GRØNLANDS GEOLOGISKE UNDERSØGELSE
BULLETIN No. 41

AN INTRUSION BRECCIA WITH ASSOCIATED ULTRABASICS FROM SERMERSÛT, SOUTH-WEST GREENLAND

BY

ERLING BONDESEN

WITH 10 FIGURES IN THE TEXT
AND 1 PLATE

Reprinted from
Meddelelser om Grønland Bd. 169, Nr. 7

KØBENHAVN
BIANCO LUNOS BOGTRYKKERI A/S
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CONTENTS

Abstract.

A detailed 1:500 map and a description of some peculiar breccia structures are presented. The breccia was emplaced in the Precambrian basement rocks, consisting mainly of granodioritic gneisses and amphibolites. The structures of the breccia are highly irregular consisting of lots of connected dyke-shaped bodies. More distinct dykes of the breccia matrix run out into the gneisses. The breccia itself consists of a matrix of mineral fragments and numerous inclusions of rock fragments, the majority of which are of exotic origin. Associated with the breccia are some larger soapstone bodies of which smaller fragments are found in the breccia.
The breccia is thought to have been emplaced by gas drilling in connection with the intrusion of the soapstones in a solid/subsolid stage.
The chronological significance of the breccia is emphasized.

INTRODUCTION

During mapping work for the Geological Survey of Greenland (Grønlands Geologiske Undersøgelse, G.G.U.) in the Ivigtut area some peculiar breccia structures of intrusive character and with associated ultrabasic rocks were found on the island Sermersût (ca. 45 km west-north-west of the cryolite mine at Ivigtut). These breccias turned out to be of chronological significance for the Precambrian basement of south-west Greenland.

The author decided after a short reconnaissance to make a detailed map of a relatively well-exposed area on the south coast of the small inlet on the south side of the island Sermersût (fig. 1). The map was made on the scale of 1:500 (Pl. 1).

This paper is a presentation of the map thus produced and the chronological data and observations collected during the mapping. This is done not only because of the importance of the area as a "key area" to the understanding of the Precambrian chronology, but also to present a description of the peculiar structures and a comparison with other breccia structures of a similar sort.

The author is greatly indebted to the board of G.G.U. for excellent facilities during the field work and for permission to publish the present paper. The laboratory work has been carried out in the Mineralogical Museum, University of Copenhagen. The author wishes here to express his gratitude to his teacher Prof. Dr. A. Noe-Nygaard (director of the Mineralogical Museum) for excellent working conditions in the institute and for inspiring advice during the study. He would also like to express special thanks to Prof. Dr. Asger Berthelsen (University of Aarhus) for instructive discussions and for critical supervision in structural geology as well as in field geology and to Prof. Dr. H. Sørensen (University of Copenhagen) for valuable discussions. Thanks are also due to my colleagues mag. scient. N. Henriksen and stud. mag. B. Kraul Jensen for great help in the field work. Mr. T. C. R. Pulvertaft B. A. kindly critically revised the manuscript.

GENERAL GEOLOGY

The Ivigtut area.

The Ivigtut area in South-west Greenland is made up of Precambrian gneisses and schists belonging to the *Ketilidian* fold belt defined by WEGMANN (1938). Here they are found in a migmatitic infrastructure and a non-migmatitic but metamorphosed suprastructure (BERTHELSEN 1960).

After folding and migmatitisation the Ivigtut area underwent dyke intrusion (*Kuanitic dykes*), renewed metamorphism and granitisation (*Sanetrutian period*), dyke intrusion and cratogenesis (*Gardar cycle*) and finally more dyke intrusion (*post-Gardar*) (BERTHELSEN 1960, HENRIKSEN 1960).

The complex folded migmatitic gneisses are quartz-dioritic to granitic gneisses of highly varied structural design. They are interbedded with different sorts of amphibolites and mica schists. Gabbro-anorthosites, anorthosites, and ultrabasic rocks (hornblendites and soapstones) of metasomatic origin are also found mainly as inclusions and boudins. (J. BONDAM 1955, OEN ING SOEN 1961). A gneiss unit carrying these inclusions—"the gabbro-anorthosite series"—can be followed as a structural niveau which probably also has a stratigraphical significance (BERTHELSEN, BONDESEN and BAK JENSEN 1962). Ultrabasic rocks, however, also occur outside the gabbro-anorthosite series.

The island Sermersût.

The island Sermersût (fig. 1), where the breccia structures in question are found, is situated ca. 45 km west-north-west of the cryolite mine at Ivigtut. It is one of the spectacular mountainous islands on the outer seaboard in the northwestern part of the G.G.U. Ivigtut sheet (1:100 000). The rocks belong exclusively to the infrastructure.

The geological sketch map (fig. 1) shows in the north-western part the "gabbro-anorthosite series" in a synform. The main part of the island consists of quartz-dioritic and granodioritic gneisses with interbedded amphibolite horizons. On the eastern part of the island a big recumbent

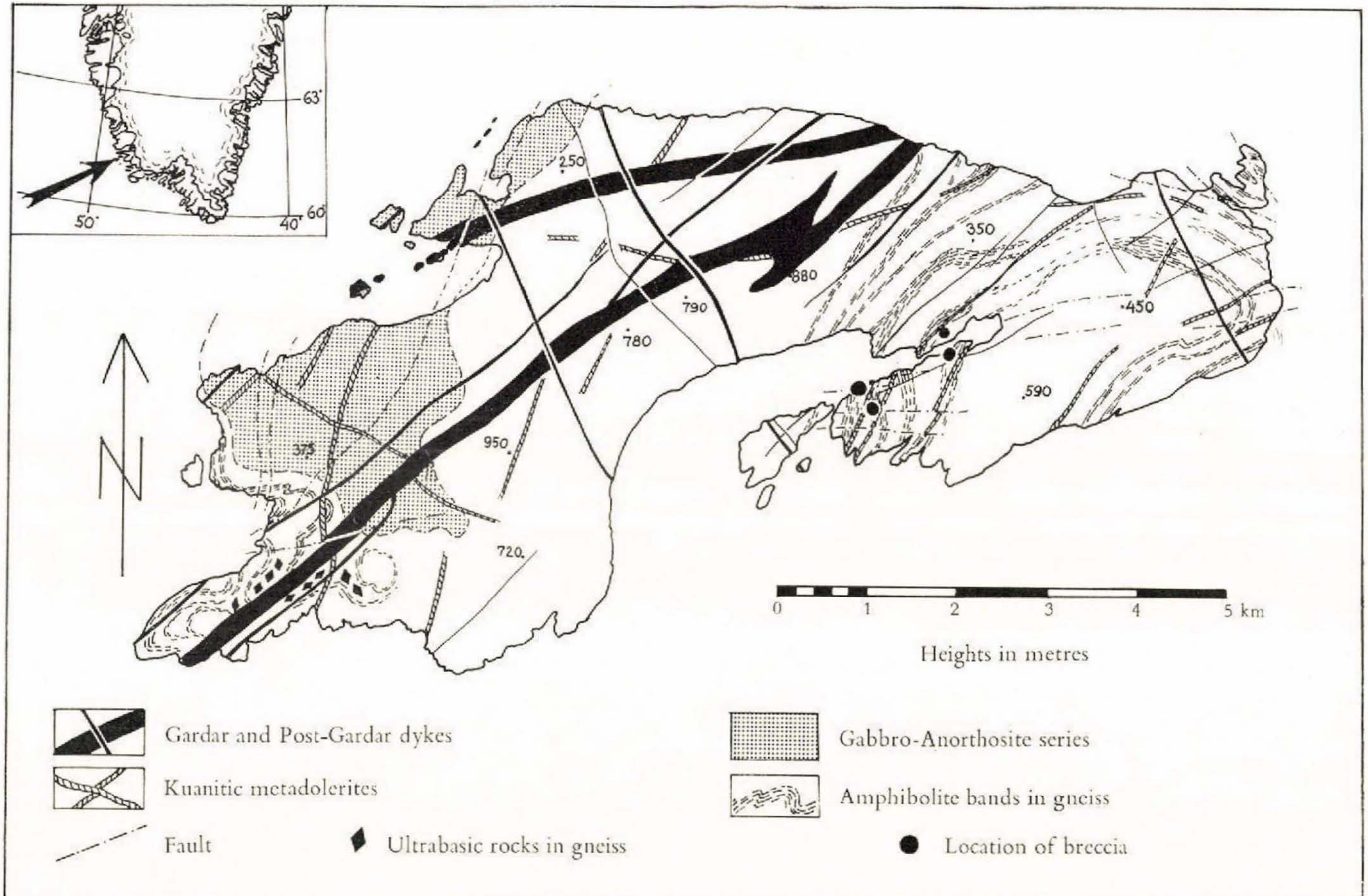

Fig. 1. Geological sketch map of Sermersût, showing the position of the breccias.

antiform with a weakly-bent axial plane indicated by the trend of amphibolite horizons forms the main geological structure. The big recumbent antiform can be shown to consist of refolded isoclinal folds which latter presumably represent relict pre-migmatitic fold structures.

The central part of this antiform consists of small-folded banded and foliated gneisses. The gneisses in between the amphibolite bands often show a characteristic wavy structure, a structure due to a later semiplastic deformation along shear planes oblique to the bedding planes and foliation planes. The amphibolite horizons may be banded along their margins. Boudins of amphibolite are also often seen. Fold structures of mesoscopic scale are common in the amphibolite bands as well as in the gneisses.

The rocks in this part of the island are quartz-dioritic and granodioritic epidote biotite gneisses occasionally with garnet. Relict hornblende being alterated to biotite also occurs. Common accessories are allanite, sphene, zircon (in rather rounded grains) and apatite.

The amphibolites are hornblende-actinolite amphibolites often with garnet. The plagioclase is commonly strongly saussuritized, but well-preserved unaltered plagioclase about $40\,^0/_0$ An is found. Remarkable among the accessories is xenomorphic sphene in big grains. Apatite is also found.

The rocks have been metamorphosed first under amphibolite facies conditions and later under epidote-amphibolite facies conditions.

The gneisses and amphibolite bands are cut by numerous pegmatitic veins. These veins can be divided in two generations. The older are thin medium-grained biotite pegmatites, often of insignificant width and always less than one meter wide. The younger are broad coarse-grained biotite-magnetite pegmatites.

As shown in fig. 1 the gneisses are cut by Kuanitic dykes. The intrusion of these was followed by cratogenic movements and mylonitisation (HENRIKSEN 1960). Gardar dykes in the area are represented by granophyric dykes, spessartitic lamprophyres and olivine dolerites of several generations. The youngest north-west-trending dykes are of post-Gardar age. (BERTHELSEN 1960, HENRIKSEN 1960).

DESCRIPTION OF THE BRECCIAS

The breccia localities.

The breccias are found in four localities along the inlet on the south coast of Sermersût (fig. 1). The two eastern occurrences are small and insignificant irregular dyke-like bodies less than 2 m in width. On the north side of the narrow sound only one dyke is found, while on the south side several occur. These will subsequently be referred to as the "eastern localities".

The western localities are quantitatively far the most important. They constitute two big areas divided by a 50 m wide Kuanitic dyke, around which exposures are poor. Although there seems to be no difference in appearence between the two areas, a complete continuation has not been observed. The extension of these localities is at least 300 m in a NW-SE direction and about 150 m in a NE-SW direction. The greatest width seems to be in the coastal area. Towards SE at an altitude of 140 m the structures seem to die out suddenly, while towards NW they extend into the sea. The locality which has been the subject of detailed mapping (Pl. I) is situated between the big cross-cutting Kuanitic dyke and the coast of the inlet.

In making the detailed map topographical features were not considered. These, however, do not appreciably affect the reading of the map The terrain slopes smoothly from sea level to an altitude of about 40 metres, the gradient in the coast region being a bit steeper than that in the main part of the area. A N-S oriented grid has been drawn and each quadrant given a letter and number notation. This notation will be used in the following description in order to locate features more exactly on the map.

In addition to data and samples from the area mapped, observations from the eastern localities and the continuation of the mapped area towards SE will be mentioned.

The immediate surroundings of the main breccia.

Under this heading the rocks and the phenomema in the surroundings of the breccia shown in the map (Pl. I) will be described.

The breccia was emplaced in gneiss and amphibolites within the area mapped the country rocks are mainly gneisses. West of the breccia in squares A1, A2, B1, B2, B3, C2 and D1 a light or white nebulitic gneiss is found (figs. 3 and 4). On fresh surfaces this rock is pale rusty red. The white colour is due to a 1 cm thick weathered exfoliation mantle. The nebulitic structures are marked by a weak biotite foliation, which for example in square B3 shows fold structures. In hand specimen magnetite and also garnet can be seen. In thin section the white gneiss is seen to be a granodioritic gneiss. Microcline is subordinate to plagioclase and seems mainly to be introduced later by granitisation of a quartz-rich dioritic rock. The plagioclase (An 20—26) is strongly sericitized and saussuritized, and recrystallisation along the grain borders is pronounced. Biotite, muscovite and also secondary epidote are common, while apatite, magnetite and sphene are accessories.

Inside the breccia, "islands" of gneiss completely surrounded by breccia are often found. The rocks in these "gneiss islands" are mostly equivalent to the nebulitic gneisses just described.

In square D3 remnants of an amphibolite band in the gneiss are found. It is not possible to follow the amphibolite band outside the breccia towards south-east, so that its possible connection to the large amphibolite band east of the area mapped could not be established. The rock does not differ in thin section from the amphibolites summarized on p. 8.

East of the breccia area the gneisses are of a much less homogenized character. In squares F3, F4 and C3 veined biotite gneisses are found, and in squares G6 and G7 similar veined biotite gneisses are strongly small-folded. The composition of the gneisses in this part of the area mapped varies between quartz-rich dioritic gneisses to granodioritic gneisses. The mineral content and alterations are the same as in the gneiss described above, only biotite and epidote are much commoner.

A gneiss from square F4 differs from the gneisses already described. It is a finely banded rock, which reminds one very much of a gneissified finely laminated sediment (fig. 2). In thin section the rock can be seen to be a biotite quartz-diorite with some relict hornblende. Characteristic of the light bands are xenomorphic patches of sphene, making up several per cent of the slide. In the dark bands, where biotite is dominant, only a little sphene is found.

Pegmatites are common in the sourrounding gneisses and belong to two distinct generations (fig. 5). The older are relatively thin and not so coarse-grained as the younger generation which forms rather thick veins.

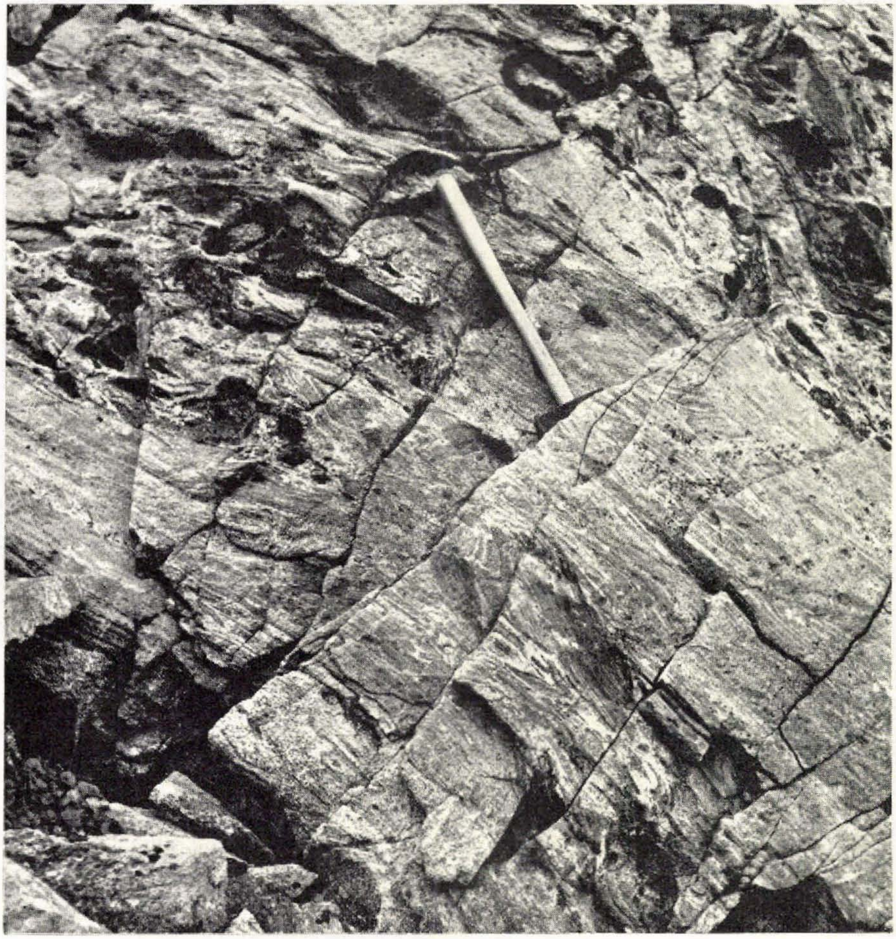

Fig. 2. From square F4. Breccia in the top left-hand corner, with intrusive veins into finely banded gneiss (lower right). The central part of the picture shows gneiss brecciated along the planes of banding. One of the fragments in the top left and the fragment over the hammer-shaft are roughly oval zoned ultrabasic inclusions with actinolite rims (dark). In the upper right a thin pegmatite can be seen crosscutting breccia.

The younger generation is magnetite-bearing, and cuts the breccia. It seems to be a general feature that the older generation is poorly developed in the area west of the breccia. Here small aplitic veins intersected by breccia as well as younger pegmatites probably represent the older generation of pegmatites.

In the area east of the breccia the two pegmatite generations can be clearly separated. The oldest generation here usually has developed pinch-and-swell structures, whereas the youngest generation is more rectilinear.

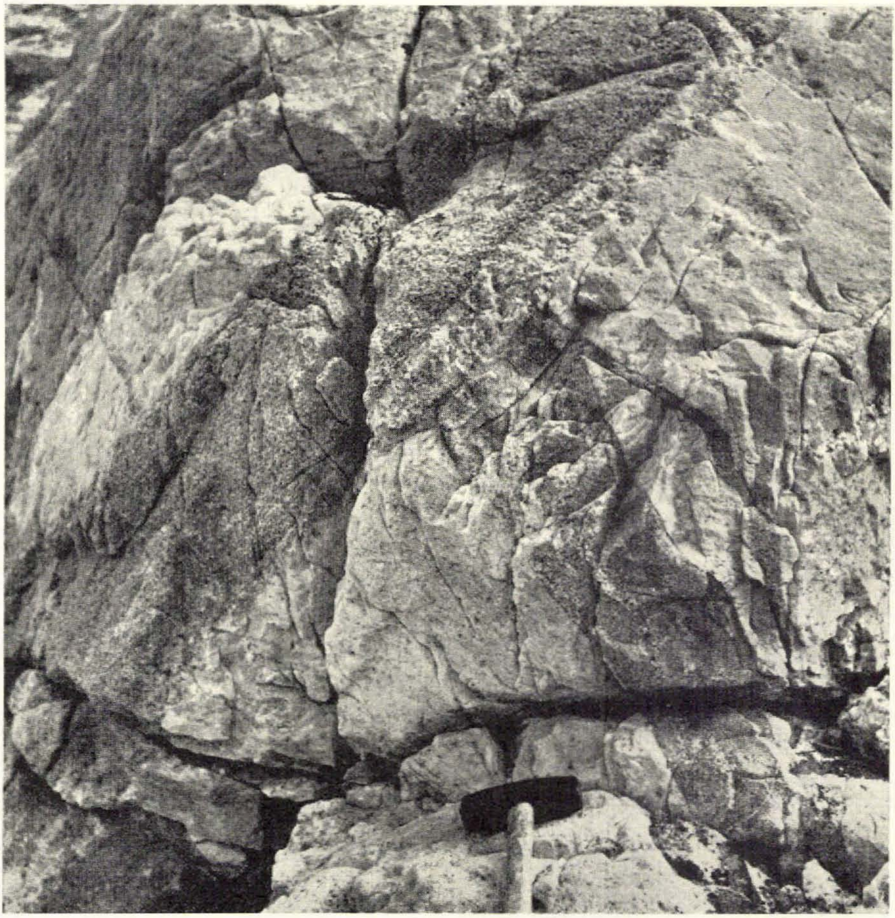

Fig. 3. Intersection between a 40 cm wide coarse-grained dyke of breccia matrix and a 25 cm wide discordant dark grey biotite-rich quartz-dioritic dyke with an apophysis. A pegmatitic vein belonging to the older generation can be seen along the edge of the matrix dyke. Foliation in the white nebulitic gneiss can be seen just over the hammer-head. From square A2—B2.

In the gneisses west of the breccia several coarse-grained veins up to 1 m wide occur. In square C2 these veins contain hornblenditic lumps — a feature characteristic of the breccia. These discordant veins are more frequent towards the breccia contacts and several veins can be followed up to the breccia from which they appear to originate (figs. 3 and 4). East of the breccia similar but smaller veins occur. However their direct connection to the breccia cannot be seen. The petrography of these veins will be described in conjunction with the breccia matrix of which they seem to be dykes.

In squares A2 and B2 a dark grey discordant biotite-rich quartz-dioritic dyke about 25 cm wide can be seen. This dyke crosscuts the

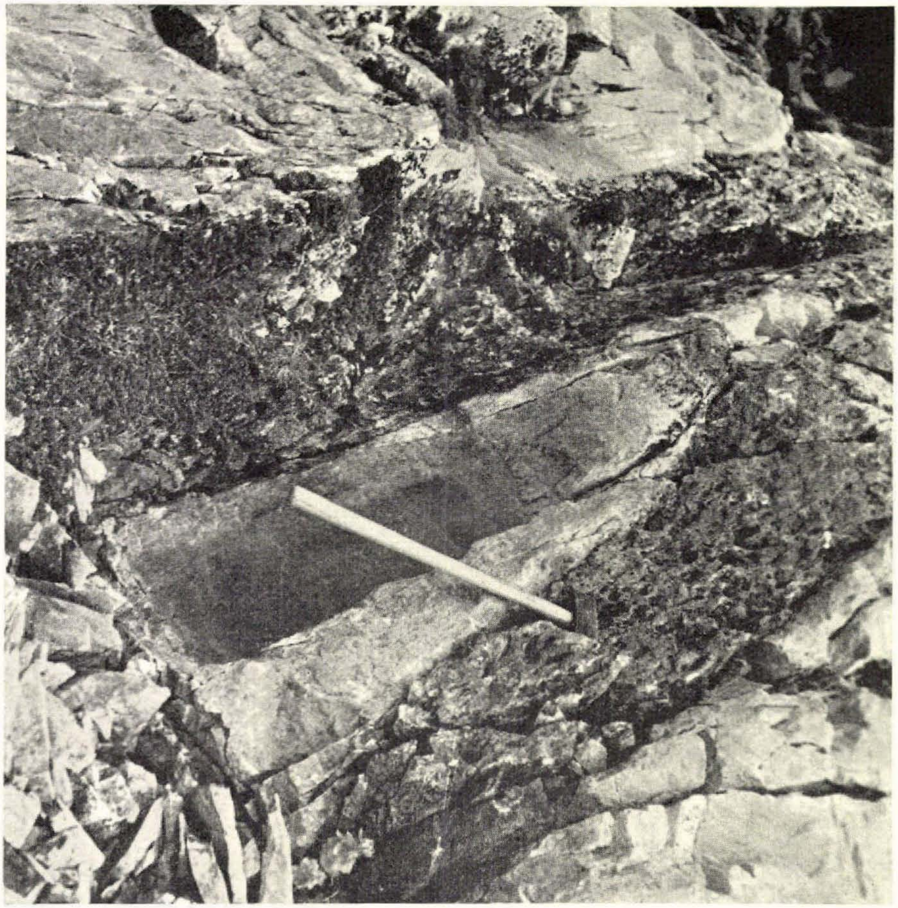

Fig. 4. A branching dyke of breccia matrix. The matrix in these dykes is very coarse-grained and the dykes contain numerous small inclusions. The country rock is a light nebulitic gneiss. From square C3.

gneiss foliation as well as the aplitic veins, but is cut by pegmatites and dykes of breccia matrix (fig. 3). The dyke has clearly intrusive relations and has a small apophysis. The rock is medium-grained with hetero-granoblastic texture and consists mainly of strongly altered plagioclase (sericitized) and quartz (ca. 50 %). In thin section muscovite is next in abundance, although there is sufficient biotite to give the rock a dark grey appearance. Epidote and small ore grains are common and idiomorphic apatite accessory. Along the contacts of the dyke there seems to be a somewhat greater representation of the dark minerals. Although no petrographic data points to the origin of the dyke, the structure leaves no doubt of its origin as an intrusive dyke.

In square G6 a dyke of uncertain relations is found. It is displaced by a small fault which does not displace the breccia and the small dykes of breccia matrix. As in the older discordant dyke in squares A2 and B2, the contacts are somewhat richer in mafics (biotite) and the intrusive character is clearly seen from " en bajonet" structure and apophyses, besides complete discordance to the gneiss structures. Although the textural relations with phenoblastic felspars recall some of the dykes of breccia matrix the dyke is in appearance and presumably also chronologically analogous to the already mentioned dyke older than the breccia.

Besides pegmatites and dykes earlier than and contemporaneous with the breccia, still younger dykes are found inside the area mapped. In the eastern part of the map (Pl. I) two generations of Kuanitic dykes occur. These are slightly metamorphosed basic dykes, now amphibolites with doleritic textures preserved in the central part and the margins tectonised to a chloritic schist.

Along the south-west margin of the breccia an approximately 1 m wide doleritic dyke runs in a NNW direction. This dyke belongs to the youngest generation of dykes in the Ivigtut area as a whole — the so-called post-Gardar dykes.

It should also be mentioned that crushing younger than the Kuanitic dykes affected the area mapped. Several small west-north-west-trending faults with sinistral displacement are thus found. The faulting has only a weak effect on the surrounding rocks as a reddening or an epidotisation and chloritisation (green colouring). In addition to joint coatings, veins of epidote and quartz veins occur associated with these mylonites (fig. 5).

The shape and structure of the main breccia.

The shape of the breccia seems to be highly irregular and it is very difficult to find any pattern in the occurrence of the structures. Fig. 6 shows a generalised and interpreted sketch map of the breccia. It could from this be described as a complex swarm of irregular dykes.

The eastern contact is characterized by smooth curves and amoeboid forms (fig. 5). It has not been possible here to discover the dip of the contact.

The western contact is characterized by sharp edges and straight lines. The dip of the contact varies between 20° and 60° towards south-west, which roughly corresponds to the regional dip. The trend of the contact also roughly corresponds to the regional strike, although there is no doubt of the discordance of the breccia. The western and south-western contact region is furthermore dominated by branched dykes, which trend "en échelon" into the gneisses southwest of the contact. From the dip of contact and the occurrence of the numerous dykes it is suggested that this region represents the upper part of the breccia, whereas

Fig. 5. Breccia tongues in square G 6. The smooth curving contact is indicated with the dotted line. An intersecting pegmatitic vein can be seen crossing from the upper left corner. In the lower right a younger epidotic vein intersects both pegmatite and breccia. The breccia here contains relatively few inclusions.

the northeastern contact corresponds to the lower part. Thus the breccia as a whole forms an irregular elongated inclined body parallel to the structure of the country rocks.

Inside the breccia complicated irregular forms are found. From bigger areas of breccia a large number of dyke-shaped tongues protude. These, like the contacts, generally trend north-west south-east, and dip south-west.

The protruding dykes-shaped tongues are commonly joined so that larger gneiss "islands" are formed. Measurements of planar elements from these gneiss "islands" generally coincide with the structures outside the breccia. However, some of the measurements deviate considerably

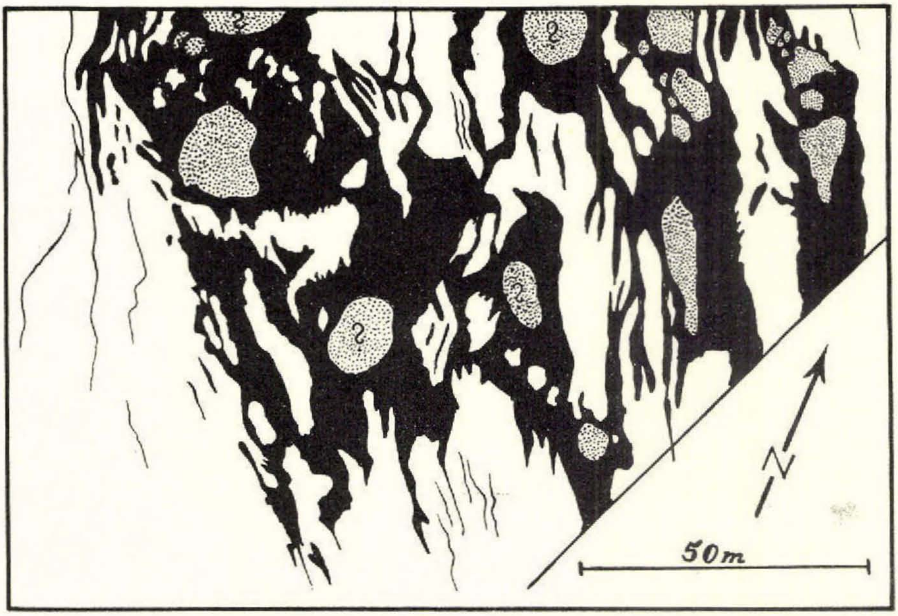

Fig. 6. Generalised and interpreted sketch map of the mapped breccia locality. Black is breccia and dotted is big ultrabasic inclusions. Those marked with a question mark are unexposed ultrabasics, the existence of which is inferred from numerous small zoned ultrabasic inclusions at the level of exposure. White is country-rock and major gneiss "islands" in the breccia.

from the general strike and dip. This could be caused by the folding prior to the formation of the breccia. A comparison on a stereographic projection of these measurements with measurements from outside the breccia show that they generally fall outside the great circle zone corresponding to the fold axis.

It is therefore suggested that the gneiss "islands" from which these measurements have been taken were rotated as inclusions in the breccia. tI should be mentioned that some measurements taken from outside the breccia also fall off the great circle zone. This is caused by the influence of an earlier fold axis, since the area as a whole can be shown to have been double-folded prior to the breccia formation.

The basis for comparison, however, has been taken from the immediate surroundings of the breccia, where only the effects of the last folding prior to the brecciation are apparent.

The breccias outside the area mapped in detail, south-east of this and in the eastern localities, also seem to have a subconcordant trend along the big amphibolite bands. Where breccia occurs in amphibolite this rigid rock completely controls the trend and more regular sill-shaped bodies result.

Fig. 7. Local brecciation of amphibolite. The breccia matrix is "agmatizing" the amphibolite of which the fragments are oriented at random. From square D 3.

Breccia-gneiss contact relations.

In the following a number of characteristic contact phenomena between the breccia and the gneisses will be dealt with.

Contact phenomena resulting from the emplacements of the breccia are found along the internal contacts of the breccia against gneiss "islands".

In square F4, as already mentioned, a finely banded gneiss is found (fig. 2). Approaching the breccia this rock is brecciated along banding planes and forms together with the matrix a "migmatite". Small veins of a homogeneous medium-grained rock directly connected with the matrix of the breccia has been forced in between the fractured gneiss pieces and in between the banding of the gneiss.

In square D3 part of an amphibolite band occurs. This amphibolite has been locally brecciated. Angular blocks of amphibolite are found in a coarse-grained homogeneous mass of the matrix. The orientation of the blocks is random. No exotic blocks are found in this part of the breccia, and it therefore seems possible that this part of the breccia, in the neighbourhood of the rigid amphibolite band, has been a pocket with little or no movement during the formation of the breccia (fig. 7).

Along the southwestern contact there are clear indications of a sorting of breccia fragments according to size, and an orientation of these. It is not a sorting after density, as leucocratic inclusions and ultrabasic inclusions are found side by side (fig. 8).

In the dykes along the southwestern contact orientation of inclusions is also common (fig. 4).

As the northeastern contact differs from the southwestern one with regard to shape and structure, so also do the contact relations differ. In squares F6 and G6 the contacts are sheared and the formation of a foliated biotite gneiss is the result. Inclusions 25—30 cm from the contact are sheared and elongated regardless of the nature of the material. The same relations are found in the tongues in square G3 and likewise have been observed south-east of the area mapped in detail. Dykes of matrix are also foliated parallel to their contacts.

In all these cases it is rather difficult to locate the contacts exactly, as both the matrix and the surrounding gneisses, which are rocks of similar composition, are foliated in a 10—20 cm wide zone parallel to the contacts. It is the author's opinion that the smooth curving of the contact must be viewed in connection with this foliation. The deformation which is responsible for the formation of this foliation does not seem to be related to the emplacement of the breccia, but must rather be connected with the regional semiplastic deformation, during which the wavy gneisses were formed (BERTHELSEN, BONDESEN and BAK JENSEN 1962). This deformation happened just before or at the same time as the formation of the younger pegmatites. These have often been formed in the small plastomylonites which are characteristic for the wavy gneissess (see p. 8). The foliated zone along the breccia contacts is often displaced by the youngest pegmatites (fig. 5) but small pegmatites which turn parallel to to the foliated zone without any macroscopic textural change have also been observed.

The matrix of the breccia.

The matrix of the breccia varies in texture as well as in composition from place to place. Besides there seems to be a difference between the matrix in the breccia itself and the dykes of matrix in the surroundings.

Fig. 8. Sorted and oriented inclusions in the breccia not far from the southwestern contact. The densely-packed inclusions are very different in origin. The white patches are gneiss inclusions. The rock to the right (see p. 20) is a microbreccia very like the matrix.

The matrix in the breccia itself is mostly a pale grey homogeneous medium-grained rock. In places it becomes more coarse-grained with small patches of dark minerals. A darker grey medium-grained biotite-rich slightly foliated rock is found in square F5.

All samples sectioned (8 in number) from the main breccia area are quartz-dioritic in composition. Plagioclase (24—28 $^0/_0$ An) is the predominant mineral. Very altered grains consisting of clinozoisite and sericite seem to be remnants of plagioclases of much higher anorthite content. The relatively unaltered plagioclase grains are usually angular to subangular in shape, without any regard to crystal idiomorphism. Many of the plagioclase grains seem to be broken fragments.

Recrystallization to small rounded blebs along the edges of the plagioclase grains is common as is also recrystallization along twin planes, cleavage planes and fractures. The recrystallized plagioclase is probably albitic in composition. In all cases it has considerably lower refractive indices than the primary plagioclase. However it has not been possible to measure the composition of the very small grains. Secondary alteration, such as saussuritization and sericitization, in the primary plagioclase is common.

The quartz always shows undulating extinction. The grain size of this mineral varies considerably. The quantitative proportion of quartz to plagioclase varies from 1:10 to 1:3. All the quartz, except for a few small rounded recrystallized patches, seems to be primary.

The dark minerals are mainly a light brownish pleochroic biotite, often in bent flakes, a pale bluish amphibole, muscovite and epidote (mainly secondary). The amphibole is always found to be a relic from alteration to biotite. The accessories are apatite, calcite, ore and rounded zircons as inclusions in quartz and biotite surrounded by pleochroic haloes. Sphene, which is common in the amphibolites and gneisses, is remarkably rare if not absent.

One of the samples, which represents the coarse-grained inhomogeneous matrix to the right in fig. 8, is interesting because it is clearly microbreccia. In section, parts with crushed quartz grains change with parts of big angular plagioclase grains. Other discrete parts of the slide consists of biotite and amphibole, and bigger areas of unaltered amphibole are also found. Calcite is common in between the bigger nearly monomineralic patches, together with a fine-grained mass of feldspar and quartz, which originally could have been rock powder. As a whole the rock has undergone the same secondary alterations as are found in the rest of the breccia and in the surrounding gneisses.

The petrography of the dykes of matrix in the surrounding rocks seems to be slightly different. The grain size is considerably coarser than that of the major part of the main breccia. The quartz: plagioclase proportion varies from place to place from 1:8 to 1:4. A small content of microclin in the matrix dykes in the southwestern gneiss area is caused by a weak later metasomatism, which also influenced the gneisses. This however cannot be traced into the main breccia area.

From the foregoing descriptions it will be apparent to the reader that the breccia matrix has all the characteristics of a microbreccia, the constitutent particles being fragments of mineral grains. This has however been to some extent disguised due to the action of the later metamorphism.

Inclusions in the breccia.

In all breccia localities inclusions play an important part. Their quantitative relation to matrix, however, varies from place to place (cf. figs. 5 and 9). Moreover the different sorts of inclusions vary in size, shape and frequency.

In the following the inclusions will be described in their order of abundance:

1) Ultrabasic and hornblenditic inclusions.
2) Amphibolitic inclusions.
3) Gneiss inclusions.
4) Gabbro-anorthositic and anorthositic inclusions.
5) Other inclusions.

1) Ultrabasic and hornblenditic inclusions.

Ultrabasic inclusions are far the most common type of inclusion. They occur in different sizes and belong to different petrological types. These can be grouped as follows:

Big ultrabasic inclusions.
Smaller zoned ultrabasic inclusions.
Hornblenditic inclusions.

Big ultrabasic inclusions.

As seen from the map Pl. 1 big ultrabasic bodies are found in several places inside the area mapped in detail. This is also the case in the continuation of the area to the south-east. Ultrabasic blocks of metre size have not been found in the eastern localities.

The bigger ultrabasic bodies seem to be elongated, probably elipsiod, lumps, which are everywhere surrounded by breccia and matrix, although in several places they nearly come in contact with the surrounding gneisses. In squares G5, F5, G4 and G3 one gets the impression that the general elongated shape of the breccia has determined the shape of the ultrabasic bodies. In F5 some smaller blocks, but still of metre size, are presumably isolated fragments of the bigger body in G5.

The ultrabasics are all talc-soapstones, except for the big body in squares C3 and D3, which contains some antigorite. All the bodies have an outer zone of actinolite of varying width. This is especially the case in the isolated fragments of the big body in square G5 where up to 20 cm long radiating actinolite needles from an outer crust. Some of the bigger talc-soapstone bodies have furthermore a central core of a magnesite-talc rock with some accessory ore. In other cases the central part of the bodies is porphyroblastic with isolated big idiomorphic grains of magnesite.

Internal breccia structures are found within the ultrabasics in squares G5 and F5 (fig. 10). In the interfragmentary space actinolite, coarse laminated talc and antigorite are found. The fragments within the bigger ultrabasic bodies are angular to subangular with rounded corners. Marginally situated framgents are rounded and remind one very much of pillow structures. A zonal mineral arrangement with an outer actinolite zone and an inner core of talc is also discernible in these.

Younger pegmatites can be followed into the big ultrabasic bodies in fissures with thin coatings of quartz or fillings of coarse laminated talc.

Smaller zoned ultrabasic inclusions.

These inclusions are very common inside the area mapped. They are mostly less than 50 cm in diameter, usually spherical or elipsoidal, and in most cases zoned. (Fig. 2 and 9).

An outer crust of radiating needles of actinolite is characteristic. In the smallest inclusions a fine-grained aggregate of a light green actinolite without preferred orientation forms the centre. Larger inclusions, over 10 cm in diameter, can have several concentric zones. Besides the crust with radiating actinolite needles, an inner zone, with whitish green talc, is found. In this zone, which is the thickest, larger laminated talc crystals and ore grains also occur. The long radiating actinolite needles from the crust zone can persist far into the inner zone. The central core is normally of yellow colour and consists of about 60 % magnesite, 35 % talc and ore. In some of the ultrabasic inclusions coarse laminated amesite is present. This type of ultrabasic inclusion is closely related to the big ultrabasics.

A few examples of another zoned type of ultrabasic inclusion have a fine aggregate of yellow tremolite inside the actinolite crust. In amongst the tremolite magnesite is found.

Hornblenditic inclusions.

Pure hornblendite inclusions are also present in the breccia, and may be grouped under ultrabasic inclusions. Although rounded forms are found, their shape is usually angular to subangular. A general mineral orientation is generally developed. The size varies from centimetres to over half a metre in the longest direction. The grain-size varies from medium-grained with a light green colour to coarse-grained with a black colour.

The hornblenditic inclusions grade with increasing plagioclase content into amphibolites, and they probably originate from the ultramafic parts of the amphibolite bands.

2) Amphibolitic inclusions.

Amphibolitic inclusions are always angular to subangular in shape and relatively coarse-grained. A preferred orientation of mineral grains is present. Varieties with more or less pronounced banding are met with. Garnet amphibolites are also found.

The petrology of the amphibolitic inclusions is very close to that of the amphibolitic bands (see p. 8) which occur frequently on the eastern Sermersût (fig. 1). Dark grey biotite gneisses and leucocratic hornblende schists, which are often found as a granitisation product of the amphibolite bands, are also found as inclusions in the breccia. However these should be grouped under (3). It seems therefore most likely that the amphibolite inclusions originate from the amphibolite bands in eastern Sermersût. Structurally these amphibolite bands occur both over and under the present level of the breccia.

3) Gneiss inclusions.

Different forms of biotite gneiss are common as inclusions in the area mapped as well as in the other breccia localities. Their shape is always rounded or even amoeboid. They are, as figs. 9 and 10 show, often completely homogeneous and white, but can when they are larger than 50 cm long, preserve their original structures such as banding and nebulitic small folds. None of the numerous gneiss inclusions can with certainty be correlated with the gneisses on eastern Sermersût. However the variety in these gneisses is so great that correlation would be invalid.

It should be mentioned that although gneisses are the most common rocks surrounding the breccia for a long way around, gneiss inclusions in the breccia are of minor quantitative importance.

4) Gabbro-anorthositic and anorthositic inclusions.

Angular blocks of gabbro-anorthositic and anorthositic origin occur as a smaller but easily recognizable group of inclusions. Although not absent in the area mapped, they seem to be more common on the eastern localities.

The size of the blocks seldom reaches 30 cm in the longest direction. The grain size is generally moderate, although the texture indicates that the grain size has originally been coarse. However this is also the case in the boudin-shaped gabbro-anorthosite inclusions found in the "gabbro-anorthosite series".

In the majority of the inclusions the plagioclase and the hornblende has been altered into an aggregate of clinozoisite, sericite and biotite.

Fig. 9. Breccia rich in inclusions bordered by homogeneous matrix. In the top of the picture gneiss and below that matrix (m). Different sorts of inclusions are seen: x: small zoned ultrabasics, z: big inclusion of fine-grained actinolite rock, gn.: different sorts of gneissic inclusions, an.: a gabbro-anorthositic inclusion. The majority of the inclusions in this picture are amphibolites and ultrabasics. From square E5.

Pennine chlorite is also found. In one slide comparatively well-preserved relict plagioclase (58—70 $^0/_0$ An) was found.

As mentioned, these rocks belong to the "gabbro-anorthosite series", which is a distinct structural level in the infrastructure. The rocks of the "gabbro-anorthosite series" are not found in the immediate surroundings of the breccia. The nearest localities are found at a level 1—1.5 km higher structurally than the present level of exposure of the breccia. The "gabbro-anorthosite series" has not for certain been at a lower level.

5) Other inclusions.

Under this heading inclusions of different types, of which only one or few examples are known, shall be mentioned.

Quartzitic inclusions have been found in very few instances. It has not been possible from microscopic study to decide whether they originate from sedimentary quartzites, which are found in the suprastructure, or whether they originate from vein quartz. It should be mentioned that the vein quartz in the immediate surroundings of the breccia is younger than the breccia.

Banded metamorphic schists, with chlorite bands, rutile, plagioclase and quartz, are also found. The border zone of such a fragment against the matrix of the breccia is characterized by frequent crystals of brown and blue pleochroic tourmaline. The rock seems to be of far lower metamorphic grade than other rock fragments, and to be unmigmatized. Thus it could be a fragment from the rocks of the suprastructure.

Furthermore a block with a pronounced cleavage and a varved structure was found. This block, together with a light green block consisting almost entirely of actinolite and chlorite (fig. 9), an original greenstone, could also originate from the suprastructure, as both varved slates and greenstones are found there.

Inclusions of more special character are a 5 cm large block of nearly pure garnet and a 10 cm large inclusion of magnetite.

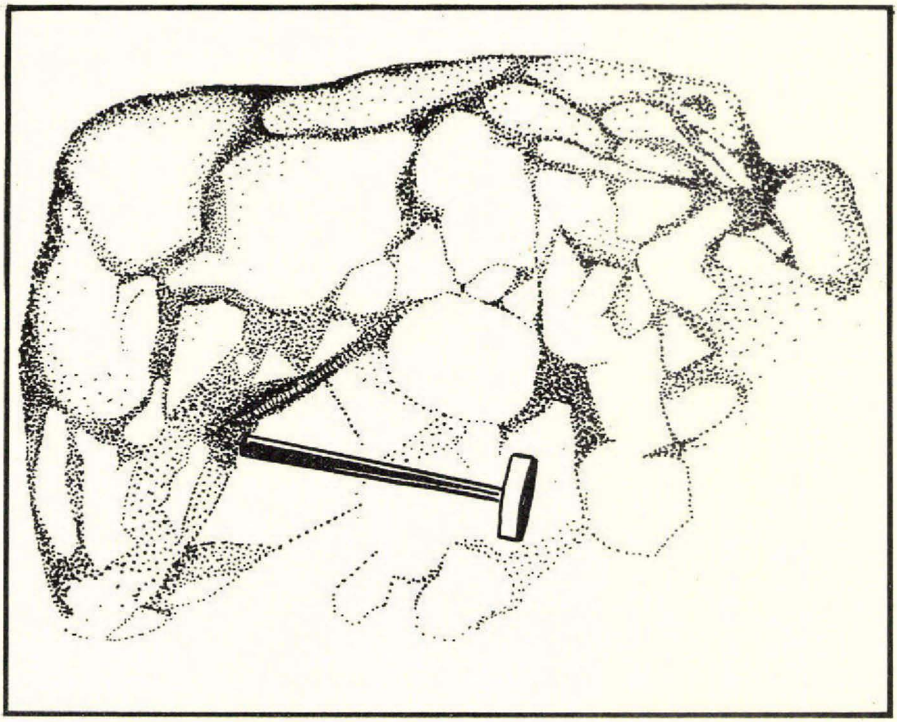

Fig. 10. Brecciated soapstone from square C4. The intensity of dotting shows the abundance of actinolite. The fragments in the central part are angular, whereas the marginal ones are pillow-shaped. A vein of fibrous talc occurs above the hammer-shaft. (Drawn from a colour photo).

PROVENANCE OF THE INCLUSIONS

Many of the inclusions may give some clue as to the formation of the breccia.

The gabbro-anorthositic and anorthositic inclusions and the few inclusions which seem to be unmigmatized rock-types possibly originating from the suprastructure, are exotic and indicate that rather long transportation has taken place. The gneiss inclusions and amphibolite fragments may be of local origin as such rocks are found in the immediate surroundings of the breccia.

Regarding the exotic inclusions the direction of transport seems to be lateral or downwards, as comparable rocks are only known from a considerably higher level. However it must be mentioned that since the formation of the breccia the area has undergone one more phase of plastic deformation and several periods of faulting. The relative position of the structural planes when the breccia was formed is therefore uncertain. The author thus prefers to let the direction of transport be an open question.

The shapes of the different types of inclusions show that they possessed different plasticity and/or mechanical cohesion during the emplacement of the breccia. Gneiss and quartzitic inclusions often have amoeboid forms and seem to have been rather plastic or abraidable. Anorthositic, amphibolitic and horblenditic inclusions on the other hand are mainly angular or subangular in shape, and thus appear to have been rather rigid. An angular fragment of amphibolite has been observed with one corner pressed into a gneiss fragment.

Some of the numerous small zoned ultrabasic soapstone inclusions seem to have been part of the bigger bodies, and petrographically they have many features in common. Furthermore there seems to be a general increase in frequency of small ultrabasic fragments approaching the big ultrabasic inclusions.

The formation of the crust of radiating actinolite needles is later than the separation from the big ultrabasics. Their rounded shape is due to both the soft character of the soapstone and the formation of the crust. The development of the long thin actinolite crystals indicates that the adjustment of the stability relations was slow during the consolidation of the breccia. The formation of this reaction rim is probably connected to hydrothermal activity acting after the cessation of the more violent brecciating action.

The magnesite core in the ultrabasic bodies can also be considered at this point. The textural relations suggest that the ideoblastic magnesite grains are a product of activity later than the formation of the inclusions, and therefore possibly contemporaneous with the formation of the actinolite crust.

Talc-magnesite rocks, also with a central concentration of magnesite, are described by a number of previous authors. WILCOCKSON and TYLER (1933) mention talc-carbonate bodies in the Sudan and MAC GREGOR (1932) describes a concentration of magnesite marbles in the talc-carbonate rocks of Que Que, Southern Rhodesia. AMIN (1952) describes talc-magnesite-chlorite rocks from Shetland formed in shear zones in serpentines under influence of hydrothermal fluids. All these examples show parageneses identical to the Sermersût breccia ultrabasics and are interpreted as results of hydrothermal activity. In the present case also it is reasonable to regard the magnesite centres as results of hydrothermal activity accompanied by high CO_2-pressure, processes which also resulted in the formation of the actinolite reaction rims.

POSSIBLE MECHANISM OF FORMATION

Regarding the breccia structures treated in the present paper, sedimentary and tectonic deformation can be left out of consideration as the cause of brecciation. Solution activity, as for example in a boiling hot spring, could produce irregular structure similar to the Sermersût breccia (PETERS 1953) but such a mechanism should not be able to produce features like the matrix dykes in the surroundings. Also it seems impossible to connect the ultrabasics to such a mechanism. The breccia is clearly a cross-cutting intrusive phenomenon associated with volcanic or igneous activity and possibly with the formation of the ultrabasic rocks.

The matrix of the breccia does not seem to have been a proper magma. The quartz:plagioclase ratio varies as described, as well as the composition of the plagioclase (page 19). Relic grains of evidently highly calcic plagioclase also exist. The mineralogical similarity of the matrix to the gneisses and the textural relations with angular plagioclase grains and fine-grained interstitial material suggest that the matrix too represents a breccia with the fragments on the scale of mineral grains. The rock described on p. 20 (fig. 8) is intermediate between a breccia of mineral fragments and one of rock fragments.

Except for most of the ultrabasics, the inclusions of the breccia represent fragments of the country rock. Some of these have been transported for long distance. This transportation took place through rather narrow channels. The bigger soapstone bodies were also transported along these channels.

In the absence of magma only gases can be regarded as the transporting agent and it is therefore concluded that the emplacement of the breccia is the result of high pressure gas action, which had a drilling effect. The structure of the breccia as a whole seems to be non-dilational although some of the bigger gneiss "islands" are rotated. This is what characterizes the fluidized intrusive breccia and dykes of REYNOLDS (1954). Some widening, however, occurs, where some of the small matrix dykes in the surroundings show dilation which could have been caused by collapse after the cessation of gas action. The brecciation seen in fig. 2 shows that an intrusive push was exerted.

From the occurrence of the numerous small ultrabasic inclusions as well as the arrangement of the big ultrabasic bodies (fig. 6) it would be natural to connect the gas action to the transport of the soapstones. As the bigger soapstone bodies are fragmented and brecciated these are thought to have been transported in a solid state. The pillow-shaped fragments peripheral to the bigger ultrabasic bodies could indicate that the ultrabasics possessed some plasticity towards their margins during the emplacement of the breccia. On the other hand the surrounding matrix medium would have had a purely mechanical abraiding effect on the soft solid soapstone and thus have been responsible for the rounded shapes.

It should be mentioned that H. H. Hess (1938) postulates the existence of a low temperature H_2O-rich primary peridotite magma of a composition similar to serpentine, which should lead to volcanic activity characterized by the escape of large amounts of gas. In 1955 Hess advanced his theory that serpentines are able to intrude in a solid state.

No trace can be seen of the gases which are regarded as having acted during the formation of the breccia. The presence of magnesite could be explained by a very high CO_2-pressure during the post-brecciation hydrothermal activity. Whether this is a direct product of the condensed gases or has a completely other source is difficult to say. Hydrous minerals occur and calcite is also present in the matrix although very subordinate. However the later metamorphism would have removed and rearranged all traces of volatile constituents.

THE CHRONOLOGICAL SIGNIFICANCE OF THE BRECCIAS

While the post-Ketilidian chronology in south-west Greenland is well established, a complete understanding of the sequence of Ketilidian and pre-Kilitidian events has not yet been achieved. The systematic mapping carried out by G.G.U. in the Ivigtut area has lead to the supposition that several phases of deformation have succeeded each other in the Ketilidian orogeny.

Regarding the Sermersût area, the author can demonstrate three phases of plastic deformation, the first of which probably took place in a pre-migmatitic stage. The second deformation was accompanied by a thorough migmatitisation with the formation of the main geological structure. The rocks were metamorphosed under amphibolite facies conditions and were severely pegmatitised. The third deformation lead to a large scale bending and buckling and was accompanied by metamorphism under epidote-amphibolite facies conditions, granitisation and pegmatitisation. (Berthelsen, Bondesen and Bak Jensen 1962).

The breccia structures under consideration fall in between the two later phases of plastic deformation. This is evinced by the fact that the breccias cut the migmatitic structures, but are intersected by the youngest pegmatites and were metamorphosed under epidote-amphibolite facies conditions.

The formation of breccia dykes in the surrounding gneisses show that complete consolidation had taken place before brecciation, i. e. between the two later phases of deformation. The latest of these took place in semiplastic conditions and is responsible for the formation of wavy structures. The pegmatites formed are rectilinear and often developed in fissures with minor faulting.

Igneous activity is known in the interval during which the brecciation occurred. In the Ivigtut area ultrabasic rocks (dunites, serpentines and soapstones) occurring as plugs, sills and large lensoid bodies, are found. These ultrabasics were emplaced into the migmatitic gneisses after the second deformation (Berthelsen 1960). Ultrabasic bodies of this generation are not found in the immediate surroundings of the breccia. The nearest localities are situated at 3 km (fig. 1) away on westernmost Sermersût and on the neighbouring island to the east, Tôrnârssuk. Here the rocks are dunitic. Breccia structures similar to those described in this paper have not yet been found elsewhere.

Whether the Sermersût breccia is contemporaneous with the emplacement of these ultrabasics or later cannot be proved. BERTHELSEN (1960) considers the breccia to be later. This is also the author's opinion, as the soapstones in the breccia, if originating from the dunites mentioned, are brecciated and therefore could be such material rearranged in solid state.

Double intrusion of ultrabasic rocks has previously been described in the literature. HIESSLEITNER (1951) states that in many cases ultrabasics have been transported into new environments. This secondary intrusion is suggested by SØRENSEN (1954) to be the result of serpentinisation at a high level in the crust. WILKINSON (1953) shows examples of double intrusion from Queensland.

The possibility that the formation of the breccia and the ultrabasics elsewhere in the Ivigtut region were contemporaneous, however, should not be left out of consideration. If this were the case the breccia shows an example of the ultrabasic intrusive activity dealt with by HESS (1938 and 1955) (see p. 29). However the chronological position of the breccia does not suit this view, as HESS regarded serpentines to be intruded during the first orogenic movements. It could be suggested here that the intermediate period of consolidation between the two phases of movement actually represented a period between two orogenic cycles, and that the ultrabasics really represent the geosynclinal serpentines of HESS. The ultrabasics would then have been intruded into basement, the existence of which has recently been demonstrated further east (BONDESEN 1962). However this demands a revision of the chronological scheme for which sufficient data is not yet available.

COMPARISONS

The Sermersût breccia can be compared to various sorts of intrusive breccias differing highly in their geological setting, chronological position and petrological character.

It would be natural to compare the Sermersût breccia to breccias of volcanic provinces, established eruptive breccias. Many of these are supposed to have been formed under influence of volcanic gases. Thus CLOOS (1941) has suggested gas drilling as the cause of the structure in the Schwabian tuff-pipes. REYNOLDS (1954) advocates the industrial fluidization process as responsible for many gas-emplaced breccias and gives a series of examples.

By comparing the Sermersût breccia to volcanic breccias the petrological differences must be mentioned. While most volcanic breccias contain mainly fragments of igneous rocks, such fragments (apart from the ultrabasics) have not been found in the Sermersût breccia. Also the matrix of this has no petrographic resemblance to the tuffaceous matrix of volcanic breccias. However there are structural similarities, which add to the evidence of gas-eruption in Sermersût. Dykes and vents of breccia formed by gas eruptions are well known from the British Tertiary province, e. g. from the Central Volcanic Complex of Arran (KING 1953) and from Glas Eilean, Ardnamurchan (RICHEY 1940), where veins form net structures extending from the vent. As mentioned the Sermersût breccias are not related to any inter-Ketilidian volcanism.

Other breccias which besides structural similarities also have petrological similarities to the Sermersût occurrences are the Sudbury breccias, especially the types "vein" and "stockwork" of FAIRBAIRN and ROBSON (1942). The "vein" breccias of Sudbury can be compared to the dykes of breccia matrix, while the inclusion-rich parts of the Sermersût breccia are very similar to the "stockwork" breccias. Both the structure and shape of inclusions and the relation of matrix to inclusions and surroundings are like the Sermersût breccia. Also in Sudbury exotic blocks are found among blocks of local origin. Differences are found in the occurrence of ultrabasics in the Sermersût breccias (although not in the eastern localities) and in the final mineralisation in Sudbury.

The Sudbury breccias were emplaced during the post-Huronian deformation, presumably chronologically later in relation to orogenic movements than the Sermersût breccia. Their formation was caused by aqueous fluids at elevated temperature and pressure forming a mobile matrix, which in time attained sufficiant volume to transport fragments.

Another breccia similar in structural appearance to the Sermersût breccia is the Bull Domingo breccia in the Blue Mountains (Peters 1950). This breccia has been interpretated as an explosive breccia, but is regarded by Peters as the pipe of a boiling spring formed in an area of intersecting faults. The inclusions and the matrix show many similarities to Sermersût, however in Bull Domingo a final mineralisation also took place. The geological setting is similar to the Sermersût breccia.

Other breccias caused by gas-stream action in dyke and vent form are described from Co. Donegal (Pitcher and Read 1952, French and Pitcher 1959) and from West Cork, Ireland (Coe 1959 and pers. comm.). The breccias from Donegal are of more regular shape than the Sermersût breccias although there are associated dykes. One of the Cork examples is very similar in structure to the Sermersût breccia. Furthermore these breccias are late kinematic. Petrographically however there are differences, which are not purely caused by the different surroundings. The matrices of the Donegal breccias are appinitic and granophyric (Pitcher and Read 1952) and "felsitic of complex origin" (French and Pitcher 1959). Appinites and hornblende lamprophyres are associated in the matrix and found as inclusions (Coe pers. comm.). These rock types have no likeness to the ultrabasics in the Sermersût breccia so there is still a striking difference on this point, although the modes of emplacement are regarded as similar. The Irish breccias are regarded as closely related to the emplacement of granite plutons. As far as is known granites of the same relative age as the Sermersût breccia have not been formed in the Ivigtut region.

Zonal arrangement in gas emplaced breccias is common. Cloos (1941) noted the zonal arrangement in the Schwabian tuffpipes and the same is found in the Irish breccias mentioned. Zonarity is regarded by Reynolds (1954) as a result of fluidization. The interior zone has been the site of rapid flow of breccia material in gas suspension, whereas the outer zone represents low gas velocity and relative stagnation.

In the Sermersût breccia zoning is only weak and the transported fragments including the big ultrabasics form the bulk of the included material. An outer zone consisting of the inclusion-poor marginal parts and the dykes can be established. This outer zone consists mainly of quartzo-felspathic material, which was derived from the country rock. Also the relatively sharp border in fig. 8 could indicate zonarity, in any case a sudden change in gas velocity. Such a change could be due to the sheltering effect of the irregular wall rock.

Breccias involving ultrabasic rocks are known from Queensland (WILKINSON 1953) and Eastern Papua, New Guinea (GREEN 1961). The Queensland breccias are suggested to be due to the intrusion and brecciation of earlier peridotite bodies by a later magma approximating to serpentine in composition. With respect to the double intrusion they are probably similar to the Sermersût breccia. The Papuan breccias are interpreted as "vent and extrusive breccias resulting from the penetration, brecciation and local entrainment (fluidization) of peridotitic country rock by volcanic gases. Olivine alkali basalt was probably the parental magma responsible for the gaseous activity" (GREEN 1961). In the absence of ultrabasic country rocks in Sermersût, the ultrabasics nature of the Papuan breccias has little direct bearing on the problem of the ultrabasic inclusions in the Sermersût breccia. No definite statement can be made concerning the composition of the parental magma responsible for gaseous activity in Sermersût.

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

MEDD. OM GRØNLD. BD. 169. NR. 7. (ERLING BONDESEN)

PL. 1