase with deformed twin lamellae. Quartz shows undulating extinction. The hornblende is pleochroic from yellow green to dark green, biotite from yellowish to dark brown. Apatite forms an abundant accessory.

Sample **35837, 1**, which was collected close to **35837, 2**, represents a biotite gneiss of granitic composition. It contains feldspar, quartz, biotite and accessory apatite, zircon and allanite. The predominant feldspar is a grid twinned, faintly microperthitic microcline. The oligoclase is slightly less calcic than that of **35837, 2**. Myrmekite was noticed. The biotite is pleochroic from yellowish to brown. Apatite is common, but less abundant than in **35837, 2**.

Specimen **19214** shows a very fine grained, light coloured gneiss, which probably originates from an arkose or quartzite. It occurs in a banded rock series found almost at the head of the Alángua fjord. The almost white rock has a few dark stripes. The texture is granoblastic. The minerals are quartz, plagioclase (25 $^0/_0$ An), microcline and scarce yellow to dark brown biotite. A few grains of pyrite and rounded zircons form the accessories. A little sericite and clinozoizite has developed by saussuritisation of the plagioclase.

A semi-quantitative spectrographic analysis of sulfide-bearing biotite schist has given the following results:

Table 3. Trace elements in sulphide-bearing schist, Alángua. (Analist Mr. Ib Sørensen, cand. polyt. et lic. techn.).

p.p.m.	Sn	Pb	Ag	Cu	Zn	Co	Ni	Cr	Mo	V	Ba	Sr	Ti	La	Y
Sp. 6295	÷	÷	÷	2000	÷	30	300	300	÷	300	300	300	3000	÷	÷

The part of the Alángua complex discussed here has a northsouth extension of about 50 km. Within this belt the degree of metamorphism appears to increase from north to south. North of the Alángua fjord the rocks belong to the uppermost amphibolite facies, H. Sørensen (1953, p. 7). South of the Alángua fjord, hypersthene has been found in some of the gneisses and this mineral has also been met with as far south as Talerulik. In places the presence of hypersthene may be caused by metasomatic or tectonic digestion of ultrabasic inclusions, but in other places the orthopyroxene seems to be a true component of the gneisses or schists. The finding of antiperthitic plagioclase in the gneiss south of Alángua may also be mentioned in this connection, since it is indicative of a rather deep facies.

Still further to the south-east, proper granulite facies rocks are found on the Tovqussaq peninsula (Nordland complex).

VI. EXTENSION, STRUCTURE AND COMPOSITION OF THE FINNEFJELD COMPLEX

South of the Alángua complex a considerable area is built up of a rather homogeneous hornblende-biotite-bearing gneiss of more or less quartz-dioritic composition. This gneiss is called the Finnefjeld gneiss, from the highest mountain of the region (1097 m), and the Finnefjeld gneiss region as a whole is spoken of as the Finnefjeld complex (BERTHELSEN, 1950 and 1957), fig. 8 and Pl. 1.

The typical Finnefjeld gneiss is met with at the head of the Alángua fjord, around the Kangia fjord and south as far as Uivfaq. The northwestern border to the Alángua complex is sharp in the fjord region but less distinct approaching the Napassoq archipelago and Talerulik. The southeastern limits of the Finnefjeld complex are diffuse where studied on the Uivfaq peninsula. Here, the Finnefjeld gneiss grades gradually into the more heterogeneous, in part agmatitic, gneisses of the Nordland complex. To the north-east, the strike of the Finnefjeld complex seems to curve into that in the diopside-biotite gneisses of Sdr. Isortoq, mapped by Dr. RAMBERG in 1949. These gneisses are rich in calc-silicate inclusions. At the head of the Alángua fjord and east of it, the Finnefjeld gneiss also contains similar dark coloured inclusions.

Around the narrow strait, which connects the Alángua and Kangia fjords, a thick layer of massive amphibolite occurs in the Finnefjeld gneiss. On the north coast of the strait this layer terminates with a isoclinal hinge zone with a very steep southern plunge. Conformable, folded white pegmatites are developed here within the amphibolite.

This amphibolite reoccurs on the largest island in the Alángua fjord and on the mainland to the north, limited by closures to the north and the south (fig. 8). The steep axial plunge in the two isoclinal hinge zones indicates that the amphibolite here occupies a strongly accentuated depression within an isoclinal synform. On the southeast point of the island just mentioned, folded granulated pegmatites which carry garnet, zircon and biotite, were found (fig. 8). The amphibolite, which here is strongly

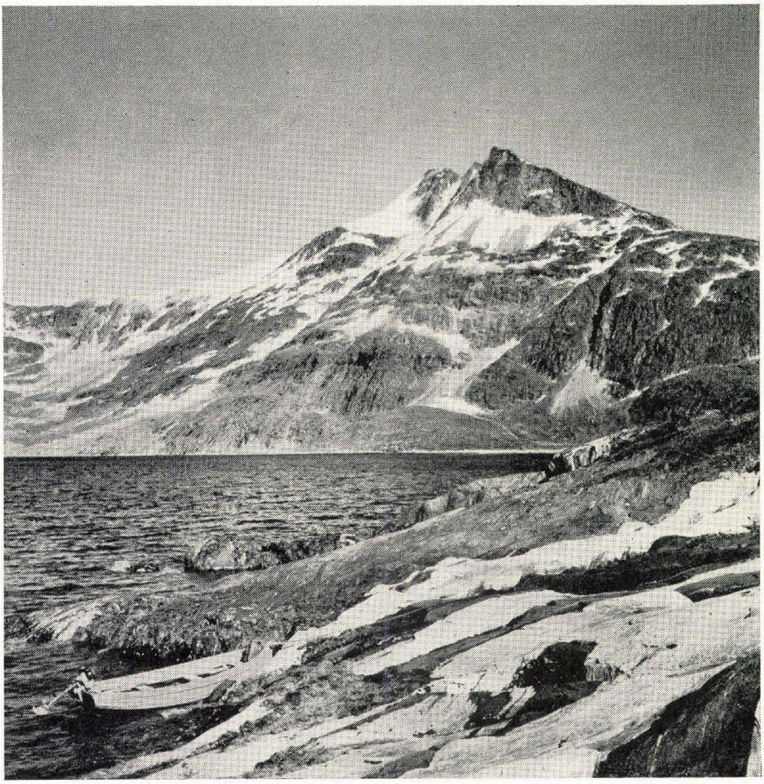

Fig. 8. View of Finnefjeld (1097 m) from the west. In the foreground an isoclinal closure in amphibolite with conformable white pegmatites can be seen. Photo GGU, A.B.

lineated (see fig. 68, H. Ramberg, 1952), contains also rows of small calc-silicate inclusions. Further to the north, it was seen to enclose large ultrabasic bodies.

Close to the border to the Alángua complex, the Finnefjeld gneiss shows at several localities nebulitic structures which are very reminiscent of those found in the most homogeneous gneiss layers of the Alángua complex. In other places ghostly traces of schist bands may be seen (fig. 9), and at one locality a skarn inclusion (with magnetite/diopside) was found. On the point south of the entrance of the Kangia fjord nebulitic accordion folds are well displayed.

Apart from these features, the structures observed within these gneisses are: 1) a foliation, 2) an occasional lineation, and 3) a local veining by conformable plagioclase pegmatites, which may be sheared (fig. 10).

The composition of the Finnefjeld gneiss seems to be fairly constant throughout the complex, as will be apparent from the following descrip-

Fig. 9. Nebulitic banding in Finnefjeld gneiss on the east coast of Portussoq. Note that the contrasts in the photograph have been increased artificially. Photo GGU, A.B.

tions of thin sections (the location of the samples can be read from fig. 2).

13405. Point north-west of Finnefjeld (collected by H. SØRENSEN).

A grey, medium grained, foliated gneiss with crystalloblastic texture. The minerals are plagioclase (25–28 $^0/_0$ An), quartz, olive to brown biotite, bluish green hornblende and accessory apatite and ore. Small rounded to vermicular quartz grains associated with the hornblende indicate the uralitic nature of this mineral.

4005. South coast, head of Kangia fjord.

A medium to fine grained, grey rock with a prominent foliation. The texture is hemi-granoblastic to cataclastic with seams of lepidoblastic biotite. The minerals are plagioclase (ca. 30 $^0/_0$ An), quartz, biotite, some microcline hornblende, and accessory sphene, apatite and ore. The biotite is yellowish to very dark, while hornblende is pleochroic from yellow-green to bluish green. The microcline occurs is interstitial grains

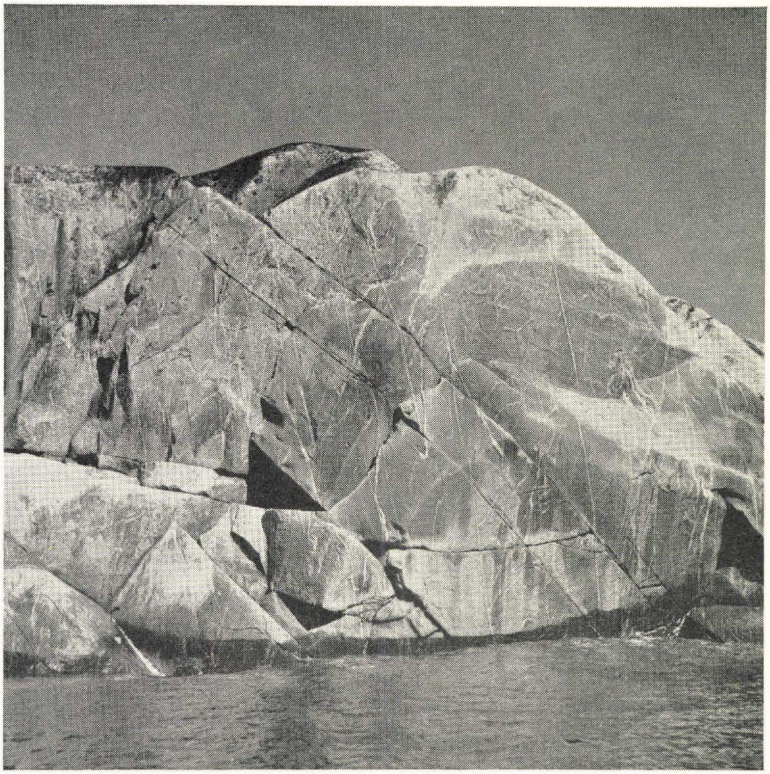

Fig. 10. Homogeneous Finnefjeld gneiss, south-east coast of Portussoq. Note the folding indicated by the thin pegmatitic veins. Photo GGU, A.B.

and seams. In the hand specimen, up to 1 cm long crystals of allanite was seen.

31410. North-west coast of Kangia, close to Ikererssarssuk (collected by H. Sørensen).

A grey medium to fine grained faintly foliated rock with a blasto-cataclastic texture. The minerals are plagioclase (24–26 $^0/_0$ An), quartz, olive-green biotite, green hornblende, a little microcline, abundant sphene, some epidote, apatite and ore. Biotite, sphene and epidote seem to have been formed at the expense of the hornblende.

18280. South coast Ikerasârssuk (collected by H. Sørensen).

A rather dark grey, medium to fine grained strongly foliated gneis with a few conformable light coloured bands. The texture is granoblastic to cataclastic. The minerals are plagioclase (34 $^0/_0$ An), quartz, olive-green to bluish green hornblende, yellow-green to brown biotite, a little epidote and allanite, abundant apatite, a few grains of zircon and a little ore.

19149. Talerulik.

A greyish, medium to fine grained homogeneous gneiss with some more light coloured bands. The texture is blasto-cataclastic to cataclastic. The minerals are plagioclase (about 28 $^0/_0$ An), quartz, yellow green to faint brown biotite, microcline (interstitial, forming myrmekite in the cataclastic parts), green-blue hornblende, abundant apatite, a little epidote, zircon and ore.

VII. METAMORPHIC EVOLUTION OF THE FINNEFJELD GNEISS

Although microcline has been found in some of the specimens, the descriptions given above indicate the general quartz-dioritic composition of the Finnefjeld gneiss. The fact that microcline, when occurring, forms interstitial grains of myrmekite within cataclased parts of the rocks, suggests that potassium may have been introduced at a late stage during the metamorphic evolution. The biotitisation of the hornblende and the formation of epidote and allanite were most probably features connected to this episode. In this connection it should be stressed that the epidote is associated with the mafic minerals and hence is of no value as a mineral facies indicator. The plagioclase, which has an An content varying from 24 to 34 $^0/_0$, never shows any sign of saussuritisation. Therefore the Finnefjeld gneisses may confidently be classified as lowgrade amphibolite facies rocks.

Three features, however, show that the Finnefjeld gneisses have a more complex metamorphic history.

1. Relic granulite facies parageneses have been found within small patches in the Finnefjeld gneiss (e.g. on the south coast of Alángua, due west of Finnefjeld). In these places, the gneiss carries hypersthene and blue quartz. Where the dark coloured pyroxene gneiss passes into the surrounding grey gneiss, the hypersthene becomes uralitised while the quartz preserves its blue colour for longer distances.
2. Viewed against this background, the common occurrence of bluish green hornblende often containing vermicular quartz inclusions suggests that most if not all of the Finnefjeld gneisses were originally hypersthene-bearing.
3. The occurrences of dioritic rocks which are comparable to the pyroxene diorite at Tovqussaq (BERTHELSEN, 1960b, pp. 112–142).

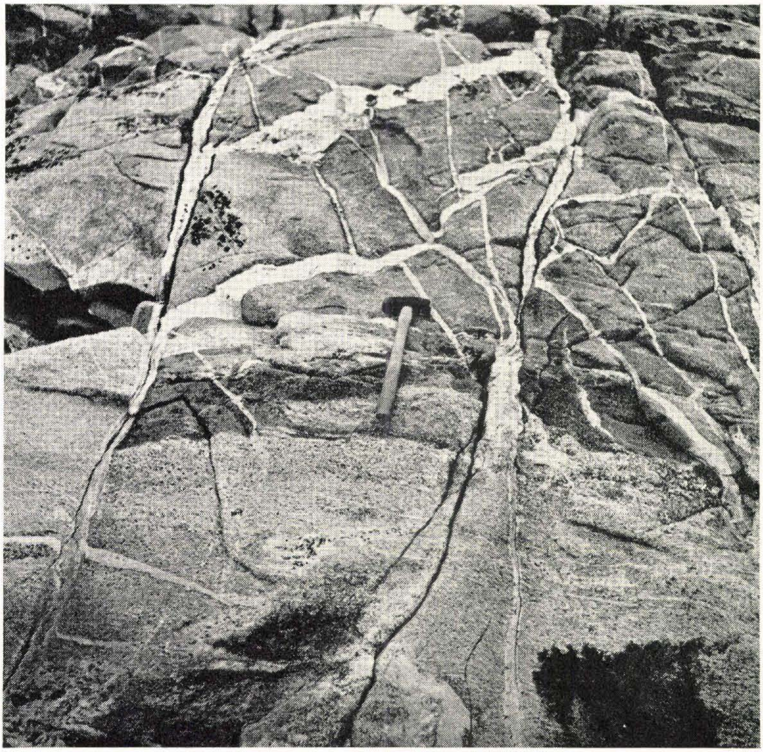

Fig. 11. Agmatitic contact of the diorite dyke on the north coast at the head of the Alángua fjord. The veins which traverse the diorite (upper half of fig.) are less well developed within the enclosing gneiss. Photo GGU, A.B.

At the head of the Alángua fjord, a dyke shaped diorite body has been found on the north coast. The dyke is about 50 metres broad and has been traced for 300 metres inland striking in a N–S direction. It is agmatitic along the contacts (fig. 11), but it is homogeneous in its central parts. Here, however, it is cut by mylonites and thin grey dykes which latter continue as pegmatites in the enclosing Finnefjeld gneiss. The main diorite dyke gives off narrow apophyses which cut an older generation of pegmatites in the gneiss, but which are themselves cut by the youngest pegmatites, fig. 12.

The diorite dyke is composed of hornblende diorite, but as may be read from the following description there can be little doubt that it originally has been pyroxene-bearing.

19216. Hornblende diorite from the central part of the dyke.

A dark grey, medium grained rock with an interlobate, hemigranoblastic texture where the basic minerals form aggregates with irregular outlines. The minerals are plagioclase, hornblende, some quartz, a little biotite and epidote and accessory apatite and ore. The plagioclase, which

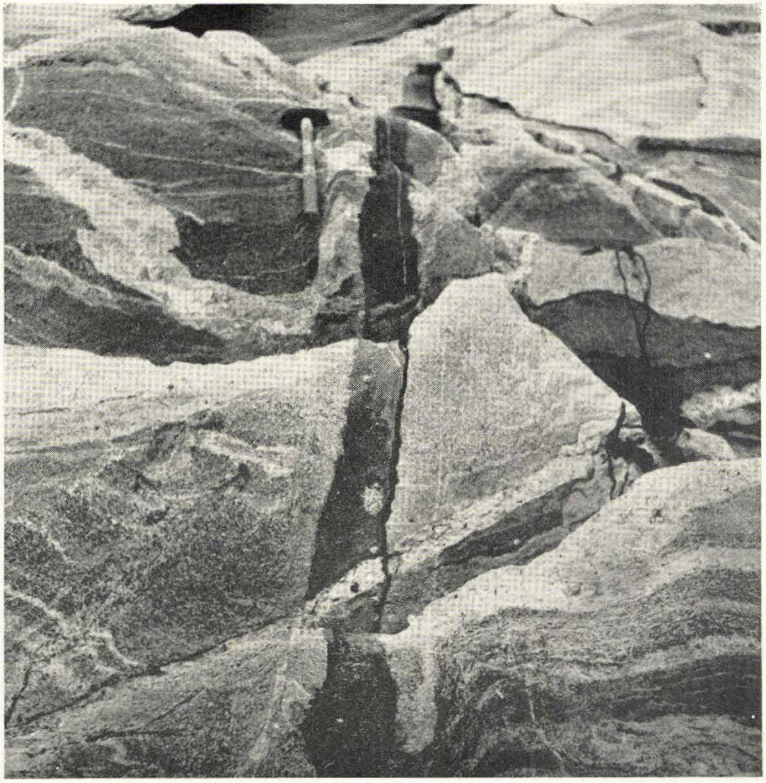

Fig. 12: Apophysis given off from the diorite dyke pictured in fig. 11. The apophysis cuts an older folded pegmatite (near the hammer), but is cut itself by a younger undeformed pegmatite (in the foreground). Photo GGU, A.B.

constitutes a little more than the half of the rock, shows deformed twin lamellae and undulate extinction. The larger grains are zoned and the An content varies from 34 to 32 $^0/_0$. Some scattered sericite scales are found in the plagioclase in addition to small grains of apatite and epidote, the latter forming idio- to hypidioblastic crystals. The hornblende is pleochroic from yellowish (X), to green (Y) and bluish green (Z). It contains small aggregates and amoeboid grains of quartz and in some hornblendes inclusions of ore with a relic schiller-arrangement are seen. Small amounts of quartz are also found associated with the granoblastic plagioclase. Biotite is found in a few flakes which are pleochroic from pale yellow to deep grey-brown.

A thin apophysis related to the main dyke is represented by specimen 19215 described below. As would be expected, this rock has suffered more from the retrograde metamorphism to which the main dyke also has been subjected. Thus, the hornblende has been completely altered into biotite and epidote.

19215. Altered diorite aplite given off by main dyke.

The fine grained dark rock consists of plagioclase, quartz, dark green biotite, abundant epidote and ore, and apatite and calcite in addition. The texture is cataclastic and the biotite is swept around the feldspar or quartz. The gneissic wall rock shows the same minerals, but is more leucocratic and even more influenced by cataclasis.

Another occurrence of diorite was found on the north coast of the short peninsula at the head of the Alángua fjord. This diorite shows a sharp contact to the surrounding quartz-dioritic gneiss. Late pegmatites cut the contact. A sample from the central part of this occurrence contains relic pyroxenes, diopside and hypersthene. The samples from nearer the contact show more uralitised types. The description of the pyroxene-bearing diorite follows.

19219. Pyroxene diorite.

A medium to coarse grained, greenish grey rock with an interlobate granoblastic texture. (In general the coloured minerals exhibit an amoeboid to poikiloblastic texture). The minerals are plagioclase, hornblende, diopside, hypersthene, some quartz and accessory apatite and ore. The plagioclase is andesinic (36–37 $^0/_0$ An) and shows deformed albite twins. Its quantity equals that of the mafic minerals. The hornblende is pleochroic from yellowish (X) to olive green (Y) and emerald green (Z). It forms large irregular grains and aggregates of smaller grains which poikiloblastically include small blebs or vermicular individuals of quartz. Some grains show ore inclusions in a schiller arrangement. In places it can be seen that the hornblende has formed at the expense of diopside and the uralitisation has proceeded along the cleavage planes of the diopside. This latter mineral is greenish and faintly pleochroic. Occasionally it contains small irregular grains of hypersthene or partly rims this mineral. The pinkish hypersthene is somewhat pleochroic and may show schiller structure.

Within the neighbouring Nordland complex, similar pyroxene diorites of transgressive habit are known to have formed metasomatically towards the end of or after the final culmination of an orogenic phase characterised by granulite facies metamorphism (i.e. during the intermediate period). In the author's experience, these dioritic rocks are alien to proper amphibolite facies rocks. Thus, where locally occurring in amphibolite facies rocks, they may bear witness of a former higher grade metamorphism of these (Berthelsen, 1955).

Reconsidering the feature enumerated above, the author finds ample evidence in support of the view that the Finnefjeld gneisses represent original granulite facies rocks, within which transgressive bodies of pyroxene diorite have formed. During a subsequent period of metamorphism (and shearing), the gneisses and the diorites recrystallised under lower grade metamorphic conditions.

As was pointed out above, the recrystallisation seemingly took place under conditions corresponding the low-grade amphibolite facies. This statement seems to agree with the results obtained from the study of the retrograde altered diorites. Thus in specimen 19216, epidote was found in the calcic andesine, while it does not occur in the more sodic plagioclases (30–35 $^{0}/_{0}$ An).

Following this line of thought, the relatively high content of sphene in the Finnefjeld gneiss may be explained by the release, during the subsequent recrystallisation, of the titanium incorporated in the mafic granulite facies minerals.

The occurrence of nebulitic and local agmatitic structures within the relic hypersthene-bearing varieties of the Finnefjeld gneiss suggest that these rocks passed through a long and complicated evolution before granulite facies conditions were obtained.

Since we know that the Finnefjeld gneiss passes gradually into the more heterogeneous gneisses of the Nordland complex to the south, and since the NW- to NNW-trending axes of this latter complex can be traced into the Finnefjeld complex, one may conclude that these two complexes have undergone a rather similar development in granulite facies. Assuming that the pyroxene diorites were formed simultaneously within the two complexes, the granulite facies metamorphism within the two respective complexes can be fairly positively correlated.

The post-dioritic evolution, however, took radically different trends within the two complexes. Within the Finnefjeld complex, strong penetrative movements effaced most older structures and facilitated a thorough recrystallisation. Thus the complex attained its present homogeneous character which makes it simulate a synkinematic tonalitic massif.

VIII. THE STRUCTURAL RELATION BETWEEN THE ALÁNGUA AND THE FINNEFJELD COMPLEXES

In 1953, only the southern part of the Alángua complex was surveyed from a structural point of view, and even this part of the complex has not yet been mapped in sufficiently great detail for a complete geological map to be presented. Nevertheless, the natural sections displayed by the coastal cliffs made it possible to obtain an impression of the tectonic style, and when combined with the reconnaissance mapping a first approach towards an analysis of the structures can be made.

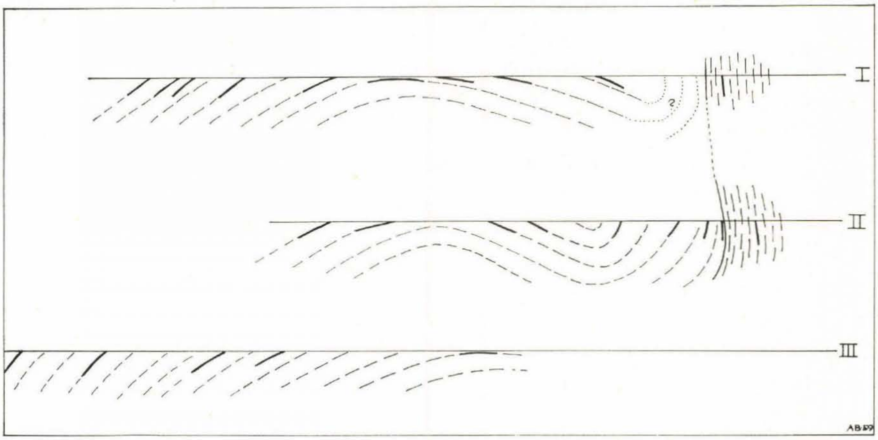

Fig. 13. Longitudinal profiles illustrating the variations in axial plunge within the Alángua fjord area (for the location of the profiles, I, II, and III, see fig. 4). To the right in the profiles, the Finnefjeld gneiss is included.

The highly complicated fold tectonics of the Alángua fjord area are characterised by disharmoneous, overturned to recumbent folds. The axial plunge shows variations from horizontal to vertical, a variation which can be fitted into larger depressions and culminations. The trend of the fold axes is north-easterly in the fjord area, but changes gradually to a more N–S direction towards the south and the north, see fig. 4.

Discussion is confined here to the better studied Alángua fjord region of which three longitudinal profiles have been prepared, fig. 13. The location of these profiles is shown on the tectonic map of fig. 4. In these three profiles, a gentle culmination in the axes may be seen. The culmination zone trends NNV–SSE crossing the fjord. Further to the north-east, a deep depression is found. The fold axes here steepen into a vertical to slightly overturned position. This has obviously been caused by an active push exerted by the more massive Finnefjeld complex, which in this area has been thrust in a north-westerly direction over the Alángua complex.

The same phase of movement may be recognised from the profile shown in fig. 14. This profile is partly compiled from field sketches and partly constructed from the reconnaissance map. It does not pretend to any great accuracy, but may serve as an illustration of the style of folding found within the transition zone between the Alángua complex and the Finnefjeld gneisses. In the north-west part of the profile (on the island Igdlutsiait), the style is seemingly simple with open folds. Semi-concordant pegmatites (P) are here woven into the layers of garnet amphibolite, mica schists and semipelitic gneisses. Further to the north-west and outside the profile, H. Sørensen has demonstrated the exis-

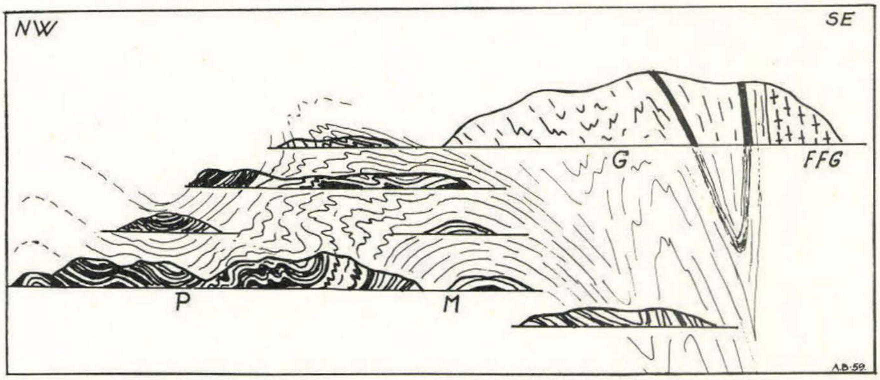

Fig. 14. Composite profile illustrating the fold structures on the islands Igdlutsiait and Portussoq. P: pegmatites, M: migmatitic schists and gneisses, G: gneiss, FFG: Finnefjeld gneiss.

tence of larger recumbent folds which are refolded by open folds. Lithological repetitions within the strata of Igdlutsiait have also been observed and it is quite possible that the open folds on this island have been formed within the flanks of older large recumbent structures.

In the central part of the combined profile, the open folds pass into overturned to recumbent disharmoneous structures within the strongly migmatised schists (M). The asymmetric smallfolds group themselves into a larger anticlinal structure which seemingly has favoured the local advance of the paratectonic migmatitisation. Further to the south-east agmatitic gneisses, more homogeneous only slightly banded gneisses (G) (fig. 15) and a layer of biotite schist occupy a composite synform. Within the overturned south-eastern flank of this synform, the Finnefjeld gneiss (F.F.G.) makes its appearance on south-eastern Portussoq.

To summarise, it can be said that older recumbent folds within the Alángua complex seem to have been refolded with increasing intensity towards the border to the Finnefjeld complex. This refolding was accompanied by paratectonic migmatisation. Recalling the complex axial relations in this region, it seems natural to correlate this refolding and migmatisation with the deformation phase during which the Finnefjeld complex was thrust over the Alángua complex. The incipient granitisation, the late recrystallisation and migmatisation of the ultrabasic rocks within the central Alángua complex should most probably belong to this phase.

The border between the Alángua and the Finnefjeld complexes is nearly vertical in the archipelago south of the entrance to the Alángua fjord. South of Napassoq, the border is transgressive to the fold structures. Here it may be seen how the gneissic rocks replace the eastern flank of a southward plunging antiform. Only the amphibolitic schists

Fig. 15: Smallfolded gneiss near the contact to the Finnefjeld gneiss, south coast of Portussoq. A fairly flat-lying fold axis controls the outcrop pattern. Photo GGU, A.B.

persist for any length into the gneiss, while schists of pelitic or semi-pelitic composition have only been preserved in the western flank of this structure.

These relations suggest that the Finnefjeld gneisses have developed by transformation of parts of the Alángua complex. Stratigraphically the two complexes apparently contain the same rocks and their present differences in structure and composition are due to their different evolutions in two separate Stockwerke (structural levels). This concept has been synthesised in the tectonogram, fig. 16, from which it may also be seen that a close relation exists between the strongly accentuated depressions and culminations in the isoclinally folded amphibolite (just south of the complex border) and the local overriding of the Finnefjeld complex onto the Alángua basin.

Although the synthesis just outlined is at present favoured by the author, he would like to point out an alternative theory. According to this, the rocks of the Alángua complex are younger than those of the

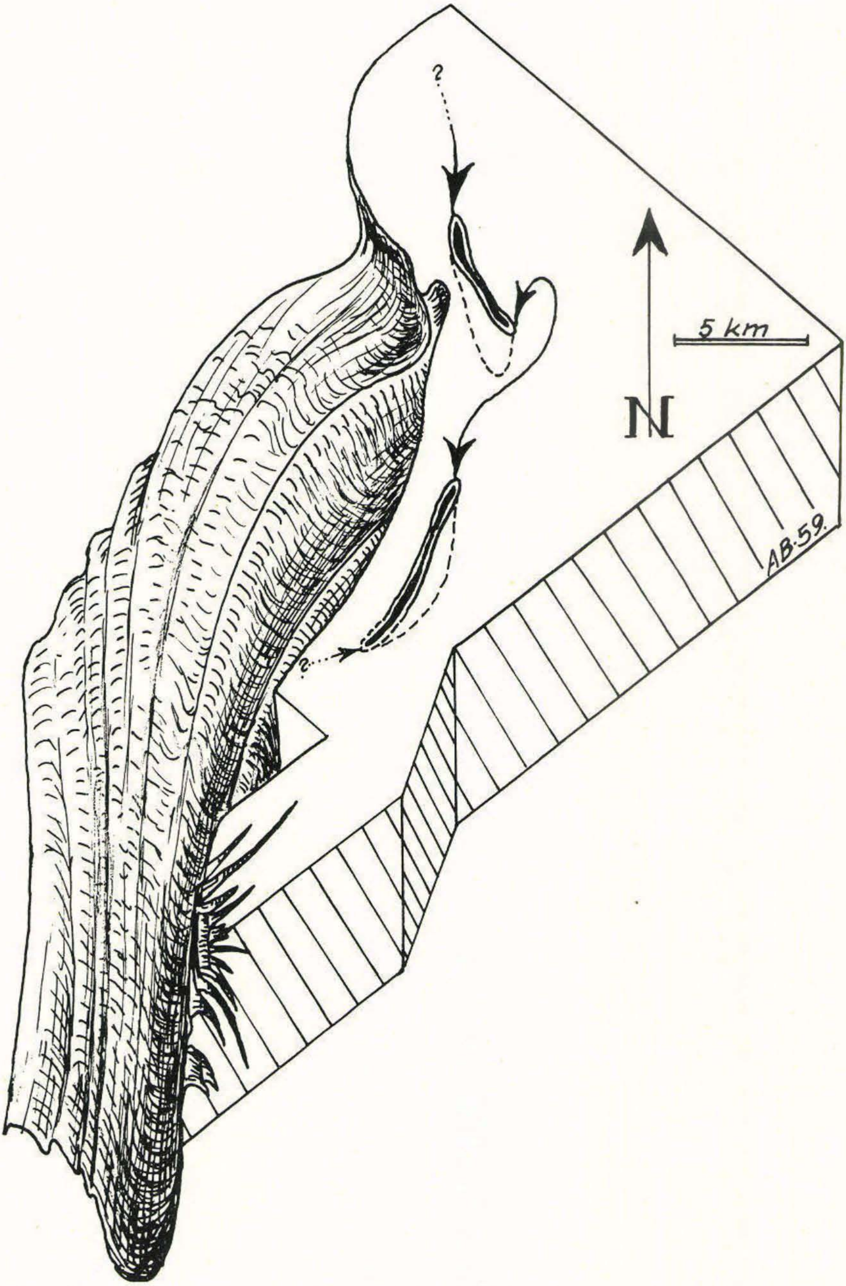

Fig. 16. Tectonogram showing the structural relation between the Alángua complex and the Finnefjeld complex. The depressions and culminations shown by the isoclinally folded amphibolite south of the complex border are also indicated.

Finnefjeld complex, and originally a major discordance existed between the two complexes. This theory refutes, however, the seemingly replacive nature of the Finnefjeld gneiss south of Napassoq. To be retained, it must be postulated that the antiform of this region hides older isoclines or tectonic slides which are responsible for the 'dying out' or the apparent progressive replacement of the pelitic schist layers within the eastern flank of the antiform. According to this theory, the isoclinally folded amphibolite south of the complex border would represent down-folded Alángua rocks and not a resister. In this connection it may also be mentioned that in 1949 Dr. H. Ramberg, on the south shore of Sdr. Isortoq close to the complex border, found a quartzitic flagstone, which conceivably represents a sheared conglomerate.

Against this alternative theory, the following facts can be put forward:

1. The lithological similarities which exist between the rocks of the Alángua complex and those of the Finnefjeld and Nordland complexes, when the latter are considered as having been more transformed.
2. The structural analysis of Tovqussap nunâ and other parts of the Nordland complex has brought out that in this region large scale north-west directed tectonic transport (Smalledal phase) can be discerned during an advanced stage of the progressive metamorphism, probably corresponding to amphibolite facies. The folds developed during the Smalledal phase recall in their style and kinematics the overturned to recumbent folds of the Alángua complex.

Although far from being conclusive, these facts strongly suggest that all three complexes have shared a common progressive metamorphism and deformation (Smalledal phase). Form then on their evolutionary paths divided. In the two southern complexes granulite facies conditions prevailed during the Pâkitsoq phase and the Langø subphase, while the northern complex remained in amphibolite facies. With the onset of the posthumous phase the compositional differences between the amphibolite and the granulite facies complexes gave rise to the development of the Finnefjeld complex through diaphtoritic transformations and shearing accompanying its local overriding onto the Alángua complex.

This interpretation explains the metachronous homoaxial nature of the Alángua structures and the metachronous polyaxial relations of the two southern complexes.

Future field studies within and along the borders of the Alángua complex possibly could produce a more definite answer to this problem.

IX. ECONOMIC GEOLOGY

No mineral deposits of economic interest were found during the survey of the southern Sukkertoppen district. This fact, however, does not exclude the possible existence of such occurrences. Many inland regions are still untouched and valuable minerals have been reported from several localities throughout the region—although they never have been found in greater concentrations.

Sulfides: Sulfides, mainly pyrite and pyrrhotite, occur disseminated in layers of mica schists and amphibolitic schists, which form 'rust zones'. Occasionally the sulfide-bearing rocks carry a noteworthy amount of chalcopyrite (see tables 1 and 3).

Magnetite: Magnetite-rich siliceous calc-silicate has been recorded as a thin band associated with pyribolite on the Tovqussaq peninsula (BERTHELSEN, 1960b, p. 52). As scattered grains, magnetite has also been observed in pegmatites in the Fiskefjord area.

Molybdenite: A pegmatite in amphibolite, just west of the complex border on the south coast of Sdr. Isortoq, carries scattered grains of molybdenite. Traces of this mineral has also been found associated with ultrabasic rocks at Tovqussaq.

Feldspar: Some pegmatites on the Tovqussaq peninsula carry microcline individuals exceeding 10 cms in size, but since similar pegmatites in most other cases have been moved and mylonitised, no great workable concentrations of feldspar can be expected.

Ultrabasic rocks and their associated minerals: These rocks, which have been studied by H. SØRENSEN (1952, 1953, 1954, and 1955), deserve consideration from an economic point of view. H. SØRENSEN has reported the finding of corundum (as single grains), monazite and zircon in association with the ultrabasites of the Alángua complex. The same author (H. SØRENSEN, 1955) also found the rare mineral sapphirine in these rocks.

The olivine-rich, very big ultrabasic masses met with in the Fiskefjord area possibly could be of economic interest since they are the most pure olivine rocks of the whole region.

Soapstone is found at several localities, most of which are already known to the Greenlanders.

Talc is found as vein fillings in the ultrabasic rocks in the Fiskefjord area (e.g. north-east of Tasiussarssuaq, see Pl. 1).

Radioactive minerals: No systematic search with Geiger Müller counters has been made in connection with the mapping, but a somewhat radioactive mineral, allanite, was found to be common in pegmatites within the Alángua complex. Scattered grains of allanite may also be seen in the Finnefjeld gneiss at the head of Kangia. The granitic rocks of the Nordland complex carry allanite, but as very small and scattered grains.

The Fiskefjord faulting apparently was not accompanied by mineralisation. The retrograde alterations attached to the faulting were, however, responsible for the formation of serpentinites and soapstones at the expense of former olivinites and peridotites.

The basic dykes include some abnormal types which carry more than 90 % of mafic minerals and which do not carry apatite (BERTHELSEN and BRIDGWATER, 1960). However, no concentrations of ore minerals have been noticed within these dykes.

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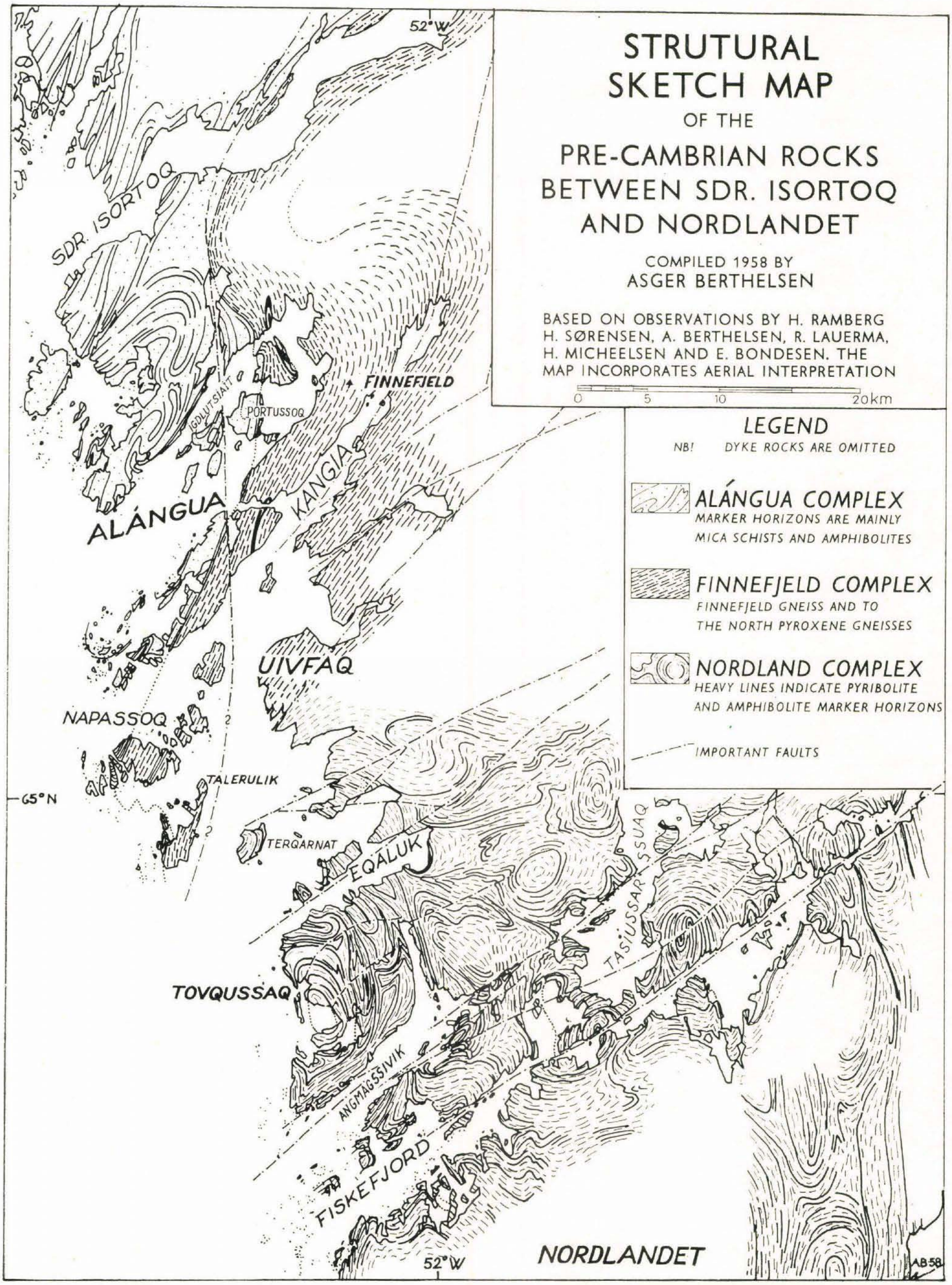
STRUTURAL
SKETCH MAP
OF THE
PRE-CAMBRIAN ROCKS
BETWEEN SDR. ISORTOQ
AND NORDLANDET
COMPILED 1958 BY
ASGER BERTHELSEN
BASED ON OBSERVATIONS BY H. RAMBERG
H. SØRENSEN, A. BERTHELSEN, R. LAUERMA,
H. MICHEELSEN AND E. BONDESEN. THE
MAP INCORPORATES AERIAL INTERPRETATION
0 5 10 20km
LEGEND
NB! DYKE ROCKS ARE OMITTED
ALÁNGUA COMPLEX
MARKER HORIZONS ARE MAINLY
MICA SCHISTS AND AMPHIBOLITES
FINNEFJELD COMPLEX
FINNEFJELD GNEISS AND TO
THE NORTH PYROXENE GNEISSES
NORDLAND COMPLEX
HEAVY LINES INDICATE PYRIBOLITE
AND AMPHIBOLITE MARKER HORIZONS
IMPORTANT FAULTS
52° W
SDR. ISORTOQ
FINNEFJELD
PORTUSSOQ
IGDLUTSIAIT
ALÁNGUA
KANGIA
UIVFAQ
NAPASSOQ
TALERULIK
65° N
TERQARNAT
EQALUK
TASIUSSARSSUAQ
TOVQUSSAQ
ANGMAGSSIVIK
FISKEFJORD
52° W
NORDLANDET
AB58