MEDDELELSER OM GRØNLAND
UDGIVNE AF
KOMMISSIONEN FOR VIDENSKABELIGE UNDERSØGELSER I GRØNLAND
BD. 136 · NR. 6

ON THE GEOLOGY OF A METAMORPHIC COMPLEX IN WEST GREENLAND

THE ISLANDS OF ANARSSUIT, ISUAMIUT, AND EQÛTIT

BY

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WITH 22 FIGURES IN THE TEXT
AND 1 MAP

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1954

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ACKNOWLEDGMENTS

Material for the present work was collected in the summer 1948 during field work for the Geological Survey of Greenland. It was worked up at the Mineralogical Museum of Copenhagen during my last years of study at the University of that city. I should like here to express my gratitude to all who in some way helped me during the progress of my work, in particular to Professor, Dr. phil. A. Noe-Nygaard, Director of the Mineralogical Museum, for guidance and assistance as well as for extraordinarily good working conditions at his museum during my years of study. My thanks are also due to the Board of Management of the Greenland Geological Survey for giving me the opportunity of field work in Greenland, to Professor, Dr. phil. H. Ramberg, who introduced me to the geology of pre-Cambrian rocks, to my working companion from the summer 1948, mag. scient. H. Sørensen, and to the Geodetic Institute for the loan of air photographs of the area investigated. Mr. A. H. Nielsen from the Cryolite Company Øresund carried out four chemical analyses, Mag. scient. H. Pauly certain ore determinations and Mag. scient. A. Berthelsen prepared the thin sections, while Mrs. Aase Holst has undertaken the translation. To all of them I tender my sincere thanks.

INTRODUCTION AND EARLIER STUDIES

The field examined consists of small island groups belonging to the skerry archipelago near the settlement of Egedesminde in North Greenland. More exactly, the islands are situated N—NW of the settlement which is on the south side of Disko Bugt.

There must be special reasons for justifying a separate study of so small an area. The investigations of West Greenland undertaken by the Geological Survey of Greenland in recent years have made a new classification of this region possible. H. RAMBERG (1948, 1949) segregates two orogens of different ages. The northernmost of them which only is of interest in the present connection has its southern boundary along the latitude 66°45′ N or a line through Itivdleq-Itivdlînguaq (*vide* RAMBERG). It is not yet possible to determine the northern boundary of this ancient mountain range. RAMBERG bases his classification of the orogen on the mineral facies in such a way that the central zone or the core of the folding range has a higher degree of metamorphism than the flanks, the former being in granulite facies and the latter in amphibolite and epidote-amphibolite facies. RAMBERG believes that the major parts of the rocks within this field of 37 500 square kilometres is of sedimentary origin. So far it has not been possible to find sediments so little altered that their origin is immediately apparent. From this statement the island groups which will be described in the following pages should be excepted. The fact that rocks of obviously sedimentary origin occur here is the best explanation of the islands having been marked out for special treatment. They offer the opportunity of gathering information about the nature of the primary material which to a great extent has been lost by the more advanced metamorphism. Similar conditions exist in intrusive magmagenous greenstones. It may be definitely established that the greenstones in question are of magmatic origin, and their course of development reflects certain features which must be significant for an evaluation of the more highly metamorphosed rocks of the southern border areas where the origin of the amphibolites is more problematic.

The three groups of islands covered by the investigations are from west to east: Anarssuit, Isuamiut and Eqûtit. They are small islets. Isuamiut is the largest with an area of app. 3 square kilometres. The smallest are rocks of a few square metres at high water. None of the islands are very high. Topographical material shows the highest point, 67 metres above sea level, to be at the eastern end of Anarssuit. At Isuamiut the highest point is 55 metres above the sea. The rounded outlines of some of the islands bear evidence of former glaciation. The greenstones in particular have preserved the outlines during the time passed since the ice receded. The steeply standing schists, on the other hand, have not been able to resist the action of exogenous geological forces. Everywhere on the coasts where these rocks appear in profile, small creeks and inlets break the contours of the coast line. Observations on the islands clearly reveal the schists especially on the eastern half of Isuamiut. The very fine-grained weathering products of the ore-carrying schists are of an intense ochre colour which is caused by the oxidization products of the iron. Definitely glaciogenous accumulation products were not found anywhere although such are sure to have passed into the thin alluvial layer which in places covers the rocks. The lower, moist localities have been filled out with bogs and knolls. Small dammed-up ponds at different levels are not infrequent.

Though the islands are situated in a much trafficked part of the west coast of Greenland, they have practically not been investigated and are seldom referred to in literature. They were, however, visited early by older geologists. The first visit so far known was made in 1812 by K. L. Giesecke, the mineralogist, who came to Isuarmiut (now Isuamiut) on May 28th, 1812. In his "Mineralogische Rejsejournal über Grönland" he relates that on the island he found ash-grey and bluish grey schists which in places were very rusty on account of pyrrhotite. He further notes the presence of hornblende, garnet and calcite as well as a cover of peat, two feet thick, here and there, and that the islands had formerly been inhabited. They offered ideal conditions for fishing. As late as in 1948 there were still many ruins of dwellings (loc. 1) and burial places with bones (loc. 2). In his Mineralogia Groenlandica, 1905, O. B. Bøggild says that in 1872 K. J. V. Steenstrup collected garnet on the island of Erkrodit (now Eqûtit). He also refers to Giesecke's visit to Isuamiut in 1812. Since then the islands were not mentioned in geological literature until 1930, when they were included without special comments in "Zur Geologie von Westgrönland, besonders der Umgebung der Diskobucht und Umanak-Fjordes" by H. K. E. Krueger. As already mentioned they reappear, although peripherically, in works from 1948—49 by H. Ramberg.

MAPS AND TECHNIQUE

The topographical foundation of the field-work was a map to the scale of 1:250.000 from the Geodetic Institute of Copenhagen. As the largest island of the area does not exceed the length of 2000 metres, the scale was not suitable. During my work in the field I mapped out the area to an app. scale of 1:25.000 by using the mutual position of the islands. While making my geological observations I plotted the outlines during a circumnavigation of the islands and on cross-country walks. On my return to Copenhagen I revised my material by means of aerial photographs kindly lent me by the Geodetic Institute. The final results deviated to some extent from the maps drawn in the field. In almost all cases, however, it was possible to enter the geological observations on the new map, although I had some difficulty in finding the position of some of the geological boundaries. They are indicated by full lines in places where they could be definitely determined and by dotted lines in areas where they could not be followed with certainty either on account of weathering products or because my material did not enable me to plot them with the accuracy required for a map of the scale used. This means that the position of the borders is not within the accuracy normally afforded by a 1:20.000 scale map, a circumstance easily explained by the unsatisfactory field maps. It will, however, in no way alter the picture of the geological structure.

A Leitz polarization microscope, model KM, was used for the microscopic and optic determinations in the laboratory. Certain feldspar determinations were made by means of a four-axis universal stage Leitz UT4. This was also used to determine the anorthite content and twin laws by measuring coordinates of the three optical symmetry planes and plotting stereograms. For evaluation of the latter the curves plotted by M. Reinhard (1931) were used. Where the state of preservation and the size of the feldspars did not permit the use of this method, extinction angles of typical optic orientations were measured. In some cases the universal stage was also used to determine hornblende and chlorite.

Birefringence was determined with a Berek compensator from E. Leitz in connection with the universal stage. The retardation values were measured on a curve plotted for the compensator in question. Quartz was used as basis for measuring the thickness during the birefringence determinations. The refringence determinations are for yellow light. The spec. gravity was determined in distilled water at 20° C. A pair of scales were used for the rocks, Westphal balance for the minerals.

FOLDING CONDITIONS AND INTRUSION MECHANISM

A rough distinction may be made between two types of rock within the area investigated, viz.:

1. Sedimentogenous rocks of a metamorphic type, crystalline schists, and
2. magmagenous rocks of a metamorphic type, amphibolites (greenstones).

The nature of the two series varies somewhat locally, but it is always possible to distinguish them in the field. The series alternate in such a way that layers of schists of varying thickness always occur delimited by intermediate intrusive layers the thickness of which also varies. The whole area has been subjected to strong tectonical influences as all strata are folded in an upright position. The horizontal map presents a fair illustration of the folding. Besides serving as a geological map it gives a satisfactory profile across the folding axis. This is everywhere exceedingly steep whereby the surface of the islands also becomes a section almost at right angles to the folding axis. The folding has been moderate. The angle between the folded strata, i. e., the angle between syn- and anticlinals is often very obtuse, and an acute angle is only seen once or twice. This only holds good of folds already determined. The hypothetical folds are—as shown by the structural map—of a different degree of folding. Secondary folds occur in the syn- and anticlinals and are particularly handsome in the north-west corner of Isuamiut (loc. 3).

Here a dark rust-coloured schist has been exposed (Fig. 1). The folding axis is almost vertical. In these folds the height of the limbs is only a few metres, and the angle between them ab. 60°. Similar occurrences may be met with elsewhere but on a smaller scale. Fine folding structures also occur at the easternmost point of Isuamiut. The minor folds are often indicated by "garnet strings" on light-coloured weatherring surfaces of garnet-mica schists.

Looking at the map it is tempting to assume that the original magmatic rocks are strata intruded into the sediment series during the

Fig. 1. Steep fold in mica schist. Western Isuamiut. Loc. 3.
(H. Sørensen phot.).

folding process. The theory may be supported by the following points. If the intrusion had been pre-kinematic, magma could not, as here, have been injected into the limbs, anti- and synclinals, and the injections would not have been of a phacolitic type. Both at Anarssuit and Isuamiut material has been pressed into the folds where the strata are bent. The sedimentary layers have been forced aside in such a manner that had they been pre-kinematic, the intrusive bodies would have acquired forms unknown from other regions with the same mechanism. In some cases, however, the intrusive magma has followed the stratification of the sediments, and in such instances the magnitude of the intruding layers remains constant. Examples of this are South and East Isuamiut. On the other hand, this structure might indicate a pre-kinematic intrusion of sills in the sediments of the original geosynclinal flank. But then, as said before, the great concentration of material in the axial planes will be hard to explain. The columns in greenstone offer equally ambiguous evidence. In many places they are beautifully preserved at right angles to the cooling surface (loc. 4, 5, 6), a state of preservation which cannot be associated with pre-kinematic intrusion, as it would have been lost during the folding process. In a few other places there is no conformity between columns and cooling surface. These few instances may easily be explained by later minor disturbances or a contact surface which no longer exists (see also below). The most plausible explanation seems to be a syn- or post-kinematic intrusion. Where the intrusive strata narrow, it may be seen that the schists complete the wedge. Such wedges occur in the southwest part of the largest island of the Anarssuit group and on the southwesternmost island of the Eqûtit group. In the latter place it is only partly wedged.

An occurrence not without interest and closely connected with the intrusion mechanism is to be found on the southwesterly point of Isuamiut (loc. 8). In the schist zone which stretches east–west across the headland are a couple of lentil-shaped "xenoliths" one meter long and consisting of greenstone. The "xenoliths" are very similar to a concretionary occurrence as the surrounding layers of schists have a pronounced bulge. This, however, is not the case. It is the extreme end of a long, tongue-shaped intrusion—a small lateral apophysis from one of the larger intrusive strata close by. Partial movements during the folding process have given the apophysis its rounded, lenticular appearance. Similar phenomena occur at Equtit in connection with the formation of pegmatite which will be mentioned later.

The opposite, viz. sedimentary strata wedged in the magma series, may also be observed in the northeast corner of the large island of the Anarssuit group (loc. 9). Here the sedimentary lentil is ab. 10 metres thick and ab. 150 metres long. Its boundaries are difficult to determine. At the northern end it is clearly wedged in the greenstone, while the southern end is lost in the area, partly hidden by vegetation and partly by loose weathering material. This occurrence may, of course, be accounted for in the same way as the xenolith occurrence mentioned above.

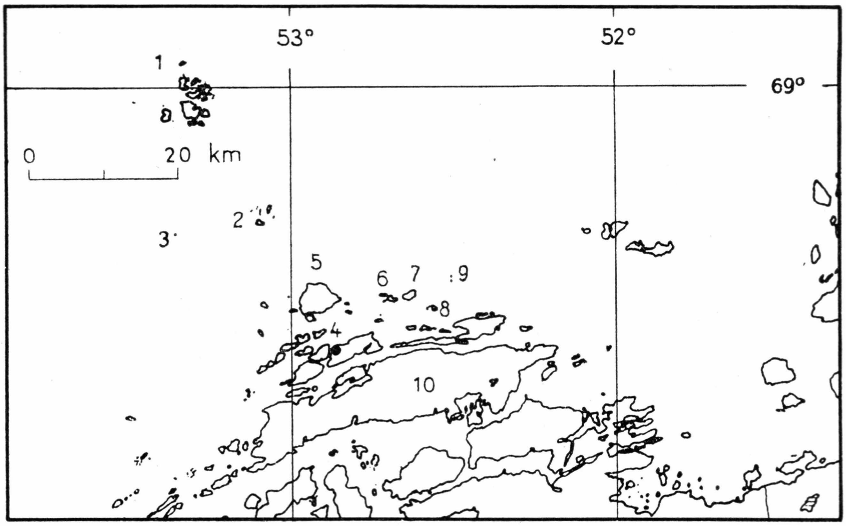
The biggest dimensions in sedimentary series not divided by magma are to be found at Isuamiut, where the series measures ab. 400 metres.

In order to establish the connection between the sedimentary series from the different islands we must first explain the spatial connection between the islands. Three factors must be taken into account:

1. The relation between the folding axes in the different islands,
2. the fracture line systems,
3. the connection between identical layers in the sediments.

The third point cannot be discussed in the present work as conditions have been blurred by the metamorphism, and the extent of the field work did not allow for a connecting up of such possible layers.

As the island groups of Anarssuit and Isuamiut petrographically are very similar, it would be interesting to draw parallels between them. Such a comparison, however, would rest on a very slight foundation. The area is small, the structure local and, as already mentioned, the sedimentogenous layers lack definite horizons. A reconstruction of the mutual connection of the other islands and the relationship of the whole



On the basis of Geodetic Institutes map.

Fig. 2. Index map of the area. 1: Kronprinsens Ejland. 2: Hunde Ejland. 3: Rotten. 4. Egedesminde settlement. 5: Manîtsoq. 6: Anarssuit. 7: Isuamiut. 8: Eqûtit. 9: Sãtuarssuit. 10: Sarqardlît.

area with neighbouring regions would prove even more difficult. At Eqûtit garnet-staurolite schists occur, and gneiss in all the three Sãtuarssuit islands. The latter rock also occurs in all islands south and west of the field in question. An exception to this generalization is the northeast corner of Manîtsoq with rock types reminiscent of those from Anarssuit and Isuamiut (Fig. 2). Here is a border area deserving a detailed treatment in connection with the small islands. Unfortunately, very little time was reserved for field work, six days only, and I do not consider my observations good enough to justify the inclusion of this special area in the investigation. Whether it really is a boundary of the gneiss, will be discussed later.

Hunde Ejland is presumably of the same origin as the islands of the field investigated. The assumption, though, is based on a visit of only a few hours to this group of islands. Gneiss also occurs on Kronprinsens Ejland. Accordingly, the border of the lower metamorphosed rocks may be drawn along a line running across the small, isolated island north of Eqûtit (Sãtuarssuit), east of Eqûtit, south of Anarssuit, touching the northeast corner of Manîtsoq, west of Hunde Ejland (it is not known if Rotten is included), and east of Kronprinsens Ejland (Fig. 2).

By an attempt at reconstructing the original connection between the three island groups and the gneiss area south of them the following axial orientations will have to be taken into account. An average of six axial determinations in the gneiss area gives an axial direction of

Fig. 3. Structural map.

N 63° E, and the axial gradient 11° SW. At Eqûtit the axial orientation is N 57° E, pitching 50°—40° SW, at Isuamiut N 47° E, 60° SW and, finally, at Anarssuit N 19° W, 70° SE. Thus the two island groups of Anarssuit and Isuamiut have almost the same axial gradient of 70° SE and 60° SW respectively. The axial direction, on the other hand, differs by 66°. A plausible explanation of this circumstance may be found if each group represents an original folding system with converging folding axes. With this assumption it is not necessary to rotate the islands in relation to each other in order to obtain axial conformity. Supporting this theory is the fact that the southern part of Isuamiut is built up of steep alternate layers of micaceous schists, and greenstone, an occurrence also observed in the southernmost islands of the Anarssuit group. If those schists and intrusive strata are assumed to correspond, it will be possible to connect the two groups as shown on the structural map (Fig. 3). On account of the great axis disagreement between the island groups the proposed correlation involves a strong torsion of the hypothetical folding limb, which is introduced to connect the groups. This torsion may well have caused the formation of the channel which exists between Anarssuit and Isuamiut. The correlation of the structures of the largest islands of the Anarssuit group is as uncertain as between the groups mentioned above. The folding axes of the two islands have almost the same orientation and the same gradient of the horizontal plane. The only reasonable solution of the problem seems to be the assumption of a shear-thrust plane in the direction NE—SW with a movement as shown on the structural map. The smallest island to the northeast in relation to the largest. Such a mechanism is very probable in the soft clay schists which are the basis of the crystalline schists. It also explains the channel between the two islands. But, as already mentioned, the correlation is extremely hypothetical and has only been suggested as an attempt to correlate the islands.

It is a little more difficult to fit the Eqûtit group into the original sequences of strata. The axial gradient is smaller than in the other groups, and the axial direction also differs from the preceding two groups. If, however, the structural relationship between Anarssuit and Isuamiut is correct, it must be supposed that the islands come from a field in the orogen where axial depressions were frequent. The anomalies in the orientation are then more understandable, but it will hardly be possible to establish a direct connection between all the islands on basis of the material available.

The axial direction of the gneiss district east and northeast of Egedesminde was N 63° E and the gradient 11° SW. These are mean values of slightly different measurings over a fairly large field and, accordingly, figures which closely express the orientation of the regional folding axis. This value plainly disagrees with the axial values of the three island groups. Consequently certain data indicate that the island groups are "loose elements" in the orogen.

In addition to the lack of axial conformity between the islands and the southern complex other structural differences should be noted. A study of the geological map of the gneiss area will soon reveal that in most cases it is hard if not impossible to determine which is synclinal and which anticlinal. This is due to the fact that we are dealing with isoclinal folds, an occurrence which is quite consistent with the rock material, a highly crystallized primary material formed as gray granitic or granodioritic gneisses which structurally are banded and augen gneisses. Thus there can be no doubt that here is a lower level of the Nagssuqtog folding, the part of the mountain chain characterized by floating folds. With this in view it is at once realized that the northern groups are on quite a different storey of the folding chain. The gentle folding here cannot belong to the same deep level as the gneiss. Two points are in favour of this theory:

1. The slight folding,
2. the lower metamorphism of the schists.

Both make it difficult for me to believe in an immediate connection with the gneiss complex. Against it is the fact that a very steep temperature front may account for the difference in the stage of metamorphism of the rock material. These circumstances will be further discussed in connection with the greenstones¹).

It may definitely be maintained that the release of tensions which took place in the crust of the earth were the same in the gneiss field and the archipelago. Very marked cliff lines cut across the islands. The number of such lines is not very large, but the zones are very well defined and beautifully formed. At Anarssuit there is a straight cliff

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¹) Apart from minor alterations the present work was written during the years 1949—50 as a prize-essay for the University of Copenhagen. Since then a publication has been sent out by A. Noe-Nygaard and A. Berthelsen under the title: On the Structure of a High-metamorphic Gneiss Complex in West Greenland, with a General Discussion on Related Problems. Geol. Soc. of Denmark. Vol. 12. Part 2. 1952. pp. 250—265. The authors' observations fully confirm the theories advanced in the present work regarding style of folding and metamorphism. Noe-Nygaard and Berthelsen took their material from a de-granitisized complex in the central part of the Nagssugtoqides where granulite facies and simple folds prevail. Into their "synopsis of our present concept of the genetic relation between the degree of regional metamorphism and the style of deformation" (p. 264) it is possible to fit the Egedesminde archipelago of the present work. The lower facies with intrusions, overfolds and overthrusts is quite evident although thrusting is visible only in the hypothetical connexion folds. Between these extremes is the granitisized area with "fliessfalten" in amphibolite facies (the area south of the islands).

north–south. At Isuamiut there are three in two directions, one N 30° W and the other N 25° E. In the first direction are two parallel cliff zones one of which in parts coincides with the coast line. All the walls are nearly vertical. Between the two parallel west zones at Isuamiut the rock material is missing which has caused the formation of a flat-bottomed valley with vertical sides. Eqûtit likewise presents two parallel cliff lines in the direction N 70° W with a slight southerly dip. As these zones on the whole are parallel with the strike of the rocks, there is reason to believe that this underlines the distinct outline they add to the landscape. A third cliff cuts through the northwesternmost island of the same group. It is difficult to see whether dislocations have taken place along these lines. Investigations in the field revealed no tectonic slickenside surfaces on the cliff walls. Judging from the material available there is good agreement between the cliff zone directions of the gneiss and the zones studied here. The agreement may also be conclusively proved by a comparison between the orientation values of the present work and Krueger's results (Krueger 1930). The cliff lines in the gneiss recorded by Krueger have been supplemented with many new ones which are in complete agreement with the former. Here and there in the cliff zones tectonic slickenside surfaces with epidote covering have been found. In the localities in question—the south side of the Sarqardlît island and the northern point of Umîvik—it was possible to determine the direction of the movement of the individual blocks. A preliminary study of these vertical sliding planes shows that the movement was horizontal so that an eastern element moved northwards in relation to a west block. It may not be possible to apply these observations directly to the archipelago. As, however, the cliff lines in the two areas are in close conformity and as in both localities the lines intersect the folds, the cliff zones may with certainty be referred to the same release of tension. This means that if shifting has taken place in the archipelago, the movement here must have been of the same type as that of the gneiss complex. It may further be concluded that the weak zones must be post-orogenic.

SEDIMENTOGENOUS CRYSTALLINE SCHISTS

The Garnet-Staurolite Schists at Eqûtit.

The sediments cannot be treated as a whole as they vary much from place to place and from stratum to stratum. It is possible to distinguish between two principal types of crystalline schists, viz. the schists at Eqûtit which are staurolite and garnet-staurolite schists, and those from the other two island groups, Anarssuit and Isuamiut, which chiefly are mica schists of varied composition and structure. Within their small field the garnet-staurolite schists vary somewhat in habitus from one locality to the other. In the central zones and in the northern part of the main island regularly developed schists occur. They are schistose though with no definite schist cleavage. With regard to size there is good agreement between the individual grains. Porphyroblasts and very fine-grained varieties were not observed. Staurolite is the largest-sized mineral though only a few millimetres long. The colour of the rock is greyish-brown. In the southern and south-eastern part of the island schists of quite a different appearance occur. Large porphyroblasts of staurolite embedded in a very fine-grained mass of muscovite and quartz are a common occurrence here. On weathered surfaces the rock is of a light bronze colour. Very fine-grained varieties of the same colour but without large porphyroblasts are to be found on one of the small northwesterly islands (loc. 13). The mineral assemblage is composed of plagioclase, staurolite, garnet, biotite, quartz, scapolite, chlorite, muscovite, hornblende, apatite, zircon and ore minerals. The first four predominate both as to number and size. The garnets are not evenly distributed over the whole area. They seem to be most frequent in the northern half of the island where on weathering surfaces they may appear in large quantities and attain the size of some 5 millimetres. It is a violet-pink, non-transparent almandine-pyrope which crystallizes into rhombic dodecahedron and icositetrahedron. The specific gravity is 4.065 and the index of refraction 1.975 ± 0.005. According to WINCHELL this corresponds to a composition as Mg : Fe = 30 : 70. The predominant mineral is staurolite. As said before the habit of the staurolite varies in the different localities. The large porphyroblasts reach a size of 5—6 centimetres along the longitudinal axis. Prismatic crystals without twinning occur as well as crystal twins grown together in a rectangular or oblique cross. The colour is brown and the crystals dull and lustreless. Under the microscope the staurolite is faintly pleochroitic with α and β grey, γ yellow, $+2V = 89^\circ \pm {}^1/_2{}^\circ$. The staurolite is filled

Fig. 4. Staurolite schist of gneissose structure. The large staurolite individuals (dotted signature) which all have inclusions of quarts drops dominating the picture, are either an- or euhedral. One zirkon crystal with a pronounced halo may be seen in the largest staurolite individual. The same crystal shows the mechanism of the absorption of the quartz inclusions. The large biotite flake to the right has numerous highly pleochroitic spots. The feldspar is seritized. The dotted line in the staurolite marks a boundary between twin individuals. (G. G. U. 36052. Ab 33 × magn. lin.).

with numerous inclusions of quartz, scapolite and grains of ore. Quartz and scapolite are the most interesting in the present connection. In a number of crystals the two minerals occur as quite small, drop-like inclusions arranged as rows of beads parallel with the cleavage plane of the schist. From this stage to the stage where the staurolite crystal elements only can be in conformity by simultaneous extinction under crossed Nicols all transitory forms occur. These staurolite crystals thus contain so many quartz (and scapolite) inclusions that they appear sponge-like. As already mentioned the position of the quartz drops is in close harmony with the schistosity plane of the schist. The growth of the staurolite crystals may be seen particularly clearly in Fig. 4 where a series of quartz grains about to be embedded are seen along the edge of the staurolite crystal. In cleavage planes a dipyre-scapolite with corroded outlines occur. Along the borders between the two minerals it may be seen how parts of scapolite have been cut off from growing staurolite whereby scapolite occurs as an inclusion in the staurolite. The scapolite has $N_0 - N_e = 0.000(8)$ which corresponds to $Ma_{75}Me_{25}$. After traces of a shear movement we find an occurrence of chlorite in which this mineral presents a beautiful ultra-blue interference colour. The formation of this penninite seems to have been completed before the shearing movement ceased as there are traces of a mechanical action in the mineral. The undulating extinction displayed by some of the scapolites may be ascribed to this late movement. In the immediately surroundings of chlorites staurolite shows a mechanical formation of breccia. The large individuals of biotite have also suffered greatly, but on account of the resilience of cleavage laminae this mineral has not been broken like the fragile staurolite. In most cases the movement has only caused a bending which may be observed either directly from the course of the cleavages or from a very undulating extinction. The biotite is highly pleochroitic with

α light yellow-brown, colourless
β dark brown
γ dark brown, non-transparent in the thick layers,

the optic character is negative with a axial angle approaching zero. Refringence is $N_m = 1.642 \pm 0.003$. In section by β and γ a very large number of pleochroitic enclosures may be seen surrounding small zircon crystals of 0.01—0.02 millimetres or less. The pleochroitic haloes attain a diameter of 0.1 millimeter and their absorption is the highest along the strongest absorption directions of the biotite. In the α direction of the biotite with minimum absorption the phenomenon may be difficult to see. In addition to zircon, some quartz, muscovite and staurolite are also enclosed in the biotite.

The plagioclase is an oligoclase with 18—20 $^0/_0$ An. On the universal stage by reflected light a few individuals show a handsome labradorization. All the plagioclases are very impure on account of advanced seritization most highly developed in the central zones of the plagioclases. There is a faint indication of twins, but it is impossible to establish reliable twin laws as no sufficiently pure crystals were found. It is curious that in some of the plagioclases the enclosed scales of muscovite show folding with "microchevron" folds. It is tempting to assume that such folds have been formed after the growth of the muscovite and later cemented into the plagioclase. If so, there is here another evidence of folding movements after the recrystallization had set in. In this connection it should be noted that the plagioclase shows no sign of mechanical action which it would have done if the structure had taken form after the formation of the mineral. The plagioclase contains a very small quantity of zircon. Apatite is present as small nematoblasts scattered in the rock. Small crystals of hornblende have the same mode of occurrence. Of accessory opaque minerals both magnetic pyrites and magnetite are present.

As mentioned in the chapter on greenstones these have not run the same course of metamorphism oscillation at both ends of the complex. A late phase in their development shows a rise in temperature which has not been the same everywhere in the complex but most pronounced in the eastern part of the archipelago. Here a thermal front has had an upward bulge. This explains why the schists at Eqûtit are at a higher stage of metamorphism than those on the other islands. As the movements of temperature can only be registered after the intrusion, it is impossible to say whether the bulge existed before. There are, however, certain indications that the staurolite schists have reached their higher stage of metamorphism after the intrusion. The particular mineral assemblage is not due to PT-conditions alone but also determined by chemical conditions. The analysis shows a chemical composition considerably different from that of Anarssuit and Isuamiut. There is ab. 10 per cent less SiO_2 and ab. 8 per cent more Al_2O_3 and a little more FeO and Fe_2O_3. As the chemical conditions are rather special, the difference in facies between the areas may be less than first expected. Garnet is of the same composition in both places.

An interesting point is the time of the growth of the staurolite. The microscope revealed signs of a late growth. Numerous quartz grains enclosed as rows of beads along the cleavage plane and inclusions along the borders of the staurolite grains point this way as do the good state of preservation and the absence of crushing. Staurolite is not a high-temperature mineral, and it is very doubtful whether it can be formed at temperatures which produce plagioclase with 55 $^0/_0$ An. Moreover, the axial angle is wide which corresponds to a low temperature.

In the chapter on greenstones these are referred to the amphibolite facies belonging to the final stage of the pre-Cambrian re-crystallization. In 1927 Th. Vogt described staurolite schists from Sulitelma and associated them with amphibolite facies. The mineral paragenesis of Eqûtit is identical with that of Sulitelma except for the absence of kyanite (and andalusite). In his schists Vogt found an oligoclase with a composition of 28 $^0/_0$ An. Against those schists Vogt found a plagioclase with ab. 55 $^0/_0$ An in the magmagenous rocks which he associated with amphibolite facies. Vogt was fortunate in being able to observe series of rock development, both progressive and regressive, which made his

Chemical Composition of Staurolite Schist G.G.U. 36052/48.
(A.H.N. anal.).

SiO_2	51.98	850
TiO_2	1.12	14
Al_2O_3	25.73	252
FeO	10.62[1]	147
MnO	0.10	1
MgO	2.69	67
CaO	1.17	21
Na_2O	2.60	42
K_2O	1.83	19
P_2O_5	nil	..
$H_2O\pm$	2.43	135
ZrO_2	nil	..
Cr_2O_3	nil	..
Cl	tr.	..
S	0.32	..
	100.59	
—O	0.16	
	100.43	

FM = 215 = 38.5
A = 189 = 33.9
K = 19 = 3.4
H = 135 = 24.2
100.0

grouping more certain. It means briefly that the two series of rock types represented at Eqûtit show the effect of the same PT-conditions but a widely different mineral assemblage determined by different chemical conditions. It has thus become highly probable that staurolite and plagioclase correspond in temperature. However, on account of the abovementioned relation of the garnet-mica schists and the optical data of the staurolite, the staurolite schists must belong to a lower facies than the greenstones.

In his work on the genesis of the West Greenland gneiss complex Ramberg (1948) states that andalusite occurs at Eqûtit. The present writer is unable to deny this but can only state that he has searched

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[1] Determination of total content of iron. The Doelter-Pratt method for the determination of Fe^{2+} in silicates is not applicable to staurolite and certain other ferro-magnesian minerals. Modifications suggested by various writers cannot guarantee accurate results. *Vide* e. g. Penfield & Pratt, Am. Journ. Sc. 47 (1894) p. 84—85, and J. Jakob, Schweiz. mineral. petrogr. Mitteil. XXI (1941) p. 124 etc. I have not had the opportunity of trying the new methods with sodium metafluoborate as a flux (H. P. Rowledge; M. H. Hey). (A. H. N.)

in vain for the mineral in the samples collected. For this reason it has not been included in the present work. With its high Al-content andalusite would have been a natural part of the mineral assemblage. In that case there would have been no equilibrium as an assemblage consisting of andalusite and staurolite is unstable. Staurolite is distinctly a stress mineral, a fact already demonstrated in 1918 by H. Backlund in his work on the Taimyr rocks. Staurolite is thus in complete agreement with the stress structures at Eqûtit. Andalusite, on the other hand, is not a typical stress mineral like staurolite. P. Eskola (1939) gives the following reaction between the two minerals: 5 andalusite + almandine + 3 *aq.* = 3 staurolite + 2 quartz.

The consequence is that andalusite and staurolite are not an equilibrium system. When both minerals occur together, it is due to "unfavourable experimental conditions". The question remains whether it is possible from the total chemical composition to determine if it is staurolite or Al_2SiO_5 which is in equilibrium at Eqûtit. The analysis shows a large amount of Fe. Accordingly, the possibility should exist that muscovite could absorb Fe and form biotite, or the garnet absorb more Fe. In this way more Al would be liberated for the formation of Al_2SiO_5. J. Suzuki (1930) investigated the chemical conditions of the formation of staurolite-carrying rocks. He found that the occurrence of staurolite was conditioned by limited chemical conditions. He demonstrated that a high Fe-content in relation to potassium is necessary and that the occurrence belongs to strata deficient in Ca. This view is confirmed in the present work where a further condition is added.

F. J. Turner (1935) and T. Barth (1936) assume that the molecular water occurs on an equal footing with the metal oxygens. Molecular water should thus determine when an Al_2SiO_5-mineral or staurolite is obtained, as indicated by Eskola's equation quoted above. The matter can be explained by a diagram. A triangle diagram cannot be applied whereas a tetrahedral diagram after Philipsborn (1928) will be serviceable (*vide* Barth, 1936).

In Fig. 5 the corner H represents hydrogen in the molecular water. K corresponds to potassium, A to aluminium and FM to iron, magnesium and manganese. As the four minerals in question nearly always occur together with garnet, biotite and muscovite, they have been entered in the diagram as fixed minerals. Staurolite and Al_2SiO_5 (andalusite, kyanite and sillimanite) have also been entered. It is then desirable to have the following components represented: K_2O, Al_2O_3, MgO, MnO, FeO, and H_2O^+. TiO_2 has been left out, it is a secondary component and too little is known of the amount of it which occurs in the minerals in question. Nor has SiO_2 been included as it is of no importance to the formation of the minerals mentioned (Suzuki 1930). H_2O^- is obviously of no interest. CaO and Na_2O have been deducted from Al_2O_3. MgO has been added to MnO and FeO. Strictly speaking, this is not quite correct on account of biotite and garnet in which minerals an exchange of Mg and Fe takes place. Accordingly, these two components should be placed

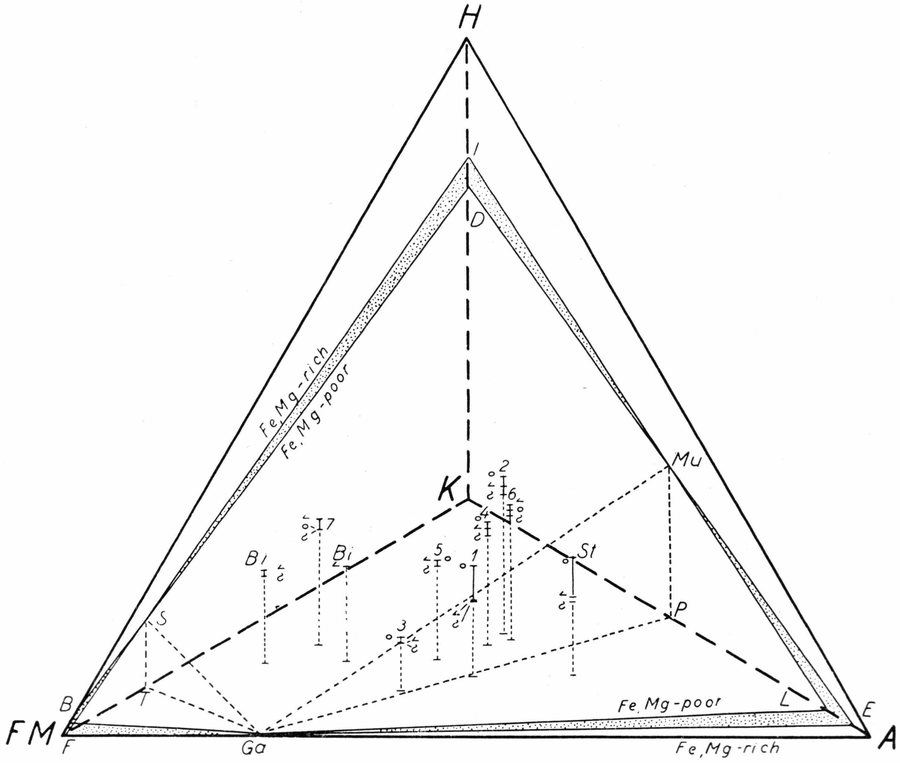

Fig. 5. Diagram to illustrate the chemical equilibrium conditions in crystalline schists with staurolite and/or Al_2SiO_5-minerals. *St* = staurolite, *Bi* = biotite, o = point of projection corresponding to the recalculated rock analysis, ∠ = intersection point for the Fe, Mg-rich biotite plane with the vertical axis through the "point of analysis", and ∂ = the corresponding intersection point for the Fe, Mg-poor biotite plane.

in different corners but, four corners being maximum, they must be placed together. This favours the staurolite which has no exchange of Mg and Fe. Certain unknown factors are eliminated by the definite placing of biotite and garnet. As it is not possible to make accurate determinations of Fe^{3+} and Fe^{2+}, in silicates containing Mn (staurolite), it has been preferred to group Fe_2O_3 and FeO under a common FeO, cf. footnote to Analysis 36052, p. 23. This has been done in an analysis of a staurolite schist in which Fe^{3+} and Fe^{2+} have not been separately determined. In analyses of Fe^{3+} and Fe^{2+} available in literature they have for the sake of comparison been converted into FeO. Where literature gives quantitative accessory determinations of ore and apatite corrections have been made accordingly.

The tetrahedron is divided into three parts by means of two planes, one, GaFIL, through Fe, Mg-rich biotite, muscovite and garnet, and another, GaBDE, through Fe, Mg-deficient biotite, muscovite and garnet. Both planes are extreme positions and in each case are merged into one, corresponding to a certain composition of biotite. If a point of analysis made on the total chemical composition is on the H-side of such a plane, there is a possibility of development of staurolite but not of Al_2SiO_5. If the point of analysis falls somewhere between the two extreme positions, both staurolite and Al_2SiO_5 will be developed.

The discussion of the biotite composition reveals certain curious features. In this discussion the K-side of the tetrahedron must be divided into two along the plane GaMuP. On the A-side of this plane conditions are as follows: If a point of analysis in the tetrahedron moves by an increasing content of water, the possibility of a formation of staurolite is greater, and the Fe, Mg-content of the accompanying biotite is correspondingly reduced. If the point moves in the opposite direction, Al_2SiO_5 is stabilized, staurolite disappears and biotite becomes richer in Fe, Mg. Further, a definite quantitative relation must exist between biotite and staurolite-Al_2SiO_5. On the K-side of the GaMuP-plane a Fe, Mg-rich biotite corresponds to an occurrence of staurolite, while a biotite deficient in Fe, Mg corresponds to an Al_2SiO_5 paragenesis. Here the biotite has the opposite effect. Since the planes are determined by the composition of the biotite, they are fixed on the KH-side of the tetrahedron. On its A-side they must have the opposite values if the construction is to serve its purpose. Similar conditions exist on the FM-side of the plane GaTS. The present considerations are based on the assumption that the Al-content of the rock is large enough to allow for the presence of either Al_2SiO_5 or staurolite conditions. Since biotite is much more common than staurolite in the rocks, this mineral must have quite limited possibilities of formation. The biotite is first built up in a rock with a composition determined by certain PT-conditions. If the biotite has thus adapted itself with an equilibrium at certain PT-conditions, a formation of staurolite is possible if there is a surplus of Fe, Mg and sufficient water. If these components are missing, Al_2SiO_5 and not staurolite is developed. Should there be a surplus of Fe, Mg from the formation of biotite, another way out (e. g. an oxidised form) must be found for it if there is no water. If it is supposed that water is plentiful but Fe, Mg only suffices for the biotite, there is still no possibility of the formation of staurolite. Accordingly, in addition to an ample supply of Al two other conditions must be fulfilled, definite proportions of (Fe, Mg)O and water. Biotite is the first mineral to adapt itself to a composition relative to the PT-conditions. Such a composition is obviously not always that richest in Fe, Mg. It may adapt itself to any composition in each case determined by PT. This means that the composition of biotite might serve as indicator of conditions prevalent when development of staurolite became possible. The diagram above explains why staurolite is a much rarer occurrence than biotite. There must be a remainder of both water and Fe, Mg in suitable quantities after the requirements of the biotite have been satisfied. A slight variance in the potassium content of the rock does not, on the other hand, seem to be of decisive importance to the end product. If, as frequently and naturally happens, the Fe, Mg-*aq* relation is not suitable, Al_2SiO_5 will be developed. If the quantity of water is insufficient, Al_2SiO_5 will be developed and a surplus of Fe, Mg remain. A shortage of Fe, Mg prevents the formation of staurolite. It will thus be seen that the total content of water in the rock plays a decisive part in determining which minerals will be formed in each case. A check on the conditions by means of analyses available from literature has been made in the tetrahedron diagram Fig. 5. Only analyses of rocks have been included which in modal mineral assemblage carry garnet, biotite and muscovite besides staurolite and Al_2SiO_5 or staurolite only. Further, only such analyses have been used where the determinations of water have referred wholly or partly to molecular water, which in the latter case unfortunately involves a slight error.

Analysis No. 1. G.G.U. 36052. Staurolite schist.

Anal. A. H. NIELSEN.

The rock only carries staurolite of which there is a large amount. The projection point is far above both biotite planes but near their intersection line. Here is an error as the determination of the water content makes no distinction between H_2O^+ and H_2O^-. However, the error is very slight as, in this case, *aq*⁻ is only a few hundreths per cent. Concerning A, FM, K and H see analysis.

Analysis No. 2. T. BARTH 1936. Chloritoid schist No. 19.

The rock carries 1 $^0/_0$ staurolite and the projection point is on the "water side" of the biotite planes.

A	34.0
FM	24.8
K	6.1
H	35.1
	100.0

Analysis No. 3. T. Barth 1936. Garnet schist No. 11.

The rock carries 5.3 $^0/_0$ staurolite and 5.5 $^0/_0$ kyanite. The point of analysis is very near the intersection line between the biotite planes with a slight tendency towards the "H-side".

A	32.0
FM	49.7
H	11.1
K	7.2
	100.0

Analysis No. 4. T. Barth 1936. Garnet schist No. 7.

The rock contains 2.9 $^0/_0$ staurolite, and the point of analysis is well above both planes.

A	33.7
FM	29.6
H	27.4
K	9.3
	100.0

Analysis No. 5. J. Suzuki 1930. Staurolite-andalusite-biotite gneiss.

Point of analysis exactly on the Fe, Mg-rich plane.

A	31.2
FM	38.5
H	20.9
K	9.4
	100.0

Analysis No. 6. A. Strecheisen 1928. Staurolite schist gneiss.

The rock carries andalusite, sillimanite, kyanite and staurolite. Point of analysis exactly between the two biotite planes.

A	36.7
FM	25.3
H	28.9
K	9.1
	100.0

Analysis No. 7. J. Königsberger 1913. Staurolite-biotite schist.

Point of analysis very near Fe, Mg-poor plane but still between the planes. No separate H_2O determination.

A	12.9
FM	49.8
H	26.2
K	11.1
	100.0

The brief survey shows that out of seven analyses the projection point in six cases falls where it might be expected. One only, No. 3, is not quite consistent, but the deviation is small. With the point of analysis near the intersection line of the planes it will always be more difficult to illustrate conditions than with a projection point anywhere else in the diagram. It was not possible to check the composition of the biotite as the determinations of this mineral usually are incomplete with regard to Fe, Mg:Al-conditions which are of particular interest in the present connection.

The Mica Schists at Anarssuit and Isuamiut.

As already mentioned there is a pronounced difference between the mineral compositions of the schists in the various islands. Eqûtit stands alone with its garnet and garnet-staurolite schists. Staurolite, among others, determines the border between the sedimentary rocks at Eqûtit and the other two island groups. This part of the rocks in the area chiefly consists of garnet-carrying mica schists of varied appearance. They are mostly very dark, fine-grained rocks often with a large content of ore minerals. On weathered surfaces the latter often give the rock colours varying from pure ochre to rust as has been mentioned before. Ash-grey schists which on weathered surfaces are light grey are also very common. Examples of this type of rock may be observed at the south-eastern corner of Isuamiut (loc. 14) and in one or two small series at Anarssuit. The dark rust-coloured schists occur particularly in the eastern and northern part of Isuamiut. Almost all schists contain a large or small quantity of porphyroblasts formed at different points of the mineralogical and structural development of the schists. If we disregard these phenomena and only consider the ground substance, it is perceptible that there is a definite relation between the size of the grains and the colour. The darker the rock, the more fine-grained it is. Indeed, the darkest varieties are so fine-grained that the individual mineral components can only be distinguished when magnified 500 times. Their small size thus makes an accurate microscopical determination impossible. In samples one is more inclined to call them slates than schists. This interdependence of colour and size of grains is no doubt due to the content of carbon which is present in minute particles. The state of the carbon cannot be determined under the microscope. The fine particles plainly reveal the stratification of the primary sediments and have proved valuable for the study of the structural formation of the rocks. The occurrence has its natural explanation in the fact that the transportation of materials and the building up of the minerals in connection herewith must have been slower during recrystallization in the carbon-rich sediments than in those containing less carbon, the carbon particles having retarded the deposition of material near the surfaces of the crystals. If, on the other hand, the crystals possess a crystallization energy sufficient for overcoming this obstacle, the small carbon particles will be cemented into the crystal as may be seen from the porphyroblasts frequently occurring in the schists. A confirmation of the interdependence just mentioned is to be found in the more coarsely crystallized schists at Eqûtit. At this place the microscope revealed no trace of carbon particles. Alternating stratification is very pronounced. The schists vary much from one stratum to the other. There are series varying between several rock types within a thickness of a few metres. It is obvious that the original stratification with its different sediments of varying composition was not always lost during the metamorphism of the rocks. The specific gravity of some of the schists is very high. It varies from the ordinary specific gravity of stone, ab. 2.70, to a maximum of 3.19. Quartzite occurs as a special part of the sediment series. Both veins and lentils conformally with the schistosity are very frequent. The veins are light bluish-grey and appear as broad, solid ridges. The occurrence may be most favourably investigated on the northwest peninsula of Isuamiut. At Anarssuit it may be observed stretching from east to west in the series away from the central part of the south side of the second largest island, at the place where the folding axis has been obliterated by erosion. A large number of small quartzite lentils the size of a clenched fist occur at the eastern end of Isuamiut. The small lumps may "grow" together to form a longer band like a string of beads. If observations from a single profile are supplemented with rocks of different habits or special structural features as well as with the abovementioned quartzite, an adequate impression of the petrographical peculiarities of the sediment series will be obtained.

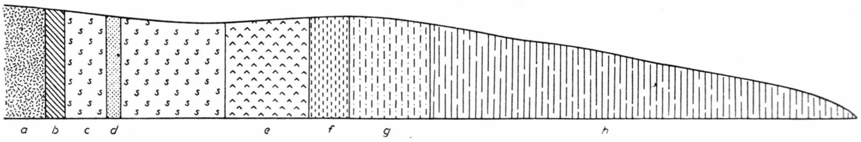

Fig. 6. Profile through a sequence of crystalline schists near loc. 15.

a. Greenstone, green amphibolite.
b. Brownish contact metamorphosed transition.
c. Light gray mica schist.
d. Bluish quartzite.
e. Dark rust-coloured mica schist.
f. Light rust-coloured mica schist.
g. Dark mica schist with many garnets.
h. Black, rusty, fine-grained and ore-carrying mica schist.

The easternmost headland of the second largest Anarssuit island affords good opportunity for a closer study of a whole profile (loc. 15, Fig. 6). This is incomplete at one side. From the data available it cannot be determined whether it is the upper or lower part of the series, nor is it of importance in the present connection. The headland has a sequence of ab. 100 metres. The position of the strata is almost vertical and, as always, the outline against the medium-grained greenstone is sharp. The nearest two metres display a contact metamorphism which suddenly disappears. The next twenty metres consist of light grey, fine-grained mica schists with a quartzite band two metres thick. The next ten metres are dark, rust-coloured schists. They are succeeded by a smaller one of ab. four metres of light, rust-coloured mica schists. From here the schists grow darker and more fine-grained until they end at the easternmost point in a black schists very rich in pyrite.

A clear contact metamorphism may be observed between the greenstone and the schist. The contact may be traced about two metres into the profile. An occurrence of amphibole may be determined from a sample. The minerals are the same as in the other schists with an addition of two new ones: ferrotremolite and cummingtonite. Both amphiboles are prismatic, the cummingtonite crystals being longer and with a more prismatic cleavage. The ferrotremolite has:

α pale yellow
β yellow-green
γ bluish-green

$\gamma \wedge c = 10°$ and $N_{\mathrm{p}} = 1.668 \pm 0.003$. The relation between Fe and Mg thus becomes app. 9:1. The cummingtonite is almost transparent and colourless. The pleochroism is so faint that it is almost impossible to determine the shades, if any. $N_{\mathrm{m}} = 1.672 \pm 0.003$ and $\gamma \wedge c = 17°$ which corresponds to Fe:Mg = 65:35. Characteristic of the contact is, firstly, a supply of iron from the greenstone causing the formation of two iron-rich amphiboles at a higher temperature than generally prevalent in the central part of the schist profile. Or, secondly, the amount of biotite being reduced that no iron has been added from the greenstone and the alteration has been caused by the high temperature solely at the expense of iron from the schist itself. The light grey schist which follows the contact is characterized by its lack of minerals. The samples contain, as already mentioned, a schistose, fine-grained rock but the schistosity is not very pronounced. It varies from light grey to darker layers of ab. 5 millimetres. These equidistant layers are placed at an angle of ab. 35° with the plane of schistosity. The microscope reveals that the bands coincide with large or small quantities of biotite in the rock, i. e., the light bands contain less biotite while the flakes of this mineral are small being not more than 0.15 mm. The dark bands are the richest in biotite with larger flakes —0.20 mm. There is thus every reason to assume that the bands represent an original stratification in the rock. They are an expression of regularly varying sedimentation conditions. In addition to mica a pale pink garnet occurs in idioblasts of 0.8 mm across scattered over the whole rock. The groundmass is a fine-grained granular mass of quartz grains of 0.05 mm. Some large grains of scapolite have the same habit as the quartz and may often be observed in orderly rows, presumably former cracks. Traces of the minerals of the contact metamorphism do not exist any more.

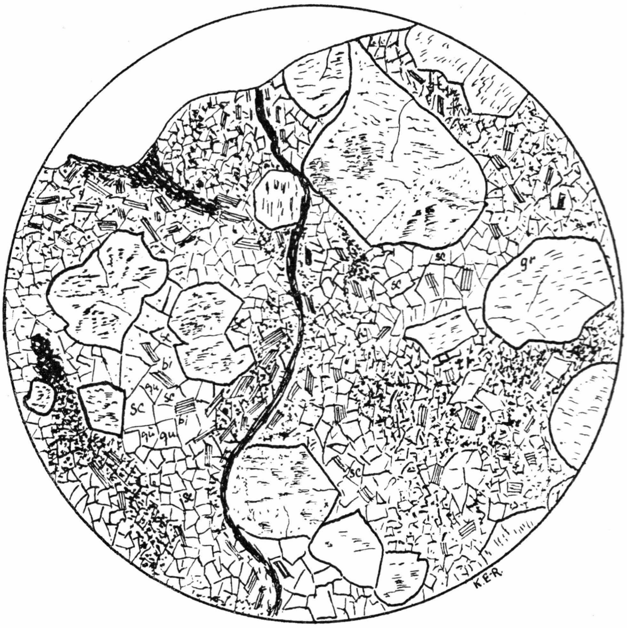

Fig. 7. Garnet-mica schist. Garnet porphyroblasts, small, in heterogranular groundmass of schistose structure. A small fracture zone across the schistosity. Several biotite flakes have the same directional orientation. A single garnet has rotated so that the helicitic structure does not agree with that of the other garnets. (G. G. U. 36084/5. Ab. 5 × mag. lin.)

Under the microscope the next zone of 10 metres of dark, rust-coloured schists proved to consist of a fine-grained granular mass of a sometimes undulating quartz. Of the same magnitude as the quartz is a brown, pleochroitic biotite. The predominant mineral is doubtless garnet which abounds as large idioblasts. Both groundmass and porphyroblasts are cloudy on account of a considerable content of carbon (Fig. 7). By joining the helicitic structure of the garnets produced by the carbon particles to the structural remains found in the groundmass it is possible

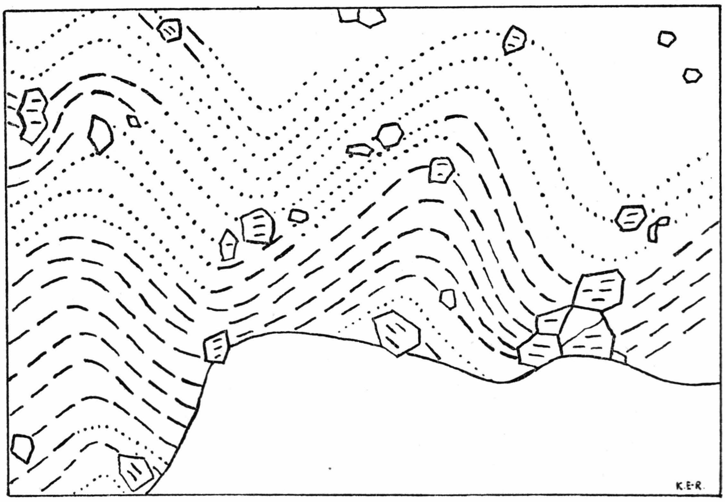

Fig. 8. Skeleton drawing of the structure in garnet-mica schists. It will be seen that the garnet idioblasts chiefly crystallize in the axial planes and avoid the folding flanks. The structure is characterized by small, early crystallized scales of biotite. The dotted signature indicates hypothetical folds. (Ab. 5 × magn. lin.).

to make a closer study of the microstructure. This reveals a clear, folding structure as shown in Fig. 8. As far as can be seen from the maximum enlargement the very small flakes of biotite associated with this structure are rarely mechanically deformed. In one or two places they have been torn to pieces. Garnets occur at some of the controllable points in the axial plane. From this may be concluded that the folding movement gave the schist its structure prior to the formation of garnet. The crystallization of the very small flakes of mica may well have started before the folding. As already mentioned only some of them were deformed, but as we are dealing with very small, flexible minerals, this does not exclude the abovementioned possibility. The garnets preferably occurred in zones where a minimum pressure prevailed. The helicitic structure which never shows a rotation of the garnets proves that the garnet grains were not pushed into the axial planes during a folding movement. Traces of later micro-fractures may be observed across the main structural direction. Scapolite occurs here as in the preceding rock and also a small number of ore grains which no doubt are pyrrhotites.

The next four metres of light, rust-coloured schists soon pass into a somewhat darker zone of a thickness of ab. 10 metres. On fresh cleavage surfaces it appears as a dark grey, fine-grained schist with many larger grains of garnet. As usual the groundmass is of a schistose structure with the difference that the schistosity is not caused by mica but by chlorite. The quartz is very undulating in extinction with prismatic inclusions showing parallel extinction with anomalous interference colours and a refraction index far above that of the quartz. To judge from the interference colour it may be penninite or an epidote mineral. Two minerals, chlorite and garnet, are very conspicuous. The chlorite, which spreads across the whole rock, has a certain directive arrangement of its flakes but not more pronounced that flakes at right angles to the schistosity may be observed. The chlorite is an optically negative penninite with strong blue anomalous interference colours. It is pleochroitic according to

α light green
β greyish green
γ greyish green.

Repeated twinning is clearly seen and in some cases determinable. In eight certain instances twinning according to the mica law, — plane (001) was found. The penninite occurs very frequently in close connection with the garnet. Fig. 9 shows that at a slightly rolling movement of the garnet the penninite was heavily bent by its contact with the harder and to mechanical actions more resistant garnet. This and other examples of a slight "post-garnet" movement need not affect the development just mentioned of a formation of garnet after that of the microfolds. In many places there are traces of late post-crystalline movements, and the slight deformations mentioned may well belong to such movements. The garnet—pale pink under the microscope—is the only mineral in this rock which reveals helicitic structure of carbon particles. They are all arranged according to a clearly parallel orientation but with a different degree of concentration so that the highest concentration is to be found at the boundaries between the different rhombododecahedral parts of which the garnet is built up. In this way we get a clear division of the garnet into six sections. Scapolite occurs in addition to accessory grains of ore. Having the same birefringence as the scapolite mentioned in connection with another schist the present mineral is presumably a dipyre. It occurs as small, equigranular grains in transverse bands as the boundary mineral of quartz and penninite. A few grains attain a size of 0.5 mm.

From the rock discussed above there is a continous transition to darker schists which occupy the last 50 metres of the profile. The appearance of the rocks only varies slightly throughout the zone. First comes a dark grey, almost black, fine-grained, pyrite-carrying, plane-schistose rock with a specific gravity of 2.68. Then a black, fine-grained, compact rock. A slight stratification is caused by graduation of the colours. Schistosity and cleavage are only slightly developed. Rust-coloured weathering mantle. Specific gravity 3.19. Nearest the water the properties of the rocks do not vary much from the type just mentioned though the content of the evenly distributed ore minerals may vary slightly. No doubt this influences the specific gravity which for the two samples is 2.91 and 2.78 respectively. The ore minerals are pyrrhotite and chalcopyrite.

On basis of the profile studied the following development should be evident. Already before the folding movement the clayey shale had started a recrystallization process with the formation of chlorite and biotite. At the closing stage a few garnets were formed after which the folding set in. During the movement some of the garnets were rolled which caused a compression of the chlorite flakes. The microfolding structure in the groundmass of the schists was formed. On top hereof the later development of garnets took place during which the garnets apparently in some cases showed a preference for the axial planes. Accordingly, the folding should be dated to the time when the garnets were at their height. If the occurrence of garnets is not a purely local incident, it means that garnet is not such a typical stress mineral as often supposed. When it has been possible to crystallize in small cavities which leaves

Fig. 9. Faintly rotated garnet porphyroblast in schistose garnet-chlorite schist. The laminae of chlorite have been bent towards the garnet on both sides. Between the deformed laminae of chlorite are small irregular cavities with highly granulated, fine-grained material. Along the rim of the garnet are corrosion hollows with formations of chlorite and grains of ore. (G. G. U. 36084/8. Ab. 38 × magn. lin.).

more room for expansion, the garnets have done so. This circumstance should of course be more closely investigated.

In order to make the picture of the schists more complete rocks from various localities in the islands should be mentioned in connection with the profile. At the south-easternmost point of Anarssuit (loc. 16) a fold lies in the water. One feature of this fold is the profile discussed. A sample from the other flank reveals a schist quite identical with those of the profile. There are, however, a few unusual features of the structure which should be noted. In one schist (Fig. 10) porphyroblasts occur consisting of garnet, biotite and a light green chlorite, $+2V =$ ab. 70°, faint pleochroism where α' has greater absorption then γ', clinochlore. In the twin lamellae a helicitic structure is very prevalent. It forms an angle with the present plane of crystallization which varies from one porphyroblast to the next. Corresponding conditions exist for the biotite grains. Besides these facts which indicate a rotation of the chlorite and the biotite, an extension of the said minerals into schlieren at the ends and quartz-scapolite fillings in odd "triangles" at this place also point

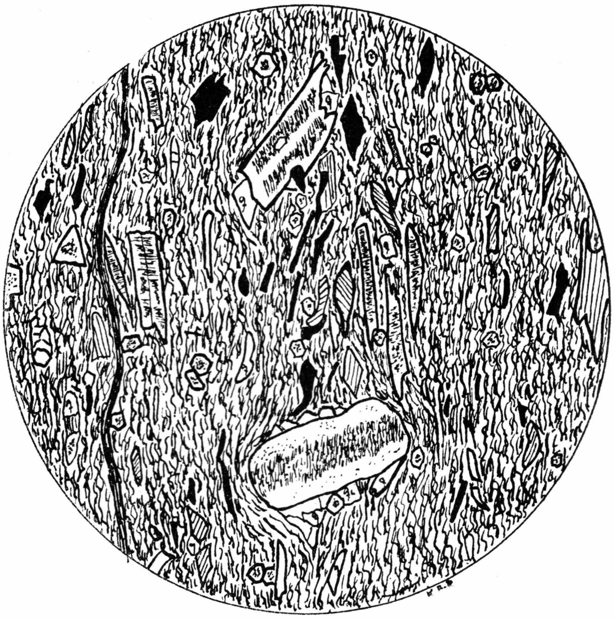

Fig. 10. Dark mica schist. In the schistose, fine-grained groundmass is a number of chlorite? (chloritoid?) and biotite porphyroblasts and grains of ore. The large chlorite individuals present a clearly helicitic structure of carbon particles. Similar structures may be seen in some biotite flakes, which does not appear from the drawing. Both chlorite? (chloritoid?) and biotite show signs of rotation, in some cases without having been crushed. In the sheltered zones the cavities have later been filled with quartz and scapolite. (G. G. U. 37896. Ab. 35 × magn. lin.).

in the same direction. Conditions here support the theory of a folding movement after recrystallization had begun. A study of the development is made more difficult by the fact that biotite and chlorite occur as rotation porphyroblasts. Both minerals are early recrystallization products and they also occur as fine-grained groundmass in the schist. They were formed as porphyroblasts at an early date perhaps before the recrystallization of the groundmass. It is of course difficult to account for a growth of this kind. As it is not known exactly from where the sample comes, the possibility of a contact effect cannot be excluded. If biotite and chlorite could rotate without being destroyed, as seen from Fig. 10, it must have been in a soft mass. It must be admitted that in case of the green mineral there may be an error of determination. As only a single slice of the sample is available (the sample was used for analysis) it has not been possible to undertake a closer investigation than may be made from a thin section. Here, however, the properties point to chlorite. It is, on the other hand, hard to understand that in the low-metamorphic assemblage it should be a more resistant mineral since in that case the mineral would be of a more "high-metamorphic" nature. Finally, if biotite can rotate, so can chlorite. It is regrettable that the determination is uncertain at the point where it might have been possible to reveal an important feature in the development of the schist. The optical data also indicate chloritoid which agrees with the physical character of the mineral.

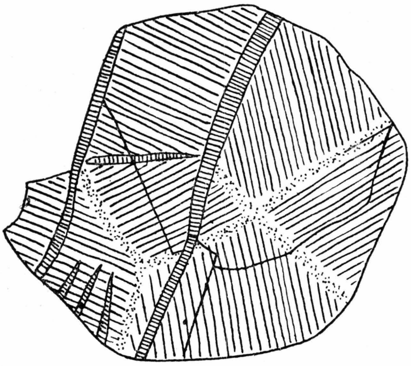

Fig. 11. Almandine pyrope idioblast. The garnet is divided into differently orientated, bi-axial parts. The borders between the different parts of the garnet are marked by helicitic carbon particles. (G. G. U. 36070. 25 × magn. lin.).

The composition of the garnet mentioned is in close conformity with the garnet from Eqûtit. Mg : Fe = 30 : 70 on basis of a specific gravity of 4.09 and refringence 1.795 ± 0.005. A very large content of carbon makes the garnet cloudy and dark. Identical compositions of garnet in two schist series with different metamorphism are not unknown from other areas, and this rather reduces the significance of garnet as index mineral for minor facies alterations.

In thin sections of 0.06 mm twinning may be observed in garnets contained in a schist of a rather unusual appearance in this locality. The occurrence is due to an intergrowth of twelve rhombododecahedrons in such a way that the points of these bodies meet in the centre of the garnet. The outlines are accentuated by a fairly large concentration of carbon particles. Besides this condition which, as said before, may be found elsewhere in the islands, the conoscope revealed a plainly biaxial axis figure. A very typical first bisectric section even enables us to determine the optical sign as positive. Fig. 11 shows which parts of a randomly chosen garnet are optically connected. The rock comes from the southern inlet on the island farthest to the north-west (loc. 17). It is black with big, red garnets placed between radiating units. The radii may be as much as one centimetre long. Under the microscope the black colour proves to be due to carbon particles enclosed in a colourless grunerite

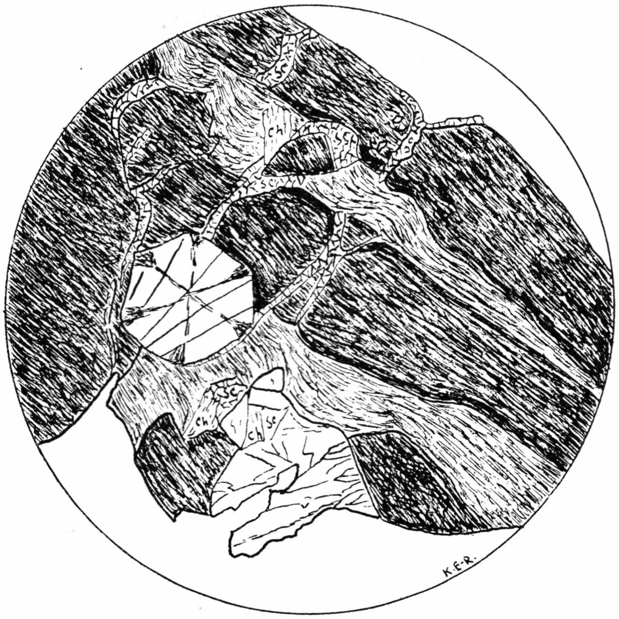

Fig. 12. Maculose structure with porphyroblasts of garnet and grunerite. The rock is characterized by its large content of carbon particles. The groundmass is fine-grained and slightly folded. During their development the garnet porphyroblasts have only enclosed carbon particles along the intergrowth planes. The position of the latter in the garnet also forms the border between slightly optically an-isotropic parts. (G. G. U. 36070. Ab. 8 × magn. lin.).

with $\div 2V = 86$ and $N_g = 1.706 \pm 0.003$. The development of grunerite set in at an early stage. It was strong, and in its course a large number of carbon particles was accumulated along the boundaries. In the central parts the quantity is smaller. Later a transverse fracture of the grunerite was caused by a mechanical action while the more plastic groundmass was only plasto-deformed or remained unaffected. The transverse cracks were filled anew with quartz and scapolite. The disturbance thus indicated is no doubt younger than the folding movement as the grunerite must have been formed either after or simultaneously with the garnet (Fig. 12).

A change of the pressure direction conditions may be traced both macro- and microscopically in a light-coloured mica schist at the easternmost point of the largest Isuamiut island (loc. 14). A transversal schistosity may be observed in an inclusion-like occurrence which is ab. one metre in the longest direction. The angle between the two planes of foliation of the "inclusion" is ab. 30—40°. One coincides with the main structural direction of the locality. The microscope reveals that prevalent visible direction—i. e. the structural direction of the relics—is accentuated by a pronounced development of yellow-brown, highly pleochroitic flakes of biotite. Between the biotite bands a schistose structural direction has been developed which forms an angle varying from 30° to 40° with the bands. The new direction is also underlined by a biotite but in much smaller grains. It would thus be natural to assume that the large flakes of biotite are the oldest which were crystallized at an early stage of the metamorphism. They may have started pre-kinematically or at an early stage of the folding. According to the development discussed above the former seems the more probable. After the folding, or perhaps even before, the final pressure direction conditions were established, and the main structure of the schist had taken form. Whether the relic schistosity represents a more extensive stratum or is a relic cross bedding, cannot easily be determined. Principally it is of no importance, and both theories are equally probable,

Finally, some rocks should be mentioned the appearance of which varies much from the ordinary schists. On weathered surfaces at the southeast corner of Isuamiut (loc. 12) light green chlorite schists occur interwoven with small turmaline idioblasts. The same mineral occurs as porphyroblasts in large numbers. The chlorite is very faintly pleochroitic with

α pale yellow-green
β pale yellow-green
γ light yellow-green

optically positive with a very small axial angle. N_m is very close to 1.630 which according to A. WINCHELL corresponds to a medium Fe-content, Mg:Fe = 60:40 to 40:60. The tourmaline, which in the porphyroblasts attain a length of some centimetres, has

ε colourless
ω greyish green.

The base sections show that the tourmaline is optically negative with a very small axial angle. N_0 is very close to 1.650. On basis of the pleochroitic conditions it is referred to the elbaite-schorlite series with the composition elb:sch, i. e., Li:Fe = ab. 85:15 determined by the refringence. The occurrence of tourmaline is a proof that the metamorphism took place without major metasomatic alterations. S. Hjelmqvist (1938) demonstrated that tourmaline chiefly occurs in connection with Al_2O_3-rich rocks. Thus, an absorption of the B-content of the sea water during sedimentation takes place and increases with the Al-content of the sediments. The tourmaline was built up from this primary B-content and not from outside supplies of volatile substances from pegmatites etc., which quite agrees with the pegmatites of the area.

Chemical analyses of garnet-mica schists.

	37896. Anarssuit.		36064. Isuamiut. Anal. A.H.Nielsen.	
SiO_2	59.59	993	59.75	996
TiO_2	0.72	9	0.75	9
Al_2O_3	18.31	179	17.90	175
Fe_2O_3	1.56	10	1.70	11
FeO	6.66	93	8.50	118
MnO	0.26	4	0.33	4
MgO	2.04	50	2.22	56
CaO	1.90	34	0.35	6
Na_2O	1.63	26	0.22	4
K_2O	3.35	36	5.73	61
P_2O_5	0.07	..	0.06	..
H_2O+	3.00	167	2.66	148
H_2O-	0.13	7		
Cr_2O_3	..	..	nil	..
NiO	..	..	nil	..
C	0.33	..		
F	0.05	..		
	99.60		100.17	
A	51.1		39.8	
C	13.2		2.1	
F	35.6		58.2	
	99.9		100.1	

Because of the low metamorphism degree of the garnet-mica schists a study of their genesis does not present many difficulties. Their low degree of recrystallization was reached along the usual lines: chlorite-muscovite-biotite and garnet. Two analyses of the schists are available, one—37896—from Anarssuit and one—36064—from Isuamiut. Introduced into an ACF-diagram (Fig. 13) 36064 is very near the AF-side of the diagram on the equilibrium line between anorthite and garnet. The other analysis shows 37896 to be far removed from 36064 in the diagram (Fig. 13) in spite of the close chemical agreement between the minerals. The reason for this is that, contrary to 36064, 37896 contains a large amount of pyrite. There will thus be a correction of — 3.5 % FeO. In this way the diagram appears to show a larger content of Ca than is really the case. This does not, however, alter the equilibrium diagram. The ACF point will in any case fall within the triangle anorthite-muscovite-garnet. It is not quite correct to enter anorthite in the diagram as the rocks only contain small amounts of plagioclase (albite). In the present treatment of the schists albite has not been mentioned as component but in some cases there are indications of albite. In "lucky" grains oblique axis figures may be seen which is the only "sure" sign of albite. The Ca- and Na-contents are very small in both analyses. The schists contain some scapolite. The question arises whether the scapolite does not enter into the diagram on an equal footing with anorthite? Sometimes scapolite occurs sporadically in small rows but may often be found in sheltered cavities etc. I consider it correct to introduce

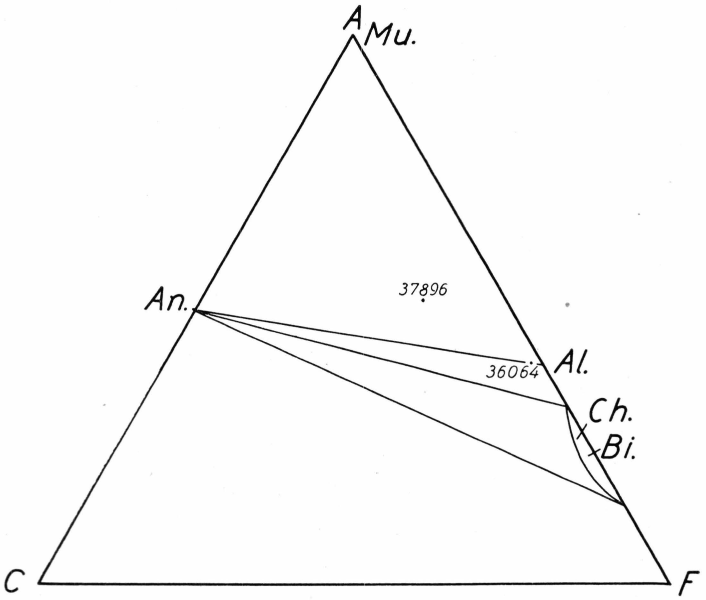

Fig. 13. ACF-diagram for garnet mica schists.

mejonite together with anorthite. The Ca-content cannot be used for plagioclase which, firstly, hardly contains anorthite and, secondly, scarcely exists in the rock. Scapolite, on the other hand, frequently occurs in the schist. It is certain, though, that scapolite is not a secondary mineral in these rocks in the sense of transformed plagioclase, e. g. by hydratisation. Scapolite with mejonite in the molecule cannot come from albite. The Ca-content of the scapolite may come from a primary Ca-content in the sediment, which is highly probable. But it may also have been introduced from elsewhere, which is probable, too, as large transportations of Ca took place in the greenstones. Regardless of these problems scapolite should, I think, be ranked with albite. It carries a great deal of the Ca contained in the rock and, according to the diagram, is in equilibrium with muscovite and garnet.

The Quartzites.

It has already been mentioned that quartzites play a considerable part as petrographical component in the area in question. On account of their weather-resisting nature they are very conspicuous in the area. They are easily distinguishable as light grey or grey ridges. At a distance they are very similar to weather-resisting dykes. In samples from fresh surfaces the colour may vary a little. Very dark varities are frequent, and the rocks are then bluish-black. Slightly weathered rocks of a faintly light green appearance also occur. In this case the petrographic character of the rock is more like sandstone. Such a rock was found on the largest north-eastern headland of Isuamiut. The deviation is a local occurrence and was only found in the area mentioned.

A determination of the specific gravity of one of the most typical quartzites, the light grey with a faint bluish tint, gave 2.68.

All the quartzites are fairly uniform as to mineral assemblage and degree of recrystallization. In all instances there is a hetero-granular groundmass, the size of the quartz grains being from 0.05 mm to 0.6 mm. All grains have sharp edges and are fully recrystallized. A large number shows a highly undulating extinction. Cementing mantles round the quartz grains were not observed, but in a number of rocks the content of carbon particles was considerable. In that case the carbon particles were arranged along the rims of the quartz grains. Carbon particles were hardly ever found in the central parts of the grains, and if it happened, only in very small quantities. A clear interdependence seems to exist between the quantity of carbon particles and the colour of the quartz on fresh cleavage surfaces. The more carbon there is, the darker bluish-black is the quartzite. The accessories are few in number and quantity. The most important is a light green, faintly pleochroitic chlorite with faint penninite interference colours. This mineral which contrary to the quartz has no undulating extinction, has crystallized in small nematoblastic crystals between the quartz grains. Very small, scattered flakes of biotite also occur. In one or two thin sections pale pink garnets may be observed. It is seen that during crystallization carbon particles have been more easily incorporated in the garnets than quartz. Both minerals may here be observed side by side under the same conditions. On account of the carbon particles the garnet shows a plainly helicitic structure, while the quartz is quite pure. The garnet has, as it were, formed a net which closely surrounds the quartz grains (Fig. 14). This might indicate a late formation of the individual garnets at a time when a small rest of the garnet components have gathered and been limited to a random place among the quartz grains determined by the latter. All "odd triangles" have been filled out with one or more grains of ore of which one by transilumination of a very dark red mantle could be determined as hematite.

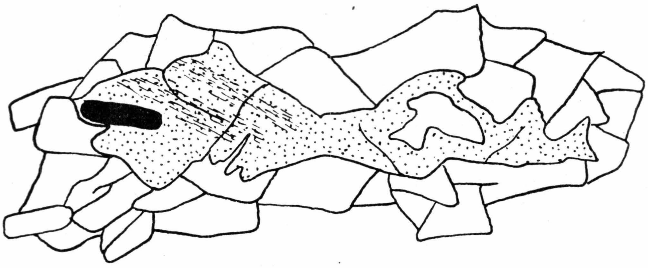

Fig. 14. Almandine pyrope with webbed structure developed in quartzite round the quartz individuals. To the left a grain of ore (magnetite?) and a slight chloritisation in the garnet. (G. G. U. 36029. Ab. 50 × magn. lin.).

Finally, one section revealed a solitary mineral occurring as a relic of a habit unchanged from the primary sedimentation. The thin section was made from a quartzite from the northern part of Isuamiut. In spite of a thorough search only one grain was found. Although only a single grain could be studied it was so unmistakable in appearance that no doubt could be left of its origin. The grain has a diameter of 0.15 mm. The colour is dark brown. According to the relief the refringence must be ab. 1.65. The section approaches a basal section of a uniaxial crystal which is optically negative. In connection with the outline the basic section might indicate tourmaline. If the determination should prove erronous, which is unlikely, the mineral is still interesting as a direct representative of the sediments which are the foundation of the crystalline schists. If the determination is correct, it will be possible by simple calculation to get an idea of the size of the quartz grains which doubtless have been the chief constituents of the primary sediments. Such a calculation would obviously rest on a very slender foundation. Any theory as to the mineral composition of the rocks which had weathered and served as sedimentation material can hardly be advanced. In view of the considerable content of quartz and the tourmaline there is an indication of rocks with a granitic composition. If, however, the specific gravity of the tourmaline in question is said to be 3.10, the following formula may be applied (Barth, Correns, Eskola. 1939)

$$r{:}r' = (D' - 1):(D - 1)$$

where

r = radius of quartz grain
r' = radius of tourmaline
D = spec. grav. of quartz (2.65)
D' = spec. grav. of tourmaline (ab. 3.10).

If r of this equation is found, it follows that the quartz grains have had a diameter of ab. 0.2 mm. It is, of course, risky to draw general conclusions from this slender material. If it is done, one gets an indication of the conditions under which sedimentation took place. It cannot have been deep sea sedimentation, which is consistent with the circumstance already mentioned that the rocks belong to the flank occurrences from the Nagssugtoqidic geosynclinal. The sediments were deposited in areas nearer the coast. The possible cross bedding structure indicates the same origin. The degree of roundness of the tourmaline is quite good. As tourmaline and quarts are almost equally hard, a similar curve may be assumed for the quartz, but it will hardly be possible to say anything about route of transportation, sedimentation, etc.

MAGMAGENOUS GREEN AMPHIBOLITES

The Structure.

The greenstones vary a good deal from place to place both to the eye and under the microscope. Both colour, size of grains and structure change much within limited areas. In spite hereof it is possible to distinguish two main types, a very fine-grained rock and a more coarse-grained type. In the former the individual grains can only be discerned under a magnifying glass. Certain types are very compact and tough when beaten. At the north-easternmost corner of the largest Anarssuit island they are even hard and ringing (loc. 7). The colour of the fine-grained rocks is fairly constant. It is greyish green and may in some localities be lighter. Examples of highly schistose, fine-grained rocks may be found on the island farthest south in the Anarssuit group (loc. 10). The other main type is so coarse-grained that some of its minerals in the sample are visible to the naked eye. Here hornblende is predominant. On weathered surfaces it appears as small lentil-shaped spots as much as 2 mm broad and 3—4 mm long. The hornblende individuals are embedded in a finely granulated, light-coloured mass the components of which can only be determined under the microscope. In many places the lenticular hornblende individuals give the rock a schist-like character which, however, is not very pronounced if one attempts to cleave the rock. The schist-like character is only apparent here and there and, generally speaking, the rock is fairly uniform in all three dimensions when subjected to mechanical action. On freshly cut surfaces the colour is dark greyish-green. Greener types also occur especially at the western end of the northernmost Anarssuit island (loc. 5). During the survey lack of time and maps prevented the introduction of all the types into the geological map.

The specific gravity of the greenstones is rather high. In the following localities it was determined at

Loc.	G.G.U.	Sp. gr.
Equtit	36067	2.95
—	36058	3.04
Isuamiut	36012	3.02

In many places the structure of the greenstones is columnar and may be finely developed, e. g. in the north-western corners of the largest and second largest islands of the Anarssuit group (loc. 5 & 7). Here the columns are some metres long and up to 50 centimetres across. The columns have been most regularly developed in both localities. Their longitudinal direction varies. There is not always as good agreement as could be desired between the longitudinal direction and the cooling contact of the columns against the sediment series. In one of the northernmost creeks at the north side of the largest island of the Anarssuit group (loc. 6) the strike of the schist is N 45° E vertical, while the longitudinal direction of the columns in the greenstone is N 40° W with a dip of 10—15° SE. In other words, the columns are almost at right angles to the cooling surface. Another locality where the agreement seems to be good between the sediment contact and the columnar direction, is on the north side of the northernmost Anarssuit island (loc. 5). The observation was made from a motor boat late at night, and it was not possible to make a closer study of the occurrence.

Columns which cannot be referred to any contact surface no doubt owe their existence to a special alteration during or after the folding movement. It may, however, also be due to the development of a contact surface at a spot which no longer exists. An example of such "detached" columns is to be found at the far north corner of the largest Anarssuit island. Quite near a sediment contact but almost parallel to it the columns stand in a vertical position in the coastal rocks.

Other structural occurrences should be mentioned in brief. At the westernmost headland (loc. 11) of the long southern double island of the Anarssuit group the joint net is very fine-meshed. It divides the greenstone, which is compact, hard and ringing, into cubes the sides of which are a few centimetres. On the south side of the same island the cubes change into small columns and pillars which attain a size of 2—3 cm across. They are vertical and parallel with the contacts. They are not cooling columns but merely a triple-rectiangular joint net. Its horizontal plane is most strongly developed, and the two vertical planes are fainter but closer.

The Petrography.

Under the microscope the greenstones proved to consist of the following minerals: hornblende, plagioclase, clinozoisite (epidote), olivine, scapolite, quartz, garnet, calcite, chlorite, rutile, magnetite, ilmenite and leucoxene. The hornblende is a common, green hornblende its optical data varying slightly in the different localities. On an average the following conditions prevail:

α very pale green
β pale yellow
γ bluish green
$\gamma \wedge c = 19°—20°$
$— 2V =$ ab. 70°
$r < v$ slightly oblique
$N_m =$ ab. 1.66.

The pleochroism has the same tendency everywhere. When the angle $\gamma \wedge c$ decreases, the tendency to absorption seems to increase in particular for γ. In the coarse-grained variety of greenstone at Isuamiut $\gamma \wedge c = 19°$, while in the fine-grained, light green varieties from south Anarssuit the same value goes right down to 13°—15° and N_m remains very nearly constant. These data almost hold good for a green hornblende according to WINCHELL's tables. $\gamma \wedge c = 13°—15°$ might suggest an addition of ferro-tremolite at the western end of the complex. The large absorption after γ in relation to α points in the same direction. The shape of the hornblende individuals varies so much that a division into two principal groups seems justified. One group is made up of large, short-prismatic individuals often of the same dimension in all directions. They may attain a length of 5 mm. An ophitic intergrowth of them is a very common occurrence. This group may be explained as uralitized pyroxenes from the original magma (Fig. 15). However, all individuals plainly consists of hornblende, and no trace of pyroxene was found except for the fact that two sets of cleavage directions were observed in a single individual from an island of the Eqûtit group. The angle of one set between the normals of the cleavage surfaces is 88° and that of the other 124°. It is very evident here that the latter set predominates. The other group is made up of smaller crystals which are markedly nematoblastic. These nematoblasts may be explained as new crystallizations during the last stage of the greenstone development, while the uralitic crystals must be products from the first phase and its corresponding fall in temperature. The small nematoblasts occur as individuals forming an integral part of the fine-grained ground mass or as minute needles enclosed in the plagioclases. Very long individuals where the ratio between breadth and length is 1:15 are not infrequent. Often the crystals have no definite orientation which possibly corresponds to the final stage with its relief of pressure. It may be said of all rock types that the crystals are intergrown to form a blastophitic structure. The borders of the uralite may be frayed on account of a mechanical action. It is evident that some crystals have been crushed under the pressure so that the borders between the individual elements of a crystal may be clearly seen with crossed Nicols as the extinction varies for the different parts of the crystals. The colour distribution of the hornblende is not clear. If, for instance, one of the green absorption directions is observed slightly magnified it, will be seen that a number of lighter spots are distributed over the hornblende. They may determine the basic colour while the green colour appears as scattered spots, but the first-named condition is the more frequent. At stronger magnification the light spots prove to be reaction zones with a lower birefringence surrounding small, drop-shaped inclusions (Fig. 16). The inclusions are so minute that only few reach a size of 0.01 mm. They must be quartz. The outline against the reaction zone is sharply defined. The outer boundary of the reaction zone follows the cleavage of the hornblende along a straight line. In other directions it is rounded against soft, corroded forms. There are, however, exceptions. Reaction zones may occur where a pseudopod-like projection juts out across the cleavage direction of the hornblende. The refringence of the transition zone is higher than quartz and lower than hornblende. Strongly magnified the inclusions appear to be very numerous. Their orientation is everywhere parallel with the longitudinal direction of the hornblende. The minute size of the drops made a determination difficult. It must therefore be assumed that some of them are

Fig. 15. Greenstone or green amphibolite. Short-prismatic uralitic hornblende individuals in a fine-grained groundmass. The three small ellipsoidal grains bottom left are olivine. North-south in the fourth quadrant are a number of scapolite grains. (G. G. U. 36054. Ab. 9 × magn. lin.).

plagioclase. A zonary extinction seems to be certain in one or two places. Of other inclusions rutile of a maximum size of 0.02 mm was observed as well as ilmenite surrounded by handsome leucoxene mantles of which a few are reddish-brown when transluminated. The matrix of the hornblende is a finely granulated mass the principal components of which are plagioclase and zoisite. The plagioclases are all xenomorphic. The grains vary much in size, many individuals being from 0.01—2 mm. Almost all grains are minute, and thin sections show no clear crystallographic direction. At Eqûtit the state of preservation is fairly good and allows accurate determinations. Zonary extinction is a common occurrence in material from all the islands. In individuals with zonary extinction, which were examined, the structure proved to be inversely zonary so that the central part is less rich in anorthite than the peripheral. From a determination of the maximum extinction angle at (001) corresponding values to andesine with 35 $^0/_0$ An were obtained for the central parts. The peripheral parts had the composition of 55—60 $^0/_0$ An which corresponds to labradorite. Three determinations from the northwesternmost islands of the Eqûtit group gave $-2V = 86, 88, 86$ respectively for the central parts. Here co-ordinates for crystallographic reference planes were measured which gave a good determination of An. REINHARD's tables gave An 30—35 $^0/_0$ which corresponds to acid oligoclase. Twin laws were in all cases complex Manebach. At Anarssuit deter-

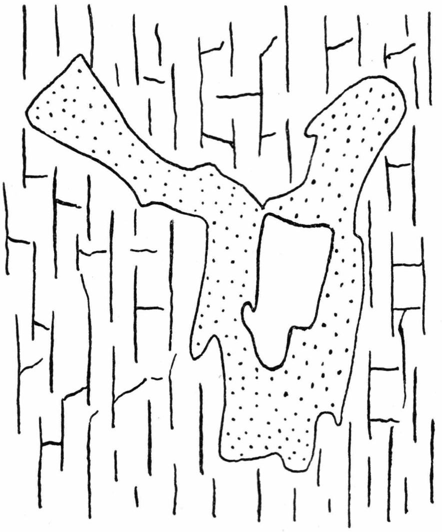

Fig. 16. Detail in greenstone. Reaction rim round a quartz (plagioclase) inclusion in green hornblende. In the main the reaction rims follow the longitudinal direction, but pseudopod-like processes as shown to the north-west in the drawing may occur. (Ab. 3500 × magn. lin.).

minations of the central parts of the plagioclases gave a composition of 28—30 $^0/_0$ An. In parts where a determination of the peripheral parts was possible, the An-content was between 40 and 45 $^0/_0$. The peripheral parts may contain one or two per cent more An, but the accuracy is very doubtful on account of the neighbouring grains.

Sericite is frequent as a polluting secondary product sporadically distributed in the plagioclase.

Everywhere in the greenstones clinozoisite occurs in small grains without idioblastic crystals. The quantity of the mineral varies somewhat. It should be mentioned that in nearly all cases the quantitative determinations of the minerals depend on a subjective estimate. The condition of the rocks and the size of the grains do not as a rule permit a reasonably accurate geometrical integration, for which reason a subjective review of the occurrence should be as valuable, since it does not give figures which might be incorrect. It is a transparent to faintly yellow clinozoisite with strong ultra-blue interference colours. The axial dispersion $\varrho < v$ is very pronounced. The grains are evenly distributed all over the rock with no preference for any one mineral. The clinozoisite does occur as inclusions in the plagioclase grains but always as clean, well defined grains which never suggest saussurite. The clinozoisite thus presumably occurs on an equal footing with plagioclase and hornblende. This petrogenetically important condition was further confirmed by the chemical analyses.

It should be noted that quarts and scapolite nearly always occur together. Although they mix with the plagioclase as ground mass mineral, the two minerals cannot quite be ranged on an equal with plagioclase. They occur together in large or small accumulations. The size of the individual grains here vary considerably from the ground mass and has a linear extension often several times larger than that of the proper groundmass grains. In all cases the minerals are granoblastic. The concentrations are often oblong. The formation of scapolite presumably took place along weak zones in the greenstones. These zones must have been minute as no traces of them can be observed apart from the scapolite occurrence. The scapolite must to a large extent have been formed at the expense of the plagioclase. This was very evident in places where border areas between the two minerals could be investigated. The scapolite cuts into the plagioclase and laces off part of the latter mineral (Fig. 17). The border between the minerals is not always clearly defined. Near such a plagioclase-scapolite boundary is a large number of droplike inclusions of plagioclase. The longer the distance from the plagioclase boundary the smaller the number of inclusions becomes. At last they only appear under crossed Nicols as shining spots in the more strongly birefringent scapolite. They are also remarkable in having preserved their own optic character. Scapolite has an acid composition which remains constant at all the islands. $N_o = 1.54$ and $N_o - N_e = 0.000(8)$ which, according to WINCHELL, corresponds to a dipyre with the composition $Ma_{80}Me_{20}$. Needle-shaped inclusions often in rows are very frequent. The maximum length of the needles is 0.02 mm. The refringence is far above that of the scapolite. The colour is a delicate bluish-green and pleochroism cannot with certainty be observed in the small grains, but the small needles are undoubtedly hornblende since some of them have oblique extinction.

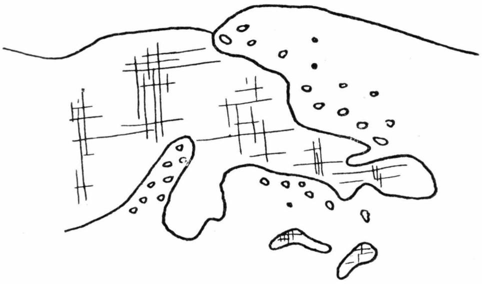

Fig. 17. Structural detail from greenstone. The sketch shows the mechanism of the progress of the scapolite. Coming from the right the scapolite sends projections into the plagioclase and by "pincer-movements" cuts off drops of the plagioclase. To the right such a process is nearing its completion. The number of plagioclase drops decreases from the border towards the scapolite.

Chlorite occurs all over the area. Quantitatively it is not an important component. The longest crystals are 1 mm. It is a light green, faintly pleochroitic chlorite occasionally with anomalous interference colours. The chlorite is often boundary mineral against the hornblende. The contact is sharp, but as the result of a mechanical action the free end of the chlorite flakes are very often bent which enables us to register that a movement took place after the formation of chlorite. In other instances the chlorite have been bent to the shape of an integration mark. In such cases the extinction is highly undulating and extends as dark bands across the crystals. It may be ascertained that the chlorite is a secondary occurrence and that movements still took place after its formation.

Olivine was only found in one locality. It occurs as an accessory mineral in very small quantities. The grains are rounded and lenticular. The largest size is ab. 2 mm in the longest direction. The optic data are: $-2V =$ ab. 86°, N_g between 1.73 and 1.74 and $N_g - N_p = 0.04$ corresponding to a chrysolite with ab. 25 $^0/_0$ fayalite in the molecule. In thin section the mineral is colourless and laks pleochroism.

Finally, the greenstones contain a number of accessories. Ilmenite is a very common ore mineral. It is often covered with a leucoxene mantle. Ilmenite seems to be evenly distributed in the rock. Of other ore minerals hematite should be mentioned which has the same distribution as ilmenite though in smaller quantities. In most cases it is easily distinguishable from the ilmenite as it is often translucent along the borders, whereby the typical maroon colour appears. Magnetite also occurs as a number of grains display a steel-grey colour by reflected light. In one instance a pale pink garnet was observed.

The Deformation Zones of the Greenstones.

In connection with the traces of the shearing movements which intersect the greenstones a special mineral assemblage is met with which is closely related to a structure peculiar to these zones. The result of the shearing movement is mylonite zones with a pronounced cataclasis. Very well developed, perfect "fiederklüfte" are often formed. According to my observations such zones had their best form in the western part of Isuamiut where the two large parallel fracture zones with a N—NW direction also may be observed. Here the greenstones are intersected everywhere by mylonite zones. Unfortunately, there was not time to undertake the measurings needed for explaining the development of the action which has been particularly effective in this part of the area. A very large number of measurings have to be made as the mylonites cut across one another in all directions. Thus, during a short visit and with insufficient maps at disposal it will not be possible to make an analysis of the occurrences. It seems, however, as if two shearing movements have taken place at different times. Fig. 18 shows two mylonite zones in a greenstone of the coarse-grained type. The orientation of the older one is E—W. Later it has been intersected by a NE—SW movement. The dislocation is not very great. The movement must have taken place slowly and smoothly so that a smearing-out of the finer structure of the rock has been possible. The picture also shows how the crushed sliding zone has become the centre of an extensive release of tension. North of the mylonite zone with the direction E—W the rock has broken into blocks as the ultimate strength was not sufficient to withstand the tension. No gliding movement took place here, and the real deformation took place with pronounced microcataclasis inside the mylonite zone. Under the microscope a pale hornblende proved to be the principal mineral. The groundmass is an indefinable brown opaque mass which on account of its fine-grained nature which is revealed under crossed Nicols must presumably be "rock powder" from the crushing. The visible fragments all have sharp outlines with undulating extinction.

Fig. 18. Deformation zones in greenstones. Western Isuamiut. In close proximity to loc. 3. (H. Sørensen phot.).

Idioblastic pistacite crystals float in the groundmass. The hornblende, the principal mineral in these zones, is a light-coloured hornblende with

α colourless
β light yellow-green
γ light bluish-green

and $-2V$ = ab. 75°, birefringence medium. This actinolitic hornblende contains a great many inclusions. Numerous pistacite drops with plainly anomalous interference colours are embedded in it as well as the usual drops of quartz with surrounding reaction haloes. Zirkon is thinly distributed here and there, while ilmenite with leucoxene mantles is very frequent. The idioblastic crystals of the abovementioned clinozoisite attain a length of 0.2 mm. Its interference colours are strongly ultrablue. The crystals which are colourless and without pleochroism are elongated along the b-axis and twinning on (001) occurs. Cleavage on the same plane is characteristic. Incidental intergrowths frequently occur. The negative axial angle is 88°—89°, $\alpha \wedge c = +2$, which corresponds to epidote, more exactly pistacite with the relation Al : Fe = 9 : 1. In the pistacite no individual showed signs of a mechanical process, which means that the formation of the mineral after the deforming movement had ceased. Hornblende, on the other hand, was strongly affected. Both plastically deformed individuals and broken up individuals are very common. Almost all crystals show signs of the movement which took place. Plagioclase does not enter as component of the groundmass. Its absence is doubtless due to the fact that it is hidden in the Ca-rich pistacite which it helped to form. The conditions mentioned, however, have their limitations. A number of fracture zones differ from those described above. The fissures run an irregular course and are no doubt more or less open gashes. In the fissures a separation of minerals took place later, they do not extend over more than a few metres and are seldom more than one or two centimetres wide. If such fissures occur, there are many of them, enough to fill a small area. The fissures are easily observed as their various light-coloured, coarse-grained minerals stand out against the dark greenstones. They are most abundant on the southwest foreland of the large Isuamiut island (loc. 12). A white, coarsely crystalline calcite forms part of the material of the veins. It may occur isolated as a handsome white marble but is equally frequent in connection with a macroscopical, brown zoisite, the individual grains of which are up to 5 mm long. Under the microscope the latter mineral is colourless and non-pleochroitic, but with clear ultra-blue interference colours. The two refringence indices α and γ both lie between 1.71 and 1.72. The positive axial angle approaches 61° with the axial plane at right angles to the cleavage (001). According to A. Winchell this should be a β-zoisite with ab. 5 $^0/_0$ Fe in the molecule which is consistent with the brown colour. To meet with a plagioclase here would seem absurd, but it does exist—abundantly—in a very coarse-grained variety almost pegmatitic the size of the individual grains being measured in centimetres. In an acline twin the maximum extinction for a conjugated twin in the zone $\perp$ (001) was determined at —67°.4, which corresponds to 42 $^0/_0$ An. The maximum extinction of (001) is $+63° = 43$ $^0/_0$ An. In addition to the acline twin, twins after the albite-Carlsbad complex were observed. A mineral paragenesis with a Ca-surplus as in the present case can only have been formed by a supply of Ca from elsewhere. Presumably the assemblage cannot have been formed at the expense of Ca-poor andesine seeing that the end product is an andesine containing more Ca than at the start. The phenomenon should no doubt be associated with the pegmatites and should perhaps have been mentioned together with these.

Discussion of the material.

For several reasons the name greenstone is petrographically unfortunate. Firstly, it is too far-reaching. A whole series of mineral parageneses have in time been grouped under this heading which of course is very unpractical. The terms greenstone and greenschist are used indiscriminately which also is unfortunate as greenschist often is associated with P. Eskola's greenschist facies, a fact not always implied by the designation. From the point of petrography it is to be wished that both terms were discarded or only applied closely connected with the greenschist facies. But as this facies is subdivided as our knowledge of metamorphism progresses, the term is no longer justified. However, greenstone and greenschist is so deeply rooted in geological terminology that the names are associated not only with certain rock types but also with an intrusion mechanism in folding ranges and the time of intrusion in relation to the growth of the latter. Though the term has become more general and even less definable, it will be all the harder to get rid of. Thus it is not very fortunate that the intrusive links have been called greenstones in the present work. A more correct designation would have been green plagioclase-clinozoisite amphibolites. But as mentioned above, greenstone is a neutral term, and for the sake of convenience it has been chosen to cover the various amphibolite types and the structural occurrences associated with them.

Several uncertain points enter into the discussion about the origin of amphibolites in pre-Cambrian areas. In the main amphibolites may have been formed metamorphically at the expense of 1) impure calcium deposits, 2) pure calcium deposits plus a metasomatic contribution and, 3) intrusive basic rocks (Barth 1930). It is not always possible from structural conditions to decide with which of the three one is dealing. This is the first uncertain point. If, however, field observations enable us to determine the leading group, one important point of uncertainty has been eliminated. In our small archipelagic field the greenstones bear unmistakable evidence of their magmagenous origin. The following circumstances are in favour of this theory:

1. the abovementioned cooling columns at right angles to the contact surfaces against the schist,
2. the basaltic composition (norm. plag. 55 $^0/_0$ An.),
3. the uralitic hornblende individuals,
4. the contact metamorphism in the schist, and
5. the shape of the intrusive bodies (tendency to phacolite) as mentioned before.

There can be no doubt that this certain origin has a significance far beyond the archipelagic field. It may be of importance for an evaluation of the amphibolitic xenoliths which occur in the more high-metamorphic areas farther south, where the special characteristics of an intrusion structure have been lost. The matter should of course be more closely investigated over a larger area before conclusions can be drawn.

If the metamorphism of the greenstones and the crystalline schists shall be explained, it must be assumed that the metamorphism took place without major metasomatic alterations. There is no indication, structurally or mineralogically, of an addition of foreign components or a removal of own components. The transport or exchange of material which must have taken place during the recrystallisation process has been confined to the area itself. A limited separation of scapolite and quartz pegmatites indicate a migration of material but only over short distances. It must therefore be assumed that the present chemical composition truly represents the original intrusive basaltic magma. A comparison between the normative and the modal mineral assemblages is valuable as the normative is sure to come very close to the original assemblage. Besides the normative plagioclase with 55 $^0/_0$ An in the molecule and the orthorhombic- and monoclinal pyroxenes, the molecule contains a small quantity of olivine with a composition of 38 $^0/_0$—46 $^0/_0$ fa. The modal mineral assemblage is quite different. Olivine occurs in small quantities, its composition being ab. 25 $^0/_0$ fa. The few grains may be regarded as relics, since the temperature has been too low for the formation of an olivine. The pyroxenes have disappeared and exist either as recrystallized products or uralitic hornblende. Both have the same optic characteristics and have reached their equilibrium along different roads. The plagioclase appears in quite a new form with inverse zoned structure the central parts having 30 $^0/_0$—35 $^0/_0$ An. As already mentioned the zoning is of different intensity in the east and the west. In the east the peripheral parts have 55 $^0/_0$—60 $^0/_0$ An, while in the west the same parts only reach 45 $^0/_0$ in the individuals determined. A newcomer is clinozoisite. It should be noted that hornblende is the only femic mineral occurring with the clinozoisite. This also seems to hold good of amphibolites elsewhere. The possibility of clinozoisite occurring as a modal mineral in a purely magmagenous rock is in my opinion not very great and has as far as is known not been observed in a purely magmagenous rock. Epidote, on the other hand, was registered as a magmatic product by P. Eskola (1915) from observations in the Orijärvi district where it occurred with orthite and biotite. However, I do not believe that the clinozoisite in the present basaltic greenstone is a primary magmatic mineral. This exclusion is important to our understanding of the development of the greenstones. Apart from this probable exclusion a more tangible proof may be found in the inverse zonary plagioclase. The zonary parts of the plagioclase has a more acid composition than the normative. A recrystallization of the plagioclases with a resulting formation of clinozoisite must have taken place. However, a study of the whole course of development compared with the structural conditions can only be made after a survey of the facies and the plagioclase-clinozoisite conditions.

In Eskola's original facies classification he distinguished among many others between amphibolite facies and epidote-amphibolite facies. Accordingly, the index mineral was epidote which he interpreted as a low-metamorphic transformation product not occurring as an independent mineral equal with plagioclase and hornblende. In his extensive work from 1927 on the geology of the Sulitelma field T. Vogt followed the same line but demonstrated the existence of a transitional equilibrium phase. Even before Vogt's book was published, F. Becke (1921) had regarded clinozoisite as an independent mineral in equilibrium with the other components. He was later supported by I. Barth (1936) and other Norwegians such as H. Ramberg (1943), I. Rosenqvist (1943) and T. Strand (1943). This trend of development is quite interesting and fully confirmed by the islands of the Egedesminde archipelago. It has been illustrated in the usual ACF-diagram (Fig. 19) where the earlier diagrams for amphibolite facies and epidote-amphibolite facies have been combined. It should be justifiable to place clinozoisite and plagioclase side by side as they have the same mode of occurrence in the rock. Two analyses of the greenstones lie within the hatched area, the only field of the diagram where all three minerals, plagioclase, clinozoisite and hornblende, are in equilibrium. For the amphibolites of the primitive

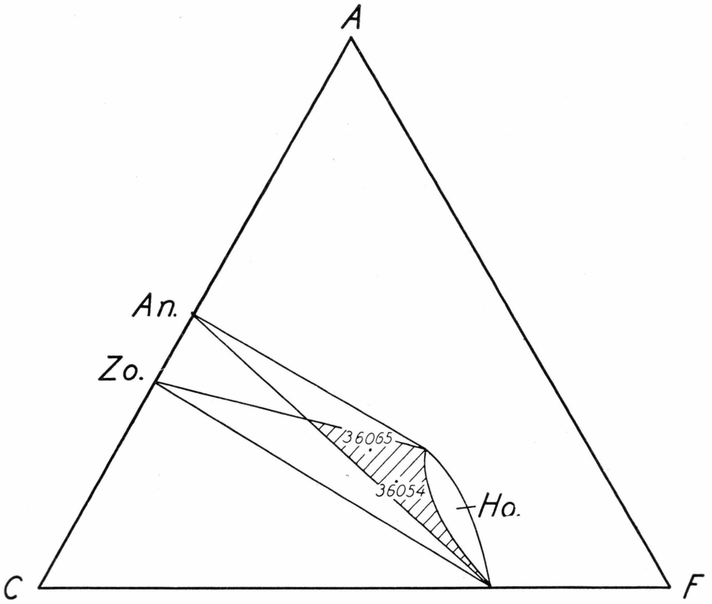

Fig. 19. ACF-diagram for zoisite-plagioclase.

rocks in Valdres Trygve Strand (1943) found that during the formation of an amphibolite the plagioclase was developed with a maximum equilibrium An-content of 35—40 per cent together with clinozoisite. When this composition of plagioclase had been reached, clinozoisite continued its development alone from the material which was not used for hornblende. The said composition of plagioclase should then be regarded as a kind of basic value for the assemblage plagioclase-zoisite dependent on the chemical composition. These conditions are quite consistent with the archipelagic field at Egedesminde. Here the plagioclase has in the cores a composition of 30—40 $^0/_0$ An. In this connection the central parts should be considered rather than the peripheral more basic plagioclase which is an equilibrium plagioclase from a much later metamorphism. The circumstance that a basic plagioclase with 55—60 $^0/_0$ An may occur with clinozoisite should be viewed on basis of the zonary development of the plagioclase and does not alter anything in the basic conditions mentioned above. The clinozoisite and the equilibrium plagioclase were developed at a low temperature and under increasing pressure. Later PT-conditions changed in the opposite direction, and the clinozoisite was no longer stable with a basic plagioclase. Calcium from the clinozoisite migrated to the plagioclase which has been stable with a large content of calcium. This also confirms the aforementioned ACF-diagram.

A brief summary of the various observations seems to show that clinozoisite (epidote) has lost its former value as index mineral between epidote-amphibolite facies and amphibolite facies. It only retains its position when the composition of the equilibrium plagioclase in the peripheral parts of zonary plagioclases is taken into consideration, these being the parts which determine the "immediate" facies position.

If the considerations above hold good, the greenstones must be referred to amphibolite facies with (H. Ramberg, 1949) a slightly higher metamorphism in the east than in the west. Such a distribution of the metamorphism is quite consistent with the fact that the garnet-staurolite schists at Eqûtit represent a higher stage of metamorphism than the garnet-biotite schists from the other two island groups. The greenstones present distinct transition characteristics between epidote-amphibolite and amphibolite facies. The structure is a curious medley of great variation. It is typical of other areas in epidote-amphibolite facies, e. g. in Valdres, Norway. More highly metamorphic amphibolites have a more regular gneissic structure. It is remarkable that inspite of altered mineralogy and facies the greenstones are not yet rid of its old structural character.

The assemblage plagioclase-zoisite has gradually been so well cleared up that general geological experience shows that a rising temperature favours basic plagioclase and makes zoisite unstable (epidote), while pressure works in the opposite direction. Consequently, the development in the field investigated first reflects a beginning fall in temperature after the magma had been consolidated with a recrystallization of 30—40 $^0/_0$ An in the plagioclase. Simultaneously an increasing pressure set in. The fall in temperature must have continued under the equilibrium plagioclase with the development of zoisite. Later the character of the two PT factors changed. A strong rise in temperature set in principally at the eastern end, whereby plagioclase reached 55—60 $^0/_0$ An peripherally. As said before, the correctness of this theory is confirmed by the crystalline schists. Thus everything speaks in favour of an irregular thermal front at this spot. It seems to rise steeply between the two easternmost islands. It would, however, be justifiable to assume that the irregular thermal front registered here has a larger regional extension and, consequently, is the cause of the very sudden change from more high-temperature gneissic rocks in the south to the small archipelagic field. I further believe that this explains the relation of the field to the gneisses in the north-east corner of the island Manîtsoq. The transition from gneiss to the more low-metamorphic sediments occurs over some hundred metres. Among the crystalline schists are rocks with a high-temperature mineral content, e. g. stable potassium feldspar. In this area the same selective metamorphism as in our small islands may be observed. Comparatively high-metamorphic rocks lie close to low- metamorphic. It is difficult to determine whether the first fall in temperature and the first pressure increase set in immediately after the intrusion. It is curious that P and T should have opposite values at the same time. The circumstance might be explained if it is assumed that the injection took place at comparatively great depth in the geosynclinal border area. After the consolidation of the magma the area was raised to a higher level within the range, while the high pressure may be due to a folding phase in the vicinity. The development of the folding in the islands need not have caused the increase of pressure. The last decrease of pressure may well be explained by a decreasing folding phase, while the rise in temperature undoubtedly is due to a higher thermal front. In places this may have produced bulges of which one has hit the Eqûtit group so that the metamorphism of the greenstones and the sedimentogenous schists have increased each at their stage while the difference between their respective facies has remained distinct.

In the chapter on the staurolite schists they were mentioned as corresponding to a low amphibolite facies. This is confirmed here. F. J. Turner demonstrated that the An-content of a plagioclase increases more rapidly with the temperature at the basic than at the acid end. The An-increase only sets in when a certain limit has been reached. Evidently this point has just been passed by the greenstones which are on the border between oligoclase and andesine. This accounts for the

Chemical analysis of greenstone. G.G.U. 36065/48. A.H.N. anal.

SiO_2	50.40	840	or	1.67	
TiO_2	1.34	16	ab	20.96	
Al_2O_3	13.98	137	an	26.13	
Fe_2O_3	1.43	9			
FeO	10.18	141	sal	48.76	V %
MnO	0.23	3			
MgO	8.61	215	wo	10.44	
CaO	10.47	187	fs	10.43	
Na_2O	2.52	40	en	19.60	
K_2O	0.26	3	fa	1.63	
P_2O_5	0.08	1	fo	2.94	
H_2O^+	0.92	51	ap	0.34	
H_2O^-	0.04	2	py	1.46	
S	0.09	..	il	2.43	
Cr_2O_3	nil	..	mt	2.09	
	100.55		fem	51.36	V %
—O	0.05				
			A	24.6	
	100.50		C	34.5	
			F	40.9	
				100.0	

Chemical analysis of greenstone. G.G.U. 36054/48. A.H.N. anal.

SiO_2	50.25	831	or	1.11	
TiO_2	1.38	17	ab	24.10	
Al_2O_3	15.91	156	an	30.02	
Fe_2O_3	2.14	13			
FeO	8.59	119	sal	55.23	V %
MnO	0.18	3			
MgO	6.42	160	wo	10.44	
CaO	11.24	201	fs	10.43	
Na_2O	2.86	46	en	14.00	
K_2O	0.17	2	fa	2.04	
P_2O_5	0.12	1	fo	2.80	
H_2O^+	1.10	62	ap	0.34	
H_2O^-	nil	..	il	2.58	
ZrO_2	nil	..	mt	3.02	
Cl	tr.	..			
SO_3	0.23	3	fem	45.65	V %
Cr_2O_3	nil	..			
BaO	nil	..	A	20.3	
			C	33.2	
	100.59		F	46.5	
				100.0	

great difference in the plagioclases of the two series, which has already been mentioned. The evolution reflects a regressive plus a progressive development in the greenstones, while the schists only point to a progressive development. The aforementioned first fall in temperature with a decreasing metamorphism of the greenstones has not gone deep enough to prevent the schists from continuing their progressive development. At this stage the development of the two series have approached one another without ever reaching an equilibrium. The last rise in temperature interrupted this approach, and since then both series have moved towards higher metamorphism stages.

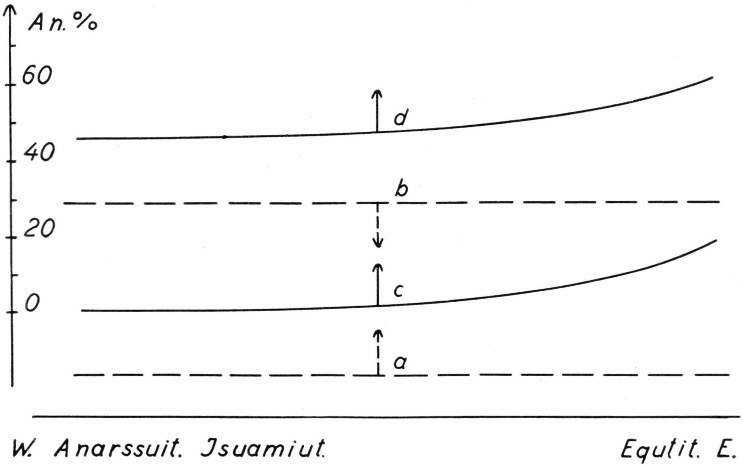

Fig. 20. Outline of the development of the metamorphism.
Abc. = Rising degree of metamorphism.
a. = 1. stage. Progressive met. in the schist series.
b. = 1. — Regressive met. in the greenstones.
c. = 2. — Progressive met. in the schist series.
d. = 2. — Progressive met. in the greenstones.

PEGMATITES

Within the area pegmatites play a special part. They are few and can be treated as a whole. It is known that the pegmatites are not evenly distributed on all the islands. The number of dykes and veins increases eastwards and is consequently the largest at Eqûtit. No pegmatites at all were found at Anarssuit. At Isuamiut a single one was observed in the greenstone at the north-east end of the island. At Eqûtit, on the other hand, pegmatites abound both on the small and the large islands of the group. Generally the pegmatites are small, only a few metres long, lenticular and placed close together in the areas where they occur. In the staurolite schist the pegmatites are larger and often attain a maximum length of 50 metres and a thickness of ab. 5 metres. One large dyke at the northern point of the third island from the north-west corner should be noted (loc. 13) as well as the one the dimensions of which have just been mentioned on the north side of the third largest island of the Eqûtit group. The number of large dykes in the staurolite schist is not as large as that of small veins in the greenstones.

A common trait of the pegmatites is that they are composed of very few minerals of which quartz of a transparent to milky-white type is predominant. The aforementioned largest dykes consist almost exclusively of this mineral, although the first contains a small amount of feldspar with a total aggregate size of ab. 20 centimetres. The feldspar is a dark, greyish-brown plagioclase with the following oblique extinction at right angles to the crystallographical a-axis:

$$\begin{aligned} \alpha' \wedge (010) &= \div 3 \\ \alpha' \wedge \quad — \quad &= \div 1 \end{aligned}$$

which corresponds to an oligoclase with an An-content of 18 per cent. Several determinations of the angle of extinction between α and (001) as well as α and (010) all gave 20 $^0/_0$ An.

Especially remarkable are the pegmatites occurring in connection with the basic greenstone xenoliths in the schist. Xenoliths or xenolith-like bodies as results of intrusive-mechanical conditions have been mentioned earlier. On the south side of the largest Eqûtit island a lenticularly elongated greenstone inclusion stands out which shows signs of a partial movement in the surrounding schists. The pressure effect resulted in shear joints which were developed as "fiederklüfte" (Fig. 21). Later on may be in equilibrium with the release of tension these "klüfte" have been filled with pegmatitic material. Another pegmatite occurrence connected with the inclusions also deserves to be mentioned in brief. On the third largest Eqûtit island next to the abovementioned large, pure quartz pegmatite is a xenolith the strike of which is conformable with the schist on the direction E—W. Originally, it was presumably a long lenticular body of ab. 35 metres with regular outlines. Its breaking was followed by a formation of pegmatite at the fractures and along a central zone (Fig. 22). The pegmatite is a white plagioclase pegmatite highly deficient in minerals and here, too, quartz predominates. At right angles to the crystallographical a-axis the plagioclase has the following extinction:

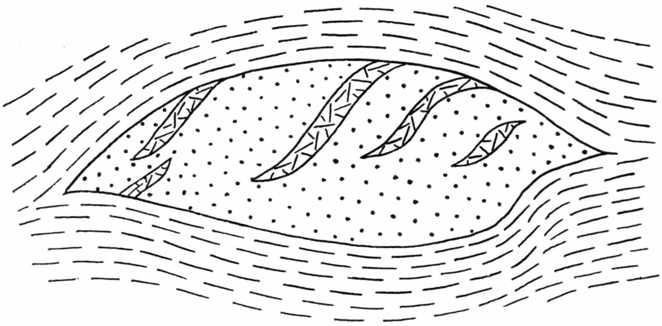

Fig. 21. Rolled-out lentil of greenstone (stippled) with "Fiederklüfte" structure in garnet-staurolite schist. The "Fiederklüfte" fissures are filled with quartz (plagioclase)-pegmatitic material (homogenous hatching). Length ab. 1.5 meter.

$$\alpha' \wedge (001) = \div 63.5$$
$$\alpha' \wedge (001) = \div 63.5$$
$$\alpha' \wedge (001) = \div 65.5$$

and, correspondingly,

$$\alpha \wedge (010) = +25.5$$

which, according to K. Chudoba (1932), corresponds to ab. 45 $^0/_0$ An. The angle of extinction

$$\alpha \wedge (001) \perp \gamma = \div 12 = 42\ ^0/_0\ \text{An.}$$

Finally, a dark brown biotite should be noted which occurs sparingly in large flakes together with small quantities of chlorite.

The paragenesis of pegmatite seems to be in perfect equilibrium with the complex. It is typical that quartz is the predominant mineral and often the only mineral present. Potassium feldspar was not observed anywhere. In composition the plagioclase is placed between the extreme values determined by the staurolite plagioclase and the peripheral parts of the greenstone plagioclases. Their value is not constant but seems to vary occasionally. The 18—20 $^0/_0$ An in the pegmatites may be explained as a composition arrived at by closer association with the staurolite schist which presented a similar composition of the plagioclase. The 42—45 $^0/_0$ An elsewhere may be connected with the greenstones. However, this interdependence does not seem convincing, as the pegmatites with the apparently random composition sometimes are associated with the schists and sometimes with the greenstones. The only regular feature of their plagioclase composition seems to be that this always lies in the interval between staurolite-schist plagioclase and greenstone plagioclase (peripheral). If the pegmatites were assumed to be magmatic injections of residuary solutions from the original magma of the greenstones, there should be evidence of such a process. During their progress to the occurrence they would somehow have come in contact with schist series rich in potassium and aluminium. They must then inevitably have picked up material for the formation of potassium feldspar. This mineral, however, does not occur despite an abundance of quartz. If they were magmatic differentiation products, tourmaline and other minerals with volatile components should be expected, but they do not occur. As mentioned in connection with the schists rather large concentrations of tourmaline were observed. This mineral was connected with deposits containing aluminium, supplied with boron from the sea water and consequently not originating from pegmatites. As shown in Figs. 21 and 22 the pegmatites have, very typically, invaded fissures and defective zones. That magmatic pegmatites should do so seems highly improbable.

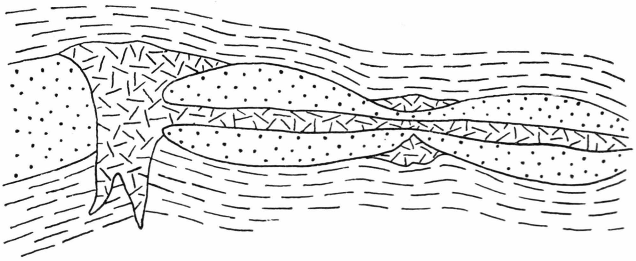

Fig. 22. Thin layer of greenstone (stippled) rolled out with boudins in garnet-staurolite schist. Protruding quartz-plagioclase pegmatite marked with homogenous hatching. Actual length ab. 35 metres.

They are much more likely to have been formed in connection with the course of recrystallization which took place in the greenstones. Great transformations of material took place in the greenstones during both processes, both where the original plagioclase (55 $^0/_0$ An norm.) recrystallized with max. 30 $^0/_0$ An and where the inverse zonary plagioclase was developed. In the transformation Ca has been a chief component in the reciprocal transformations between plagioclase, zoisite and hornblende. The details of the mechanical process of the transformation are not important for our understanding of the transformation whether it has been a partial melting with the formation of a semifluid phase or a migration in a more solid phase. Twice during the development of the greenstones an exchange of calcium from one mineral to the other took place, and so it is highly probable that a quantity of calcium has not migrated directly to another mineral but towards potential low-pressure areas as shown by the illustrations. This explains why the pegmatites occur just in these typical places, and why the development always resulted in plagioclase. The composition of plagioclase which, although varied, always keeps within the regular limits is also explained by the same theory. How large an amount of calcium is liberated during the transformations and how much reaches its "destination" will be accidental. It also makes the formation of pegmatites probable both during the first and the second (or at any rate the last) phase of the development of the greenstones. A pegmatitic plagioclase with 40—45 $^0/_0$ An would hardly have been developed during the first stage. As demonstrated by I. Rosenqvist (1942) the solubility of aluminate ion decreases when the pressure is reduced. As that was the case during the last phase, conditions have been favourable for the pegmatitic plagioclase. One might ask why potassium feldspar was not formed in the same way. The answer must be that the temperature was never sufficiently high for potassium to be activated into the formation of feldspar.

During the transformations the state of the greenstones was presumably semifluid, and the crystals were tightly packed in some solution. The abundance of quartz in the pegmatites points to such hydrothermal conditions and so does their occurrence in low pressure zones and fissures. But, on the other hand, such an assumption might lead us to expect that the series had been more damaged than is the case. The two series are widely different and not equally susceptible to metamorphism. The schists are definitely slower at adopting a high degree of metamorphism than the greenstones. But this does not facilitate our understanding of a high remelting of the greenstones without a marked effect on the schists. The pegmatites have doubtless obtained their material by more gentle processes. Either circulating aqueous solutions at a temperature of a few hundred centigrades have been the means of transportation, or the transport of material has been a migration in the solid state at a temperature suitable for activation.

SUMMARY

The field investigated consists of some islets in the skerry archipelago of the southern Disko Bugt on the west coast of Greenland. It belongs to the northern flank of the pre-Cambrian Nagssugtoq orogen in which the gneissification has reached a stage where a determination of the original nature of the primary material often is difficult if not impossible. The metamorphism of the rocks of the archipelagic field is so slight that a fairly accurate determination of their genesis is possible. In many cases the original sedimentogenous nature is immediately apparent.

The islands contain two main groups of rocks of widely different origin, a magmagenous series of greenstone and a sedimentogenous series of mica schists.

The data of the mutual connexion between the archipelago and the more southerly gneiss complex may be grouped under two main headings, structure and petrography. Of these the first group seems to indicate that the area is a "loose element" in the orogen, as there is great lack of structural conformity between the archipelago and the gneiss complex in the south. The other group justifies the assumption that a thermal front has oscillated whereby great differences in regional thermal metamorphism may exist within very limited areas. These circumstances should bring the archipelago in closer connexion with the gneiss complex. However, no definite statement can be given owing to insufficient investigations in the field. The following seems to prove that we are dealing with flank formations in the geosynclinal: The degree of metamorphism is lower than in the gneiss complex farther south, the folding is, different and peculiar to the islands, in one place probably a relic of a cross bedding structure and, finally, a single grain of sand was found in a quartzite.

The greenstone series, which is of magmatic origin, has intruded into the sediment series. A distinction has been made between two types of intrusions: sills and phacolites, but between these two main types all stages of transition exist. The time of the intrusion is apparently synkinematic, but one or two features might indicate a pre-kinematic in-

trusion. In the description the sedimentogenous rocks have been divided into two main groups according to their degree of metamorphism. On the westernmost island groups, Anarssuit and Isuamiut, garnet-mica schists and quartzite occur. The mineral assemblage is grouped round variations of the assemblage garnet, chlorite, muscovite, biotite, grunerite and quartz, albite and scapolite. The primary material of the schists is presumably Ca-deficient clay deposits with ab. 5 $^0/_0$ K_2O. The sources of derivation has most likely had a granitic composition. There are certain indications that the transformations did not involve major metasomatic changes. The principal line of development of the schists seem to have been this: A recrystallization has begun before the injection of magma, whereupon a folding phase of early "garnet-syngarnet" age has been active, and, finally, a deformation after the grunerite stage with formation of scapolite has taken place. Other traits of development have been mentioned, but a correlation has not been possible. Certain structural characteristics indicate that garnet is less affected by stress than generally assumed. Further, scapolite seems to occur on an equal footing with albite. Eqûtit, the easternmost group of islands, deviates from the others by presenting a somewhat different mineral assemblage, a growth of garnet-staurolite-oligoclase-muscovite schists. The structures of these islands emphasize the stress paragenesis. Here, too, are signs—although doubtful—of recrystallization before the time of intrusion. Garnet has the same composition as on the other islands with a lower degree of metamorphism. The occurrence of oligoclase may have two reasons. As shown by F. J. TURNER, it may be due to stress on one side, but may also be determined by the equilibrium conditions. The assemblage is characterized by a deficiency in Al_2SiO_5-minerals which is explained by the abundance of muscovite. On basis of the theory advanced by BARTH and TURNER that water occurs on equal terms with the other oxides, water is assumed to play an important part in the selection of the mineral assemblage. Given sufficient water staurolite but not Al_2SiO_5-minerals are developed, and conversely with insufficient water. This view is confirmed by a chemical analysis entered into a tetrahedron diagram which also serves to illustrate the occurrence.

The intrusive link in the complex is formed by greenstone (clinozoisite-plagioclase amphibolites). A description of the greenstones is given and evidence of their magmatic origin submitted, which is supported by cooling columns, basaltic chemical conditions, uralitic amphiboles, basaltic spec. gravity, contact metamorphism in the schists, and phacolite bodies. The course of development is described, the principal features being: An equilibrium plagioclase with max. 30—40 $^0/_0$ An was formed at increasing pressure and falling temperature, whereupon the left-over Ca was used for amphiboles and clinozoisite. The second half of the course of development involves rising temperature and reduced pressure (perhaps the phase during which the staurolite schists were developed?). During this process an inverse zonary plagioclase with a maximum peripheral An-content of 55—60 per cent was developed. Two chemical analyses of the greenstones have been entered in an ACF-diagram drawn up according to earlier amphibolite facies and epidote-amphibolite facies. Clinozoisite and plagioclase are in equilibrium as two independent minerals, which is a confirmation of examinations under the microscope. With H. Ramberg's new limit to amphibolite facies and epidote-amphibolite facies with a composition of plagioclase of 30 $^0/_0$ An as basis, the greenstones are assumed to be in amphibolite facies and with facies higher in the east than in the west. The structure is characteristically in harmony with the position of the facies.

The last chapter deals with the few pegmatites of the area. They are supposed to be "residual products" preferably from the recrystallization of the greenstones. They are quartz pegmatites with a little plagioclase of varied composition. Despite a large content of potassium in the schists and an ample supply of quartz, potassium feldspar was not demonstrable.

POSTSCRIPT

The present work was completed in the spring of 1951, but for various reasons publication was unfortunately delayed until now. During the three years that have elapsed since its completion, investigations of the West Greenland geology have progressed, and certain points in the book do not quite represent the author's view of the problems to-day. As the area discussed cannot be re-examined in a not too distant future, the present work with its limitations is submitted as a description of the area, on which a future, more detailed field investigation may be based.

Copenhagen, January, 1954. K. Ellitsgaard-Rasmussen.

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Færdig fra trykkeriet den 20. maj 1954.