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The geological setting and mineralizations west of Lilianmine, South Greenland

by

Martin Ghisler

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THE GEOLOGICAL SETTING AND MINERALIZATIONS WEST OF LILIANMINE, SOUTH GREENLAND

by

MARTIN GHISLER

With 7 figures and 1 map

1968

Abstract

The coastal strip of green schists at the south side of Kobberminebugt consists of a sequence of alternating meta-volcanic rocks and meta-sediments. Uralite porphyrite and subordinate plagioclase porphyrite represent the volcanic component of the geosynclinal deposits, whereas no meta-sediments have been recognized with certainty in the area under consideration. Pillow structures indicate the extrusive origin of the basic lavaflows and its original porphyritic texture is well-preserved at one locality. Different grades of pressure and metamorphism during the Ketilidian orogeny have elsewhere given rise to a transitional series from uralite porphyrite to schistose greenstone.

A small composite intrusion with sharp contacts and a characteristic joint system is regarded to be an appinitic suite of Sanerutian age. A monzonitic magma was intruded into the centre of a gabbro body, a probable early derivative of which is represented by a hornblendite. A ringdyke of quartz dioritic composition intruded the basic rocks, the age relation to the monzonite remaining uncertain.

Some irregular intrusive bodies of pink felsite, which in some places have the character of quartz porphyries, are based on the dolerite chronology, shown to be of Gardar age.

A swarm of pegmatite dykes extends from the biotite granite of the Nunarssuit intrusive complex into the green schists. The subhorizontal pegmatites are interesting because of their rare minerals such as beryl, amazonestone, molybdenite, and aegirine with pseudomorphs of hematite in large crystals. Copper sulphides occur in the pegmatites, but are most important in the hydrothermal mineralizations along faults and shear zones, joints and fracture fillings. Bigger concentrations of ore have only been found in two places, but they are not of economic importance.

Geophysical measurements with a magnetometer have shown anomalies in the green schists, which mainly are regarded to be due to different grades of compaction of the metamorphosed magnetite-bearing volcanic rocks.

Geochemical analyses have been made on 4 rock samples, the results of which in relation with the distribution pattern of the mineralizations in the field suggest, that the copper necessary for the formation of the ores has been extracted from the green schists by hydrothermal activity, in this area related with the intrusion of the biotite granite.

Trace element determinations on 2 botanical samples were made to test the possibilities for applicating two common plants in the region in geo-botanical prospecting.

CONTENTS

I. INTRODUCTION

The area under consideration is situated on the peninsula immediately west of the abandoned copper mines, Josvamine and Lilianmine, about 40 km south of the cryolite mining community of Ivigtut (see index map on map 1). A coastal strip 500 - 1500 m wide and 3 km long of mainly Precambrian green schists has been mapped in detail together with the surrounding rocks, with special regard to mineralization. Six weeks were spent by the writer in the field in the summer of 1964 as participant of the Grønlands Geologiske Undersøgelse expedition. This report is regarded as supplementary to the previous work published by Harry and Oen (1964).

Many problems of the complex Precambrian history of the Ivigtut-Nunarssuit region still remain to be solved. At present three major cycles can be distinguished: the pre-Ketilidian, the Ketilidian and the Gardar (Higgins and Bondesen, 1966). The metasediments and metavolcanics of Kobberminebugt occur at a high level in the stratigraphic column of the Ketilidian geosynclinal sediments (Allaart, Bridgwater and Henriksen, in press). This Ketilidian supracrustal series was folded and metamorphosed under epidote-amphibolite facies conditions during the Ketilidian orogeny (Wegmann, 1938). Several generations of now metamorphosed basic dykes are known from this period, on the basis of which one may distinguish two "plutonic episodes" (Watterson, 1965), the second taking place in Sanerutian time (Berthelsen, 1961).

The Gardar cycle was initiated by deposition of a sequence of sandstone and volcanics, called the Eriksfjord Formation (Poulsen, 1964), now only preserved in the Igaliko region. Numerous generations of dykes were intruded, pre-dating the emplacement of the alkaline plutons of this region, of which the Nunarssuit complex (Harry and Pulvertaft, 1963) is a most important member.

Finally a swarm of NW-trending basic dykes were intruded in Mesozoic time (Larsen, 1966).

II. KETILIDIAN ROCKS

1) The green schists

It was suggested by Berthelsen and Noe-Nygaard (1965) that the supracrustal series of Kobberminebugt probably belongs to the youngest Ketilidian geosynclinal sediments known in the Ivigtut region. The stratigraphic section from the inner part of Kobberminebugt has been described by Watterson (1965), and Allaart et. al. (in press) have proposed the name Ilordleq Group for this green schist series, which they consider to overly the supracrustal rocks belonging to the Qipisarqo Group (Higgins and Bondesen, 1966).

The present area is the westernmost part of the impersistent strip of Ilordleq Group green schists running along the coast of the south side of Kobberminebugt. Although the group consists of interbedded metavolcanic and metasedimentary rocks, here only the originally volcanic rocks have been recognized with certainty. Though no correlation of the strata has been possible, an attempt is made to show the composite stratigraphic section of the supracrustals in this area (fig. 1) It indicates that Watterson's 1500 m section in the Ilordleq area is a minimum thickness. The most distinctive rock-types are described in the following sections.

The lithological layering is roughly concordant with foliation, schistosity and shear zones, all striking north-east. The strike averages 30^{o} in the central and eastern part with a variation in dip between 60^{o} SE to vertical, whereas bigger differences in orientation are observed in the western part, the variations in strike and dip being due to the intrusion of the biotite granite. Minor folds observed in a few places have axes plunging to the north-east at 20^{o} in accordance with the constructed fold axes for the area as a whole.

a) Plagioclase porphyrite

Rocks similar to the plagioclase porphyrites described by Sederholm (1923) from the Pellinge district of Finland are found in an area near Lilianmine and as small areas on the peninsula immediately

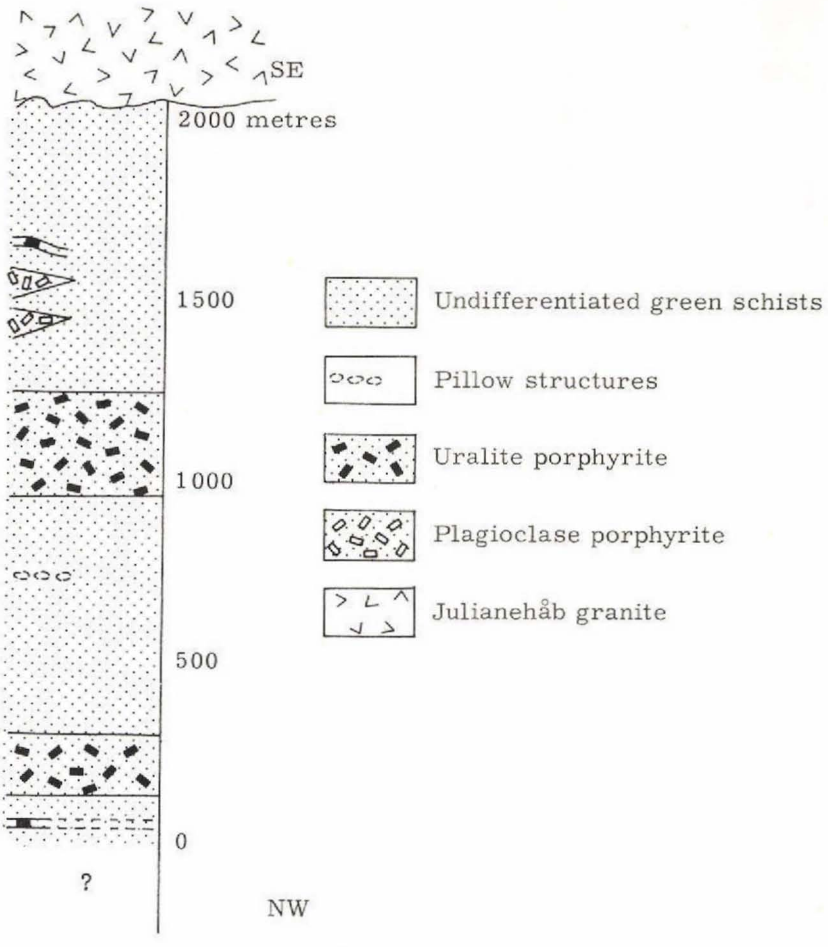

Fig. 1 Composite stratigraphic section of the supracrustal rocks in the area west of Lilianmine.

to the west with gradational contacts to the surrounding green schists. Harry and Oen (1964, p. 14) describe the same rock occurring within the green schists farther to the east along the shore of Kobberminebugt, the porphyrite generally concordant with the foliation of the adjacent schists but sometimes transecting the latter at small angles. In contrast to the surrounding green schists the plagioclase porphyrite has no schistosity, but several metre-wide shear zones in an east-west direction give evidence of later deformation.

The rock is massive and unfoliated in hand specimen, with numerous feldspar phenocrysts in a grey, fine-grained groundmass. The phenocrysts are 0.2 - 1.0 cm big, euhedral to subhedral with elongated rectangular forms. In thin section (51801) under the microscope the relic phenocrysts are seen to be completely altered due to the regional metamorphism, and so the original composition of the plagioclase is not determinable. The core consists of a fine-grained aggregate of epidote, surrounded by a zone of saussuritized plagioclase and radiating aggregates of actinolitic hornblende and a little epidote with an outermost border zone consisting of albite. The groundmass is built up of greenish brown biotite showing relic flow structures arranged conformably around the phenocrysts, aggregates of pale green hornblende, and very fine-grained albite (grains less than 0.1 mm in size). Accessories are chlorite, often associated with sphene, orthoclase, ore and also a little quartz. Euhedral crystals of hornblende have grown through the biotite layers into the phenocrysts, showing their later metamorphic origin. They are themselves penetrated by albite, which forms replacement perthites with orthoclase.

Within the plagioclase porphyrite rock are found numerous epidote lenses varying in size from 1 cm to 0.5 m and epidote layers parallel to schistosity which reach a maximum width of 1 m and a length of 50 m; both contain quartz, alkali feldspar, magnetite, hematite and copper sulphides in different amounts. The formation of epidote-rich rock took place during the Ketilidian regional metamorphism under epidote-amphibolite facies conditions, accentuated by later epidotization correlated with ore mineralizations in Gardar time. These facts have been thoroughly treated by Harry and Oen (1964).

b) Uralite porphyrite

This rock, which in many respects recalls the uralite porphyrites of Sederholm (1923), represents an extensive type within the area. Contacts to the surrounding rocks are transitional nevertheless two north-east striking units can be recognized in the stratigraphic section 300 m wide in the central part and 200 m wide in the western part respectively. This rock-type originally dominated the area, but different grades of pressure and metamorphism during the Ketilidian plutonism have given rise to a transitional series from uralite porphyrite to schistose greenstone, as demonstrated in the following. In the field the rock has been mapped as uralite porphyrite as far as hornblende phenocrysts were distinct, but otherwise as undifferentiated green schists, even if the porphyritic origin of the rock still was recognizable by the presence of deformed, lense-shaped phenocrysts.

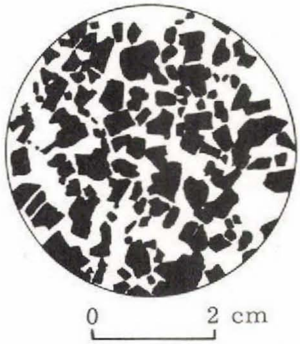

Fig. 2 Uralite porphyrite. Traced from a polished rock surface of sample 56461.

A rock preserved as a small relic within the gabbro on the peninsula northeast of Sorttop most resembles structurally the original volcanic rock. In hand specimen it appears as a porphyritic rock with short, prismatic, greenish black phenocrysts, the size of which is 1 - 3 mm and generally does not exceed 6 mm, set in a grey, fine-grained matrix (fig. 2). Some of the hornblende phenocrysts in their central parts are altered to biotite. In thin section (56461) two different types of phenocrysts may be distinguished:
60 % are crystals of pleochroic hornblende with colours from brownish green to bluish green. Twins parallel to {100} are common, and in a few cases polysynthetic twin lamellae are seen in the same crystal. Extinction angles $\gamma \wedge c$ are near 20°. Brownish green, fine-grained biotite replaces the hornblende mainly along the amphibole cleavages. The remaining phenocrysts have less distinct crystal shapes and consist of patchy areas of colourless pyroxene flecked with small plates of green pleochroic amphibole. The latter type contains 4 - 7 % ore as scattered grains, whereas this is absent within the first type of probably primary hornblende. The plagioclase does not form macroscopic phenocrysts, but in thin section several subhedral crystals measuring 1 mm in length are seen, which

according to Sederholm (1923, p. 23) may be regarded as porphyritic constituents. The groundmass, with an average grain size of 0.1 mm, consists mainly of hypidiomorphic plagioclase and actinolitic hornblende with a brighter colour than the phenocrysts. The plagioclase shows a variable grain size from 0.1 - 1.0 mm, with an anorthite content of 25 - 28 % An [1]. Accessories are apatite and ore. As the plagioclase composition can not be regarded to be the original one because of the regional metamorphism, the microscopic examination does not reveal the composition of the original basic volcanic rock.

In the south-westernmost part of the area the uralite porphyrite has still a well preserved porphyritic texture, but the phenocrysts have rounded corners and are in thin section (51818) seen to consist of fine-grained aggregates of hornblende and ore. Relics of saussuritized plagioclase phenocrysts are frequent. The groundmass, with an average grain size of 0.1 mm, consists of actinolitic hornblende, olive-green biotite and partly saussuritized plagioclase (An 25 %). Accessories are magnetite with leucoxene rims, apatite and epidote. On the peninsula west of Lilianmine the rock is foliated (51900), the hornblende phenocrysts being lens-shaped and metamorphosed to brown biotite and magnetite. The groundmass consists of actinolitic hornblende, biotite, quartz and albite, the two latter minerals having invaded both the altered plagioclase and hornblende phenocrysts. The foliation of the rock is due to the parallel orientation of the mafic minerals. The mafic "lenses" consist of brown biotite with a magnetite content as high as 20 % (51865), whereas the fine-grained mafic components outside the relic phenocrysts are green biotite, actinolite, several types of chlorite with the characteristic green thuringite, epidote in aggregates, and only 2 % ore. The leucocratic components are relics of saussuritized plagioclase, albite, quartz and accessory apatite. Big porphyroblastic aggregates several cm across (56464) are composed of anhedral quartz, the grain size of which varies from 3 mm in the centre to 0.5 mm near the borders. During the growth of these post-kinematic porphyroblasts the mafics around were intensely compacted.

[1] If nothing else is mentioned all plagioclase determinations in the following have been done on the universal stage according to Reinhard (1931).

It is seen from this description that the original porphyritic rock can still be recognized in the green schists, even after strong deformation and alteration during the regional metamorphism.

400 m west of Lilianmine a uralite porphyrite dyke or sill (51802) has been found which cuts the green schist host rock slightly discordantly. It is 50 cm wide, without any fine-grained contact, and traceable only a few tens of metres. Later alkali feldspar, epidote and hematite are present, but the porphyritic rock is very similar to the one described above (56461).

The uralite porphyrites, which form horizons up to several hundred metres in thickness concordant with the general layering, are thought to be metavolcanics of extrusive origin; this is also suggested by the pillow structures within the green schists described below. The discordant uralite porphyrite body on the other hand indicates an intrusive origin for some of these rocks. This fact, however, does not disprove the general extrusive origin of these rocks already suggested by Watterson (1965, p. 17), as this dyke has intruded overlying rocks and may well belong to a later stage of the volcanic activity producing rocks of very similar petrographic appearance.

c) Pillow structures

Pillow structures have already been observed by Wegmann (1938) at the nearby Josvamine, and Harry and Oen (1964, p. 11) describe a locality near the shore north of Sorttop, where readily recognizable pillow structures are visible. The pillows are light grey oval bodies, generally 15 - 30 cm long, reaching a maximum length of half a metre. They are lying in a darker matrix, the minerals of which are arranged conformably around the pillows. Their shape suggests a "younging" to the south-east and their long axes are slightly discordant to the schistosity in the surrounding green schists (fig. 3). Small fractures within the pillows are filled with hornblende, chlorite, albite and orthoclase. In thin section (56449) the primary minerals are altered to greenish brown biotite and hornblende, sometimes forming lenses with a high magnetite content, and saussuritized plagioclase. The very fine-grained groundmass of the pillows (0.05 mm) consists of allotriomorphic quartz, albite and aggregates of actinolitic hornblende, these three minerals invading the others and reflecting the regional metamorphism. A characteristic feature is the occurrence of numerous 1.5 mm long, almond-shaped quartz vesicles, composed of 0.15 mm big individuals, arranged parallel to the rounded shape of the pillow. They are regarded as amygdales.

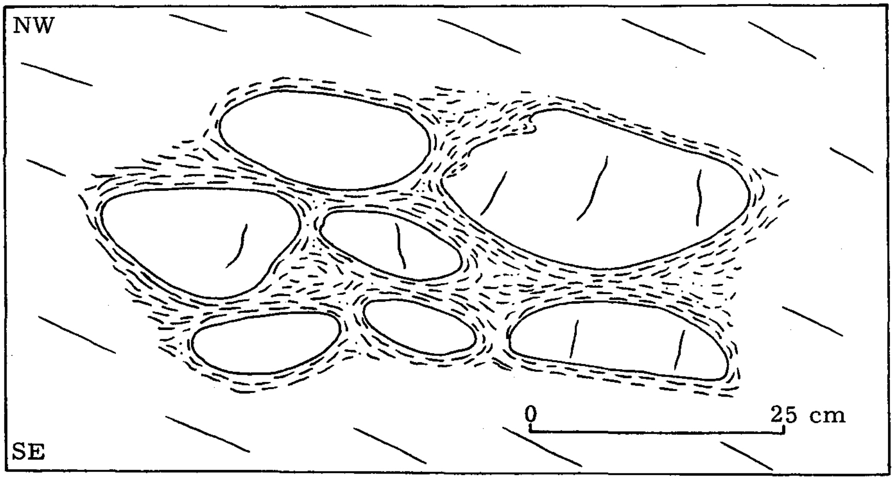

Fig. 3 Pillow structures within the green schists north of Sorttop.

These pillow structures cause a very characteristic erosional surface pattern in an area of about 100 m^2. Similar patterns were observed at several localities within the map area, but in no other case were pillow structures recognized with certainty.

d) Banded schists

In addition to the well-defined rocks described above, the green schist belt includes fine-grained, grey to green banded schists, forming stratigraphic units rarely more than 1 m wide. They are often strongly crushed due to transcurrent shearing in contrast to the surrounding, less competent green schists, which were slightly folded. The foliation and lineation clearly visible in hand specimens are not so evident in thin section (56482). The mafics are dominated by pale green hornblende in close association with ore, and less frequent are epidote and chlorite. The grain size of the mafics is about 0.3 mm in contrast to a very fine-grained groundmass (0.02 mm) consisting of quartz and albite. A few relics of strongly saussuritized plagioclase grains were seen. This rock in many respects resembles the metasediments described by Watterson (1965), and may be regarded as such, but no evidence was observed to confirm this assumption. Some of the very fine-grained grey rocks are of probable mylonitic origin.

2) The Julianehåb granite

As this Ketilidian granite, formed during the first plutonic episode and reactivated in Sanerutian time, has been described in detail by Harry and Oen (1964), only a few remarks will be made here. In hand specimen it is a pinkish, medium-grained rock, consisting of feldspars, quartz and a very small amount of dark minerals; the colour originates from the feldspar component. In thin section (56435) the alkali feldspar is seen to be microcline and microcline-perthite. The plagioclase has oligoclase composition, and both feldspars often contain brownish alteration products. Quartz occurs as round, polycrystalline, medium- or slightly coarse-grained areas, as well as smaller interstitial grains together with albite. The mafic minerals are biotite and hornblende, with a few accessory grains of zircon, epidote, sphene, chlorite and ore.

The contact between the green schists and the Julianehåb granite is in general sharp and steep, at one place dipping 60° to the north-west with the green schists "overlying" the granite. Migmatitic boundaries are seen in several places and also transitional zones of more or less feldspatized green schists about 200 m wide are common, as a consequence of which the contacts are indicated as arbitrary on the map.

3) Metamorphosed basic dykes

In both the supracrustals and the Julianehåb granite there occur numerous metamorphosed basic dykes, called discordant amphibolites, which generally is shortened to DA. Watterson (1965) distinguishes between three groups, on the basis of which the regional plutonic development is elucidated. An attempt is made in the following to classify the amphibolitic dykes from this area in accordance with Watterson's (op. cit.) chronology.

First period DAs, which only occur in the Ketilidian supracrustals, are separated from DAs of the next period because the former only are affected by granitic veins belonging to the 1st plutonic episode. As the relationship between the dykes and such veins cannot be seen in the green schists of this area, dykes of the two first periods are not distinguishable with certainty. The uralite porphyrite dyke mentioned above is regarded as originating from the same volcanic activity as the supracrustal meta-volcanics, and so is classified as a first period DA. A green 0.5 m wide amphibolitic dyke, which can be traced discontinuously for several hundred metres parallel to the layering in the western part near the coast, is also regarded as a DA1. In places it is slightly discordant to the green schists, but has the same schistosity except for the unsheared margins. Granitic veins of uncertain origin have invaded the rock. Of the same age are probably many other small dykes or sills 20 cm to 1 m wide, always parallel to the general layering, which in the field often may be distinguished only by their structure from the supracrustal host rock.

Two types of second period dykes may be distinguished according to Watterson (op. cit.). An example of a probable green second period dyke is found on the easternmost island off the peninsula west of Lilianmine. It is a 2 m wide dyke, consisting almost entirely of green hornblende, which runs across the schistosity of the green schists, but is shear-folded by superimposed Sanerutian deformation. In places it is cut by granitic and epidote veins. An example of a grey second period dyke, which contain an appreciable amount of feldspar, is probably a 50 cm wide slightly discordant dyke on the island immediately west to the foregoing. It is cut by small granitic veins and sheared by presumably Sanerutian deformation.

While the exact chronological position of the described dykes cannot be recognized within the supracrustals, discordant amphibolites were observed within the Julianehåb granite which certainly belong to DA2. They are 1 - 3 m wide bodies occuring both as lens-shaped inclusions and as dykes traceable for several hundred metres. They are in places folded and affected by the reactivation of the Julianehåb granite during Sanerutian time (second plutonic episode). Though the contacts often are sharp, no chilled margins have been observed.

No DA3 dykes have been recognized in the area.

4) Appinitic intrusive complex

On the peninsula north-east of Sorttop is found a small composite intrusion covering an area of 400 x 200 m, which but for limitation by the sea would be somewhat bigger. The rock units are hornblendite, gabbro, monzonite and dioritic rocks, the age of which will be discussed at the end of this section.

a) Hornblendite

East and west of the peninsula are found two ultrabasic bodies several tens of metres across. To the east there are in some places sharp contacts to the surrounding gabbro which contains hornblendite inclusions, whereas transitional zones to both uralite porphyrite and gabbro are seen elsewhere. In hand specimen the rock is green, compact and medium-grained, consisting of hornblende and biotite with a little talc. In thin section (56451) it has a diablastic texture, where in only a few cases crystals 5 mm in size with original crystal shapes are recognizable in a fine-grained groundmass of alteration products. Half the rock consists of pale green hornblende, occurring as 1 - 2 mm big aggregates, the individuals in which are 0.1 mm in size. Bigger grains show strongly developed amphibole cleavage. Biotite forms 30 % of the rock. A green to colourless type is dominant, mostly as subhedral to anhedral grains 0.2 mm in size forming 2 mm aggregates, whereas a yellowish brown biotite, the grains of which are euhedral to subhedral, is less frequent. Talc, which forms 10 %, is seen as single grains with a maximum size of 0.5 mm, but mainly forms very fine-grained (0.05 mm) aggregates with hornblende. Iron oxides form 2 % of the rock, occurring equally distributed through the section with a maximum grain size of 0.3 mm, but also as 0.01 - 0.1 mm grains densely distributed in a few hornblende aggregates. Other accessories are chlorite, epidote and rutile. Though no cores of pyroxene have been observed, the pale green, sometimes fibrous amphibole is regarded as uralitic hornblende. This fact in conjunction with the mineral assemblages described suggests that this hornblendite is the alteration product of an original pyroxenite.

b) Gabbro

This rock, already mentioned by Harry and Oen (1964, p. 27), covers the biggest part of the peninsula. It has transitional contacts to the surrounding green schists, but with sharp contacts to the monzonite. In hand specimen it appears as a medium- to coarse-grained, unfoliated igneous rock with about 50 % feldspar and 50 % mafic minerals. In thin section (56452) plagioclase forming 53 % of the rock occurs as subhedral crystals between 1 and 5 mm often in areas exceeding 5 mm. The crystals, which are well-twinned after the albite and pericline laws, are in places saussuritized, but the composition is still determinable as labradorite (53 - 58 % An), sometimes with more albite-rich borders. The mafic minerals are hornblende and biotite, occurring mainly as composite aggregates 1 - 5 mm in size. The bluish-green hornblende has typical uralitic appearance; bigger grains often have ore along the cleavages. The hornblende is partly altered to both green and brown biotite, the first type dominating, which mostly occurs as fine-grained aggregates with individuals 0.15 mm in size. The mafics form 46 % of the rock, with 24 % hornblende and 22% biotite. Accessories are apatite, ore and a little chlorite and orthoclase.

A thin section from the sharp contact to the hornblendite (56460) mentioned above confirms the younger age of the gabbro, indicated by its plagioclase invading the hornblendite, by the recrystallization of the hornblende in the latter to euhedral actinolitic grains, by the deformation of biotite grains along the contact, and by the mafic minerals being less altered in the gabbro than in the hornblendite.

c) Monzonite

On the tip of the peninsula the monzonite is seen to have intruded the gabbro. This is illustrated by the fact that a shear-zone cutting the gabbro on the west coast has not affected the monzonite. The contacts are mostly steep and sharp; in some places there are apophyses of monzonite fed into the gabbro, at one locality as a 2 m wide monzonite dyke which only differs from the mother-rock in being more fine-grained. In hand specimen the monzonite is a reddish, medium- to coarse-grained rock with a granitoid appearance. After staining with cobaltinitrite (Rosenblum, 1956) the plagioclase grains are seen to be mantled by potassium feldspar. In thin section (56457) oligoclase, forming 47 % of the rock, occurs as saussuritized, rounded crystals up to 6 mm in length, mantled by orthoclase as 0.3 mm wide rims. Orthoclase also occurs interstitially as individual grains, and is sometimes replaced by albite forming perthites of "patch"-type. 31 % of the rock is potassium feldspar. Quartz, which cannot be seen in hand specimen, forms 8 % of the rock as interstitial grains, the size of which always is less than 0.5 mm. The dominating mafic mineral is bright green chlorite, occurring both as euhedral grains 0.5 - 1 mm big, and as more fine-grained aggregates. The mineral shows anomalous interference colours varying from blue to brown with a violet tint. The chlorite is an alteration product of hornblende, which is preserved in the cores of a few grains. Brown biotite is also associated with chlorite, which forms 11 % of the rock. Accessory minerals are sphene, microcline and ore.

As 60 % of the feldspar is plagioclase (oligoclase) and 40 % is orthoclase, and the quartz content is below 10 %, the rock is according to Streckeisen (1965) classified as monzonite.

Three joint systems most strongly developed in the monzonite, form the characteristic pattern often associated with intrusive bodies (Cloos, 1922). Two systems of flat-lying joints strike east-west and dip 10^{o} to the north and south respectively, producing roof-shaped surfaces. The remaining joints are vertical and strike north-east.

d) Dioritic rocks

A 2 m wide ring-dyke cuts through the gabbro with knife-sharp contacts and sends apophyses into the host rock. To the east the dyke has also intruded the hornblendite and contains 1 m big agmatitic inclusions of this rock. Several metres away from the dyke the basic rocks are feldspathized and often rich in thin leucocratic veins. The dyke is a grey, medium- to fine-grained rock (56459), which contains about 65 % feldspar, mostly plagioclase of andesine composition. It forms euhedral and subhedral 1 - 5 mm long crystals, the central parts of which are partly saussuritized, whereas the more albite-rich borders are less altered. Orthoclase occurs only in a little amount as small later veinlets. Quartz is interstitial with a grain size between 0.2 and 1.0 mm, and forms 17 % of the rock, which must therefore be classified as quartz diorite. The main mafic component is brown biotite, occurring as 0.5 - 1.0 mm long euhedral crystals and more fine-grained aggregates forming 13 % of the rock constituents. The accessories are chlorite, apatite, sphene and ore, the last often as idiomorphic grains associated with biotite.

Many other narrow dykes cutting the gabbro and hornblendite were observed, but it was not possible to map them on the scale used. They contain varying amounts of potassium feldspar and quartz, and their composition is probably transitional from diorite to monzonite. The ring-dyke is regarded as contemporaneous with the monzonite.

e) Age of the intrusive complex

The exact chronological position of the above-described intrusive complex is unknown, as it cannot be correlated with discordant amphibolites and cross-cutting granitic veins which in this region are the basis of the Ketilidian chronology established by Watterson (1965). Even its Ketilidian age is a little dubious, as no cross-cutting Gardar dolerites were observed. But all intrusive rocks are post-dated by subhorizontal pegmatites of late Gardar age and by two fault systems striking ESE and WSW respectively, all of which cut through the intrusive rocks but do not affect the felsite of early Gardar age (see p. 25). Thus intrusion in pre-Gardar time is the most probable.

None of the rocks belonging to the complex are foliated, an acceptable reason for assuming emplacement after the main Ketilidian deformation. Walton (1965) for example uses this argument when proposing that similar intrusive rocks in the Narssarssuaq region are Sanerutian in age. Watterson (1965, p. 34), however, describes some metagabbro bodies, which in general also are unfoliated, but which are post-dated by the granite from the first plutonic episode. Allaart (1967) on the other hand describes a metagabbro from Torssukåtak fjord, probably also belonging to the first plutonic episode, which is foliated. Thus it is seen that the foliated or unfoliated nature of the igneous rocks in the region does not necessarily give evidence of age relations to deformation.

The monzonite dykes west of the peninsula have intruded the uralite porphyrite, are discordant to foliation, schistosity and epidote-veins, and have agmatitic inclusions of the host rock. This shows that they are younger than the main Ketilidian deformation. There is however no field evidence to prove that the intrusive rocks all belong to the same period.

The question is - is the hornblendite an early derivative of the basic magma which gave rise to the intrusion of the gabbro, or should it be regarded as an earlier igneous rock, e.g. one contemporaneous with the emplacement of the geosynclinal volcanic rocks such as the uralite porphyrite, which at this locality is also unfoliated and has transitional contacts with the gabbro and hornblendite. The hornblendite is seen in thin section to be strongly metamorphosed, consisting of diablastic fine-grained alteration products, whereas the gabbro, monzonite and quartz diorite are less metamorphosed and still show well-preserved igneous texture. They are regarded as belonging to an appinitic suite of Sanerutian age similar to that described by Walton (1965). However, as basic derivatives are commonly associated with this suite in many places in South Greenland, the hornblendite is also assumed to belong to the same igneous activity.

III. GARDAR ROCKS

This period is characterized in South Greenland by several alkaline intrusive complexes, of which the nearby Nunarssuit complex is described by Harry and Pulvertaft (1963). The emplacement of this complex began with the intrusion of the Alángorssuaq gabbro, followed by the Helene granite, Kitsigsut syenite, biotite granite, the very extensive Nunarssuit syenite, and finally sodic granite ends the suite. Of these rocks only the biotite granite and its border relations to the green schists will be treated in the following account.

Igneous activity from the Gardar period was also marked by the intrusion of numerous dolerite dykes. None of these dykes cut the Nunarssuit intrusive complex, which on the contrary at several places is seen to truncate them. Igneous rocks af acid composition are also known from this phase of dyke intrusion; in the area described these are represented by irregular felsite and quartz porphyry bodies and by a single rhyolitic dyke.

1) Dykes

a) Dolerites

The numerous dolerite dykes are generally about 1 m wide, but a few reach widths between 10 and 20 m and are traceable for big distances. They are easy to follow in the granitic rocks, whereas the less pronounced colour contrast to the metavolcanics combined with a lower degree of exposure in these areas makes it rather difficult to trace the minor basic dykes more than a few metres within the green schist belt. Harry and Pulvertaft (1963, p. 17) discern four generations of dolerite dykes in the Nunarssuit region, representatives of which are found also in the area under consideration.

The oldest Gardar dolerites striking east-west or ESE are represented in this area by a few larger dykes, one of which is 10 - 20 m wide and runs across the central part of the map area from the coast towards the mountain Alángorssup qáqâ, showing "en echelon" structures at the contact between the Julianehåb granite and the green schists. Generally the rock is a black, fine-grained dolerite, which in places contains scattered cm-big feldspar xenocrysts (Bridgwater and Harry, 1968). In thin section (56470) the plagioclase occurs as 0.5 - 1.0 mm long crystals in subophitic intergrowths with the original pyroxenes which now are altered to fine-grained aggregates of hornblende, green biotite, chlorite and ore as a result of deuteric or hydrothermal alteration. The plagioclase with twins after the albite law shows normal continuous zoning varying in composition, from the centre to the boundary, from labradorite to andesite (around 50 % An). Ore minerals, which form 5 % of the rock, also occur as 1 mm big grains, poikilitically intergrown with mostly mafic minerals and in few cases with plagioclase.

Near the coast north of Sorttop are found different kinds of xenoliths within the dyke. Several round inclusions 10 cm across and with sharp contacts to the host rock, consist mainly of 1 - 2 mm big plagioclase crystals in a green, fine-grained groundmass. In thin section (56468) the plagioclase, in contrast to the plagioclase of the dyke, is strongly saussuritized except for the more albite-rich borders, and the crystals are penetrated by 0.1 - 0.2 mm wide veins consisting of the same minerals as the mafic groundmass - hornblende, chlorite, brown biotite and albite. 5 - 10 mm big aggregates of allotriomorphic augite grains are altered to hornblende and magnetite along the contact to the dolerite dyke. These inclusions, together with the scattered plagioclase xenocrysts mentioned above, are regarded to be early differentiates of the dolerite magma; similar inclusions have been described by Gorbatschev (1961) from dolerites in eastern central Sweden.

Contrasting with these cognate xenoliths are found other inclusions at the same locality which represent rocks completely foreign to the basic magma. A 1 m long and 30 cm wide lunar-shaped xenolith consists of coarse-grained bright green tremolitic hornblende, the crystals of which reach several cm in size, with interstitial chalcopyrite and magnetite. Along the border feldspar occurs as well and the rock appears more fine-grained. This inclusion is of interest when regarding the copper mineralizations of the area. Another xenolith 50 cm long consists of gneiss, a rock which has not been observed elsewhere in the Lilianmine area.

2nd generation dolerites, striking roughly north-south, are not very numerous in the region, but east and west of Lilianmine a dense swarm of 1 - 5 m wide dykes showing well-developed doleritic texture belongs to this generation. They are sheared and jointed due to later movements which also affected the Julianehåb granite; the joints are often filled by epidote veins.

3rd generation dolerites form the main swarm within the region and strike north-east. A big representative of this is truncated by the Alángorssuaq gabbro. Not far from the contact the dyke contains several metre-large anorthositic inclusions. Such xenoliths and plagioclase megacrysts from South Greenland are described by Bridgwater and Harry (1968). Numerous 1 - 3 m wide dykes belonging to this generation are exposed throughout the Lilianmine area, in places with cm-big, rectangular plagioclase xenocrysts.

4th generation dolerites are probably represented by a single subhorizontal, 0.5 m wide dyke, striking east-west along the coast north of Sorttop.

b) Rhyolitic dyke

Dykes of intermediate or acid composition are rare in the region and within the present area only a single 10 cm wide rhyolitic dyke has been observed 50 m south of Sorttop, cutting the felsite and a dolerite of the 3rd generation, but older than an E-W striking joint system. In hand specimen it is a greenish-grey rock, with clear quartz grains not exceeding 1 mm in size and a few feldspar phenocrysts lying in a more fine-grained groundmass. In thin section (56422) quartz is seen to be the dominating mineral, forming some 40 % of the rock. It occurs mostly as 1 mm big rounded grains with numerous needle-shaped, unidentified inclusions arranged parallel to the grains boundaries, but forms in places aggregates several mm big. Liquid inclusions are also common. Microcline, forming 15 % of the rock, occurs in quartz as inclusions 0.2 mm in size, but also as bigger individual grains, twinning always being well developed. The mafic groundmass is dominated by interstitial, yellow-brown turbid biotite, which is partly altered to a very fine-grained aggregate of which clinozoisite, chlorite, sphene and ore are common constituents.

2) Felsites and quartz porphyries

As mentioned above, real dykes of acid composition are very rare in the area, but on the other hand irregular felsitic bodies of varying size are common. Harry and Oen (1964, p. 25) supposed that they were mostly altered aplitic derivatives of the Julianehåb granite, but detailed mapping has shown that they are of Gardar age. They have generally sharp, vertical or steeply dipping intrusive contacts and send discordant apophyses into the surrounding schists. The body 500 m east of Sorttop has broken a 1st generation dolerite into pieces some tens of metres big, and has sharp intrusive contacts to the green schists on each side. The felsites are cut by 3rd generation dolerites at several localities such as on the coast north of Sorttop. But the westernmost greenish, slightly altered dyke here seems to be older than the felsite, belonging probably to the 2nd generation. The ESE-striking faults affect the 2nd generation dolerites but not the felsites, indicating that the intrusion of the felsites took place between the emplacement of 2nd and 3rd generation dolerites.

The felsites are aphanitic, usually massive, pink rocks, in places with numerous phenocrysts of both quartz and feldspar, where they are termed quartz porphyries. At one locality 500 m east of Sorttop the quartz porphyry shows columnar structure, the vertical columns forming imperfectly symmetrical hexagons about 10 cm across (51810). The felsites are essentially composed of allotriomorphic albite, potash feldspar and quartz in highly variable proportions, with a grain size generally below 0.1 mm (56455). The colour varies from pink to white, the intensity depending upon the amount of potash feldspar and hematite. On the coast east of the gabbro-monzonite intrusion 5 - 25 cm thick alternating layers of pink and white felsite can be seen. Accessory minerals are apatite, muscovite, green hornblende, chlorite, epidote, sphene, magnetite and hematite.

Porphyritic felsites are common, with phenocrysts of quartz and feldspar in approximately equal amounts. The cross-formed felsite body south of Sorttop is better termed a quartz porphyry. The density of phenocrysts is 25 per cm^2; they are generally between 2 - 6 mm in size, only 15 % exceeding 6 mm. Only after staining the potash feldspar it has been possible to find the modal composition of both the phenocrysts and the groundmass; the results are presented below.

	Quartz	Potash feldspar	Plagioclase
Number of phenocrysts > 2 mm	74	82	7
Composition of phenocrysts (278)	36 % ± 5 %	49 % ± 6 %	15 % ± 4 %
Composition of groundmass (2000 points)	30 % ± 2 %	35 % ± 2 %	34 % ± 2 %

In thin section (56446) some of the phenocrysts are seen to consist of several individuals, sometimes of both quartz and feldspar. The prismatic quartz crystals are clear, with small dotted inclusions. The feldspar is dominantly microcline or microcline-perthite, the brownish colour of which is seen with high magnification to originate from very fine-grained reddish hematite. The plagioclase has oligoclase composition, and is partly altered and sometimes replaced by potash feldspar. The allotriomorphic groundmass, which is composed of quartz, albite and hematite - impregnated potash feldspar, has in places invaded the phenocrysts. Hematite also occurs as bigger grains, forming about 1 % of the rock. Other accessories are muscovite, chlorite, actinolitic hornblende, and epidote.

From the table above it is seen that while the amount of quartz is approximately the same in the phenocrysts and the groundmass, the phenocrysts are relatively richer in potash feldspar. On the other hand the plagioclase of the phenocrysts is more anorthite-rich, but quantitatively less important compared with the considerable amount of albite in the groundmass, a relation between phenocrysts and groundmass commonly found in porphyritic rocks of acid composition.

3) Biotite granite

The biotite granite is a member of the Nunarssuit intrusive complex. The contact with the green schists east of Rødtop has a some 100 m wide marginal zone with numerous agmatitic green schist blocks of varying size situated in a fine-grained granitic rock. The inclusions are rotated showing all possible orientations of schistosity and foliation, but no permeation by granitic fluids is visible. For a distance of 400 m along the coast the green schists are seen to be penetrated by a dense network of pegmatites and granitic dykes with sharp, steep contacts, the largest reaching a width of about 100 m. Farther inland a swarm of parallel aplite dykes penetrates the green schists. Several basic dykes of both Ketilidian and Gardar age are truncated by the granite or in some cases completely granitized. Owing to petrographic convergence there is no sharp contact with the Julianehåb granite, but the transitional zone is only a few tens of metres wide.

A sample (56433) not far from the contact with the green schist, the gabbro and the Julianehåb granite, appears as a red, medium to coarse-grained granite, dominated by pinkish feldspar and with a considerable amount of mafic minerals. In thin section the dominant feldspar of this hypidiomorphic rock, the grains of which reach 5 mm, is seen to be antiperthite with a coarse patchy structure indicating replacement origin. The albite is clear, whereas the patches and veins of potassium feldspar are strongly altered. A few grains of mainly potassium feldspar show albitic rods 0.7 mm long and 0.06 mm broad probably representing an exsolution perthite. Coarse-grained altered plagioclase of oligoclase composition with very thin polysynthetic twin lamellae is a subordinate feldspar. Quartz is unimportant in this section and only occurs as 0.2 mm big interstitial grains associated with albite. The dominant mafic mineral is strongly pleochroic hornblende, yellowish to dark green, sometimes bluish green, occurring as 2 mm long, subhedral grains as well as more fine-grained aggregates often with small quartz inclusions. One grain has a core of pyroxene. Usually the hornblende is altered to brown turbid biotite along cracks and cleavage directions. Ore minerals occur mostly associated with hornblende, sometimes poikilitically intergrown with sphene. Other accessories are numerous crystals of apatite, reaching 0.5 mm in size, fluorite and zircon.

The term biotite granite is not very appropriate for this rock, which differs considerably in composition from the typical biotite granite described by Harry and Pulvertaft (1963, pp. 31 - 33). The relatively low amount of quartz and high content of mafic minerals may be regarded as a result of magmatic assimilation, where the granitic magma has incorporated constituents from the nearby supracrustals and Alángorssuaq gabbro.

4) Pegmatites

Pegmatite and aplite veins are not uncommon within the biotite granite of the complex (Harry and Pulvertaft, 1963, p. 33), but east of Rødtop their occurrence within the granite is limited to thinly distributed irregular pegmatitic bodies containing big grains of potassium feldspar with interstitial quartz, purple fluorite and hematite. The greatest development of real pegmatites is outside the intrusion within the green schists and the Julianehåb granite. Swarms of several metres thick aplites derived from the biotite granite continue up to 1 km to the east as persistent pegmatites. They vary in thickness from 10 cm to 2 m, but are in general about half a metre wide. Their orientation is always subhorizontal, dipping in a southerly direction at rarely more than 20°. Besides the ordinary pegmatites, many of these sheets contain rare minerals, as described below.

a) Ordinary pegmatites

Besides the common pegmatite minerals such as quartz, alkali feldspar, biotite and less frequently muscovite, fluorite and hematite, the pegmatites in this area are characterised by containing abundant amazonstone, the green colour of which according to Oftedal (1957) is due to fluorine ions replacing the oxygens. The pegmatites are mostly coarse-grained, but also medium-grained and aplitic types occur, often showing a zonal arrangement. In a pegmatite near Sorttop the border zone consists of quartz and amazonstone, whereas the feldspar in the more coarse-grained central part is colourless. In thin section (56445) the amazonstone is a colourless microcline-perthite with a patchy structure of replacement origin. The albite patches are about 1 mm long and 0.3 mm wide, showing very thin polysynthetic twin lamellae. Quartz occurs both as big cracked grains with a reddish tint caused by hematite impregnations, and as interstitial grains together with albite (4 % An) which also penetrates the microcline-perthites as veins.

b) Pegmatites with rare minerals

Pegmatites containing abundant beryl are found at several localities. On the north wall of Sorttop beryl is plentiful in the core of some coarse-grained pegmatites consisting mainly of quartz and colourless microcline-perthite. Amazonstone is found in these pegmatites also, but not associated with beryl. The crystals are several cm long and about 1 cm across with colours varying from pale blue to green. On the west side of the peninsula north-east of Sorttop small pegmatitic veinlets 1 cm thick contain beryl, which in places is the dominant mineral, copper-bearing sulphides and in a single case molybdenite.

A copper-bearing pegmatite north of Sorttop mentioned by Harry and Oen (1964, p. 45) is traceable for several hundred metres along the coast, the varying thickness averaging 40 cm. The lowest part is an aplitic border zone 5 cm thick, consisting of quartz and potassium feldspar, whereas the coarse-grained pegmatite consists of quartz, feldspar, small muscovite flakes, abundant purple fluorite, and copper sulphides, mainly chalcocite. Impregnations of hematite give the rock a reddish colour. Joints around the pegmatite are filled with malachite, and also the pegmatite itself and adjacent rocks show conspicuous copper staining.

c) Aegirine pegmatite

Within the Julianehåb granite, parallel to the contact to the green schists, a 1.5 m thick pegmatite is traceable for several hundred metres in the southern part of the area. It is characteristic in containing numerous green aegirine crystals reaching 20 cm in length, usually set roughly at right angles to the margin of the pegmatite. Of approximately the same size and similarly arranged are elongated intergrowths consisting of hematite and alkali feldspar, the shape of which indicates that they are pseudomorphs of the aegirine crystals. In thin section (51819) the feldspar is seen to be microcline-perthite. The quartz grains contain many amoeboid inclusions, some of which are liquid inclusions. The aegirine [1] is weakly pleochroic from greenish brown to colourless; the prismatic crystals contain big poikilitic inclusions of quartz, microcline and albite, and numerous hematite grains.

Similar pegmatites with big crystals of aegirine are described by Harry and Pulvertaft (1963, pp. 52 - 55) and are associated with the Malenefjeld granite which also belongs to the Nunarssuit complex. Aegirine pegmatites as late crystallization products of alkaline magmas are known from other places in the world, e.g. the biotite granite belonging to the Buji complex, Northern Nigeria (Greenwood, 1951).

5) Faults

Faulting took place several times during Gardar time, and has given rise to a number of narrow clefts due to erosion along the faults. Two major sets of mainly vertical faults may be distinguished in the Lilianmine area. The first system striking ESE has affected 2nd generation dolerites, but not the felsites, and thus is of early Gardar age. The second fault system - the dominant one with respect to number and the influence on the landscape - strikes roughly north-south, and repeated movement along this direction occurred. The early movements have displaced 3rd generation dolerites, but do not transect the Alángorssuaq gabbro (Harry and Pulvertaft, 1963). An example of this is the dextral transcurrent fault west of Alángorssuaq qáqâ showing a displacement of 120 m. In some places a 2 m wide mylonite may be seen; hematite-covered slickensides indicating horizontal movements are common, and near the southernmost contact between the green schists and the Julianehåb granite a 1 m wide hematite-impregnated quartz vein has invaded the fault. Movement along

[1] Aegirine with a CaO content of 0.75 % (X-ray fluorescence).

these north-south-striking faults took place again in late Gardar time, as indicated by the displacement of the subhorizontal pegmatites. The dextral fault east of Sorttop, in its central part with a 2 m wide mylonite and slickensides, has thus displaced a pegmatite and dolerite 20 m horizontally.

Besides the bigger faults described there are numerous joints and fractures belonging to the same north-south system.

IV. POST-GARDAR ROCKS

Basic dykes which are younger than all other rocks in the area and which are not displaced by any faults are characteristicly weathered to a reddish-brown colour and rounded forms due to exfoliation. Such dykes are known throughout the coastal districts of South Greenland, and a lamprophyric member of this suite near Frederikshåb has been dated 164 m.y. (Larsen, 1966). The dykes generally run NNW parallel to the main coastline, but in the present area they are cut by a later set of E-W striking dykes (Harry and Pulvertaft, 1963, p. 19). They are not very numerous in this area, varying in thickness from 0.5 - 5 metres.

In the southern part of the area a sample was taken from the most important dyke belonging to the younger generation. In hand specimen it is a fine-grained, dark rock, sometimes containing zeolitic vesicles. In thin section (56430) the rock shows doleritic texture, with 1 - 2 mm long plagioclase crystals and interstitial mafic minerals, the grain size of which averages 0.5 - 1.0 mm. The plagioclase, forming 60 % of the rock, has andesine composition (R.I. determination), showing normal zoning with the most albite-rich part near the grain boundaries. The crystals are strongly altered in parts which are emphasized by the impregnation of brown alteration products from the iron oxides. The pyroxene is a pale pinkish to brownish titanaugite, only showing weak pleochroism. It forms 25 % of the rock, occurring as subhedral grains showing zonal and hourglass structures; the latter structure is particularly common and well developed, the "hour-glass" with acute angles always being orientated parallel to the length of the crystal. The difference in colour intensity is due to varying replacement of either Mg or Ca by Fe^{2+} (Deer et al. 1963), the outer shells of zoned crystals being richer in iron than the cores. Brown to reddish brown biotite is present as small crystals in small amount (4 %) and apatite occurs as an accessory. A characteristic is the amount of ore minerals, which form 10 % of the rock; this is high compared with the Gardar dolerites of the area, which contain only about 5 % ore minerals. A polished section reveals that the ore minerals are dominated by idiomorphic grains of titanomagnetite averaging 0.2 mm in size. "Exsolution" lamellae of ilmenite are arranged parallel to {111} in an altered heterogenous groundmass, where only a minor part of the magnetite component is preserved. According to Jensen (1966) who has discussed the formation of ilmenite lamellae in titanomagnetites, exsolution is not the correct expression for this formation of ilmenite, as it is not ilmenite but ulvöspinel which is in solid solution as titanomagnetite. The ilmenite lamellae have been formed as the result of oxidation of ulvöspinel and not as the direct result of exsolution. Ilmenite and magnetite as bigger single grains are common, and composite aggregates of these two minerals occur, often poikilitically intergrown with silicate minerals (mainly biotite). Besides these iron-oxide minerals a very common ore mineral in the rock is pyrite, which is found as big single grains about 1 mm in size, in the vicinity of which the silicate minerals are extremely "rusty".

This dyke should in fact according to its mineralogical composition be called an augite-andesite dyke (Johannsen, 1962).

A 4 m wide basic dyke running immediately east of Rødtop belongs to the NNW generation of dykes. Near the coast it is flanked on each side by a 3 m wide bleached zone consisting of a coarse-grained yellowish granitic rock with milky quartz, which differs completely in colour from the surrounding red biotite granite. Farther inland, where this granitic zone is 50 m wide, the central basic dyke only reaches the surface as a few narrow veins, consisting of cm-big feldspar crystals and quartz grains in a grey, fine-grained groundmass. Movements along this zone have crushed the rock, so it has been more intensely affected by erosion than the biotite granite. At the coast the basic dyke has sharp contacts to the granitic border zone, but the amount of quartz and feldspar increases approaching the contact. Zeolitic vesicles around a cm across are found;

the mineral from one of these was identified as heulandite. In thin section (56479) the basic dyke is much more fine-grained and more strongly altered than the one described above (56430). The pinkish to reddish brown titanaugite has a stronger colour, pleochroism is very strong, but hour-glass structures are lacking. Quartz occurs both interstitially and in vesicles. The amount of oxide ore is little compared with the younger dyke, the dominant ore mineral being titanomagnetite which differs from that described above by the fact that no magnetite is left in the heterogenous altered groundmass of iron-oxides. Big grains of pyrite are common, reaching several mm in size.

No detailed investigation has been done on this dyke. At present the following explanation may be proposed: initial movements, which crushed the biotite granite, took place along a NNW direction, followed by the intrusion of a not very persistent basic dyke which incorporated granitic constituents from the mylonite. A late stage of magmatic activity bleached the granite, mainly by hydrothermal solutions dissolving the iron-oxides, as a result of which the pink colour of the biotite granite disappeared. Hydrothermal activity also caused the alteration of the plagioclase and the formation of quartz zeolitic vesicles.

V. CHRONOLOGY OF THE AREA (TABLE 1)

The chronology of the Gardar period is well established in the Lilianmine area, whereas the complex Ketilidian history only can be understood if the whole region is considered. The Ketilidian chronology of the map area is based on the present general knowledge of the geology of the Ivigtut region. As discussed earlier, the appinitic intrusive rocks described are suggested to be Sanerutian in age, although no relations to discordant amphibolites are known.

DA3 dykes belonging to the second plutonic episode are lacking in the table, as no representatives were observed, but they are known to occur in the neighbouring areas.

TABLE 1

Chronological table of the area west of Lilianmine

Mesozoic		2nd generation basic dykes		E - W
		1st generation basic dykes		NNW - SSE
GARDAR		Faulting		N - S
		Pegmatites		subhorizontal
		Biotite granite ⋮ Alangorssuaq gabbro	Nunarssuit intrusive complex	
		Faulting		N - S
		4th generation dolerite dykes		E - W
		3rd generation dolerite dykes		NE - SW
		Felsites and quartz porphyries		
		Faulting		ESE - WNW
		2nd generation dolerite dykes		N - S
		1st generation dolerite dykes		E - W
KETILIDIAN	2nd Plutonic episode (Sanerutian)	Reactivation of Julianehåb granite	Appinitic suite: Quartz diorite, Monzonite, Gabbro, Hornblendite (?)	Late Ketilidian deformation and metamorphism
		DA 2	green discordant amphibolite dykes grey discordant amphibolite dykes	
	1st Plutonic episode	Julianehåb granite		Early Ketilidian folding and metamorphism
	Sedimentation	DA 1 Basic volcanic rocks and sediments (?)	uralite porphyrite plagioclase porphyrite	
Pre-Ketilidian		gneiss xenoliths in Gardar dykes (?)		

VI. ECONOMIC GEOLOGY

Besides the above-mentioned pegmatite minerals of economic interest such as beryl, molybdenite and copper sulphides, special attention was given to the hydrothermal copper mineralizations, the existence of which within the region was known since 1852. The abandonned Josvamine and Lilianmine were operative for only a few years in the middle of the last and the beginning of this century. The latter mine consists of one horizontal shaft from the coast 80 m inland along a nearly vertical, 1 - 2 m wide, mineralized mylonite, where, in contrast to Josvamine, a proper ore vein was lacking, and from which as far as is known no copper ore at all was extracted.

The mineralizations at Josvamine and its surrounding were studied in recent years and a description published by Harry and Oen (1964). The following section is the result of supplementary work, considering particularly the mineralizations west of Lilianmine.

1) Field description of the mineralizations

Briefly, the copper mineralizations occur in the following different ways in the field:

i) in mineralized epidote lenses, the common minerals being quartz, alkali feldspar, actinolite, hematite, magnetite, bornite and chalcocite.

ii) as joint and fracture fillings parallel to the schistosity of the green schists. Two epidote generations may be distinguished, the later of which is associated with hematite, alkali feldspar and copper-bearing sulphides.

iii) as small vesicle fillings.

iv) as ore concentrations along faults and shear zones.

In addition nearly all rocks throughout the area show conspicuous copper (malachite) staining. As Harry and Oen (1964) have already thoroughly treated the different types of field occurrences of mineralizations, only the best ore concentrations from an economic point of view will be dealt with in the following. Three types of mineral associations may be distinguished:

a) Copper mineralizations

The most important copper mineralization is situated at the coast north-east of Sorttop. It is structurally controlled by a mylonite zone, which dips 45^{o} to the south-east (fig. 4). The mylonite is traceable for 100 m on land before disappearing on both sides into the sea. 75 m of this zone is mineralized by copper sulphides, associated with quartz, calcite, epidote, alkali feldspar and hematite. To the west a fracture is filled by a compact ore vein 1 - 5 cm thick along a distance of 20 m. Here in addition are found several cm-thick veins below high water mark, situated in an epidote-rich gangue. In the central part the mylonite is 7 m wide, the "upper" 3 m consisting of a grey, very fine-grained rock with joints and fracture fillings of calcite, quartz, alkali feldspar and hematite. The lower part consists of a 2 m wide zone of quartz and calcite, interweaved by 0.5 cm thick veins consisting copper minerals. This zone continues for about 25 m, then the mylonite thins out and is not mineralized. In many places the malachite-covered rock surfaces can be seen from a distance. On the west side of the N-S-striking dextral fault, the horizontal displacement of which is about 20 m, the already-mentioned subhorizontal copper-pegmatite can be followed several hundred metres along the coast, providing the highest amount of copper minerals 200 m to the west.

100 m eastward along the coast is found an irregular quartz body 6 - 10 m across, which contains 5 - 10 cm big clumps of copper ore. Though no connection between the two localities is visible, they are regarded as related, as their ore microscopy shows similar mineral assemblages.

b) Magnetite-copper mineralizations

A 1 - 2 m wide epidote zone crosses the peninsula west of Lilian-mine parallel to the schistosity of the green schists. Though it is not well exposed, the zone may be followed 450 m from coast to coast, but without it being continuous. It is in many places mineralized by magnetite- and copper-bearing sulphides in varying amount, but with magnetite being the dominant ore component.

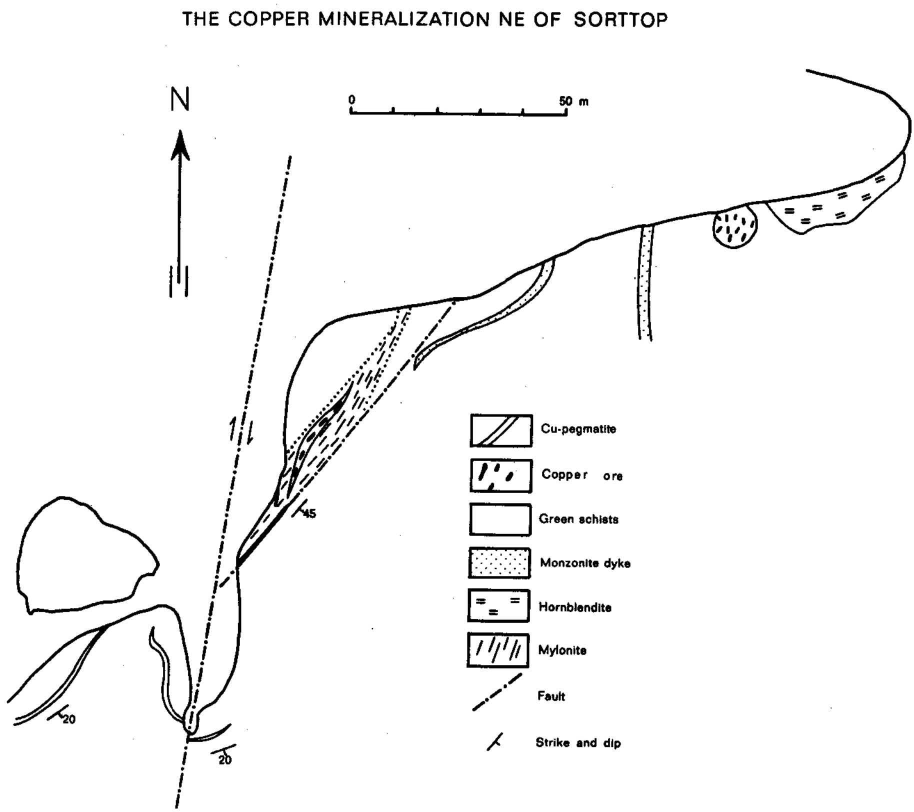

Fig. 4 Detailed sketch map around the copper mineralization at the coast north-east of Sorttop.

At the southern end, on the coast, there is a lens-shaped ore body 10 m long, 2 m wide and 4 m in a vertical direction, the longest axis being parallel to the general schistosity. The green schists around are crushed, the schistosity and foliation near the contact being conformable to the lens-shaped body. The mineral association is epidote, alkali feldspar, biotite and quartz, with considerable amounts of magnetite and copper sulphides.

100 m to the north another ore concentration is found, but is only about half-a-metre across. A NE-striking fault does not seem to affect the epidote zone; two epidote zones are found north of it, the westernmost of which near the 50 m summit contains a 50 x 25 cm big magnetite lump with

traces of copper minerals. Small magnetite lenses are found at several places to the north, but these generally show no Cu indications. At the north coast of the peninsula, fractures in a green metamorphosed dyke are mineralized in an area 3 m wide and 20 m long, the ore veins reaching a maximum width of 10 cm and consisting mainly of magnetite and copper sulphides.

c) Magnetite mineralizations

On the northernmost of the two islands north-west of Rødtop the contact between green schists and biotite granite is exposed. The island shows also a complex pattern of biotite granite and syenite, which has not been mapped. A pink, fine-grained, 1 m wide syenitic dyke with 2 cm big feldspar phenocrysts runs 100 m across the eastern tip of the island. It is mineralized by magnetite veins generally about 3 cm in length and 2 mm wide, but disseminated magnetite is also present. Joints and fractures within the dyke stained with azurite and malachite are the only Cu indications.

2) Ore microscopy

a) Copper ores

The copper ores on the coast north-east of Sorttop are nearly always malachite-covered and difficult to determinate in hand specimen. Under the microscope the very dominant ore mineral is seen to be chalcocite, with minor amounts of bornite and chalcopyrite and different alteration products of these copper minerals (56442).

The chalcocite occurs as grains and aggregates of varying size from about 7 mm to 0.1 mm. The coarser grains often show polysynthetic twin lamellae about 0.02 mm broad which commonly are lancet-shaped (Ramdohr 1960, p. 416). Besides this lamellar type, non-lamellar rhombic chalcocite is also present.

Bornite forms disseminated grains and aggregates up to 3 mm in size, nearly always as relics within chalcocite which has replaced the bornite. It may contain a network of exsolution blades of chalcopyrite (0.01 - 0.001 mm wide) parallel to $\{111\}$, suggesting formation at high temperatures. Chalcopyrite occurs in addition as small scattered grains within chalcocite. Both chalcopyrite and bornite are absent in some sections, being completely replaced by chalcocite (51806). A few grains of sphalerite partly replaced by chalcocite were observed.

In one section (56490) neodigenite occurs as 0.03 mm wide lamellae within chalcocite. Covellite occurs as big flakes up to 1 mm mainly forming an alteration product of chalcopyrite, often associated with tenorite, which is also seen along cracks and grain boundaries of chalcocite and as single small grains. Malachite veins with subordinate azurite show zonal structures, formed during the gradual deposition from hydrous solutions.

Several grains of an unidentified, greyish-white, low reflecting - about 30 - mineral are believed to be a sulpho-salt. It shows distinct reflection pleocroism and strong anisotropy. The hardness is low.

The sequence of mineral deposition at this locality started with the formation of quartz, calcite and epidote, which form the host rock. The first ore minerals were bornite, chalcopyrite and sphalerite, now occurring only as relics within chalcocite which has replaced them. With decreasing temperature rhombic chalcocite was formed probably as paramorphs after hexagonal chalcocite. Calcite was formed during the whole period of mineral deposition, as it is found both as host rock and as veins cutting all the ore minerals described. Of presumably supergene origin are covellite and tenorite, as well as malachite and azurite filling cracks and fractures.

b) Magnetite-copper ores

Polished sections of ores from the mineralized zone on the peninsula west of Lilianmine show variable ratios between magnetite and copper-bearing sulphides. Magnetite is generally present as the most dominant ore mineral, but in one section (56401) only as few scattered corroded grains 1 - 2 mm big. In several cases the sections are seen to consist entirely of irregular magnetite grains the size of which is 0.2 - 1.0 mm. Martitization of the magnetite is commonly seen as thin rims along cracks and grain boundaries (51884), and only in few cases follows the $\{111\}$ directions. Occasionally martitization also advances to form compact and irregular areas up to 0.5 mm in size. The magnetite crystallized before the copper sulphides. Epidote, filling cracks and holes within the corroded magnetite grains (56491), and radiating aggregates of actinolite (51883) are also seen to occur as later minerals.

Copper sulphides are present in varying amount; bornite and chalcocite are the most important minerals, occurring in approximately equal amounts. The coarse-grained chalcocite has sometimes replaced bornite, which is left as relic areas up to 0.5 mm in size, but generally the two minerals form myrmekitic intergrowths, where the magnitude of the bornite component averages 0.05 mm.

Chalcopyrite occurs as small grains within magnetite and as 0.01 mm broad exsolution-lamellae within bornite which follow the $\{100\}$ and $\{111\}$ directions. These exsolution-lamellae are later displaced by 0.1 mm wide chalcopyrite veins, which do not occur outside the bornite grains.

Both lamellar as well as non-lamellar rhombic chalcocite is present, formed at the expense of earlier copper minerals. Bornite is more easily replaced than chalcopyrite, which is seen from the fact that exsolution-lamellae of the latter mineral continue in chalcocite outside the grain boundaries of the bornite.

Neodigenite is a very abundant mineral, always forming parallel lamellar structures with bluish-white chalcocite.

Covellite occurs as a very common alteration product of chalcocite, chalcopyrite and neodigenite, mostly as small turbid areas, but also as idiomorphic tabular flakes. Neodigenite is more easily altered to covellite than chalcocite. Of interest is the alteration of the myrmekitic intergrowths of chalcocite and bornite, where chalcocite may be completely altered to covellite in contrast to the well preserved bornite.

A single grain of gold 0.01 mm big was observed (56491) and also an unidentified sulpho-salt, as mentioned above. Malachite with subordinate azurite forms veinlets as earlier described.

c) Magnetite ores

The magnetite ore of the island north-west of Rødtop is dominated by a network of small magnetite veins. In addition magnetite occurs as disseminated grains, which under the microscope (56481) are seen to be rounded and subhedral; the grains average about 0.3 mm in size, sometimes forming aggregates up to 2 mm across. Martitization of the magnetite is advanced, in few cases nearly complete. Nevertheless it is seen that martitization took place mainly along cracks and grain boundaries. Limonite (geothite) occurs in close association with the magnetite, as small veinlets, as several mm big grains and as impregnations of the silicates throughout the whole rock. A few very small grains of bornite and chalcopyrite were observed, together with secondary azurite and malachite - the only traces of copper minerals.

Besides at this locality smaller occurrences of magnetite ore are found in many places within the green schists always associated with epidote.

3) Geophysical investigations

An electromagnetic investigation ("slingram") of the area around Lilianmine and the peninsula to the west in the summer of 1959 (Bjerre, 1959) did not reveal any significant anomalies. Further slingram measurements made in 1963 near the inlet about 400 m west of Sorttop and indicating weak anomalies stimulated further geophysical investigations. The magnetic measurements from the summer of 1964 were carried out by a team under the direction of A. C. R. Ketelaar, and the results of this work are presented and discussed in the following. The radioactivity of the rocks and along the faults was measured by the author throughout the whole area, but no anomalous values were found.

a) Magnetic square network measurements

The area between Sorttop and the contact of the biotite granite was surveyed on the basis of a square network marked by sticks at every 100 m with the base-line roughly parallel (27^{o}) to the general strike of the green schists. The magnetometer (Askania Gfz) measurements were taken at intervals of 50 m, only in a smaller area at intervals of 25 m. The results are presented as a magnetic anomaly map (fig. 5), prepared on the basis of the measured intensity values corrected for the diurnal variations, but without any terrain corrections. The contours represent isoanomalies with an interval of 1200 gammas.

An interpretation of the magnetic map is only possible if the topographic map is considered at the same time. The highest anomalies were measured on Sorttop, a 180 m high cliff with steep walls, especially to the north side. The difference in magnetic intensities between the top and its base is some 3000 gammas. For a rock such as the green schists, containing about 5 % magnetite (volume per cent), this intensity difference is of a magnitude which may be explained by the terrain effect (Sharma, 1966). The negative anomalies in the western part reflect the north-south striking aplites and felsites, which have relatively much lower susceptibilities than the basic rocks. Smaller local variations are explained by differences in topography. The felsite body immediately east of Sorttop also gives rise to relatively low readings. The oval-shaped minimum-trough at the north coast is conformable with the boundaries of a felsite body. As its age relative to a dolerite dyke is uncertain, the contacts not being exposed, profiles with the magnetometer were measured across a possible continuation of the 10 m wide dyke through the felsite. The magnetic intensity values did not show any significant differences and thus the results confirmed the assumption that the dyke is older and does not continue through the felsite body.

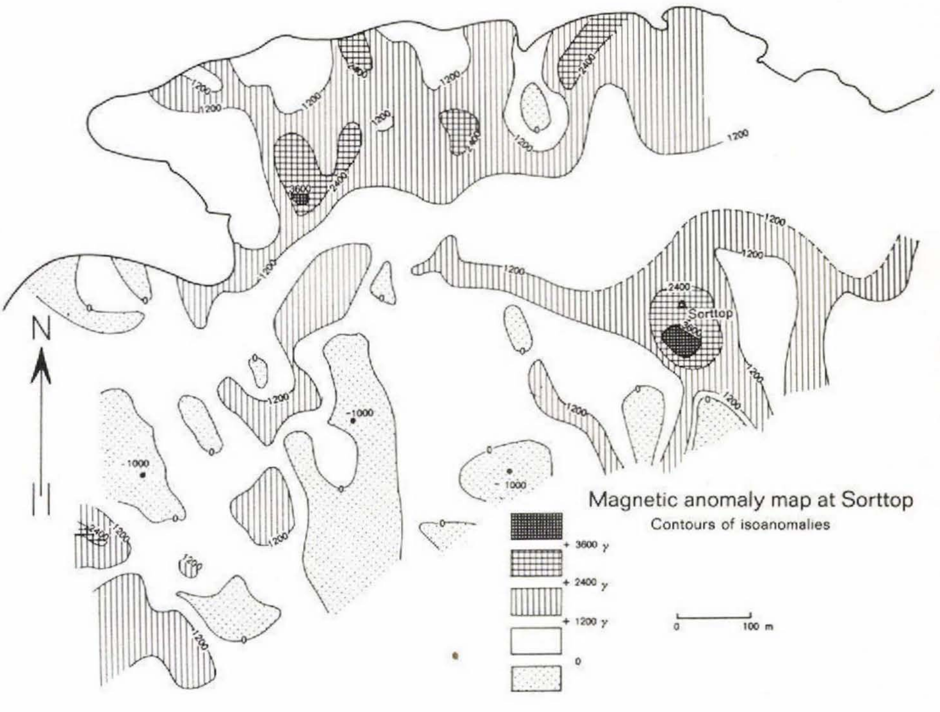

Fig. 5 Magnetic anomaly map (without terrain corrections).

The magnetic anomalies of the coastal strip consisting mainly of green shists show a tendency to a north-east orientation roughly parallel to the strike, except for some local peak values corresponding to minor hills. Field observation and microscopic investigations have shown that the magnetite of the original basic lavas was rearranged into lenses parallel to the schistosity during the regional metamorphism and deformation. The highest magnetic anomalies are found in zones where the compaction of the rock, with a resulting high magnetite content per unit volume, reaches a maximum. These zones are recognized in the field as the most deformed rock showing strongly developed schistosity.

No attempt at a detailed interpretation of the magnetic anomalies has been made. But this section indicates that the contours of the magnetic map roughly reflect the geological pattern of the area, disturbed locally by terrain effects. No significant anomalies were found around the inlet west of Sorttop corresponding to the slingram anomalies measured in 1963.

b) Magnetic profile measurements

As a big part of the peninsula west of Lilianmine is covered by vegetation, the possibility of detecting the non-exposed continuation of the magnetite-copper mineralization zone by magnetometer measurements was tested. A profile was measured across the zone near the 50 m summit, where readings starting on the magnetite lump described at p. 36 were taken with intervals of 5 m. The results are shown graphically in fig. 6. Except for the peak value representing the magnetite lump 50 x 25 cm in size, the anomalies of this 250 m wide zone are comparable with the intensity variations in the green schists measured at Sorttop. Field observations indicated that the magnetite-copper mineralization occurs as smaller lenses within an epidote-rich zone. A profile was measured along this zone with reading-intervals of 2.5 m to find out what influence the magnetic effect from known small bodies would have on the readings, and subsequently to detect non-exposed lenses below the surface. The results are shown in fig. 7, the highest intensity having been measured 1 m above the above-mentioned magnetite lump. In another place it was observed that magnetite veins in the epidote band had no influence on the readings of the instrument, whereas the peak value at 20 m perhaps represents a small magnetite body below the surface. After these initial investigations, further profile measurements at this locality were thought to be of little value. The magnetization effect from the green schists will obscure the effect from smaller lens-shaped magnetite bodies situated at a depth of only few metres, as the magnetic effect decreases to 1/8 when the distance from the instrument is doubled.

The 1959 slingram programme covering the whole peninsula did not reveal any significant anomalies. This fact suggests that no magnetite bodies bigger than 20 m occur, as the intervals between measurements in this programme were 40 m. The lack of anomalies of the imaginary component indicates that if any sulphide mineralizations are present, they must be disseminated. Accordingly rock samples were collected systematically at 50 m on both sides of the mineralized zone.

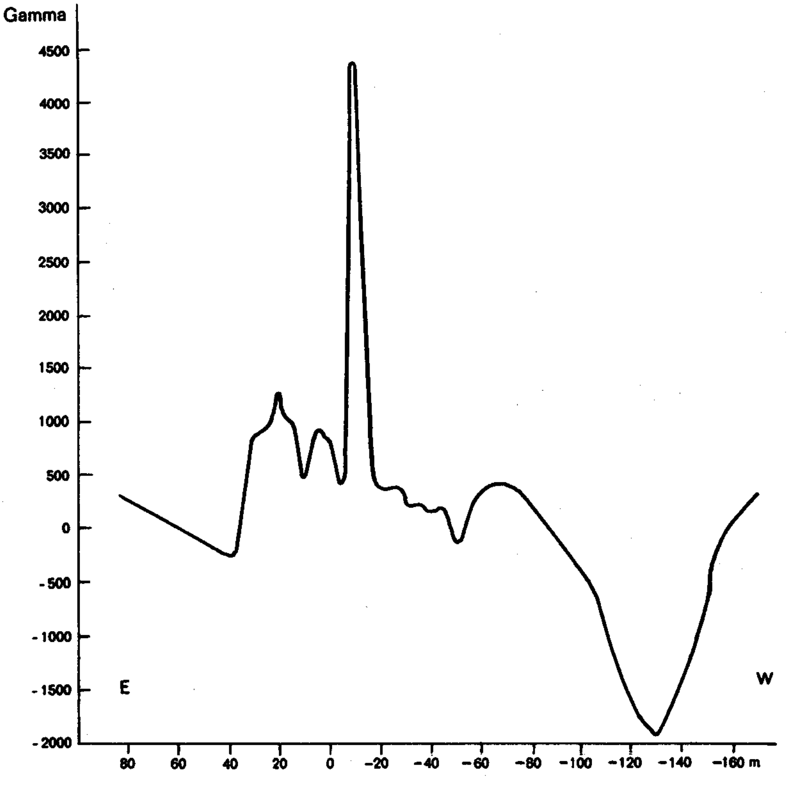

Fig. 6 Magnetic cross profile from the mineralized zone on the peninsula west of Lilianmine.

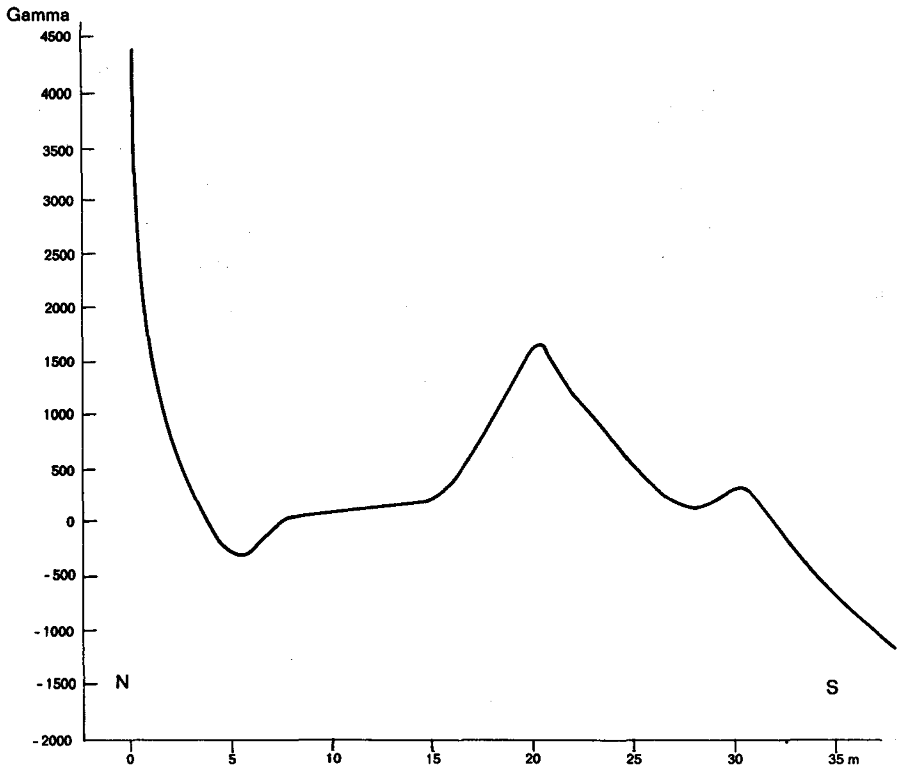

Fig. 7 Length profile from the mineralized zone on the peninsula west of Lilianmine.

4) Analytical programme

a) Rock samples

Small quantities of gold were extracted as a by-product from Josvamine, and the mineral has been observed in polished sections in a few cases. It was therefore desireable to analyse some rock samples for gold. In addition the samples were analysed for Cu, Ag and Pt. 4 representative samples were selected from a big number of systematically collected specimens. The samples were crushed to a grain size below 0.15 mm. The trace element determinations for Cu, Ag, Au and Pt were done spectrographically,for gold and platinum after the method described by Goldschmidt and Peters (1932). The Cu content of one sample was too high for a spectrographic determination, and this was subsequently analysed by X-ray fluorescence. This determination was made on the basis of the standard curve, obtained by investigations on laboratory CuS and Fe_2O_3 blended in different proportions. The X-ray fluorescence analyses on the copper ore (1) also indicated traces of Ni, Mn, Cr, and Ti. The results of the analytical work on the rock samples are presented below:

	1	2	3	4
Cu	58.5 %	130 ppm	130 ppm	90 ppm
Ag	1 %	trace	-	-
Au	-	-	-	-
Pt	-	-	-	-
Fe	11 %			

1. 56492 Copper-magnetite ore from the mineralized zone on the peninsula west of Lilianmine.
2. 51896 Uralite porphyrite near the west coast of the peninsula.
3. 53210 Schistose uralite porphyrite near the north coast of the peninsula.
4. 51828 Very schistose green schist from the zone showing high magnetic anomalies north-west of Sorttop.

The analyses show that the content of gold and platinum is negligible (below 0.05 ppm). According to Green (1959) the average content of Cu for igneous rocks is 70 ppm, whereas for mafic rocks it averages 140 ppm, which is of the same order as the present analysed green schist samples. The high Cu content of the first sample compared with a low (inaccurately determined) sulphur value (7.5 %) is explained by the fact that chalcocite is the dominant copper mineral observed in polished section. The Fe value reflects the content of magnetite. The relatively high silver content (1 %) is not unusual for this type of mineralization, and it should be mentioned here that small quantities of silver were extracted together with the copper from Josvamine (Harry and Oen, 1964, p. 7).

b) Botanical samples

Two botanical samples were collected in the immediate vicinity below the copper-magnetite mineralization from which sample 56492 was taken, as the thin layer of soil at this locality was expected to be relatively rich in the elements occurring in the ore. The first sample represents the commonest moss of the area, the second consists of Least willow, which is very common throughout the low-arctic part of Greenland. For analytical purposes material from the whole moss plant above ground was used, whereas the leaves only were selected from the Least willow. After igniting the plants in a porcelain melting-pot, the ash was reduced to powder and analysed spectrographically. The results are presented below:

	I	II
Cu	1500 ppm	1700 ppm
Ag	10 ppm	10 ppm

I. Rhacomitrium canescens (Hedw) Brid. and a little Kiaeria glacialis (Berggr) Hag.

II. Salix herbacea (Least willow)

(The plants were identified by cand.mag. K. Holmen of the Botanical Museum, Copenhagen).

Besides Cu and Ag, X-ray fluorescence analyses of sample I indicated traces of Ni, Mn and Cr, as was the case for the ore, but in addition the moss contained traces of Zn and Pb.

The Cu content in the ash of vegetation growing in unmineralized ground varies between 118 and 249 ppm (Cannon, 1960), with low values for grasses and herbs and high values for leaves from shrubs and trees. Jacobson (1956) reports Cu contents reaching 800 ppm for grasses growing in mineralized ground in Uganda. From studies in "copper mosses" Persson (1956) states that they rarely have a Cu content above 675 ppm.

Though no determination of the pH value of this locality has been made, compared with the foregoing the plants analyzed are seen to have a very high Cu content, apparently without any toxic effects. The purpose of the analyses was to find out if there is any possibility of using this two plants in Greenland to indicate non-exposed copper mineralizations. Without discussing the application of geobotanical methods in this country, it seems that these two common plants may be useful, but no attempt has been made to find out if they are sensitive enough to reflect Cu anomalies when growing on overburden of increasing thickness.

5) Estimation of the economic possibilities

a) Amount of ore

At present no deposits of economic importance have been found in the area. The best occurrence from an economic point of view is situated at the coast north-east of Sorttop (fig. 4). No drilling has been undertaken at all, but for want of more precise data for an estimate of the quantity of ore, the rule can be applied that "the depth of fissure veins may equal about half the length" (Bateman, 1959, p. 121). This assumption agrees with experience from the nearby Josvamine, where the 100 m ore vein exposed on land was mined to a depth of 88 m, the ore decreasing with depth (Ball, 1922, p. 33; Bøgvad, 1950, p. 104). An estimate for the similar occurrence north-east of Sorttop thus gives about 2000 tons of ore containing 30 tons copper. Though the quality of the ore is good, a deposit with a tonnage of this magnitude is too small for utilization.

b) Formation and origin of the ore

The physio-chemical conditions of the mineralizations are treated by Harry and Oen (1964) and only few remarks will be made here. The copper mineralizations of this area mainly differ from the one at Josvamine in their higher amount of early crystallized magnetite. Except for the magnetite on the island north of Rødtop, which is regarded as a primary component of the intrusive rock, this mineral is considered to be derived from the green schists, where magnetite has been shown to occur as a characteristic component of the now metamorphosed volcanic rocks. The lower amount of magnetite in the Josvamine ore might be explaned by its location near the boundary to the Julianehåb granite, where less magnetite was available. The copper is also regarded as derived from the green schist host rock, as the spectrographic analyses indicate. The scattered distribution of mineralizations in small veinlets nearly entirely confined to the green schists supports this assumption.

The mineralizing fluids which produced the ores in this area are related with the intrusion of the biotite granite, though earlier phases of copper concentration took place within the region during the Ketilidian orogeny (Berthelsen, 1959). The deposition thus probably occurred in late Gardar time, as the ore in many cases is connected with the subhorizontal pegmatites and at one locality was seen to transect a Gardar dolerite of 4th generation. A characteristic zonal pattern is found in the field : with increasing distance from the biotite granite the aplites are succeeded by a zone of pegmatites, which east of Sorttop are followed by hydrothermal deposits (fig. 4).The strong schistosity of the host rocks, together with faults and mylonites, provided favourable structural conditions for the circulation of ore-bearing solutions.

The origin of the copper from the green schists itself is further supported by the fact that small copper mineralizations or indications are known to occur within this rock unit the whole way along the southern part of Kobberminebugt. D. Bridgwater (personel communication) has reported small unimportant copper mineralizations of chalcopyrite from the innermost part of Kobberminebugt, the majority of which are situated within the metavolcanic member of the green schist series. In one place it was possible to correlate the hydrothermal activity which caused the formation of the copper ores with granites of Sanerutian age.

The copper-mineralized xenolith within a Gardar dolerite of 1st generation described above (p. 23) further suggests that a concentration of copper already took place at an earlier stage.

c) Concluding remarks

Though no copper mineralizations of economic importance are at present known within the green schists of the Ivigtut region, it would be worth making further studies of these rocks. Though no attempt is made to question the chronology established by Allaart et al. (in press), it is remarkable that the metavolcanics of the Ilordleq Group are the only Ketilidian geosynclinal deposits of the Ivigtut region which are known to be characterized geo-chemically by a high Cu-content. No copper mineralizations have been observed within the metavolcanics belonging to lower stratigraphic levels in the Ketilidian sediments, whereas Cu mineralizations or indications are reported from several localities in the green schists of the pre-Ketilidian Tartoq Group by Berthelsen (1954), Micheelsen (1955) and Weidmann (1964, p. 16). Thus it seems that further investigations for copper mineralizations within the green schists of the Ivigtut region should be concentrated to the areas around Sermiligarssuk and Kobberminebugt.

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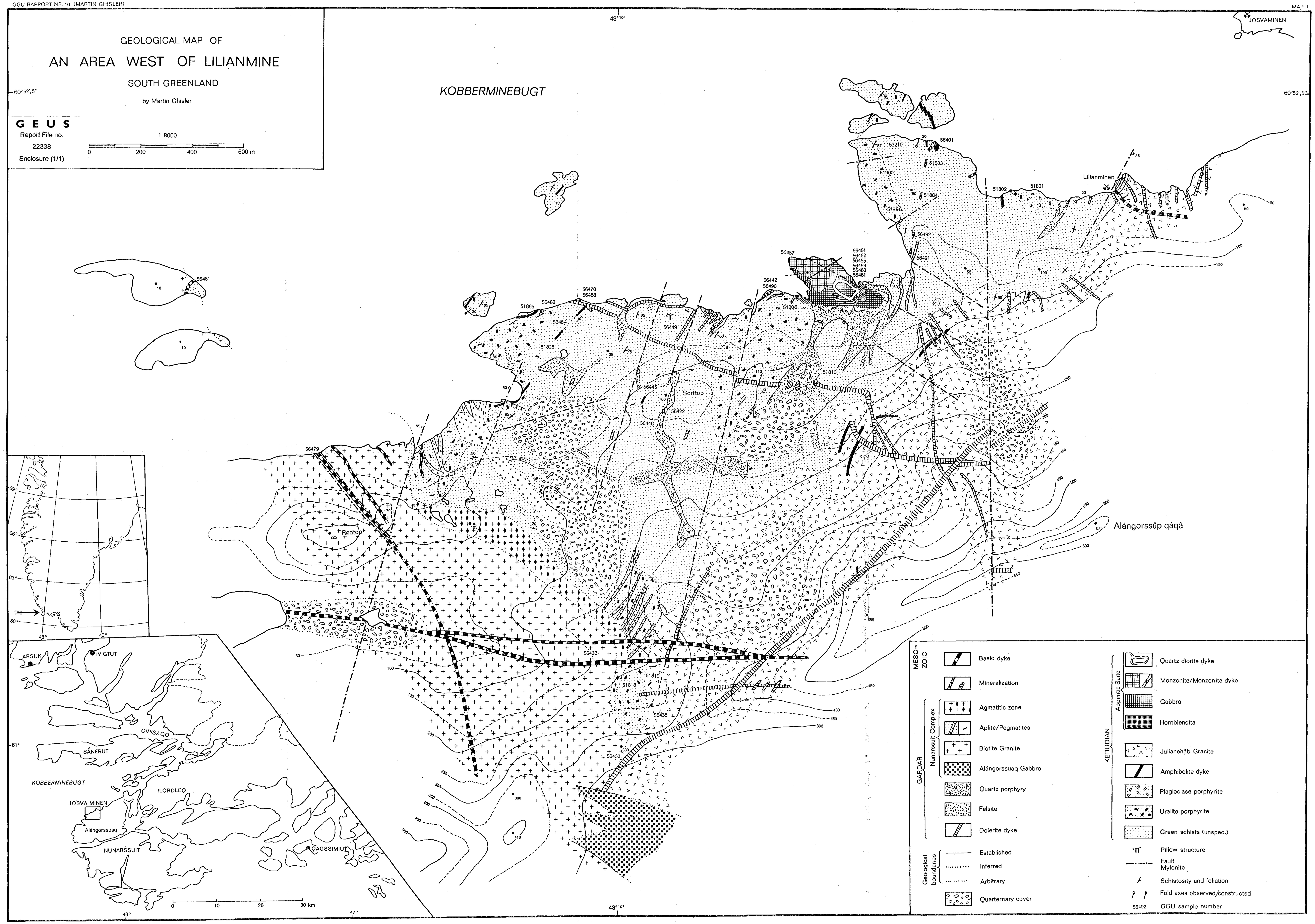
GEOLOGICAL MAP OF
AN AREA WEST OF LILIANMINE
SOUTH GREENLAND
by Martin Ghisler
GEUS
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JOSVAMINEN
Lilianminen
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Redtop
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QIPISAQO
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Basic dyke
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GARDAR
Nunarssuit Complex
Agmatitic zone
Aplite/Pegmatites
Biotite Granite
Alángorssuaq Gabbro
Quartz porphyry
Felsite
Dolerite dyke
Geological boundaries
Established
Inferred
Arbitrary
Quarternary cover
KETILIDIAN
Appinitic Suite
Quartz diorite dyke
Monzonite/Monzonite dyke
Gabbro
Hornblendite
Julianehåb Granite
Amphibolite dyke
Plagioclase porphyrite
Uralite porphyrite
Green schists (unspec.)
Pillow structure
Fault
Mylonite
Schistosity and foliation
Fold axes observed/constructed
56492 GGU sample number

Grønlands Geologiske Undersøgelse

Reports

Bulletins and Miscellaneous Papers are only available on exchange with institutions and libraries. Reports are obtainable on exchange, or may be purchased from Grønlands Geologiske Undersøgelse, Østervoldgade 5-7, Copenhagen K. Denmark.