On the Petrogenesis of the Gneiss Complexes between Sukkertoppen and Christianshaab, West-Greenland.

Preliminary Report

By

HANS RAMBERG.

Introduction.

In 1946 Grønlands Geologiske Undersøgelse[1]) began the systematic geological researchwork in West Greenland; from the very beginning dr. H. RAMBERG took over a leading part in the investigations concerned with the pre-Cambrian crystalline basement. Of course, after not more than a couple of years of field work, only rough outlines of the pattern of this immense area can be pictured; non the less we have decided to issue this short report on the progress of the investigations. Various parts of the material are at present being worked out by other members of the expeditions; the significance of the coming smaller papers and their relation to the structure of the whole gneiss complex can better be imagined when a short general—though yet preliminary—report is at hand:

Before leaving for the summer work in 1948 dr. RAMBERG has sent me the following preliminary report—on the 1946 and 47 work—on the petrogenesis of the gneiss complexes between the settlements Christianshaab and Sukkertoppen where our activity has been concentrated in main.

Being responsible for that part of the work of GGU which deals with the pre-Cambrian basement rocks in West Greenland, I took the opportunity at the International Geological Congress in London this year to introduce our work; this introduction was to a large extent based on the following paper by dr. RAMBERG which herewith is offered to geologists who are specially interested in this part of the world and/or this complex of problems.

ARNE NOE-NYGAARD.

Abstract.

The investigation treated in this paper was carried out under the auspices of the GGU[1]) and comprises the region between 66° and 69° n.l.

[1]) Geological Survey of Greenland, abbr. GGU.

in West-Greenland. Here two old chains of folded mountains have been recognized in the pre-Cambrian crystalline basement. They are separated by a period of widening and dyke injection. The older chain, designated the "Kangamiut complex" is likely to belong to the "Ketilidian" epoch of WEGMANN, the younger has been termed the "Nagssugtoqides"; its folding axes strike NE-SW. What is known of the Nagssugtoqides may be divided in three main zones according to degree of regional metamorphism: (1)A southern gneiss zone belonging to amphibolite and epidote-amphibolite facies (the Ikertoq complex), (2) a central one, belonging to granulite facies (the Isortoq complex), and (3) a northern zone also belonging to amphibolite and epidote-amphibolite facies (the Egedesminde complex).

Grønlands Geologiske Undersøgelse has now mapped and undertaken geological investigations during two summers (1946 and 1947) in the gneiss area between Sukkertoppen and Christiånshaab in West-Greenland. It will require several years to give detailed descriptions and thorough interpretations of the great amount of data and samples which thus have been gathered in the field and laboratories, not only because this particular area comprises a great number of interesting rocks and geological phenomena, but also because the processes which form rocks of these types, viz. gneisses, migmatites, pegmatites, etc., are by no means fully known in general. For these reasons a very brief summary of the results arrived at hitherto will be presented.

The area in question comprises two folded chains of apparently pre-Cambrian age (fig. 1). During these periods of orogeny the gneisses and their vein segregations have received their present structure and mineral associations, and partly also their bulk chemical composition.

The oldest of the two chains is situated south of a definite demarcation zone extending east- and south-eastward along the fiord Itivdleq, north of the mouth of the well-known fiord Søndre Strømfjord or Kangerdlugssuaq (in West-Greenland). This boundary zone which exhibits structure indicating intensive plastical and ruptural motion in the solid rocks, crosses the fiord Kangerdlugssuaq at Itivdlinguaq, and continues farther south-eastward. In this zone, along which the two folded chains are welded together, are frequently encountered soapstones and related rocks of considerably lower degree of metamorphism than that in the surrounding gneisses. However, the demarcation zone does not seem to be a continuous zone of low degree of metamorphism. So, for instance, along the fiord Itivdleq the very intensive plastical and ruptural deformation has in part taken place not significantly below the degree of temperature of metamorphism to which the adjacent gneisses belong.

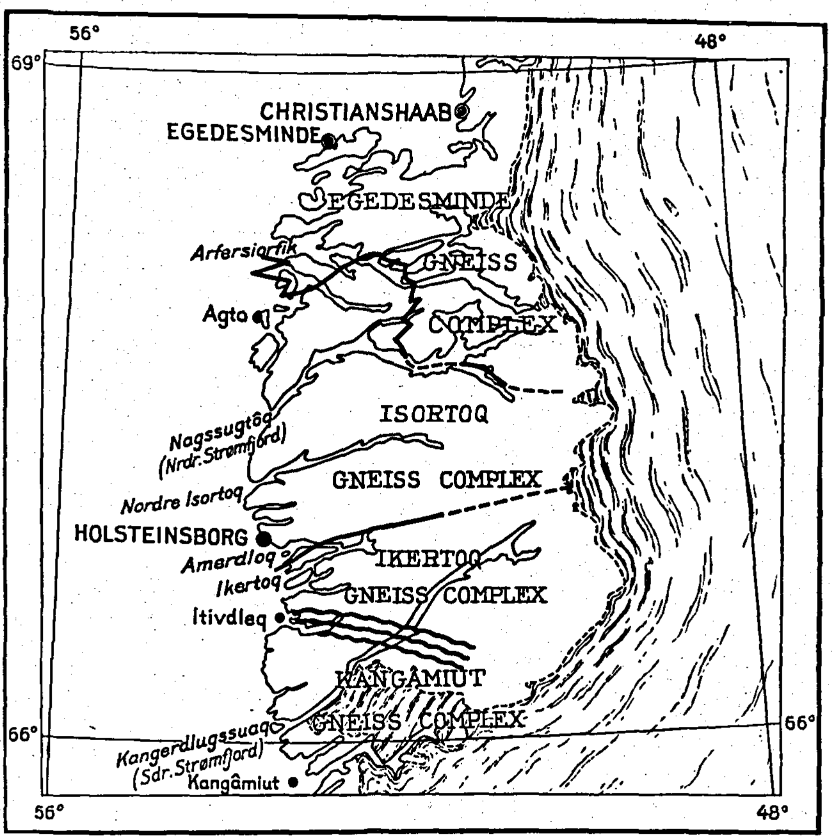


Fig. 1. Sketch map showing the different metamorphic facies of the Nagssugtoqides in West-Greenland. The Egedesminde gneiss complex and the Ikertoq gneiss complex are formed in amphibolite and partly epidote-amphibolite facies. The Isortoq gneiss complex is formed in granulite facies. The boundary zone between the old Kangâmiut complex and the younger Nagssugtoqides is also indicated.

The northernmost part of this oldest chain consists of the so-called "Sukkertoppen granite" which correctly is a hypersthene-bearing quartz-dioritic gneiss, usually very poor in potash feldspar. The last-mentioned mineral occurs almost solely in the form of antiperthitic inclusions in the andesinic plagioclase. In other words, the Sukkertoppen granite is an enderbitic gneiss. To the south this enderbitic gneiss complex extends to a little south of the colony Sukkertoppen, whereas its extension to the east is still uncertain.

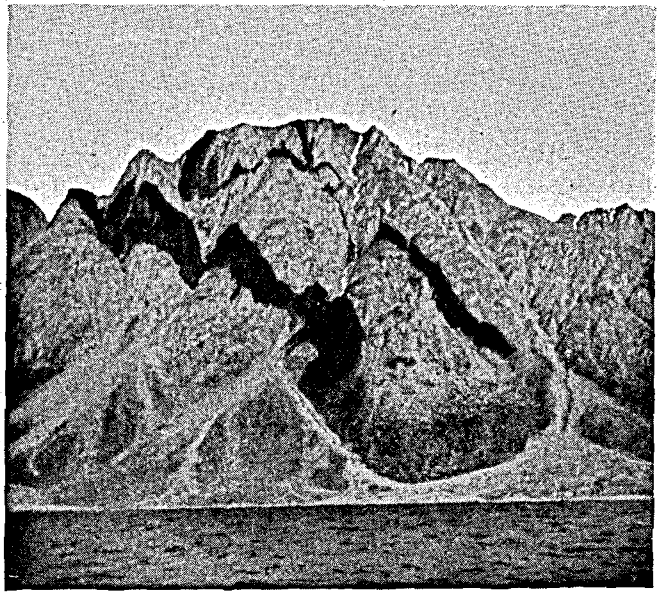
As the outpost Kangâmiut is situated in the middle part of the above-mentioned complex which is so typical that it should have its own name, let us call it the "Kangâmiut complex". The main strike in the Kangâmiut complex is about SW-NE, and the dip is usually quite steep. The Kangâmiut complex is full of basic inclusions, bands, boudins, and remnants of hypersthene-bearing amphibolites. Only in a couple of cases is encountered marble, which of course is highly altered. Rusty zones containing pyrite and grains of graphite along with garnet are quite common indicating that sedimentary material is intermingled in the complex. However, as a whole the Kangâmiut complex is rather homogeneous and remnants of obvious sedimentary origin such as mica-schist, quartzites, khondalites or kinzigites are rare.

Conformable and cross-cutting pegmatites, often containing small amounts of rhombic pyroxene, are rather typical features of the Kangâmiut complex.

A thick swarm of vertical diabase dikes interject the complex in south-westerly direction.

It is reasonable to believe that the Kangâmiut complex and the heterogeneous gneisses south of it, for instance around the fiord Søndre Isortoq, belong to the same period of orogeny, because the main strike and the folding axes are parallel in the two areas. The same swarm of diabase dikes which cut the Kangâmiut complex, and which in this paper will be called the Kangâmiut diabases, occur also in the gneisses to the south. Indeed, diabase dikes of post-metamorphic age are frequent in this part of Greenland and are found along the whole coast south to Godthaab, Ivigtut, and Julianehaab. Thus, provided that these dikes are injected during the same period of time, we have an upper age-limit of the orogeny (or orogenies) which formed the gneisses. However, the extension to the south of the folded chain to which the Kangâmiut complex belongs is not yet determined. It is not unlikely that the Kangâmiut complex belongs to the Ketilidian orogeny of South-Greenland (C. E. WEGMANN).

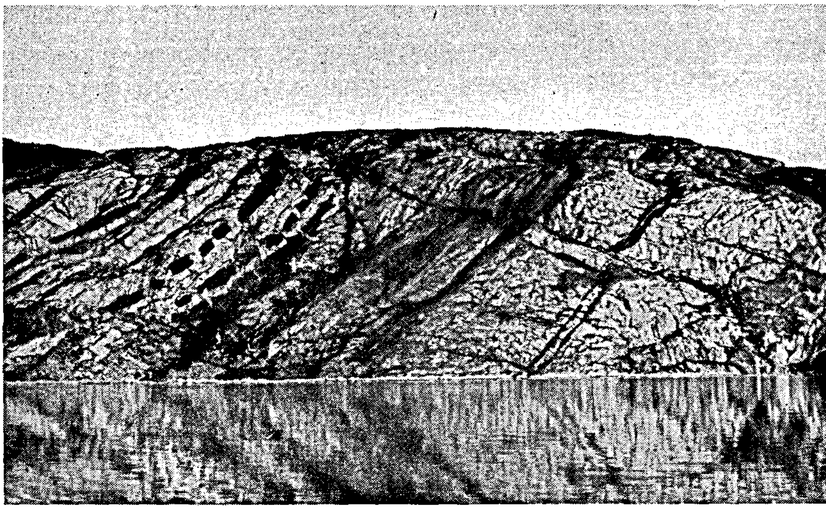
The Kangâmiut complex is formed or at least recrystallized and metasomatically altered under regional metamorphic conditions corresponding to granulite facies. Farther south along the coast amphibolite facies and epidote-amphibolite facies prevail, although locally the P,T-conditions have reached up to granulite facies for sillimanite and hypersthene are developed in some gneisses.



N-N. phot.

Fig. 2. Outer part of Søndre Strømfjord. Kangâmiut diabases as cross-cutting dykes.

The gneiss area extending north of the Kangâmiut granulite facies complex up to Jacobshavn has been more thoroughly investigated both in field and laboratory. The whole region belongs to a period of orogeny definitely younger than the period during which the Kangâmiut gneiss and the gneisses south of this were formed (the Ketilides?). The northernmost chain in question is even younger than the Kangâmiut diabase swarm, because these diabases have participated in the orogenic deformation which gave rise to the gneiss formations north of the Kangâmiut complex. When one is sailing in through the long fiord Kangerdlugssuaq it is amazing to see how the originally "young" cross-cutting Kangâmiut diabases (fig. 2) gradually begin to take part in the plastical deformation of the gneiss. The diabases are folded, recrystallized into amphibolites, affected by metasomatism, and broken into large boudins (fig. 3). At the same time pegmatites begin to develop in the fissures which opened up in the rather rigid altered diabases. A metamorphic differentiation also took place in such a way that the central part of the diabases was altered into a rather coarse-gained grey-colored rock of biotite, plagioclase and quartz,



N-N. phot.

Fig. 3. Inner part of Søndre Strømfjord. Boudinage in the Ikertoq gneiss complex.

whereas the margins continued to be a dark amphibolite. This chemical process took place long before the plastical creep in the country gneiss was able completely to develop a conformable structure with the altered diabases. Indeed, remnants of cross-cutting structure can be traced long after the diabase has undergone a rather thorough amphibolitization and biotitization, and in that way several amphibolite layers in the re-activated gneiss in Kangerdlugssuaq and Ikertoq can be traced backward into the Kangâmiut diabases.

During the orogeny the main structure of the re-activated gneiss was partly controlled by the thick swarm of Kangâmiut diabases. So, the main foliation of the newly formed gneiss is partly turned into the original strike of the diabase swarm. On the other hand, however, the orogenic motions were also able to turn and fold the rigid swarm of diabases. The longer the distance to the east and north from the old Kangâmiut complex with its fresh diabase dikes, the less the structurally-controlling effect of the gradually more and more altered diabases.

There is no reason to doubt that a great part of the "young" gneiss in the internal parts of Kangerdlugssuaq and around the fiord Ikertoq, which encloses remnants of the Kangâmiut diabases, itself is a metamorphosed variety of the Kangâmiut gneiss, or at least of gneisses belonging to the same old orogeny as the Kangâmiut complex.

Remnants of cross-cutting structure of the altered diabases are now and then seen as far north as Amerdoq. Farther north—between Holsteinsborg and Egedesminde—no discordance in the amphibolite layers is encountered except at one locality in Arfersiarfik. (In the vicinity of Egedesminde a couple of fresh post-orogenic diabases occur. These must of course be much younger than the Kangâmiut diabases and it is likely that they constitute the feeding channels of the Disko basalt formation).

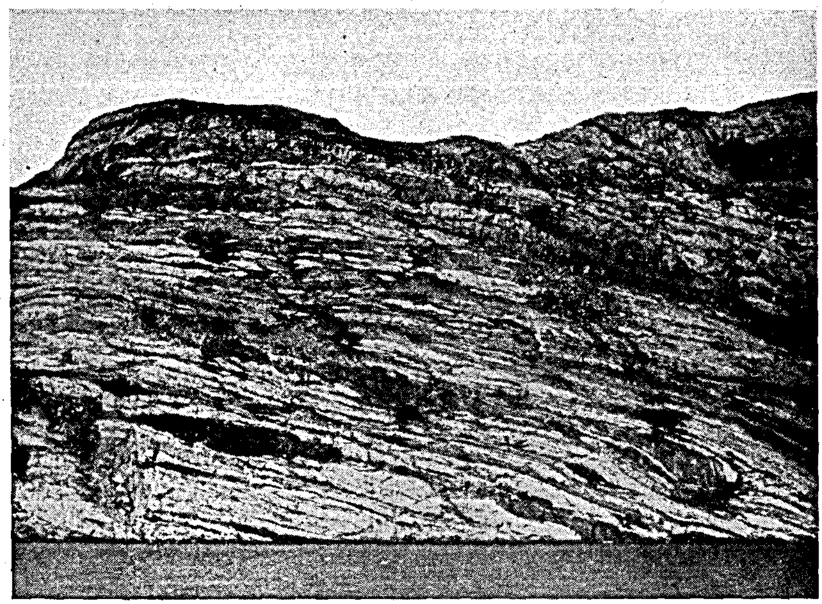
The long and branched fiord Nagssugtôq is situated in the middle part of the folded chain of post-Kangâmiut diabase age. In this fiord the most excellent exhibitions of folds and other tectonic deformations are found. Let us therefore give this pre-Cambrian folded chain the name: the Nagssugtoqides.

The Nagssugtoqides are folded around NE to SW-striking axes. Between Kangerdlugssuaq and Nordre Isortoq the axis is constantly plunging toward the southwest. In Nordre Isortoq the axis plunges toward the east, and farther north the axis is horizontal or plunges partly to the east, partly to the west.

The hitherto known part of the Nagssugtoqides is most conveniently divided into three main zones depending on the degree of regional metamorphism, viz.: one southern zone of gneisses belonging to amphibolite and epidote-amphibolite facies, a middle zone belonging to granulite facies, and a northern zone also belonging to amphibolite and epidote-amphibolite facies (see the map).

The southern zone is situated between the northern boundary of the old Kangâmiut complex and the fiord Amerdloq south of Holsteinsborg. The northern boundary of this zone, which here will be called the Ikertoq gneiss complex, is nearly comformable to the strike and extends eastward along the fiord Amerdloq and further east toward the Ice Cap.

The middle zone of granulite facies gneisses is about 150 km broad in its western part along the coast, extending across the strike from Amerdloq to Arfersiorfik south of Egedesminde. Toward the east this zone is considerably narrower because its northern boundary extends southeastward from the mouth of the fiord Arfersiorfik, and crosses the interior parts of the fiord Nagssugtôq at Kujakua. Thus the northern boundary crosses the main strike which here is E-W or SW-NE. Although this middle granulite facies zone has not



N-N. phot.

Fig. 4. Inner part of Søndre Strømfjord. Ikertoq gneiss with lenticular amphibolite.

yet been followed in the field toward the Ice Cap, occurrences of erratic boulders indicate that granulite facies actually extend to the Ice Cap.

After the fiord Isortoq, where the degree of metamorphism reaches a maximum, this middle zone of the Nagssugtoqides will be called the Isortoq gneiss complex.

North of the Isortoq gneiss complex one finds the Egedesminde gneiss complex, which in the form of amphibolite and epidote-amphibolite facies gneisses is followed across the strike at least north to the ice fiord of Jacobshavn.

The main picture of the Ikertoq and the Egedesminde gneiss complexes is rather similar. A granodioritic gneiss carrying biotite, and often common green hornblende and/or epidote, is the main rock in both complexes. Often its composition approaches a potash granite; more rarely it changes into a quartz dioritic gneiss. In this gneiss are included bands, boudinages, and other remnants of amphibolitic composition. More rarely ultrabasic old rocks are included.

Particularly in the Ikertoq gneiss rusty sedimentary bands containing pyrite and graphite are very frequent. In the same complex also a few occurrences of remnants of marble are encountered. So far no marble has been found in the Egedesminde gneiss[1]). On the other hand the Egedesminde gneiss contains rather broad zones of albite-porphyroblastic schists, which are particularly well developed around the outpost Ikamiut. Similar rocks are not encountered in the Ikertok gneiss. The typical staurolite-andalusite-garnet-schist developed on the islands Equtit near Egedesminde seems also to be foreign to the Ikertoq complex, as do the volcanic greenstones which occur on the island Ujaragtafik, northeast of Egedesminde.

Another difference between the Egedesminde gneiss and the Ikertoq gneiss is that the latter is considerably richer in amphibolitic bands with partly-preserved discordant structure. These amphibolitic bands are deformed remnants of the Kangâmiut diabases. In the northern part of the Ikertoq gneiss complex young cross-cutting kersantitic dikes are rather frequent, a type of rock not hitherto encountered in the Egedesminde gneiss.

A great number of well-developed pegmatites occur in both the Ikertoq and the Egedesminde complexes. These pegmatites are of different composition, form, size, and structure and are at the present object for a more thorough study. Potash feldspar, acid plagioclase and quartz are the main minerals which occur in varying relative amounts in the different pegmatites. Biotite, garnet, and hornblende are frequent minerals. Diopsidic pyroxene is now and then encountered, whereas the common pegmatite mineral muscovite is very rare in the pegmatites thus far investigated from the two gneiss complexes in question. Beryl and orthite are found in some pegmatites, though as a rule the pegmatites seem to be poor in "rare" minerals.

The Isortoq complex in the middle part of the Nagssugtoqides is a very interesting formation of gneisses. The main rock here is a hypersthene-bearing quartz diorite of the same type as the main gneiss of the Kangâmiut complex; yet the two complexes have no genetic connection, since they belong to different folded chains.

---

[1]) In the summer 1948 some occurrences of marble were found in the Egedesminde gneiss.

The enderbitic gneiss in the Isortoq complex may be rather homogeneous over comparatively wide areas, but usually it is full of schlieren, inclusions and boudins of hypersthene-bearing amphibolites. Thus the enderbite has a typical gneissic feature although at some locations it exhibits a rather massive structure of "magmatic" character. By help of different mineralogical, structural, and field criteria, however, it is proved that the enderbitic hypersthene-bearing gneiss was formed during re-crystallization in solid state in the course of the Nagssugtoqidian orogenesis.

Referring to the mineral association in the enderbitic gneiss, it might be mentioned that minerals such as garnet (very poor in MnO), brownish titaniferous hornblende, and diallage are often present in different amounts. Only in rare cases is potash feldspar developed as independent grains, giving the gneiss a mangeritic or charnockitic composition.

Besides thus representing a definitely higher degree of metamorphism than the Ikertoq or the Egedesminde granodioritic gneisses, the main gneiss of the Isortoq complex has also a bulk chemical composition *different from the two above-mentioned gneiss complexes.* The main enderbitic gneiss in the Isortoq complex is poor in potash, it is poor in water, and the $Fe^{\cdot\cdot\cdot}/Fe^{\cdot\cdot}$ is small as compared with the main gneiss in the Ikertoq and Egedesminde complexes.

In addition to the smaller bands and inclusions of basic rocks in the enderbitic gneiss there are now and then encountered rather large bodies of recrystallized basic rocks containing hypersthene, diallage, brownish hornblende, plagioclase, etc. These bodies may in a few cases still exhibit remnants of discordant instrusive structure, although the main rule is that they now are completely in conformity with the surrounding gneiss.

At a couple of localities small gneissous massifs of potash-rich hypersthene granite or biotite granite occur. These bodies appear to be instrusive into the enderbitic gneiss; but we have evidences for their being partly emplaced in the form of plastically moved crystalline masses, partly by sub-magmatic metasomatic diffusion of potassium, sodium, and silicon.

In the Isortoq complex of granulite facies gneisses, sillimanite- and garnet-rich graphite-bearing gneisses are common. At Utokrat in Amerdloq, in the fiords Isortoq and Nagssugtôq, and southeast of Agto, such gneisses of khondalitic affinity are frequent. In Nagssugtôq, cordierite joins the sillimanite and garnet, thus giving rise to kinzigites. It is interesting to note that these alumina-rich rocks usually are much richer in potash feldspar than the hypersthene-bearing gneisses.

Rusty zones rich in pyrite, graphite, and often garnet and biotite are commonly found among the kinzigites and khondalites, but also in the pure enderbite gneiss.

In the fiord Amerdloq, in Isortoq, and especially in Nagssugtôq, a number of extensive layers of coarse-grained marbles are beautifully exhibited. These marbles, which often are more or less metasomatically altered into diopside-scapolite skarn and which develop a great number of "reaction" minerals, are also connected with the kinzigitic and khondalitic gneisses. At some locations the newly-formed rigid lime-silicate skarn is broken into pieces which successively are distributed in the more plastic surrounding quartzo-feldspathic gneisses, just as is the case with the rigid amphibolites of diabasic origin.

Pegmatites are numerous in the Isortoq gneiss complex, though they are not so frequent nor so typically developed as in the Egedesminde and Ikertoq gneiss complexes. The reason for this is interpreted as a pressure effect: fissures and other places of low rock pressure favouring formation of pegmatites do not form so easily under the conditions which must have prevailed in the deep-seated granulite facies complex during the formation of the Nagssugtoqides.

Besides the major constituents, potash feldspar, plagioclase, and quartz, are garnet, hypersthene, biotite and ilmenite ore common minor minerals in the pegmatites. In the graphite-bearing khondalitic gneiss the pegmatite develops flakes of graphite. When occurring in skarn or marble, diopsidic pyroxene, sphene, scapolite and hornblende become typical constituents of the pegmatites. Garnet and cordierite are crucial minerals of the pegmatites encountered in the cordierite-garnet gneisses in Nagssugtôq.

After this very brief summary of the result of the descriptive part of the investigations in West-Greenland, we will shortly mention the result of our interpretation of the formation of these gneisses and their pegmatitic segregations.

Firstly, it is clear that the Nagssugtoqides are formed by orogenic deformation of a geosyncline which extended in east-westerly direction north of the Kangâmiut complex. Or perhaps more correctly: the present remnants of this geosyncline and its folded chain are now, as far as we know, only found north of the Kangâmiut complex.

The connection between the geosyncline and the Kangâmiut diabases is not clear, but it is not unlikely that these diabases represent the feeding channels for the geosynclinic basalts of the Nagssugtoqidian geosyncline. Parts of the intensively metamorphosed basic layers throughout the Nagssugtoqidian gneisses must be considered remnants of such basalts, although in the present intensively altered area no remnant of volcanic structure has yet been found. Low metamorphic greenstones connected with low-grade schists on islands north of Egedesminde may be interpreted as altered basic lavas.

It seems evident that most of the altered limestones, aluminous sediments (kinzigites, khondalites), and mud (rusty pyrite- and graphite-bearing zones) are remnants of the sediments of the Nagssugtoqidian geosyncline. However, on the the other hand it is not unlikely that some of the most altered and agmatitized inclusions of e.g. skarn rocks in the Nagssugtoqidian gneiss are sediments from an earlier period of orogeny. The old Kangâmiut complex also contains remnants of marbles and rusty pyrite, graphite-bearing zones; and as field studies show that the southernmost part of the Nagssugtoqides (the Ikertoq gneiss) is re-activated Kangâmiut gneiss, it is reasonable to believe that some of the old sedimentary inclusions of the Kangâmiut complex have survived the Nagssugtoqidian orogenesis.

This re-activating in amphibolite and epidote-amphibolite facies of the old granulite facies Kangâmiut gneiss is interesting. In spite of the seemingly great mobility during the re-activating,—e.g. the petroblastic growth of pegmatites and the intensive agmatitization and migmatitization of the diabases,—it can definitely be shown that no anatectic or palingene magma has been able to form during the process. Sub-magmatic reactions in the crystalline complexes have given birth to the whole picture.

It is remarkable that obvious sedimentogeneous metamorphic rocks are only sparsely distributed among the Nagssugtoqidian gneisses. It is likewise remarkable that the typical sedimentary rocks, such as the rusty graphite-bearing zones and the sillimanite-garnet-bearing khondalites, are developed in the form of rather thin but very extensive folded layers among the rather homogeneous quartzo-feldspathic gneisses.

Worthy of note also is the lack of quartzites throughout the hitherto investigated Nagssugtoqidian gneisses. Only small remnants of quartz-rich gneisses can be traced backward into quartzites.

The question arises: where at the present time are the thick geosynclinal sediments? The answer seems to be that the greatest part of the old sediments is now camouflaged in some of the different quartzo-feldspathic gneisses.

Only here and there do graphite, cordierite, sillimanite and great concentrations of garnet indicate the sedimentogeneous character of the gneisses. Scapolite, sphene and great concentrations of diopside in some of the amphibolites indicate that there originally was a greater amount of limestone among the Nagssugtoqidian sediments than what is now present in the form of rather pure marbles.

It is a reasonable assumption that during a period of orogeny here and there the temperature exceeds the melting-"point" of quartzo-feldspathic rocks, so that anatectic melts are formed. These melts should then give rise to the most homogeneous and massive parts of the granodioritic gneiss and should also give birth to the regionally distributed pegmatites. This theory, however, has not been very successful in the explanation of the Greenlandic pegmatites and the "magmatic"-looking homogeneous part of the gneiss. A detailed study of the structures and the mineral stabilities has forced me to the conclusion that the pegmatites are formed by metamorphic-metasomatic processes without participation of silicate melts of any kind. They are metamorphic segregations formed by diffusion of atoms, ions or molecules through the solid rocks during the Nagssugtoqidian orogeny. However, the detailed discussion of this interesting theme is outside the aim of this short paper.

With reference to the more massive parts of the quartzo-feldspathic gneiss it can be shown that they are formed in different manners: (1) recrystallization under confining pressure of old homogeneous rocks; (2) emplacement of quartzo-feldspathic material in the form of plastically "creeping" crystalline aggregates; (3) metasomatism by diffusion of energy-rich elementary particles through the complexes.

As a whole, one of the most interesting results of the study of the Nagssugtoqidian gneisses is that one can prove that the whole picture—including the pegmatites and the massive parts of the gneisses—has developed during sub-solidus metamorphic-metasomatic processes. That is so because hydrous granitic melts were not able to exist and move through the crust under the orogeneses. Even at the highest temperature developed in the regional-metamorphic area—viz. in the granulite facies gneisses of the Isortoq complex—

granitic silicate melts were unable to develop and form pegmatites. (A general paper discussing more thoroughly the formation of pegmatites and quartzo-feldspathic massifs in folded chains is now in press in the "Journal of Geology".).

During the Nagssugtoqidian period of orogeny the middle part, viz. the Isortoq complex, was formed and re-activated in granulite facies, which are the highest P, T conditions developed in regional-metamorphic areas. The Ikertoq complex to the south, and the Egedesminde complex to the north were formed in lower facies—in epidote-amphibolite facies and in amphibolite facies.

So, the Isortoq gneiss complex was formed at somewhat lower levels in the crust than the marginal complexes to the north and south. Because large-scale diffusion evidently was an important factor in the whole story of the Nagssugtoqidian orogeny, one must expect that the different positions in the gravitational field of the granulite facies complex and the Ikertoq and Egedesminde complexes gave rise to a vertical diffusion of elements between the complexes. Elements with low fictive density or great affinity to minerals, or rock-forming liquids with low density, had a tendency to diffuse from great depths to higher levels. Elements with high fictive density or strong affinity to dense phases tended to diffuse downward. (The main principles of diffusion in the gravitational field were discussed in this Journal a year ago).

H_2O was squeezed out of the mineral lattices in the deeply-buried Isortoq gneiss and forced to diffuse toward higher levels. Therefore hypersthene, garnet and sillimanite developed at the expense of hornblende, biotite and muscovite in the Isortoq complex. Epidote, hornblende, biotite, muscovite and other hydrous minerals developed in the superincumbent Ikertoq and Egedesminde complexes[1]).

For the same reason the large atoms of potassium, which in addition is strongly bond in the light potash feldspar, was squeezed out of the Isortoq gneiss, leaving preferably enderbitic rocks here. The upwardly diffusing potassium consolidated at higher levels giving rise to granitic and granodioritic gneisses in the Ikertoq and Egedesminde complexes. Only under particular conditions was potassium able to concentrate in the granulite facies complex: viz. (1) potas-

[1]) To be sure, the effect of gravitative diffusion was by no means the sole cause for the development of hydrous minerals in the amphibolite facies and anhydrous minerals in the granulite facies complex. Temperature worked in the same direction because it was high in the granulite facies and lower in the amphibolite facies.

sium migrated into fissures and other places of low mechanical pressure, giving rise to much greater concentrations of potash feldspar in the pegmatites than in the country enderbitic gneiss; (2) the potash feldspar was concentrated in rocks with high concentration of alumina (kinzigites and khondalites), due to the law of mass action.

Chemical analyses show that the average degree of oxidation is higher in the Ikertoq and Egedesminde rocks than in the Isortoq gneiss. That is due to the chemical squeezing out of the light and large atoms of oxygen at deep levels, and the tendency of upward migration of this element.

Sodium and silicon also show a tendency to diffuse upward in the gravitational field. Referring to sodium, however, this element is also strongly bond in plagioclase, which has a higher density than potash feldspar. Thus plagioclase is stable at considerable depths in the crust, where it forms large bodies or layers of anorthosites. Therefore, sodium did not tend to diffuse up from the Isortoq complex with the same activity as did potassium.

The distribution of silica between the granulite facies complex and the amphibolite facies complexes is not yet investigated. But since the Ikertoq and Egedesminde complexes are rich in granitic gneisses, and the Isortoq complex is rich in quartz-dioritic gneisses with about 61% SiO_2, it is reasonable to believe that the two amphibolite facies complexes as a whole are richer in SiO_2 than the granulite facies complex. This harmonizes with the actually existing tendency of upward diffusion of Si.

However, we must also believe that Na and Si have diffused up into the granulite facies area from still deeper parts of the crust[1]). The mineral reactions which took place in the Isortoq gneiss complex due to this Si- and Na-metasomatism is very interesting, though we cannot discuss these processes in detail in this paper. It should only be mentioned that the Si- and Na-metasomatism altered the hornblende-biotite gneisses into hypersthene-bearing gneisses under simultaneous liberation of titanium and iron from the silicate lattices. The liberated titanium and iron then took part in the metasomatic migration of elements and consolidated here and there into titanic iron ore.

Great massifs of anorthosites are born in deeper parts of granulite

---

[1]) This chemical squeezing of Si, K and some Na out of the rocks in deeper parts of granulite facies areas is partly considered a reason for the formation of anorthosites at these low levels.

facies areas. However, in Greenland such rocks are still not found. The present writer has shown that titanic iron ore, which in most cases is connected with anorthosites, is formed by diffusion of Ti and Fe from unstable titaniferous iron-rich silicates (hornblende and biotite) under Si and Na metasomatism at P,T-conditions corresponding to granulite facies. Si and Na diffuse up from the deepest levels in granulite facies areas where anorthosites are formed. At higher levels, but still in granulite facies, the migrating silicon and sodium alter hornblende and biotite into hypersthene and plagioclase under liberation of titanium and iron. Due to the effect of the gravitational field, the activated Ti and Fe tend to diffuse downward and consolidate at lower levels in granulite facies areas, where anorthosites also are formed.

The Isortoq gneiss complex seems to have formed preferably in the upper part of the granulite facies shell of the crust, so that vast massifs of anorthosites were not developed. Therefore, large deposits of titanic iron ore are not encountered in the part of the Isortoq enderbitic gneiss which has been investigated so far. However, small segregations of titanic iron ore are frequently encountered in the gneisses throughout the Isortoq complex, and it is very likely that more detailed studies of this vast area will result in detection of large bodies of titanic iron ore.

The material which constituted the processes discussed briefly in this paper were in part the sediments and volcanic rocks of the Nagssugtoqidian geosyncline, in part the old pre-Nagssugtoqidian crystalline basement.

It appears that the story of the Nagssugtoqidian orogeny can best be told if we assume that the different processes constituting the orogeneses were equilibriopetal processes aiming at a re-stabilizing of an unstable part of the crust. The forces which gave rise to the orogenetic compression and the folding of the geosyncline must be seen in intimate relation to the metamorphic recrystallization, to the formation of segregation pegmatites, and to the large-scale metasomatism with its migration of activated atoms, ions or molecules through the solid rocks.

May, 1, 1948.

HANS RAMBERG,
Grønlands Geologiske Undersøgelse,
p. t. University of Chicago.

Færdig fra Trykkeriet den 17. Januar 1949.

23