# Meddelelser om Grønland

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# Meddelelser om Grønland,

udgivne af

Commissionen for Ledelsen af de geologiske og geographiske
Undersøgelser i Grønland.

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## GEOLOGY OF THE COUNTRY AROUND JULIANEHAAB, GREENLAND

BY

N. V. Ussing.

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## BERETNING OM DEN GEOLOGISKE EKSPEDITION TIL JULIANEHAAB DISTRIKT I SOMMEREN 1900

AF

N. V. Ussing.

# Geology

of the

# Country around Julianehaab, Greenland.

By

**N. V. Ussing.**

1911

At the time of N. V. Ussing's death in July 1911 this treatise was almost ready for the press. Chapters 1—3 were already in the press; chapters 4 and 6 had been translated, and apparently revised, of chapter 5 there was only the Danish manuscript, and the translation had not yet been undertaken.

According to a wish expressed by Ussing the Committee for the geological and geographical investigation of Greenland entrusted me with the task of undertaking the publication of the treatise. As regards the chapters which were already translated only quite formal corrections have been made in the proofs, and the fifth chapter has been translated in close conformity with Ussing's Danish manuscript.

*O. B. Bøggild.*

# CHAPTER I.

# INTRODUCTION.

The country around Julianehaab is of great interest to geological science for more than one reason. It is the locality of a large number of rare minerals; it is the only part of South Greenland where a sedimentary rock-formation is found which is newer than the Archæan and Algonkian series; and, above all, it is remarkable for the occurrence of complexes of highly differentiated igneous rocks which afford extremely favourable conditions for geological study. The occurrences of the minerals and the sedimentary formation are dealt with by previous explorers in several publications. In the present paper will be found the results of a study of the general geology of the country and of the geology and petrography of the igneous rocks.

## GEOGRAPHY.

The settlement of Julianehaab ("Juliana-Hope") is situated on the south-west coast of Greenland, in 60° 43′ N. lat. and 46° 1′ W. long., about 160 kilometers north-west of Cape Farewell (Plate I). The entire south-west coast of Greenland is difficult of access by sea, the approach being barred, during a great part of the summer, by the Polar pack-ice which moves in a southerly direction along the east coast of Greenland but, after having reached Cape Farewell, turns off towards the west and the north-west. But the pack-ice provides good conditions for seal-hunting and, for Greenland, this coast is densely populated. That part of the country which is not ice-covered consists here, as elsewhere in Greenland, of a rather small strip bounded on the one side by the ocean and on the other by the inland-ice: at Julianehaab the distance from the margin of the inland-ice to the outermost skerries in the ocean is about ninety kilometers.

The coast-line is intersected by a large number of fjords with an average direction from south-west to north-east. Some of them at their heads meet with the outlets of the inland-ice and receive icebergs from it. The outer skerries and the peninsulas have low, bare cliffs, but further inwards, the mountains become gradually higher and some vegetation occurs upon their lower slopes. Bordering the inner parts of the fjords we find magnificent snowcapped mountains, and here a comparatively rich vegetation covers the floor of the valleys. But nowhere is the least trace of a wood to be found; this in combination with the numerous floating icebergs which are seen in the fjords even during the warmest summer months, has the effect of rendering the general character of the scenery entirely Arctic in spite of the relatively low latitude.

At Julianehaab the mean temperature for the whole year is very near 0° Centigrade, and for the summer months (July, August) it is about 8°. Around the inner branches of the long fjords the summer is even somewhat warmer, and trees could possibly grow there, if there were localities where they could be sheltered from the dry and strong easterly gales. The rainfall is considerable; at Ivigtut, about 120 kilometers west of the district we are considering, the average annual rainfall is 1·24 meters, and it is probably similar at Julianehaab. The snow-line is at a height of 1100 to 1150 meters above sea-level.

Under these conditions the chemical decomposition of minerals and rocks by atmospheric agencies takes place very slowly, and the geologist can almost everywhere procure without difficulty rock-specimens in a fresh condition.

## HISTORY.

Red Erik, the first European colonist in Greenland, in the year 983 settled down in Tunugdliarfik Fjord, the longest of the fjords near Julianehaab, and it was from the same fjord that his son Leif sailed when he discovered America. But the old Norse colony which Red Erik founded, perished in the sixteenth century, and since then for more than two hundred years the southernmost part of Greenland was scarcely visited by Europeans as the new colonisation was confined to the more easily accessible tracts further to the north-west. Not until the year 1775 was the settlement of Julianehaab founded.

We owe our first knowledge of the mineralogy and geology of the country around Julianehaab to C. L. Giesecke who visited this district in 1806 and 1809. Giesecke's diary[1] shows that he made himself fairly well acquainted with the whole of the area which will be described in the present paper, its peculiar minerals and rocks having attracted his attention to a high degree. We are indebted to him for excellent collections of minerals including several which were then new to science: arfvedsonite, sodalite, and eudialyte. Moreover, he was the first to give a description of the red sandstone of Igaliko which he compares with the Old Red Sandstone of Scotland. But owing to the deficient knowledge of that time with regard to igneous rocks his descriptions of the nepheline-syenite and of the geological structure of the country are of limited value. Some varieties of the nepheline-syenite he regards as a kind of "mica-slate", but others are correctly interpreted as a "syenite" which

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[1] Giesecke's Mineralogisches Reisejournal. Meddelelser om Grønland, XXXV, pp. 15, 29—39, 211—220 (1910).

For an account of the mineralogical collections which have been made from time to time in the district of Julianehaab, see "Meddelelser om Grønland", XXXII, pp. IX—XIX (1905).

is of later origin than the ordinary granite[1]. The first notice of the occurrence of newer abyssal rocks in South Greenland is due to Giesecke, but he does not express any opinion regarding their age relative to the red sandstone.

In 1828 C. Pingel visited Julianehaab and Igaliko and some years later he published a description of the red sandstone with its porphyry-dykes[2]. The indefatigable H. Rink who, about the middle of the last century, made exhaustive and valuable contributions to the scientific knowledge of Greenland, strangely enough, scarcely occupied himself with the igneous rocks of Julianehaab, and it was not until the year 1876 that more light was thrown upon the geology of these rocks.

In that year the Danish Government began a series of systematic scientific investigations in Greenland, and the first expedition, that of K. J. V. Steenstrup who was accompanied by G. Holm and A. Kornerup made a topographical, geological, and archæological reconnaissance of the whole country around Julianehaab. Among the chief results may be mentioned a topographical and geological sketch-map of the area north of this settlement and a brief description of the geographical and geological conditions[3]. Dr. Steenstrup revisited the country in 1877, but almost the whole collection of minerals and rocks which he had brought home from these expeditions was lost when the Castle of Christiansborg, in Copenhagen, was destroyed by fire in 1884.

In 1888 and 1899 Dr. Steenstrup made other journeys to Julianehaab, chiefly for purposes of archæological and practical interest. On those occasions he took opportunity of making

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[1] C. L. Giesecke, The mineralogical Geology of Greenland (1816). Reprinted in T. Rupert Jones, Manual of Greenland, pp. 330 and 332 (London 1875).

[2] C. Pingel, Om den, af Porphyrgange gjennembrudte, røde Sandsten i det sydlige Grønland. K. Danske Videnskabernes Selskabs Skrifter (4), X, 1843.

[3] Meddelelser om Grønland. II, 1881.

new collections of minerals and rocks which he has kindly placed at my disposal for the preparation of the present paper. He also made some geological observations with special reference to the red sandstone[1]. In 1897, under the auspices of the "Commission for the Direction of Geological and Geographical Explorations in Greenland", Dr. G. Flink, of Stockholm, investigated the mineral localities north-east of Julianehaab and discovered a great number of new and interesting mineral species, which have been described by Dr. Flink and others[2]; in his report, however, Dr. Flink touches only cursorily upon geological questions.

In 1899 the "Commission for the Direction of Geological and Geographical Explorations in Greenland" enjoined the investigation of the igneous rocks of Julianehaab upon the present author, and, as a preparation, I visited the Christiania district together with Mr. O. B. Bøggild who was to take part in the expedition to Julianehaab in the following year. Owing to Professor Brögger's kind help we had an excellent opportunity of studying the large igneous complex of this district which, as is well-known, has formed the basis of some of the most classical investigations in the department of petrology.

The results of the explorations in 1900 will be found in the present report. A few supplementary observations which the author was able to make during a short stay at Julianehaab in July 1908 have been included.

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[1] K. J. V. Steenstrup, Geologiske og antikvariske Iagttagelser i Julianehaabs Distrikt. Meddelelser om Grønland, XXXIV, p. 117 (1909).

[2] G. Flink. Berättelse om en Mineralogisk Resa. Meddelelser om Grønland, XIV, p. 221 (1898). — *Idem,* On the Minerals from Narsarsuk. Ibidem. XXIV, p. 181 (1899). — C. Dreyer and V. Goldschmidt, Ueber Albit von Grönland. Ibidem, XXXIV, p. 1 (1907).

# CHAPTER II.

# THE ROCK FORMATIONS.

## SUMMARY.

From a geological point of view the greater part of Greenland is an old continent, composed of crystalline rocks mostly of Archæan age. Newer sedimentary formations of marine origin are met with near the coast in the northern and middle parts of Greenland. But the southern third of the country, south of 69° N. latitude, is extremely poor in sedimentary rocks. With the exception of the loam, sand, and gravel deposits of the Quaternary epoch, which on the whole occur in relatively small quantities, there have been found in southern Greenland only two small areas of post-Archæan sediments, both at about 61° N. lat., viz. the Arsuk group and the Red Sandstone. Since the only organic remains which have hitherto been detected in these sediments are sponge-spicules (in the Red Sandstone), an exact statement of the geological age is not possible. On the other hand, from the stratigraphical relations and the petrographical characters of the different rocks, and from a comparison of the sediments with those of East Greenland and of the north-east of Canada, we may infer not only the order of succession of the different rocks but also their probable geological age. In this way we arrive at the following classification of the formations of South Greenland:

| | |
|---|---|
| Quaternary ............ | *Moraines and alluvium.* |
| Devonian (?)............ | *Plutonic rocks (granite, nepheline-syenite, etc.) and volcanic sheets.*<br>*Red Sandstone.* |
| Algonkian (?)........... | *Plutonic rocks (granite, diorite, etc.).*<br>*Arsuk group.* |
| Archæan .............. | *Gneisses and crystalline schists.* |

The areal distribution of the rock-formation is given in the geological map, Plate I[1].

Archæan rocks are the most widely distributed rocks in South Greenland, but in the country around Julianehaab they are of minor importance. Only in the north-easternmost part of the area which we shall here consider more particularly (Plate II) there occurs a gneiss or a foliated granite which probably belongs to the Archæan period.

The Arsuk group covers only a small area situated about 150 kilometers W. N. W. of Julianehaab. Since it has no direct connection with the subject of the present paper a brief enumeration of the main rocks will suffice in this place. It consists of a succession of intensely folded slates, phyllites, dolomites, quartzites, graphite-schists, and metamorphosed diabases and tuffs. They may probably be correlated with the late-Algonkian (Keeweenawan) rocks of Labrador.

The country around Julianehaab consists almost exclusively of rocks which belong to the four upper divisions mentioned in the above table, viz. Algonkian granite (Julianehaab granite),

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[1] This map has been constructed on the basis of the reports and the geological maps published by T. Eberlin (Meddelelser om Grønland, IX), A. Jessen (ibidem, XVI), P. Sylow (ibid., VI), and K. J. V. Steenstrup ibid., II), and has been supplemented and corrected by means of the information obtained from an examination of the collections of rocks from South Greenland, in the Mineralogical Museum in Copenhagen With regard to the stretch of coast between Arsuk and Julianehaab additional information was obtained by the author's journeys in 1900 and 1908.

Devonian sandstone (Igaliko Sandstone), newer igneous rocks (volcanic sheets and abyssal rocks), and Quaternary deposits (compare map, Plate II).

## JULIANEHAAB GRANITE.

*General aspect and surface relief.* — The most widely distributed rock within the area represented in Plate II is a granite which is supposed to be of late-Algonkian age and for the sake of convenience is designated by the above name. The surface relief of the granite areas is irregularly mountainous. The heights of the mountains usually vary between 300 and 900 meters, and their forms are more or less rounded and ice-worn because, as Dr. Steenstrup has shown, the whole district has been covered by the inland-ice to at least a height of 1200 meters[1]. An essentially different scenery is seen only on Kidt-

Fig. 1. Kidtlavat Mountain (A. Kornerup).

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[1] Meddelelser om Grønland, XXXIV, p. 121 (1909).

lavat Mountain: here the granite rises in an extremely picturesque mountain ridge to a height of 1260 meters (Fig. 1).

The Julianehaab granite has great power of resisting weathering. The flanks of the mountains are frequently very steep and the talus at their foot is comparatively small in amount. In several places the surface has not suffered any desintegration since the inland-ice retired from the district, and almost everywhere the lichen-coatings impart to the mountains a dark and monotonous appearance. Near the shores and in sheltered localities fairly dense birch and willow copses may sometimes be met with.

*Petrography.* — The distinctive character of the Julianehaab granite as compared with the more ancient granitic rocks is the absence of gneissic or dynamic structures. In some cases, however, a slight indication of banding is observed, but this is of primary origin and is not accompanied by any kind of cataclastic structure. As to colour, the rock most frequently is white or light gray, but reddish varieties are by no means uncommon; near Igaliko and in some other places the granite is intensely red-coloured.

Mineralogically the rock is an ordinary hornblende-bearing biotite-granite. It is coarse-grained, compact (not miarolitic), and frequently of a pronounced porphyritic structure produced by some of the felspar crystals attaining a length of one or two centimeters while the average size of grain is much smaller. Under the microscope the dominant felspar is seen to be a microcline of the ordinary cross-hatched twin-structure, sometimes with and sometimes without perthitic veinlets. Oligoclase occurs subordinately. The quartz is allotriomorphic and mostly interstitial between the felspars. The dark-coloured constituents are a brownish-green biotite and a common green hornblende, as a rule in about equal amounts. As minor accessories occur magnetite, titanite, zircon, and apatite.

The rock has not been analysed chemically, but it may be inferred from its microscopical characters that it belongs to the granito-dioritic series of igneous rocks, following Rosenbusch's classification. This is of importance because the newer igneous rocks of the area here considered belong to the alkali series.

*Diorite.* — In several localities in South Greenland there occur smaller bodies of diorite which appear to be genetically related to the Julianehaab granite. Within the area represented in Plate II, however, the diorite is rare. One of the localities is at the inner (northern) end of Igaliko Fjord where the diorite covers an area of almost a square kilometer. This rock is medium-grained and rather dark in colour. The felspar is of a thick-tabular habit and is somewhat decomposed; the fresh portions of it prove to be andesine and the decomposition products are muscovite, epidote, and calcite. A green hornblende and a brownish-green biotite are abundantly present, and quartz occurs in small amount.

A more basic diorite is found at Sigsardlugtok, on the western side of Igaliko Fjord, and is conspicuous even at a long distance on account of its dark colour. This diorite is traversed by irregular veins of a light-coloured granitic rock.

*Ore deposit.* — A small deposit of copper-ore is found in the granite not far from Julianehaab. The locality is $8^1/_2$ kilometers due east of the settlement, in the eastern part of the island of Kekertarsuak. The ore is copper-glance with some bornite and occurs in grains, nodules, and veinlets, impregnating a breccia of various crystalline rocks (granites, felsites, gneisses, and amphibolites) with quartz as the principal cementing material. The ore is very unevenly distributed in this breccia and is, on the whole, rather scarce. In the neighbourhood of the ore deposit several diabase dykes occur having a direction from north-east to south-west.

This ore deposit was found as long ago as before 1800, and appears to be the first one known from Greenland. It was investigated by Giesecke in 1806[1]. In the middle of last century

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[1] Meddelelser om Grønland, XXXV, p. 29 (1910).

the deposit was worked for a short time, and on that occasion fifteen tons of ore are said to have been shipped to London (1852). Some years ago the locality was again visited by mining engineers, but the results were unsatisfactory.

*Geological age of the Julianehaab granite.* — As already mentioned the age of the granite cannot be fixed with full certainty, but several facts support the hypothesis of a late-Algonkian age. In the first place, it should be pointed out that granitic rocks similar to the Julianehaab granite in petrographical characters, have a very wide extension in the southernmost part of Greenland (see Plate I). They cover — with interruptions — an area which in a direction from east to west measures about 300 kilometers, and from north to south they extend over perhaps an even greater distance. This greatly extended distribution may be taken as a strong indication of a pre-Cambrian age. Secondly, the relation of this granite to the Arsuk group is of importance. The latter is separated by a strip of gneiss from the nearest granites of the Julianehaab type, but the distance is only twelve kilometers. Since the Arsuk rocks have been greatly influenced by tangential stresses while the granite does not show any trace of cataclastic structure, it is highly probable that its consolidation took place later than the processes which folded the rocks of the Arsuk group or, in other words, the granite must be younger than the Arsuk group which is probably of late-Algonkian age. Thus, judging from our present knowledge of the geology of South Greenland, it appears reasonable to attribute a late-Algonkian age to the Julianehaab granite.

## RED SANDSTONE (IGALIKO SANDSTONE) AND VOLCANIC SHEETS.

The central part of the district we are here considering (Plate II) consists of a formation of red sandstone which is in some places overlain by a succession of volcanic sheets. The sandstone rests directly upon the Julianehaab granite, and its lowermost layer has usually the character of an arkose. The total thickness of the sandstone formation is about 1200 meters, that of the volcanic series about 1000 meters. The sandstone is supposed to be of Devonian age, but as the correctness of this supposition has not been definitely proved it would be advisable to have a local name for this formation. The name "Igaliko Sandstone" has been chosen because Igaliko is the only place within the sandstone area which is inhabited.

*Distribution.* — We cannot doubt that the Igaliko Sandstone and the volcanic series must originally have had a wide extension in South Greenland. Even at the present day isolated sandstone areas appear to exist in several places in the ice-covered interior as may be inferred from the not uncommon occurrence of boulders of this rock in recent moraines of the inland-ice. But in that part of South Greenland which is free from ice, both formations have now a very inconsiderable extension and do not occur beyond the limits of the map, Plate II. Since some of the main occurrences will be described more fully in the following chapters it will suffice in this place to give a general account of these formations and a discussion of their geological age.

The total area of the Igaliko Sandstone may be reckoned at about 200 square kilometers. The largest part of this area lies between the Fjords Sermilik and Tunugdliarfik. Another important sandstone area surrounds the head of Igaliko Fjord, and a few isolated patches of the sandstone are found near the outlet of Tunugdliarfik Fjord, between Narsak and the head of Kangerdluarsuk Fjord. The volcanic rocks are entirely restricted to the peninsula between Sermilik and Tunugdliarfik where they cover an area which is less than one-fourth of the sandstone area.

The present boundaries of the sandstone area are of different kinds from a geological point of view. Towards the south-east, south of Igaliko, the border-line coincides with a large fault which runs in a direction from E. N. E. to W. S. W. Towards the north, in the low area between Tasiusak and Kagsiarsuk, the boundary, as shown by Steenstrup[1], is very irregular and its course is conditioned by the denudation: the underlying granite appears in almost all of the valleys between the numerous small sandstone hills. But even here the boundary, from a more general point of wiew, may be said to be connected with a fault, which, however, runs at a little distance north of the actual border of the sandstone. The presence of this fault is indicated by the fact that while the northernmost outlier of the sandstone, at Tasiusak, is only slightly elevated above sea-level the granite rises to very considerable heights (1272 meters) less than three kilometers north of the border of the sandstone. Towards the west, the south-west, and the east, the sandstone areas border partly upon the fjords and partly upon the newer abyssal rocks.

*General aspect and surface relief.* — The stratification is exceedingly well pronounced both in the sandstone and in the volcanic series and is on the whole almost horizontal or slightly inclined towards the south-west. The general aspect of these formations is therefore far different from that of the granite: plains and plateaus are the predominant surface forms. As the sandstone plains are situated around the middle and inner parts of the fjords where the summer climate is favourable to vegetation, and as the plains are usually covered by a thin layer of morainic material or of alluvium, they produce fertile pastures or, in other places, copses of willow and birch which may be so dense that they are difficult to penetrate. Upon the plateaus and upon the terraced sides of the mountains the vegetation is scarce; the escarpments are quite bare and even at a long distance show the dark-red colour of the sandstone which gives a peculiar character to the entire scenery.

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[1] Meddelelser om Grønland, XXXIV, p. 121 (1909).

The dark-coloured rocks of the volcanic series compose the highest of the plateaus, the Ilimausak plateau, which rises above the snow-line and is therefore covered with a cap of snow and ice. From this cap, small glaciers descend on all sides giving rise by their erosion to picturesque cirques with precipitous walls and separated by bastion-like projections of the plateau. The flat snow-cap which has an altitude of about 1100 meters is surmounted by two higher summits; the highest of these is a somewhat rounded and partly snow-covered hummock which the Greenlanders have named Ilimausak, a term denoting the plug upon the fore-end of the shaft of the harpoon, used for keeping the detachable bone fore-shaft in its right position.

A very conspicuous feature of the sandstone formation is the presence of numerous dark-coloured dykes and sills. The sills are more common in the upper than in the lower horizons, and they constitute no unimportant part of the total thickness of this formation. The dykes are very regular and almost all of them run in a N. E. to S. W. or E. N. E. to W. S. W. direction, parallel to the main direction of the fjords. As the power of resistance of the dykes and sills to erosion and weathering is different from that of the sandstone, they influence the details of the surface relief in numerous ways.

*Igaliko Sandstone.* — This is a red-coloured or brownish-red sandstone, fairly hard and resistant to weathering. It is composed of well-rounded grains of quartz mixed with a varying, but usually very small, amount of felspar grains. The cement is siliceous or, rarely, ferruginous. The outer appearance sometimes approaches that of a quartzite; in such cases the microscopical examination shows that the quartz-grains have been secondarily enlarged at the cost of the cement. Ripple-marked surfaces are often to be seen.

In several places there occur thin, subordinate beds of a dark gray shale in which fossils have been sought for in vain.

Other subordinate beds, of less common occurrence, consist of a red-and-white, jasper-like chert. The microscopic examination of a specimen of the latter kind, found by Dr. Steenstrup at Igaliko, has revealed the presence of numerous sponge-spicules.

Beds of conglomerate, from half a meter to two meters in thickness, are very common in the Igaliko Sandstone. All the pebbles are well rolled; most of them are small but in some beds they range up to two or three decimeters in diameter, and occasionally thoroughly rounded stones half a meter in length have been observed. Almost all of them consist of a red sandstone of the same appearance as that of the underlying sandstone beds; granite-pebbles have been found in a few cases while pebbles of diabase are very rare.

Where the Igaliko Sandstone comes into contact with intrusive masses of fairly large dimensions it is intensely metamorphosed. The red-coloured sandstone is altered to a white, sometimes greenish or black, indurated quartzite-like rock, and the shaly beds are transformed into a dark-coloured hornfels rich in biotite.

*Volcanic sheets.* — The Igaliko Sandstone is conformably overlain by a volcanic formation consisting of a series of lava-flows and sills which, according to their outer appearance may be designated as diabases, porphyrites, and porphyries. Intercalated beds of indurated volcanic tuffs are found, but appear to be very subordinate. The petrographical examination has proved that the volcanic rocks belong to the alkali series and should be classed as trachydolerites and alkali-trachytes.

The volcanic rocks are found almost exclusively in the vicinity of the Ilimausak batholite described below, and they form a roof over this batholite. Without exception they have been highly influenced by contact-metamorphism. No doubt the non-metamorphosed parts of the volcanic sheets were more liable to decay and have therefore been entirely removed by erosion.

*Relative age of the Red Sandstone and the volcanic sheets.* — As already mentioned the greater part of the volcanic sheets rests upon the sandstone and is, consequently, younger than this. On the other hand, it does not seem improbable that the volcanic outbursts have commenced at a time when the deposition of the sandstone was still in progress. The question of the relative age is somewhat difficult, because we have not succeeded in finding a locality where the uppermost sandstone-beds are well exposed to view and, at the same time, readily accessible, and no decisive observations have been made.

The facts which apparently indicate a partial contemporaneity of the sandstone formation and the volcanic activity are the following: (1) Although most of the volcanic sheets which occur intercalated between the sandstone-beds have the character of ordinary sills, Dr. Steenstrup has observed a few sheets whose upper surfaces present the slaggy appearance of a lava-crust: thus, in several places near Igaliko and at Musartut on the north coast of Tunugdliarfik Fjord[1]. The horizon of the "slaggy diabase" of Musartut is about 800 meters lower than the uppermost sandstone-bed. (2) While most investigators have only found sandstone-pebbles in the conglomerate-beds of the sandstone Dr. Steenstrup, after careful research, has found a conglomerate layer with numerous pebbles of diabase at an altitude of about 200 meters near Igaliko[2]. (3) At the head of Kangerdluarsuk, near the shore, an erratic is observed, about two cubic meters in size, which consists of red sandstone with a number of thin conglomerate beds; in these several pebbles of a porphyry, much like the porphyry of Ilimausak, and a few diabase pebbles are associated with the sandstone pebbles of the usual kind.

*Geological age of Igaliko Sandstone.* — Different authors have expressed widely divergent opinions as to the geological age of the sandstone of Igaliko. Giesecke (1818) classes this formation

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[1] Meddelelser om Grønland, XXXIV, p. 127, Fig. 1 (1909).

[2] Ibidem, p. 130.

as Old Red Sandstone as a matter of course[1]. Pingel (1843), on the other hand, referring to the abundance of porphyry-dykes in the sandstone, compares it with the Permian "Rotliegendes" in Germany[2], while Johnstrup is of the opinion that a pre-Cambrian age is more probable[3]. In the second volume of "Antlitz der Erde", Suess points out the analogy between the Igaliko Sandstone and the Liefde Bay group of Spitzbergen; the latter which according to Nathorst's investigations contains *Cephalaspis*, *Scaphaspis*, and plant-fossils agreeing with those of the Old Red Sandstone, is the oldest sedimentary deposit of Spitzbergen which is uninfluenced by tangential stresses, and in South Greenland the Igaliko Sandstone occupies a similar position; it is probable, therefore, that the Igaliko Sandstone is of Devonian age[4].

During recent years a number of scientific expeditions have explored the eastern coast of Greenland and have thus afforded the means of adducing for comparison the sedimentary succession of this country. The southernmost occurence of sedimentary rocks in East Greenland is in the district north of Scoresby Sound from which the expeditions of Ryder (1891—1892), Nathorst (1899), Amdrup and Hartz (1900) have provided information of great interest in regard to the question of the geological age of the Igaliko Sandstone.

Thus, in the inner branches of King Oscar's Fjord and of Emperor Frantz Joseph's Fjord (72°—74° N. lat.) Nathorst found a series of Silurian (or Cambro-Silurian) deposits resting on a basement complex of gneisses and crystalline schists[5]. This Silurian series consists of folded limestones, dolomites, slates,

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[1] Ch. L. Giesecke, The Mineralogical Geology of Greenland (1818). Reprinted in T. Rupert Jones, Manual of Greenland, p. 332 (London 1875).

[2] C. Pingel, Om den, af Porphyrgange gennembrudte, røde Sandsten. K. Danske Videnskabernes Selskabs Skrifter, 4. ser., X. p. 13 (1843).

[3] Meddelelser om Grønland, II, p. 38, (1881).

[4] E. Suess, Das Antlitz der Erde, II, p. 89 (1888).

[5] A. G. Nathorst, Bidrag till nordöstra Grönlands geologi. Geologiska Föreningens i Stockholm Förhandlingar, XXIII, p. 288 (1901).

and sandstones, and some of the strata are fossiliferous. East of these rocks he found a sandstone formation, more than 1500 meters thick the lower beds of which are of a gray colour while the upper ones are red-coloured; the beds are on the whole horizontal, though in some places no unconformity is seen at their base. The upper, red-coloured sandstone contains fish-remains (*Holoptychius* and *Asterolepis*) which prove that it must be classed as Old Red Sandstone. Later than this formation, but probably older than the Triassic, is a number of igneous rocks rich in alkalies which occur on Cape Parry (ægirine-syenite, tinguaite), on Cape Fletcher (porphyritic dyke-rocks), and in other places; they have been described by Bäckström[1] and Nordenskjöld[2].

Carboniferous sediments are wanting in the district north of Scoresby Sound (in East Greenland they are only found north of 80° N. lat.), but the Triassic system is represented by the "Fleming Inlet series" which consists of horizontal beds of more or less compact sandstones, shales, and limestones of varying colours (partly red)[3]. The unfossiliferous "Cape Brown and Hurry Inlet series" probably also belongs to the Triassic (or perhaps to the Permian)[4]; it comprises a succession of conglomerates, sandstones, and micaceous shales; some layers of this series are red-coloured while others are gray or green. The conglomerates contain pebbles of porphyries which agree with the porphyries of the igneous series of Cape Parry and Cape Fletcher. Later than these formations is a long succession of Rhætic, Jurassic, and Tertiary strata which are as a rule fossiliferous and do not contain any red-coloured sandstone deposit. Thus in eastern Greenland only two geological systems are represented by deposits of red sandstone: on the one hand

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[1] Geologiska Föreningens i Stockholm Förhandlingar, XXIII, p. 301 (1901).

[2] O. Nordenskjöld, On the Geology and Physical Geography of East-Greenland. Meddelelser om Grønland, XXVIII, p. 196 (1908).

[3] Ibidem, p. 175.

[4] Ibidem, p. 178.

the Devonian system and on the other hand the Triassic (or Permo-Triassic) system.

The distance from the Igaliko Sandstone to the nearest North American deposits of similar kind is even greater than the distance from Igaliko to King Oscar's Fjord. In New Foundland Devonian sandstone occurs on the north side of White Bay; in Nova Scotia and New Brunswick we meet with extensive deposits of Old Red Sandstone and here also the Triassic (and Permian?) series is developed as red sandstone and reaches as much as 800 meters in thickness[1]. Coarse-grained igneous rocks younger than the Devonian sandstone occur in Nova Scotia, and the well-known igneous rocks of Montreal which belong to the alkali group are later than the lower Devonian[2].

Now the distances from Igaliko to Scoresby Sound in the north-east, and to Nova Scotia in the south-west, are so large that an agreement of the petrographic characters cannot be taken as a proof of an original direct connection between the sediments. But on the other hand we are taught by geological observations in many countries that the peculiar formations which are characterised by the abundance of red sandstones poor in fossils are not of a local nature, but must have originated under physical conditions which controlled the sedimentation over areas of a very wide extension. For this reason the presence of red sandstone deposits belonging to the same two geological periods, and the absence of red sandstones belonging to other periods, both in the south-east of Canada and in East Greenland — where almost the entire series of geological systems is represented by sedimentary deposits, — may be taken as an indication that if a considerable deposit of red sandstone occurs within the area that lies between these localities it must belong to one of the same periods. Igaliko is situated almost exactly on a line drawn

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[1] Henry A. Ami, Synopsis of the Geology of Canada. Trans. Roy. Soc. of Canada (2), Vol. VI, Sect. IV (1900).

[2] F. D. Adams, The Monteregian Hills. Journal of Geology, XI, p. 239 (1903)

from the Gulf of St. Lawrence to Scoresby Sound, and it will thus be seen that the geological conditions of the sedimentary areas which lie nearest to South Greenland strongly support the view that the only geological periods to which the Igaliko Sandstone can be referred with some degree of probability are the Devonian and the Triassic.

On the other hand the following considerations will show that the assumption of a Devonian age is much more likely than that of a Triassic age. (1) The Igaliko Sandstone bears a much closer resemblance to the Devonian series of the district north of Scoresby Sound than it does to the Triassic series of this district. (2) The enormous amount of the denudation to which the plateau of South Greenland has been subjected since the formation of the Igaliko Sandstone and the volcanic series strongly suggest that the geological age of these rocks must be much older than the Mesozoic. The original thickness of the sandstone and the volcanic sheets must have amounted to several kilometers, nevertheless they have been entirely removed from thousands of square kilometers and have escaped total destruction only within a narrowly limited and deeply sunken area. A still more suggestive testimony of the great amount of the denudation lies in the fact that the nepheline-syenites and the other true abyssal rocks which are later than the sandstone are exposed to view over extensive areas of South Greenland (compare map, Plate I).

It will appear from the above discussion that a number of facts, the most important of which are due to the investigations of recent years in East Greenland, tell strongly in favour of the view, first expressed by Giesecke, that the Igaliko Sandstone is of Devonian age.

## NEWER ABYSSAL ROCKS.

The abyssal rocks of South Greenland which are later than the Igaliko sandstone are granites, syenites, nepheline-syenites, and gabbros (including essexites). The granites, the syenites, and the nepheline-syenites occur as "batholites" (large irregular masses without visible bottom). The gabbros (essexites) occur as bosses of relatively small dimensions and, more frequently, as large dykes.

The granites, the syenites, and the gabbros are of common occurrence in South Greenland, but nepheline-syenites are only found in three localities (Plate I). One of these is in the district east of Ivigtut where a nepheline-syenite of the ordinary Foya type covers a relatively small area. The two other occurrences are situated in the neighbourhood of Julianehaab and are associated with other abyssal rocks of the alkali group. A detailed description of the newer abyssal rocks in the country around Julianehaab is given in the following chapters; in this place a few remarks may be premised for orientation.

*Distribution.* — Within the area represented in Plate II there are two batholites: the Ilimausak batholite and the Igaliko batholite. The latter is the larger one, but the Ilimausak batholite is much more interesting on account of its very peculiar and complex structure, which can be made out with certainty owing to the fact that the batholite is deeply dissected by the large fjords.

The Ilimausak batholite surrounds the outer parts of Tunugdliarfik Fjord and stretches northwards as far as Sermilik, southwards to Kangerdluarsuk; north of Tunugdliarfik it reaches an altitude of 1100 meters. The original cover of the batholite is partially preserved in the Ilimausak Mountains, it consists of the volcanic sheets mentioned in the preceding pages. The maximum horizontal extension of the batholite is from north-west to south-east and amounts to about 20 kilometers; the breadth, measured in a north-easterly and south-westerly direction, is 10 to 15 kilometers. The westernmost portion is separated from the bulk of the batholite by a narrow strip of volcanic rocks, but since the natural section in the large valley north of Narsak shows that the breadth of this belt decreases rapidly downwards it must be assumed that both portions of the batholite are in contact with one another a little below the floor of the valley.

The Igaliko batholite is situated at the eastern end of Tunugdliarfik Fjord and is of much greater dimensions. Of this batholite, however, only the more easily accessible parts in the vicinity of Igaliko and along the coasts have been visited by the writer. The highest point of the Igaliko batholite is Igdlerfigsalik (1750 meters).

*Scenery.* — In its broad features the surface relief of the newer abyssal rocks has been produced by the same agencies which gave the surrounding mountains their form: first the inland-ice and subsequently the local glaciers. When exposed to the atmospheric agencies, to the actions of frost and changes of temperature, the batholitic rocks, however, behave in a very different manner from the rocks mentioned in the preceding pages: while the latter rocks are of a durable nature the newer abyssal rocks are subjected to mechanical disintegration on the largest scale. This rapid decay gives the batholites a very characteristic outer aspect. In the first place it prohibits vegetation: the mountains are almost everywhere sterile and appear with the individual colour of the rock. In the second place it produces a relatively rapid degradation of the precipitous walls, and the accumulations of debris at their feet therefore reach very considerable dimensions. The occurrence of numerous large screes, which may attain heights of many hundreds of meters, is a characteristic feature in the scenery of the newer abyssal rocks, and as the decay rapidly attacks the loose blocks of the screes the latter are usually devoid of vegetation and conspicuous at a long distance.

Yet another result of the rapid mechanical decay of the newer abyssal rocks deserves to be mentioned, viz. the strong development of the process which J. G. Andersson has termed *solifluction*[1]. The more gentle slopes, with inclinations varying from a few degrees to 20° or 30° are real "streams of stones" sometimes several kilometers in breadth, immovable during the later half of the summer when the ground is dry, but yielding at each step if you set your feet on them during the first part of the summer when scattered remains of the snow-covering are still to be seen, and water fills the interspaces in the lower part of the rubbish layer. The total thickness of this movable rubbish sheet which covers the surface of the solid rock varies between wide limits, in some of the "stone-rivers" at the head of Kangerdluarsuk (Plate VIII, Fig. 2) the thicknes was seen to be very small, 0·2 or 0·3 meters. The movable sheet contains rock-fragments of almost all sizes, but there is a preponderance of small fragments about as large as hazel-nuts and walnuts. That the sheet does move, though on the whole very slowly and at intervals, is apparent from the phenomena observed close to the larger blocks the diameter of which considerably exceeds the thickness of the rubbish sheet. On that side of each of such blocks which looks in the direction from which the "stream" moves, there is a considerable thickening of the rubbish sheet as if this would overflow the block, while on the opposite side the rubbish sheet is thinner or even wanting. This evidently indicates that the bulk of the rubbish sheet moves faster than the blocks which are more or less checked by friction against the underlying rock-surface. Distinct indications of movements are also observed in the small turf carpets which may exceptionally be found on the rubbish: the turf shows numerous fissures perpendicular to the direction of maximum inclination of the surfaces. Sometimes considerable areas of the rock surface are laid bare when one portion of a rubbish layer moves downward while the supply is temporarily stopped.

Locally broad streams of rubbish stretch from the summits

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[1] Journal of Geology, XIV, p. 91 (1906).

of the mountains in one continuous trail to the sea, and under such conditions considerable areas may be found where the solid rock is nowhere exposed to view. On the whole, however, the subaerial crumbling-down of the rocks is only in its first stages, and geological observations are only locally impeded by the rubbish covering.

*General character of rocks.* — Both batholites are entirely made up of rocks which belong to the alkali series; common to both is also the prevalence of the nepheline-syenites. But in other respects the two batholites are widely different.

The batholite of Ilimausak consists of a large number of individual rock-bodies. The nepheline-syenites are represented by lujavrites and and other relatively rare types which may be interpreted without difficulty to be produced by the differentiation of one parent magma of a peculiar composition. Besides, the batholite contains alkali-granite, alkali-syenite, and essexite.

The large Igaliko batholite is of a much more uniform structure and composition. The principal rock is a nepheline-syenite related to the ordinary Foya type; it is associated with an olivine-bearing nepheline-syenite and with a syenite of the Larvik type. As the northern and eastern parts of this batholite have not been surveyed it is possible that future investigations may reveal the presence of other rocks, but the study of the erratics has not supported any supposition of this kind.

*Geological age of the batholites.* — No direct communications have been observed between the batholites and the volcanic sheets. At the junction the rocks of the volcanic series show distinct effects of contact metamorphism and the batholitic rocks send out numerous apophyses into the surroundings whether these consist of Algonkian granite, of sandstone, or of volcanic sheets. If the dykes that traverse the batholites are excepted, the batholitic rocks must have been the latest igneous rocks of the district to consolidate among all that erosion has left to the present day. On the other hand the petrographic examination and the chemical analysis show that the batholitic rocks and those of the superincumbent volcanic series are so nearly related that it must be assumed, according to commonly accepted hypotheses, that both kinds of rocks have originated from one parent magma and belong to one cycle of igneous activity. For this reason the rocks of the batholites are here referred to the same geological period as the volcanic series or in other words, they are supposed to be of Devonian age (compare Table, p. 9).

The question whether or not the process of intrusion of the batholites was contemporaneous with the superficial igneous outbursts will be considered more fully below (see Chapter VI). It will be shown that while the study of the contact relations is insufficient to settle the question, certain observed features of the abyssal rocks themselves apparently indicate that there has been at least a partial contemporaneity between both phases of the igneous activity.

# CHAPTER III.

# DESCRIPTIVE GEOLOGY OF THE ILIMAUSAK REGION.

## INTRODUCTORY.

The region to be described in the present chapter embraces the igneous complex of Ilimausak and its surroundings. Its situation is shown on the index map, Fig. 2 and a geological map on a larger scale (about 1 : 113,000) is given on Plate III[1]. The whole region can be viewed from Mount Ilimausak, which lies in the northern part of the district, and whose two highest peaks, separated by a small glacier, reach altitudes of respectively 1370 meters and about 1450 meters.

The main direction of the four large fjords which cut through the region is from west-south-west to east-north-east. The southernmost is called *Kakortok Fjord* and lies entirely within the area of the Algonkian granite. The newer igneous rocks have their southern boundary a little to the north of the watershed between this fjord and the next one, *Kangerdluarsuk*,

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[1] The topographical foundation of the map has come essentially from the surveys made by STEENSTRUP, HOLM, and others, whose maps have been published in earlier volumes of the *Meddelelser om Grönland*. During the geological survey of the region in 1900 and 1908 no trigonometrical measurements were made, but at several places on the map details from sketches and photographs have been added for geological reasons. The heights of the hills are given in meters and are also taken for the most part from the work of earlier expeditions. The contour-lines are only intended to show the orography very roughly; they are drawn mainly from the barometric measurements and photographs of 1900.

the innermost end of which cuts deep into the nepheline-syenite body. The third fjord, *Tunugdliarfik*, cuts through the nepheline-syenite mass at its broadest, dividing it into a southern and a northern half, and the northernmost fjord, the ice-filled *Sermilik*, forms the northern boundary of the newer igneous rocks.

Within the area indicated on the map there is at present only one inhabited place, Narsak, lying in the south-western part of the peninsula between Tunugdliarfik and Sermilik.

In the following description the region is divided for the sake of convenience into six districts. The first embraces the surroundings of the inner part of Kangerdluarsuk Fjord; the second and third respectively the southern and the northern coast of Tunugdliarfik Fjord; the high mountains of Ilimausak may be considered as a fourth district, while the last two divisions are the neigbourhood of Narsak and the south coast of Sermilik Fjord.

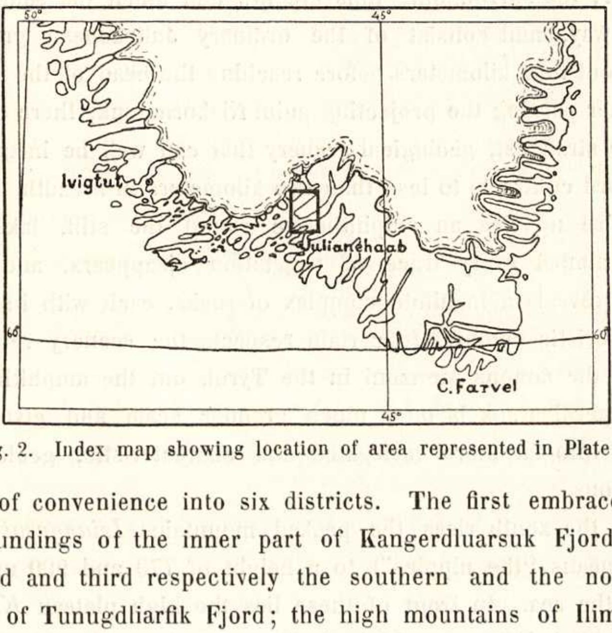

Fig. 2. Index map showing location of area represented in Plate III.

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## THE AMPHITHEATRE OF KANGERDLUARSUK.

The word Kangerdluarsuk has almost the same meaning as fjord, and half a hundred of the innumerable fjords of Greenland are called by this name by the natives. The present Kangerdluarsuk is the one which has made the name known to mineralogists; it is the place where Giesecke in 1806 found the first specimens of sodalite, arfvedsonite and eudialyte.

The Kangerdluarsuk Fjord is only about 26 kilometers long and lies so near to the colony of Julianehaab, that it is but a convenient day's journey from the colony in to the head of the fjord with the ordinary "conveyance", the women's boat. The first 22 kilometers from the mouth of the fjord offer little of interest; the surrounding hills are low and much the same the whole way, and consist of the ordinary Julianehaab granite. But about four kilometers before reaching the head of the fjord, just after passing the projecting point Niakornarsuk, there opens out the strangest, geological scenery that can well be imagined. The fjord contracts to less than two kilometers in breadth, steep cliffs rise up like an amphitheatre round the still, lake-like water, almost every trace of vegetation disappears, and one glance reveals a manifold complex of rocks, each with its own characteristic colour. In certain respects the scenery reminds one of the famous Monzoni in the Tyrol, but the amphitheatre of Kangerdluarsuk is on a much grander scale and gives an insight into far more variegated and characteristic, geological conditions.

In the south rises the peaked mountains *Iviangusat* (the word means "the nipples") to a height of 770 and 900 meters above the sea. In front of these lies the high plateau *Kringlerne*, about 400 meters high, built up of alternating black and white sheets, which produce the impression of sedimentary rocks with unusually well-pronounced stratification (Pl. V, Fig. 1 and Pl. IX); but what seem to be sedimentary layers are in reality nepheline-syenite. Towards the east the amphitheatre is bounded by Mount *Kitdlavat* ("the comb", 1260 meters), which with its magnificent series of jagged granite peaks commands the whole region (Pl. V, Fig. 3 and Pl. VII, Fig. 1). In front of

Kitdlavat lies *Laxefjæld* (660 meters) with a strangely incongruous, dark-green colour; it consists of lujavrite. Towards the north-east and north the fjord is hemmed in by lower mountains, more crumbling in their nature, with more rounded form and even slopes; they consist in part of dark-coloured lujavrite, but mostly of a white nepheline-syenite. Towards the north-west, lastly, Mount *Nunasarnausak* (750 meters) with its almost vertical sides projects right out to the fjord (Pl. V, Fig. 3 and Pl. VII, Fig. 2); its plateau form and its dark masses of sandstone and diabase are in striking contrast to the adjacent light-coloured nepheline-syenite.

On the north side of the fjord a mountain torrent has cut out a gully and given rise to the deposition of a gravel cone (Pl. VII, Fig. 2). Here by the beach there is a little grass and low shrubs, and travellers are accustomed to set up their tent at this spot. At the head of the fjord there is a brook of no great size, marked on the map as *Lille-Elv*, and a short distance to the south of this there is a more considerable water-course, which comes from the valley between Kitdlavat and Laxefjæld and which, owing to the abundance of salmon in it, is called *Laxe-Elv* (i. e. Salmon River). Close under the steep Nunasarnausak near the north side of the fjord lies the small island *Kekertausak*.

In the following detailed description of the geological features, the main types of the igneous rocks are only dealt with on broad lines, just as they appear on viewing them directly; a more exact, petrographic description will be given in the following chapter.

## THE INNERMOST END OF THE FJORD: THE NAUJAITE.

*General features.* — From the small island Kekertausak as far as the outlet of Lille Elv, or over a distance of a little more than a kilometer in west to east direction, the cliffs along the shore consist of the rock which is the most characteristic of the whole region and which in 1878 was called *sodalite-syenite* by Steenstrup[1]. The same name was later used by Lindgren for quite a different rock and by Hibsch for a third kind; it is also objectionable in so far, that the Greenland rock does not belong to the family of syenites but to the nepheline-syenites. In the sequel, therefore, Steenstrup's sodalite-syenite will be called *naujaïte* (from the locality Naujakasik).

Naujaite is a nepheline-syenite extremely rich in sodalite and with a characteristic poikilitic structure (Pl. XVIII). The rock is composed of alkali-felspar, nepheline, ægirine, arfvedsonite and eudialyte in crystals, which can often be measured in decimeters; and all these minerals are tightly and uniformly speckled with sodalite crystals, the diameter of which as a rule does not exceed half a centimeter. Each crystal of the first-mentioned minerals may contain several hundred sodalite crystals, and these lie so close, without touching one another, that the rock as a whole contains from 30 to 60 per cent of sodalite.

All the constituents are fresh and the light-coloured minerals are semi-transparent; the sodalite green or bluish green, the nepheline whitish or grayish, the felspar greenish. The eudialyte is of a fine bluish red and along with the coal-black cleavage-surfaces of the ægirine and arfvedsonite gives the face of the cliffs a beautifully variegated appearance, when seen close at hand. The eudialyte in the rock varies greatly in amount; at some places it is only seen as small spots (2 or 3 centimers in diameter) here and there, at others it may appear in such abundance that it seems to compose a fourth of the whole rock. In the latter case the crystals of eudialyte reach a size of 25 centimeters or more and enclose a very large amount of sodalite crystals.

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[1] Meddelelser om Grönland, II, 1881, p. 35.

The felspar crystals appear in the rock surfaces as large, white rectangles spotted with sodalite crystals, in form they are like thick plates, which a thickness of 2—6 centimeters whilst the length may reach 25 centimeters. The dark-coloured minerals fill the angular interspaces between the light-coloured ones and frequently reach over 30 centimeters in breadth and length. The total amount of arfvedsonite and ægirine varies between a tenth and a fifth of the rock Their relative quantity is variable; at some places one is predominant with exclusion of the other, and at other places both are present in considerable quantities.

The very large size of grain of this characteristic rock leads one to think of a pegmatite; but there can be no talk of this here. Naujaite is in fact one of the main rocks in the whole igneous complex; from the above-mentioned coastal stretch at the head of Kangerdluarsuk it extends many kilometers to the north-west, north and north-east, forming a fairly horizontal igneous mass some hundreds of meters in thickness. It rests upon lujavrite (p. 36), and it is overlain by another related rock, sodalite-foyaite, which is widely distributed in the region of Tunugdliarfik and will be described with the latter. The relation of the naujaite to these rocks makes it clear, further, that it cannot be considered as a pegmatite formation on a large scale. As will be shown below, it is connected by gradual transition with the sodalite-foyaite, and it is distinctly older (i. e. earlier consolidated) than the lujavrite.

Seen from a distance the naujaite cliffs are almost white or faintly bluish gray. On a freshly broken surface the rock usually shows a very conspicuous, violet-red colour, which quickly disappears in the light. This phenomenon has been mentioned in an earlier report.[1] The rock is everywhere of a rapidly crumbling nature, but its decay is only mechanical

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[1] Meddelelser om Grønland XIV, 1898, p. 130. — TH. ALLAN, Memorandums respecting some Minerals from Greenland. Thomson's Annals of Phil., 1813, I, p. 104.

and not accompanied by any chemical alteration; even the sodalite crystals lie quite fresh in the rubbish. At certain places, it is true, there are found varieties of the naujaite, where the sodalite has throughout been converted into spreustein, and in which the other minerals are also more less altered; but the local distribution of these varieties and the nature of the secondary minerals show, that these have not arisen from any atmospheric decay but from the action of hot sources, belonging to a period long passed away.

Owing to the rapid crumbling of the naujaite all the more level stretches are covered with a continuous layer of debris from the rock. So long as this layer is moist — thus in spring when the snows are melting — it glides slowly or at intervals abruptly downwards, thus forming an excellent example of the solifluction mentioned in the preceding chapter; later on in the summer it becomes completely dried, and no movement seems to take place in it. As a result of the crumbling of the rock and the rapid drying of the rubbish, the naujaite ground is practically devoid of vegetation. The landscape is whitish gray and waste; only here and there in a shallow depression, where a brook spreads moisture around, do we find small green shoots of plants.

A well-marked *system of partings* divides the naujaite into sheets, ranging in thickness from half a meter to three meters; on the stretch considered here, between Nunasarnausak and Lille Elv, the sheets have in general an inclination of about 15° towards the north-west, but local differences are frequent. At Lille Elv and east therefrom the inclination is on an average a little greater, about 20°, and the dip is towards the west. As a rule there are two series of almost vertical joints at right angles to each other and as the crumbling proceeds most rapidly along the joints, the rock appears divided into huge parallelopipeda (Pl. VIII, fig. 1). At many places the remains spared by the weathering have a distinctly roundish form; loose, crumbling, spheroidal masses of 2—4 meters in diameter are common.

*Pegmatites.* — Pegmatitic segregations and veins occur in great number in the naujaite. The majority are almost horizontal, following the direction of the above-mentioned partings; others have an irregular course. The thickness may be as much as some few meters, but as a rule is much less; it is variable in one and the same vein, and most of the veins thin away and die out after a short time. The mineral composition is variable, but the pegmatites always lack the poikilitic structure, which is so conspicuous in the main rock.

As an example of the pegmatite veins I may describe here in more detail one of the larger of them. The vein represented on the accompanying figure lies close above the highwater mark on the south side of the small island Kekertausak in Kangerdluarsuk. It has a certain practical interest, as considerable quantities of eudialyte were taken from it in 1888 for technical purposes. This vein is parallel with the partings of the naujaite (it dips about 10° towards the south); its breadth is variable, usually about 50—80 centimeters. It is a composite vein consisting of several parallel bands (Fig. 3, *a*—*d*). The uppermost of these (*a*) is sharply marked off from the overlying naujaite; it has a breadth of 5—20 centimeters and consists of felspar with zinnwaldite and 2—8 centimeters long prisms of ægirine; it also contains some eudialyte. Under this comes a band 0—20 centimeters thick (*b*), consisting of a green felt-like aggregate of ægirine needles with a few large (10—15 centimeters long) prisms of the same mineral; most of these larger ægirine crystals

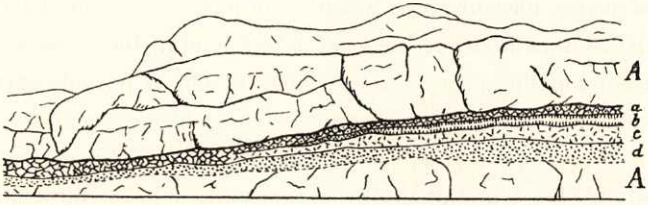

Fig. 3. Naujaite (*A*) with a pegmatitic vein (*a*—*d*).
Island of Kekertausak, from the south. Height about 2·5 meters.

lie vertically and proceed from the upper and lower borders of the band. Then comes a 10—40 centimeters broad band (*c*) of very variable character; it is composed mainly of felspar with a good deal of ægirine, which lies in part in radiating groups of crystals; further, there is a little eudialyte, rinkite, and arfvedsonite. The lowest band (*d*), has a thickness of up to 60 centimeters, but thins out wedge-like at both sides; it consists of an almost pure, coarse-grained mass of eudialyte. This eudialyte vein sometimes shows a sharp contact, sometimes a gradual transition towards the underlying naujaite, which is here unusually rich in eudialyte. At some places the three uppermost zones (*a*—*c*) are replaced by a single pegmatite zone 30—50 centimeters thick, which has very large crystals; its felspar plates measure up to 25×8 centimeters, the arfvedsonite 30×10 centimeters, the ægirine 10×2 centimeters; here also there is nepheline (e. g. 4×5 centimeters) and in pockets crystals of natrolite.

A second pegmatite vein which deserves to be mentioned, lies at the head of the fjord, in the shore cliffs a little north-west of Lille Elv. This vein is up to 0·5 meters broad and like the first-mentioned almost horizontal. It consists mainly of felspar, sodalite and arfvedsonite. The felspar crystals are up to 25 centimeters long and are quite devoid of included sodalite crystals; the latter mineral is in large green crystals, which lie between the felspars. This vein contains ægirine in long prisms, eudialyte, steenstrupine, brown schizolite, yellow sphalerite, molybdenite, zinnwaldite, albite and analcime.

## FROM LILLE ELV TO LAXEFJELD. THE LUJAVRITES AND THEIR RELATION TO THE NAUJAITE.

*The breccia zone.* — As already mentioned, the naujaite sheets have on the whole a slight dip towards the west and north-west; the lowermost sheets of the rock are thus found in the neighbourhood of the Lille Elv. Further to the east, the underlying lujavrite appears on the surface, but the junction of these two rocks is of quite a peculiar kind.

On the west side of the Lille Elv already, conspicuous black masses begin to show in the lowest parts of the white naujaite; these black masses form veins which run parallel in the main with the naujaite beds, but they also cut across these. The further we go towards the east, the more numerous and broader become the black veins, the naujaite is divided into large and small fragments and lenses, and the black rock envelops these completely, forming a continuous, greatly branched network of veins, as shown schematically in Fig. 4 (p. 38). The black veins are composed of lujavrite; their breadth is from 0·5 to 10 meters or even considerably more. The lenses of the naujaite may be 100 or 200 meters long and 10 or 20 meters in thickness, but some are quite small. The whole rock-complex between the Lille Elv and the western arm of the Laxe Elv has this characteristic structure: lenses of naujaite separated by reticular veins of lujavrite between them. In addition to the regularly rounded lenses, we now and then also find naujaite masses which have the form of sharp-edged fragments, and the structure then approaches the ordinary structure of an igneous breccia. In the cliffs about Tunugdliarfik the last form is the rule; the photograph Pl. XIII, Fig. 2, gives a good illustration of this condition.

In the parts round the outlet of the Lille Elv the lujavrites are black; here and there, however, we also find lujavrite of a pronounced green colour in veins 1—6 meters broad, which are usually flanked by black lujavrite on both sides.

Following up the Lille Elv from its mouth, the lujavrite veins become more rare and at a height of 2—300 meters above the sea the cliffs consist of a uniform naujaite. At still greater heights (further to the west) the naujaite is covered by sodalite-foyaite. Going from the heights here towards the south-east, we meet in turn the outcrops of deeper and deeper layers of the igneous mass and thus come to know the whole series. The accompanying figures (Figs. 4 and 5) illustrate this condition. Furthest to the west, at a height of 400—500 meters, we have the sodalite-foyaite and under this a thick sheet of naujaite; beneath the latter comes the just described alternation of naujaite lenses and black lujavrite, forming a sheet 100—300 meters thick which is inclined towards the west. Below and to the east the naujaite lenses become gradually scarcer and the rock-mass consists principally of black lujavrite; under this come lujavrites mainly green in colour, often alternating with the black in parallel sheets. In the Laxefjæld the green lujavrites rise to a height of 650 meters above the sea, and the platy parting of the rock has a dip here of about 25° towards the north-west. The uppermost peaks of Laxefjæld consist of augite-syenite, which rests upon the lujavrite, the contact plane being almost horizontal or with a slight inclination towards the south-east; at some places here the lujavrite is observed to send out veins into the augite-syenite; at other places the latter contains veins of nepheline-syenite pegmatite near its boundary towards the lujavrite.

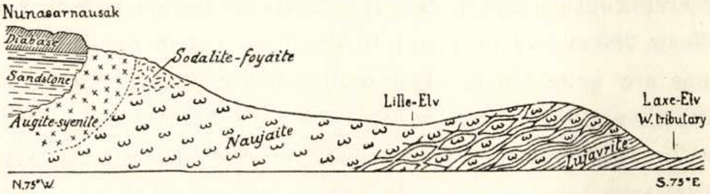

Fig. 4. Section of the nepheline-syenite complex from Nunasarnausak to Laxe Elv. — Scale 1 : 38000.

Between the lujavrite sheets of the Laxefjæld appears as a subordinate mass (Fig. 5) the characteristic, banded kakortokite; this towards the south, in the mountain called Kringlerne, swells up to a thickness of several hundred meters and will be described below. Under this we find again the black lujavrite.

*The lujavrites.* — The rocks which are called here the lujavrites, have in their general habit a good deal in common with the typical lujavrites, which we know through W. Ramsay's work from the Kola Peninsula; the dark-coloured minerals are very abundant and have the form of needles or slender prisms, and the whole rock has as a rule a well-marked flow-structure which produces an apparent schistosity. They are distinct from the Kola rocks, in that the size of grain is as a rule smaller and the black minerals are more strongly represented. In outer appearance they are very different from the ordinary igneous rocks and resemble most of all the crystalline schists; the few travellers who visited this region in the first half of the 19th century call the lujavrites "chlorite schists" or "a kind of gneiss".

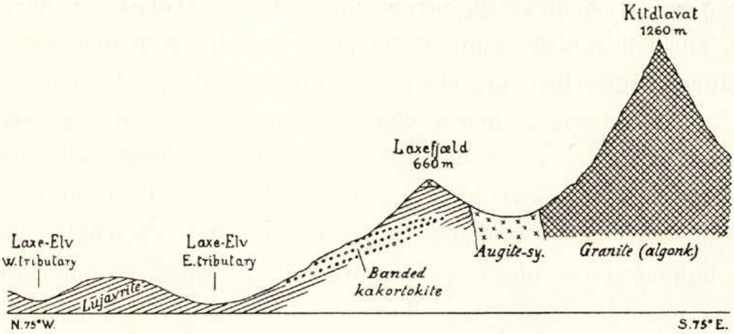

Fig. 5. Section of the nepheline-syenite complex from Laxe Elv to Kitdlavat. (continuation of the section Fig. 4). — Scale 1 : 38000.

In the chemical composition the main difference between the black and the green lujavrite is in the oxidation stage of the iron, but their external appearance is very different and each may be described separately therefore.

The black lujavrite — *arfvedsonite-lujavrite* — is in its typical form a moderately fine-grained, grayish-black rock of a somewhat schistose structure. The one conspicuous component is arfvedsonite; it contains, further, nepheline, microcline, albite and eudialyte. The arfvedsonite builds thin, coal-black and shining prisms, usually not more than 2 millimeters long and with a breadth seldom more than one fifth of the length; they are arranged parallel to the schistosity and often produce a faint, silky lustre on the surfaces of schistosity. The felspar and the nepheline may be so fresh that they are colourless, and the rock then seems quite black; just as frequently they are white or faintly brownish white, being more or less zeolitised. The nepheline is in crystals of the usual form averaging one or two millimeters in diameter. The felspar forms thin plates of similar length and arrangement as the arfvedsonite prisms. The eudialyte is in small brownish grains or crystals, which as a rule are a littler smaller than the crystals of the nepheline.

More locally we find medium-grained or even coarse-grained varieties, which are connected by transitional forms with the fine-grained. In extreme cases the arfvedsonite prisms and the felspar plates may reach up to 1 centimeter in length and 2 millimeters in thickness. Massive varieties which do not show any trace of schistosity or flow-structure are likewise of purely local occurrence.

The green lujavrite — *ægirine lujavrite* — has a glaring grass-green colour; its most conspicuous mineral component is ægirine in small needle-shaped crystals — they are rarely more than one to two millimeters long and 0·01—0·05 millimeters thick. This mineral plays here the same role as the arfvedsonite in the black lujavrite. Nepheline, felspar and eudialyte appear in the same manner as in the arfvedsonite-lujavrite. Like the latter the green rock is fine-grained and schistose, to an even greater extent as a rule. A very conspicuous difference between the two rocks arises from the fact, that whilst the first is even-grained, the ægirine-lujavrite contains relatively large crystals of arfvedsonite, which appear as black spots in the green mass. These arfvedsonite crystals are not ordinary phenocrysts, but enclose poikilitically all the other minerals of the rocks. In some cases the arfvedsonite forms irregular but fairly isometric anhedra of up to 2—3 centimeters in diameter; in others it forms prisms of $^1/_2$ to $1^1/_2$ centimeters in length and some few millimeters in thickness. In the ægirine-lujavrite near the mouth of the Lille Elv and at a few other places the arfvedsonite prisms are in radiating groups, which remind one of the turmaline 'stars' of certain granites and give the green rock a very pleasing appearance; but as a rule the arfvedsonite prisms are irregularly scattered.

The ægirine-lujavrite lacks these black arfvedsonite spots at many places; in such cases, however, close observation shows, that the arfvedsonite has been present originally but has been replaced by a brown inconspicuous substance which consists of acmite. This alteration of the arfvedsonite is also common in the pegmatitic veins and has been described on an earlier occasion[1].

When exposed to the atmosphere the lujavrites are inclined to split asunder, though not to such a great extent as the naujaite. Whilst the lattter crumbles to gravel-like debris, the lujavrite splits into large, plate-like fragments, which at many places form screes difficult to pass.

## THE PLATEAU OF KRINGLERNE.

*General features.* — The high plateau which is called "Kringlerne" is the most peculiar rocky mass in appearance in the whole region, and in geological regards is perhaps without parallel in the world. Towards the Kangerdluarsuk Fjord, Kringlerne present an abrupt fall, a naked, whitish gray wall, in which we can count about 40 black bands (Pl. V, Fig. 3 and Pl. IX). These run to some extent horizontally and, seen from a distance, seem to have great uniformity in thickness with

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[1] Meddelelser om Grønland XIV, p. 198 (1894).

equal distances between. The outer appearance of the whole mountain-mass is that of a very regular stratified sedimentary complex. Though the strata are highly crystalline one might be inclined to suppose, on first observing them, that they are of sedimentary origin — an explanation of this kind has indeed been suggested by several previous observers. As a matter of fact, however, the strata are alternating white, red and black sheets of coarse-grained igneous rocks belonging to the family of nepheline-syenites.

Above the steep wall facing the fjord there is a somewhat undulating plateau at about 400 meters above the sea, and behind the plateau rises the granite mountains of Iviangusat (Pl. V, Fig. 3). The plateau is whitish gray and the whole appears an absolutely barren waste, as the white sheets of the kakortokite crumble even more rapidly than the naujaite; not a herb is to be seen and not even the lichens are present to darken the colour of the stone. The regular alternation of the variegated sheets is continued into the rounded eminences of the plateau; round about these the outcrops of the black sheets appear as conspicuous, large rings which show a slight inclination towards the fjord. The surface of the ground thus obtains the characteristic markings which have given rise to the name Kringlerne (ring-twisted cakes).

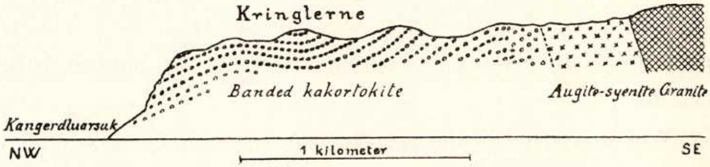

Fig. 6. North-west—south-east section of Kringlerne.
Scale of lengths and heights about 1 : 30000.

A section north-west—south-east through Kringlerne (Fig. 6) shows, that the inclination of the kakortokite sheets is somewhat variable, and that the sheets are somewhat undulating.

Nearest the fjord they have a dip of 20°—30° towards N. W. and N. N. W.; further in on the plateau they are almost horizontal and may even at places show a slight inclination in the opposite direction; still further in, the dip again becomes northwesterly, but soon afterwards the stratification gradually disappears and close to the south-east border the rock is uniform and without banded structure.

*The kakortokite.* — Petrographically the variegated sheets of Kringlerne are nearly related, so that they may be regarded as varieties of one rock-type, for which the name kakortokite has been chosen[1].

The kakortokite is a coarse-grained, distinctly miarolitic rock and recalls in its outer appearance nepheline-syenites of the type which Brögger has designated by the name foyaite[2], that is to say, the most prominent, structural feature is the plate-like form of the felspar crystals, which show a strong tendency to parallel arrangement. But the kakortokite is distinct from the ordinary foyaites by containing a very high percentage of dark-coloured minerals; in this respect it resembles the lujavrites or even exceeds them. Characteristic of the kakortokite is further the abundance of well-developed, moderately small crystals of eudialyte and the frequent occurrence of a bedded or sheeted structure.

*The "white" kakortokite* which forms the thick, white sheets is one of the most beautiful rock-types to be found anywhere. The felspar plates are white, and not semitransparent as in the naujaite and lujavrite; their thickness is 0·5—1·5 millimeters (in the varieties with coarsest grain 1·0—1·77 millimeters), their length and breadth are about ten times the thickness. They are intermingled with grayish clear grains of nepheline, black prisms or anhedra of ægirine and arfvedsonite, and bright red crystals of

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[1] From *Kakortok*, the Greenland name for the colony Julianehaab.

[2] Zeitschrift für Krystallographie XVI, 1890, p. 39.

eudialyte which attain about two millimeters in diameter. Among the minor constituents rinkite is seen almost constantly as pale-yellow, flat prisms. — In spite of its colour the white kakortokite is a melanocratic rock-type, but the pure white colour of the felspar becomes very prominent owing to the size and form of its crystals, and the contrast with the black sheets further accentuates the light colour.

*The black sheets* of the kakortokite have quite a similar size of grain and structure as the white, but the black minerals (arfvedsonite and subordinately ægirine) are here quite predominant among the constituents of the rock, making in all about two-thirds of the whole; the remaining third is felspar, nepheline and eudialyte. The eudialyte is here usually brown and not fresh. — In addition to these two principal varieties we also find very frequently a *red kakortokite.* This has the same mineral components and structure as the white and black sheets, but it contains clear red eudialyte crystals in such great quantities, that the rock is of a distinctly red colour. The red kakortokite occurs in sheets between the others; in some of the red sheets the black mineral components are almost entirely wanting, in others there are just as many of them as in the white sheets.

The white and still more the red sheets are rapidly decaying, the black somewhat harder. In the slopes of the mountain therefore the black sheets form the vertical walls, the white and the red sheets the more level terraces. Seen from a distance there seem to be sharply defined contacts between the differently coloured sheets, but closer examination shows that this is not the case. Thus, if we examine the junction of a white and a black sheet, we will observe in the white kakortokite towards the boundary that the amount of dark-coloured minerals gradually increases, and thus a perfectly even transition to the black kakortokite is effected; but usually the transitional zone only has a breadth of some few centimeters.

*Thickness and order of succession of the sheets.* — The plateau of Kringlerne is most easily ascended along the river which flows down from the small lakes south of Laxefjæld and runs towards the north-west over a number of water-falls, to end in the Laxe Elv a little distance from the mouth of the latter. The kakortokite begins here, directly covering the black lujavrite, at a height of about 80 meters above the sea, and the lowermost sheet at this place is white with a thickness of about 12 meters. This is overlain by a 4 meters thick sheet of black kakortokite, and these two main varieties now continue to alternate

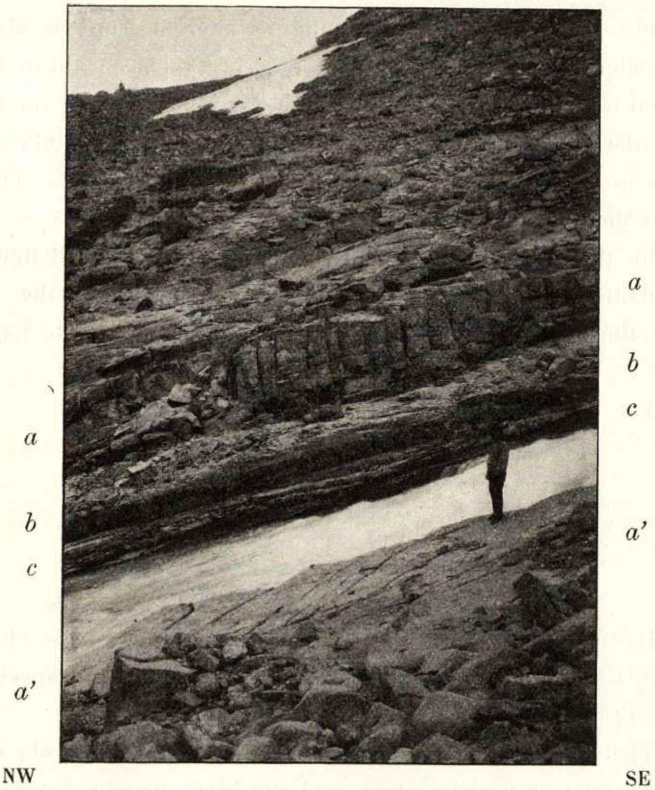

Fig. 7. Banded kakortokite. Kringlerne.
*a*, sheet of white kakortokite, 4 meters; *b*, red kakortokite, 1 meters; *c*, black kakortokite, reaches 0·4 meters above the river; *a'*, white kakortokite in the foreground.

in sheets of varying thickness. The red sheets only begin to appear somewhat higher up; at an altitude of 200 meters we meet with splendid sheets of the red variety (Fig 7); here the sheets dip about 16° towards N. 10° W. Passing from here further up towards the east, the distinctly red sheets cease, but the black and white continue to alternate up to about 350 meters above the sea, where they are replaced through a gradual transition by a uniform, more finely grained and moderately dark kakortokite, which upwards passes into lujavrite. South of the river the alternation of the white and the black sheets continues right up to over 400 meters.

In the western part of Kringlerne, north of Iviangusat Mountains, there is a spot about 180 meters above the sea where the thicknesses of some few successive kakortokite bands could be measured.

The measurements were (from above downwards):

| | | |
|---|---|---|
| white sheet ...... | thickness | not measured |
| red — ...... | — | 1/2 meters |
| black — ...... | — | 3/4 — |
| white — ...... | — | 5 — |
| red — ...... | — | 2 — |
| black — ...... | — | not measured |

Down by the fjord at the west end of Kringlerne the single sheets were unusually thin (0·1—2 meters) and not specially distinct; at this place the dip is 30° towards N. 35° W.

The average thickness of the white kakortokite sheets may be estimated at 6 to 8 meters, and the black usually have only a third of this thickness; when red sheets occur they have a similar or somewhat less thickness than the black. A very characteristic feature is, that the red sheets are situated immediately below the white; each red sheet rest upon a black, not on a white sheet.

*Relation to adjacent rocks.* — As briefly mentioned above (p. 38) the kakortokite is both covered by and rests upon lujavrite on the west side of Laxefjæld. The junction is exposed at the river on the north-east side of Kringlerne. Following up this river we first pass over uniform arfvedsonite-lujavrite, the partings of which have an inclination of about 30° towards the north. A little over 70 meters above the sea we begin to find in the lujavrite small, very flat lenses of kakortokite, 0·2—2·0 centimeters thick; these lenses, which are rich in eudialyte, are inserted parallel to the parting planes of the rock. Upwards, the lenses become more numerous and about 80 meters above the sea the lujavrite is conformably overlain by the typical, sheeted kakortokite. Further to the west, where the kakortokite-body in Kringlerne swells up to more than 300 meters in thickness, there is apparently a gradual transition from the arfvedsonite-lujavrite to the superincumbent kakortokite; the lowermost portion of the kakortokite is fairly uniform at this spot, and the differentiation into differently coloured bands begins about 10 meters higher up. Hence it follows that there cannot be any considerable difference in age between the lujavrite and the kakortokite; the latter must have consolidated simultaneously with or a little earlier than the lujavrite.

In judging the relative age it is also of interest, that the kakortokite, just like the neigbouring lujavrite, contains here and there lenses of naujaite. Four of these in all have been ohserved in the kakortokite of Kringlerne, the largest being 50 meters long.

The junction between the kakortokite and the augite-syenite, which surrounds Kringlerne towards the south and west, is finely exposed on the south shore of Kangerdluarsuk, almost right opposite the Niakornarsuk Peninsula. At this place the contact surface is vertical and has the direction N. 55° W. The kakortokite sheets have an inclination of about 30° towards the N. 35° W.; they thus lie almost at a right angle to the contact plane. At a greater distance from the augite-syenite, the kakortokite is made up of the ordinary white, red and gray sheets, but about 50 meters from the contact the sheets begin to loose their differences and the sheeted structure as well as the thick platy parting gradually disappear when we approach nearer to the contact. Moreover, the size of grain becomes variable in irregular 'schlieren' and large numbers of pegmatitic veins of some decimeters in breadth appear. The size of grain of these pegmatites (which consist of felspar, nepheline, arfvedsonite and occasionally eudialyte) frequently exceeds 1 decimeter. On the last 5 to 10 meters nearest the contact the rock changes over to a very coarse-grained foyaite, variegated white and black, which contains fragments of augite-syenite. The largest of the fragments observed was 0·3×1·5 meters. The pegmatitic veins in this border-facies are arranged parallel with the contact-plane, or they go round the augite-syenite fragments. The augite-syenite, on the other hand, shows no structural variations in towards the surface of contact. It results from these observations, that the consolidation of kakortokite has taken place later than that of the augite-syenite, but while the latter still possessed a high temperature.

*Dykes.* — Only a very small number of dykes have been seen in Kringlerne. West of Laxefjæld two vertical dykes of respectively 8 and 2 meters in breadth have ben observed, with the directions E. N. E.—W. S. W. and N. E.—S. W.; they consist of a rock-type resembling bostonite, fine-grained and light greenish gray with plate-like phenocrysts of felspar. Occasionally, small tinguaitic dykes have been seen in boulders of kakortokite.

## SOUTH-EASTERN AND SOUTHERN BORDER OF THE COMPLEX.

*General features.* — Behind the south-eastern and southern margins of the igneous complex, the Kangerdluarsuk amphitheatre is bounded by high mountains, Kidtlavat and the two Iviangusats (Pl. V, Figs. 2 and 3). These mountains are composed of Algonkian granite (Julianehaab granite). But the nepheline-syenite is not in direct contact with the granite; between them lies a narrower or broader belt of augite-syenite, which can be followed continuously for a distance of about ten kilometers from the north end of Laxefjæld towards the south and west as far as Kangerdluarsuk (Pl. III). The augite-syenite is subject to rapid decay and the syenite zone thus comes to appear as a depression for a long distance; it forms the valley between Kitdlavat and Laxefjæld (cf. Fig. 5, p. 39 and Pl. VII, Fig. 1).

North-east of Laxefjæld, near the north-eastern end of the augite-syenite belt, the conditions are as shown schematically in Fig 8. The main body of the igneous complex is here represented by ægirine-lujavrite, and this possesses as usual a very distinct system of joint planes, which split it up into thin plates. As we gradually approach the boundary, the dip of the joint planes becomes steeper, until at last they are vertical (with the direction S. 10° W.), and along a contact plane with the same direction they border on kakortokite, which at this place is not banded. The kakortokite is here only about 40 meters broad; to the east of it we find the augite-syenite, forming a belt of similar breadth. Passing from here towards the south and south-west, the augite-syenite continues as a regular belt, but its breadth gradually increases to several hundred meters; the crumbling debris of the augite-syenite and kakortokite cover the most of the plateau south of Laxefjæld, and the precise boundaries of the augite-syenite cannot be

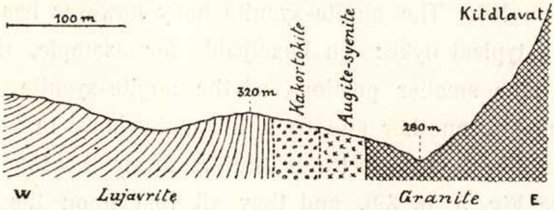

Fig. 8. West—east section through a small mountain N. E. of Laxefjæld, showing junction of newer abyssal rocks and old granite.

observed here. On the steep, north side of the eastern peak of Iviangusat the augite-syenite is seen as a broad zone, which even at a distance is very conspicuous with its dark reddish brown colour. The boundary towards the granite has here a dip of about 70° towards the south-west. On the south side of Kangerdluarsuk Fjord both boundaries of the syenite belt are exposed; here the boundary planes are vertical and strike from east-south-east to west-north-west; the breadth of the augite-syenite belt at this place is about 250 meters.

It will be seen from this, that the augite-syenite in the region considered forms a broad, dyke-like mass, whose boundary surfaces towards the surrounding rocks are vertical or inclined at large angles. The augite-syenite body however has not the form of a typical dyke; on Laxefjæld, for example, there are three or four smaller portions of the augite-syenite, isolated both from one another and from the main body in the valley east of Laxefjæld. One of these outliers forms the top of Laxefjæld (see Fig. 5, p. 39), and they all rest upon the lujavrite with more or less horizontal boundaries towards this.

*The augite-syenite.* — This rock is of coarse or medium-sized grain, and of a whitish gray colour. It consists mainly of a white felspar (size of grain about 1—3 millimeters) and is irregularly spotted with black minerals in considerable quantities. Among these a coal-black augite (with grains up to 6—7 millimeters in diameter) is predominant, and magnetite is relatively abundant. With the aid of the lens small yellowish brown grains of olivine are frequently seen. None of the constituents show a distinct crystal form; the grains are interlaced irregularly. It is only seldom and in patches that the felspar is quite fresh; it then shows a grayish clear colour with a fine blue schiller. A very characteristic feature of this rock is the reddish brown, rusty coating, which is seen everywhere on the outer surfaces and along the fissures; it is undoubtedly connected with the presence of the olivine which is rich in iron and is readily decomposed. This coating gives the augite-syenite cliffs a conspicuous, reddish brown appearance.

*Contact-facies of the augite-syenite.* — The augite-syenite shows a very marked, endomorphic contact-modification at its southern and south-eastern border, where it comes into contact with the old granite. This contact-facies is a fine-grained, white or gray rock in which the black minerals appear as small dots; locally the structure is porphyritic, due to the presence of phenocrysts of felspar. On the south shore of Kangerdluarsuk, right opposite the Niakornarsuk Peninsula, this border-zone has a breadth of 4 to 10 meters, and in it occur a few irregular veins, 1 or 2 meters broad, of a newer granite. On the north side of Iviangusat, at an altitude of 6—700 meters, there is a zone, about 8 meters broad, of a characteristic, fine-grained, dark-gray rock between the syenite and the old granite (or perhaps in the granite but very near the contact); this rock forms a dark band conspicuous even at a distance. Seen under the microscope, it consists of ægirine-augite and anorthoclase with some titanite and iron-ore; the structure seems to have been modified by contact-metamorphism. This rock is perhaps a dyke or a remnant of an ancient border-facies. Further to the east and near the foot of Kitdlavat the solid rock only projects from the debris-covered plain in small, isolated patches, but so far as could be observed, the augite-syenite with its usual fine-grained contact-modification borders directly on the Algonkian granite along the whole of this stretch.

The junction of the augite-syenite with the nepheline-syenites is only exposed at quite a few places already referred to (pp. 47—50), and it will be seen from what has been said, that the augite-syenite has consolidated earlier than the nepheline-syenites. It follows from this that the augite-syenite is not a dyke, but constitutes the first consolidated part of the batholitic complex.

*The sandstone-fragments.* — At the northern foot of the

Iviangusat peaks, close to the fjord, the augite-syenite contains numerous fragments of sandstone (one of the fragments is shown in the drawing, Pl. V, Fig. 3, and in the photograph, Pl. XI, Fig. 1). As these offer a much greater resistance to weathering than the augite-syenite, the larger of them project as dark, lichen-covered cliffs. There are four or five of these, forming short ridges with the direction almost north-south. The largest of the sandstone fragments is over 100 meters long and 50 meters broad; the dip of the sandstone beds is different in the different fragments, but usually steep (70—90°); in the 40 meters long fragment near the shore the strike was found to be S. S. E.—N. N. W., in a second fragment S. S. W.—N. N. E., in a third S.—N. In addition to the large, small sandstone fragments also occur right down to such small dimensions, that a hand-specimen may contain two or three of them.

This sandstone is very hard, almost quartzite-like; its colour is white with black spots formed by contact-metamorphism, a few beds are uniformly black-gray. On closer examination the black spots sometimes appear as short and broad pyroxene prisms of dark-green colour, quite filled with sand grains.

These large sandstone fragments in the augite-syenite are of great theoretical interest. It is obvious, namely, that they have descended from above; this will be clear from the following reason. In the whole Julianehaab region there is no other sandstone-formation than the Devonian sandstone ("Igaliko sandstone"), and the fragments must therefore belong to this formation; their petrographic characters are in agreement with this, as they are quite the same as those of the Igaliko sandstone at the places, where it has been metamorphosed by contact with the newer igneous rocks. The original position of the sandstone must therefore be above the Algonkian granite, which in the immediate proximity of the sandstone fragments rises 900 meters above them. Thus, the conclusion seems unavoidable that the sandstone fragments have arrived at their position by sinking down through the augite-syenite at a time when the latter was still in a molten condition. We are induced to consider from this, that the magma of the augite-syenite had a lower specific gravity than the sandstone, and that this condition has played some part in the mechanism of intrusion of the magma.

There is also a second feature of great theoretical interest in connection with the sandstone fragments of the augite-syenite. All these fragments, the large as well as the small, are separated from the augite-syenite by a zone of *soda-granite*, which sends out small apophyses into the sandstone and frequently contains a large number of very small rounded fragments of the latter. The width of the soda-granite veins is very variable, usually $^1/_2$—2 meters. In the neighbourhood of the sandstone fragments, but without apparent connection with them, there are irregular and branched veins, 0·1—0·5 meters broad, of soda-granite in the syenite, and at one place a quantity of small (up to the size of a fist), globular masses of coarse-grained soda-granite was found enclosed in the syenite.

This soda granite consists of yellowish-white felspar and light grayish, almost transparent quartz; in addition, it contains black minerals, which look like arfvedsonite to the naked eye, but under the microscope they prove for the most part to belong to other alkali-bearing kinds of the amphibole and pyroxene (ægirine, ægirine-augite, and catophorite-like hornblende). In the above-mentioned veins the soda-granite is medium-grained, but in the zones round the sandstone fragments it is usually coarse-grained. Directly surrounding the sandstone there is always a black zone, not more than $^1/_2$ a centimeter broad and containing exclusively black-green pyroxene or black hornblende in short prisms which lie at right angles to the surface of contact; then comes a slightly broader, white zone, which consists of large anhedra of felspar and quartz with a relatively small amount of black minerals, and outwardly the white zone passes into the more uniform soda-granite. The size of grain of the latter is sometimes variable, so that coarse grained portions may alternate with fine-grained in the most irregular manner, even within one and the same hand-specimen. At some places the soda-granite contains small patches of a conspicuous, blue, felt-like mineral, probably crocydolite, which seems to have originated by alteration of the hornblende. As a rule the junction between the soda-granite and the surrounding augite-syenite presents a sharp line; the augite-syenite retains its normal character right in to the contact, while the soda-granite shows irregular variations in the size of grain.

It follows from the manner in which this soda-granite is connected with the sandstone fragments, that it must have originated by the magma of the augite-syenite dissolving the sandstone, so that the soda-granite in this locality may be characterised as a resorption-facies of the augite-syenite. Since the conditions mentioned above show, that the soda-granite has solidified later than the surrounding augite-syenite, we must conclude that the absorption of silica has lowered the temperature of consolidation of the magma.

## IVIANGUSAT AND KITDLAVAT.

The Algonkian granite of these mountains, which form the southern and south-eastern enclosure of the newer igneous complex, is a coarse-grained, white or reddish, biotite granite with a strong tendency to porphyritic structure. The size of grain remains unchanged right on to the junction with the newer abyssal rocks, but in the proximity of the latter the habit of the granite often differs from the ordinary; thus at the junction north-east of Laxefjæld the granite was found to be rich in a mineral resembling crocydolite, which apparently replaced the original, dark-coloured components. In comparison with the newer abyssal rocks the granite is extremely resistant to weathering.

At one place a small intrusive body of nepheline-syenite was observed, namely, on the east side of Iviangusat at an altitude of about 550 meters. Here there occurs a fine-grained, grayish black arfvedsonite-lujavrite, fairly poor in eudialyte; the rock is exposed over an ellipsoidal area of many square meters which is surrounded on all sides by the granite.

The Iviangusat peaks and Kitdlavat are traversed by a number of dykes. The great majority of these may be called diabase from their macroscopic appearance. They are of a black or dark-green colour, and the larger of them are medium-grained with more close-grained marginal zones. The eastern peak of Iviangusat, for example, is traversed by several dykes of diabase, from 15 to 30 meters wide, which can be followed for kilometers through the granite; these dykes have not the usual north-west—south-easterly direction, which characterises by far the most of the larger dykes in the Julianehaab region; their direction is east—west and they have a dip of about 60° towards the south. They are thus almost parallel with the adjacent boundary-plane of the large igneous complex.

In Kitdlavat several dark-coloured dykes can be seen from a distance, running in a regular course parallel to this mountain ridge from N. N. E. to S. S. W., thus, parallel here also to the contact-surface of the granite and the augite-syenite. These dykes have not been investigated, it is probable that they form a continuation of the diabase dykes of Iviangusat.

The huge mountain Kitdlavat (Pl. VII, Fig. 1) forms, as already mentioned, a serrated ridge of surprising narrowness and steepness. It seems reasonable to suppose, that the form of the mountain is due in the main lines to its proximity to the large nepheline-syenite body; Kitdlavat forms the south-east wall of the ancient magma reservoir. The diabase dykes have probably contributed in details to the mountain obtaining by erosion its unusually pointed and picturesque appearance. The difference in outer form between Kitdlavat and Iviangusat can be naturally explained by the difference in the dip of the diabase dykes; on Iviangusat the dip as mentioned is about 60° towards the south, but on Kitdlavat the dykes are almost vertical.

## MOUNT NUNASARNAUSAK.

The amphitheatre of Kangerdluarsuk is enclosed towards the north-west by the 770 meters high Mount Nunasarnausak, which extends right out to the fjord with an almost vertical, precipitous wall. The photograph Pl. VII, Fig. 2, will give some notion of the picturesque appearance of the mountain; the coloured sketch, Pl. V, Fig. 1, shows the geological structure.

Nunasarnausak may be said to represent one large orographic block which consists of Algonkian granite and Devonian sandstone with sills of diabase. The whole block has apparently sunk some distance down into the newer abyssal rocks, and the beds show a dip of almost 10° towards the north-east or north-north-east. The uppermost part of the mountain forms a small plateau, whose surface slopes in the direction mentioned; as already described by Dr. Steenstrup, the plateau is ice-smoothed and the direction of the striation is from E. N. E. to W. S. W[1]. The highest point lies close out towards the Kangerdluarsuk Fjord and offers a magnificent view over the whole region.

The abrupt wall of the mountain towards Kangerdluarsuk presents the following succession of sedimentary and igneous rocks in descending order (cf. Pl. V, Fig. 1).

1. A sheet of *diabase* almost 150 meters thick. This sheet is marked on the cliff wall as a conspicuous, black band; it composes the uppermost plateau. The rock is of a greenish black or grayish black colour, fine-grained or medium-grained, and of a distinct ophitic structure. At some places it is

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[1] Meddelelser om Grønland II (1881), p. 33.

porphyritic with numerous tabular crystals of plagioclase about half a millimeter thick and 6 millimeters long. Epidote and calcite are often seen as alteration-products. At the junction towards the underlying sandstone the diabase assumes a dense structure. As will be mentioned later, this diabase may be classed as a trachydolerite, according to the system of Rosenbusch.

A comparison with the sections north of the Tunugdliarfik Fjord shows, that the diabase at the top of Nunasarnausak is an intrusive sheet, the original sandstone cover of which has been removed by erosion. The diabase is cut by several dykes of a reddish brown syenite-porphyry which have the direction from N. E. to S. W.; the largest of these dykes has a width of five meters.

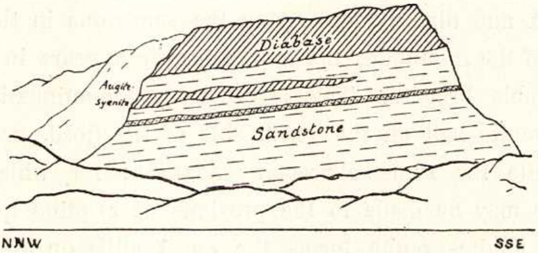

Fig. 9. Nunasarnausak, from W. S. W.
The hills in the foreground are Algonkian granite.

2. Under the thick diabase sheet lies a *sandstone* bed of about 300 meters in thickness with subordinate, thin, intrusive sheets. The whole of this part is inaccessible from Kangerdluarsuk owing to the precipitous nature of the mountain wall. The upper, about 100 meters thick, portion of the sandstone wall towards this fjord is of a pure white colour; under this comes a narrow, but conspicuous, dark coloured sill; beneath this again sandstone, which consists of alternating white and black beds. In the north-western part of the mountain the upper white sandstone layer is divided into two by an intrusive diabase sheet (see Fig. 9).

3. The *granite*, which supports the sandstone in the south-western part of Nunasarnausak, is a white or reddish biotite-granite with large (up to 2 centimeters), porphyritic crystals of felspar; it is not different from the ordinary Algonkian, Julianehaab granite. On Pl. V (Fig. 1) only the eastern point of the granite is seen, but further to the south-west the granite comes down to the beach; it composes the Niakornarsuk Peninsula and the whole region further west. A little north-west of Niakornarsuk a 20 meters dyke of a somewhat porphyritic diabase intersects the granite; the direction of the dyke corresponds with the main direction of the fjord.

4. Under the granite in the south-western part of Nunasarnausak and directly underlying the sandstone in the eastern portion of the mountain, the *augite-syenite* appears in a belt of very variable breadth. This is obviously a continuation of the augite-syenite belt on the south side of the fjord, as the rock is of quite the same character as there; for which reason reference may be made to the previous description (p. 50).

The augite-syenite forms the coast cliffs on a portion of the distance between Niakornarsuk and Kekertausak. At several places it contains veins of pegmatite which consist mainly of felspar and amphibole in crystals 5—8 centimeters long; albite, green garnet and ilvaite[1] are found as secondary products in this pegmatite. The ilvaite occupies the place of dissolved amphibole crystals. Some of the pegmatite veins are horizontal and 0·1—0·3 meters in thickness, others have an irregular course and greatly varying breadth. The ilvaite is also found in the augite-syenite itself as an alteration product.

The contact-plane between the augite-syenite and the Algonkian granite intersects the coast-line a little distance east of Niakornarsuk. Here the augite-syenite shows a 4—8 meters

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[1] The ilvaite from this locality has been described by J. LORENZEN, (Meddelelser om Grønland II, 1881, p. 67. — Zeitschrift für Krystallographie IX, 1884, p. 243. — Mineralog. Magazine V, p. 63).

broad, fine-grained border-facies, which is comparatively poor in dark-coloured minerals. The contact-plane shows an irregular, sinuous course, but is on the whole vertical and runs in a north-easterly direction.

From the place mentioned the augite-syenite belt continues towards the north-east and upwards, and the rock is here exposed in dark, steep walls; it contains rounded fragments of the sandstone. Further to the north-east the syenite belt is greatly restricted in breadth and on bending round the east end of Nunasarnausak the rock assumes the character of an igneous breccia, being quite filled with white, metamorphosed sandstone fragments resembling quartzite. The syenite sends out long and very conspicuous apophyses between the sandstone beds (see Pl. V). These apophyses are quartz-bearing. Directly east of the uppermost plateau of Nunasarnausak the augite-syenite reaches an altitude of about 650 meters, and the syenite zone continues from there downwards in a north-westerly direction with greatly increased breadth.

The contact between the augite-syenite and the uppermost diabase-sheet of Nunasarnausak is exposed to view for a long distance. The diabase shows distinct signs of contact-metamorphism to a distance of 10 meters from the contact, displaying the characteristic lustre which indicates the presence of newly formed biotite; directly at the contact the biotite flakes may attain a size of half a millimeter. The syenite sends offshoots into the diabase and contains contact-metamorphosed fragments of it.

5. Under the augite-syenite *naujaite* appears at the foot of the eastern part of Nunasarnausak. The contact surface between these two rocks intersects the north coast of the Kangerdluarsuk Fjord at a spot which lies almost due west of the small island. In consequence of the solifluction the immediate contact is not exposed to view, but as far as could be ascertained both rocks have their usual size of grain, at least to a distance of less than two meters from the contact.

The augite-syenite contains irregular pegmatite veins, one or two decimeters broad, which consist of ægirine, felspar and nepheline.

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## SOUTH COAST OF TUNUGDLIARFIK.

On the south coast of Tunugdliarfik Fjord the nepheline-syenites are exposed to view over a distance of almost ten kilometers between South Siorarsuit and Agpat (see map Pl. III). The cliffs along the coast are on the whole lower than those in the inner end of Kangerdluarsuk. At most places they descend vertically into the water and many of them are the favourite haunts of sea-birds during the breeding season. It is only at a few places that there is any convenient landing for boats. The principal landing-places and tenting-grounds, in order from west to east, are South Siorarsuit, Naujakasik, and Tupersuatsiak.

For the sake of convenience the following description is divided into three sections; first the land round South Siorarsuit, including the north-western slope of Nunasarnausak and the western border of the igneous complex; then the mountains at Naujakasik and Tupersuatsiak; and lastly, the stretch Tupersuatsiak to the eastern border of the igneous complex at Agpat.

### ENVIRONS OF SOUTH SIORARSUIT.

At South Siorarsuit a cone of detritus projects a little way out into the fjord. It has a sandy beach on which numerous small icebergs lie stranded and landing is easy here. This place is the most convenient starting place for an ascent of Nunasarnausak.

*The north-west slope of Nunasarnausak* (Fig. 10). — The uppermost part of the mountain is composed of an intrusive sheet of diabase, about 150 meters thick. It rests on a hard, white sandstone 50 to 60 meters thick, and under this is a second sill which consists of a diabase similar to that of the uppermost sheet; the thickness is much less, however, and shows considerable, local variation (from 20 to 60 meters). This second diabase sill thins out towards the south; on the southwest slope of the mountain (see Fig. 9, p. 57) the sill is seen very distinctly ending as a wedge, without appearing on the side of the mountain which looks towards Kangerdluarsuk.

The second diabase sheet rests upon 30 meters of white sandstone. Under this comes an intrusive sheet almost 20 meters thick and of great regularity; this is the same sheet that appears as the second uppermost intrusive sheet on the face of the mountain towards Kangerdluarsuk (p. 57). It is a dark reddish gray, dense rock, almost felsitic in outer appearance and probably a somewhat altered tephritic type. Passing downwards from this, we come upon a succession of sandstone beds, partly of white, partly of dark colour, alternating with ferruginous sediments which have been greatly altered by contact-metamorphism. At S. Siorarsuit the sandstone continues right down to the beach, but the strata gradually rise towards the south-west and on following the beach about 500 meters in this direction we meet with the underlying Algonkian granite. Further to the south-west the granite rises gradually to form a coastal strip of several hundred meters in breadth; at the

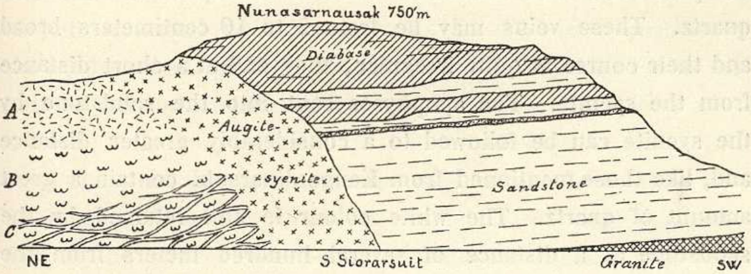

Fig. 10. North-west slope of Nunasarnausak, above S. Siorarsuit.

*A*, sodalite-foyaite covered by pulaskite; *B*. naujaite; *C*, naujaite with veins of lujavrite.

south-west point of the sandstone area the sandstone-covered surface of the granite lies about 200 meters above the sea.

The junction between the sandstone and the granite is exposed along the whole of this distance and the granite is seen to be older than the sandstone. The lowermost beds of the latter are granite-conglomerate or at some places arkose.

It is of interest to note, that the sandstone gradually assumes its usual red colour as we get further away from the newer igneous rocks. At S. Siorarsuit, directly at the contact with the syenite, the sandstone appears as a snow-white, very compact rock, with numerous veins of transparent, colourless quartz. These veins may be from 2 to 10 centimeters broad and their course is quite irregular; they end at a short distance from the syenite. The apophyses sent into the sandstone by the syenite can be followed to a considerably greater distance and, like those mentioned from Kangerdluarsuk, contain a great amount of quartz. The white colour is still retained by the sandstone at a distance of several hundred meters from the syenite, but at a still greater distance red portions begin little by little to appear; it is the lowermost beds of the sandstone which first show this change in appearance. At the point furthest to the south-west the lowermost 50 meters of the sandstone are of the ordinary red colour, but even here the upper sandstone beds have been discoloured.

Towards the north-east the sandstone beds and the intrusive sheets of Nunasarnausak border upon the great igneous complex. As the figure (p. 61) shows, the sandstone is not in direct contact with the nepheline-syenites but is separated from them by a zone of augite-syenite. This is the continuation of the earlier mentioned augite-syenite of Kangerdluarsuk and has almost the same general character. It should be mentioned, however, that the syenite at the shore by S. Siorarsuit has a reddish colour for a short distance and its felspar crystals show a strong tendency to assume a form which gives short rectangular sections. The appearance of the rock thus recalls that of certain varieties of syenite (nordmarkite) on the shore of Tunugdliarfik lying directly opposite.

The syenite shows as usual a fine-grained border-modification at the junction with the sandstone and the diabase, and is thus distinctly more recent than these; on the other hand, the coarse-grained syenite extends right out to the contact towards the nepheline-syenites.

The nepheline-syenites appear close to the north-east of S. Siorarsuit and from there extend further in an easterly and south-easterly direction. The cliffs of the coast consist of naujaite traversed by lujavrite veins in the same manner as above described (p. 37). Higher up the lujavrite veins are wanting but the naujaite continues until about 400 meters above the sea; it is here covered by the sodalite-foyaite and a little more than 100 meters higher up, this in turn is overlain by a white syenite poor in nepheline, which forms the uppermost part of the plateau north-east of Nunasarnausak. The rocks last mentioned and their mutual relations will be dealt with in more detail in the next section (Environs of Naujakasik and Tupersuatsiak).

*The ilvaite locality at S. Siorarsuit.* — The igneous rocks of S. Siorarsuit have been described above as naujaite, lujavrite and augite-syenite, but over an area of perhaps a quarter of a square kilometer their appearance is very different from the ordinary, their original mineral constituents being partially or wholly replaced by new. Within this area, which stretches from S. Siorarsuit a little over half a kilometer along the coast towards the east, the rocks have been intensely altered by chemical processes, which without doubt must be referred to pneumatolytical action. Where these processes have only been at work to a small extent, the original structure of the rock has been preserved, but at many places the alteration processes have effected changes of a more radical kind, and in such cases the original nature of the rock is more or less disguised. In the first stages of the alteration there is a copious formation of yellowish green epidote, a mineral which is otherwise quite absent from these rocks. Where the pneumatolytic metamorphism is further advanced, the rock contains a considerable amount of other secondary minerals: micaceous hæmatite, small green garnet crystals, fluorite, albite in well-formed crystals, and as the most characteristic product splendid crystals of ilvaite showing a rich diversity of crystal forms[1]. The different stages of the metamorphism are most readily seen in the naujaite owing to the peculiar structure of this rock. In the partially altered naujaite the sodalite and the nepheline are replaced by a mixture of epidote and a white, spreustein-like aggregate which consists in part of secondary felspar; some pseudomorphs consist almost entirely of spreustein, others mainly of epidote. The dark-coloured minerals in the naujaite are already at this stage entirely converted into a dark-green, flaky chlorite; the felspar on the other hand is unchanged except that it has assumed a slightly reddish colour. With further alteration the felspar is also attacked and becomes dull and spreustein-like, ilvaite develops in place of the chlorite and small scales of hæmatite appear here and there.

## ENVIRONS OF NAUJAKASIK AND TUPERSUATSIAK.

*The coast-cliffs.* — At Naujakasik ("the bad gull-cliff") a small rocky platform is found at the beach, which permits of easy landing. At Tupersuatsiak ("place suitable to set up tents") there is a small bay and within this a small green plot (Pl. XII). Between the two places the coast-line is formed by a continuous, vertical cliff-wall of 100—200 meters in height, and above

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[1] O. B. Böggild, On ilvaite from Siorarsuit. Meddelelser om Grønland XXV, p. 43 (1902). — V. Goldschmidt, Ueber Albit von Grönland. Meddelelser om Grønland XXXIV (1907).

this the land rises more evenly in a southerly direction with bare and rapidly decaying hills of nepheline-syenite, between which the solifluction gives rise to long, even slopes.

The cliffs of the coast from Naujakasik to Tupersuatsiak consist of typical naujaite. Veins of lujavrite occur locally, but they are of quite subordinate importance on this stretch. Well-marked and almost horizontal partings divide the naujaite into beds of 2—10 meters in thickness. This structure is illustrated by the photograph Pl. XI, Fig. 2.

*Pegmatites of the naujaite.* — The commonest pegmatitic segregations in this part of the naujaite area have the form of almost horizontal veins or sheets, which run along the parting surfaces and as a rule have a thickness of 10—20 centimeters. They consist of the same minerals as the naujaite, but in contrast to this do not have a poikilitic structure; their thick felspar plates, their eudialyte, and their arfvedsonite have almost the same size as in the surrounding naujaite, but they are not dotted with small sodalite crystals, and we thus obtain the impression from a rapid examination, that these pegmatites are even more coarse-grained than the naujaite. The sodalite is not constantly present, but where it occurs it forms crystals of similar size to those of the other constituents (up to 12 centimeters in length); the anhedra of the nepheline are also larger than in the naujaite. The sodalite is idiomorphic towards the felspar, and the latter is idiomorphic towards nepheline and the coloured minerals. Among the last, ainigmatite is sometimes specially abundant; the crystals of this mineral frequently lie quite embedded in the eudialyte. The largest quantity of ainigmatite was found at Tupersuatsiak; here the pegmatite veins form small horizontal ledges in the hill and hundreds of the ainigmatite crystals could be collected on these ledges. Locally eudialyte is also very abundant as large, red anhedra enveloping felspar and the other light-coloured minerals. At Naujakasik well-formed crystals of the brown variety of eudialyte can be picked out in large quantities from the arfvedsonite of the pegmatites.

In addition to these regular pegmatitic sheets, three kinds of newer pegmatitic veins can be distinguished, which follow an irregular, winding course and are of varying thickness. The one kind consists chiefly of felspar crystals and arfvedsonite anhedra which may be over half a meter long. This kind of pegmatite is not rare in the Naujakasik district, but the finest examples are found on Nunarsuatsiak, north of Tunugdliarfik Fjord (see below). The pegmatitic veins of the second kind are much narrower and contain well-formed, prismatic crystals of arfvedsonite, frequently over 2 centimeters in thickness and imbedded in a granular aggregate of zeolites; these veins have been most frequently observed in the district east of Tupersuatsiak. Lastly, the veins containing steenstrupine occur here and there over the whole district; as a rule they are only of restricted width and consist mainly of ægirine, steenstrupine and lithium-mica, imbedded in a fine-grained albite. Sometimes these veins also contain schizolite.

*The sodalite-foyaite.* — As already pointed out, the naujaite is covered by a rock which is here provisionally termed sodalite-foyaite. This rock is much like the naujaite in general appearance and can not be distinguished from it at a distance. On closer observation, however, it is seen that the sodalite-foyaite does not have a poikilitic but a foyaitic structure with thick, tabular, felspar crystals; further, the order of crystallisation is different in the two rocks, and the sodalite-foyaite is considerably richer in dark-coloured minerals.

The felspar of the sodalite-foyaite is white or grayish; the tabular crystals are about 2 millimeters thick and 1—2 centimeters in length and breadth, but occasionally the thickness reaches up to 4 millimeters and the length to 5 centimeters. Nepheline is abundant, also sodalite, but somewhat less than in the naujaite, and these minerals have crystallised partly simultaneously with, partly later than the felspar. The quantity of eudialyte is extremely variable; at a few places the whole rock appears red from this mineral, but often we can walk 20 and even 50 meters over naked surface of sodalite-foyaite without seeing a single eudialyte crystal. Ainigmatite, ægirine and arfvedsonite are constant components, and the arfvedsonite is as usual the last mineral to crystallise; sometimes a little rinkite can be seen macroscopically.

Like the naujaite the sodalite-foyaite has a well-marked system of almost horizontal partings, which divide it into thick beds; the partings in both rocks are parallel to one another and also to the direction of the transitional zone between the rocks. A banded structure has been observed in a foyaite hill, two or three kilometers north-east of Nunasarnausak; at this place the foyaite contains numerous, almost horizontal, very coarse-grained bands which are richer in arfvedsonite than the bulk of the rock.

*Transition from naujaite to sodalite-foyaite.* — There is no distinct contact between the sodalite-foyaite and the underlying naujaite, the two are connected by a gradual transition. The transitional zone has as a rule a thickness of some meters. On ascending we can observe how the felspar plates in the uppermost beds of the naujaite gradually become smaller and the poikilitic sodalite crystals fewer and fewer; at the same time a later generation of sodalite appears as interstitial anhedra between the other constituents.

*Shape of the sodalite-foyaite body.* — A little to the west of Tupersuatsiak the transitional zone between the naujaite and sodalite-foyaite lies 90 meters above the sea, and from this spot it rises towards the west, south and east. One and a half kilometers further west, at Naujakasik, it lies at a height of about 200 meters, and at S. Siorarsuit about 400 meters above the sea. Towards the south-west and south the transitional zone rises almost as rapidly as the mountain surface itself, and as a result of this the sodalite-foyaite forms the surface of the ground over nearly the whole stretch from Tupersuatsiak to Nunasarnausak, whereas down towards Kangerdluarsuk the naujaite lies exposed on the slopes of the mountain. From Tupersuatsiak towards the east the transitional zone rises somewhat more rapidly; already a short distance to the east of Tupersuatsiak it is met with at a height of 150 meters and a little further to the east the naujaite forms the surface of the plateau, the sodalite-foyaite having been removed by erosion.

Taken as a whole the sodalite-foyaite thus forms a thick sheet or stratum which rests upon the naujaite. At places the thickness is considerably over 150 meters. The sheet is not quite horizontal, but forms a flat basin with the lowest part lying close to the west of Tupersuatsiak and rising from there to the east, south and west (Fig. 11). The district south of the Tunugdliarfik Fjord contains only the southern half of the basin; the remainder is found in the mountains north of the fjord. The earlier mentioned, oldest pegmatite sheets of the naujaite as well as the very distinct system of parting, run parallel with the under-surface of the sodalite-foyaite, and the same is the case with the lujavrite veins in the deeper part of the naujaite. Thus the nepheline-syenites constitute a stratified igneous complex which is built up of a number of slightly concave sheets, the one above the other (cf. also the figures pp. 38 and 61).

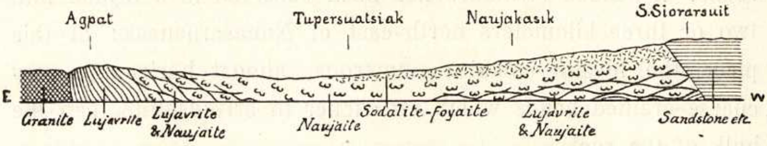

Fig. 11. Schematic section along the southern coast of Tunugdliarfik, from Agpat to S. Siorarsuit: showing stratiform arrangement of the different varieties of nepheline-syenite. — Length of section about 10 kilometers.

*Transitional forms covering the sodalite-foyaite.* — At a few places within the district considered here the sodalite-foyaite sheet in its uppermost portion assumes a divergent character, and is covered by other coarse-grained rocks. Conditions of this kind are seen on the plateau north-east of Nunasarnausak and at a place which lies a little over 200 meters above the sea, south-west of Tupersuatsiak

At the former place the sodalite-foyaite is overlain by a foyaite poor in sodalite, and the foyaite in turn is covered by pulaskite. Between these rocks no sharp boundaries can be drawn, but they are connected with one another by insensible gradations. The foyaite differs from the sodalite-foyaite in the following characters. The sodalite is much scarcer or quite wanting, the felspar plates are relatively thinner, and the structure is thus more distinctly "trachytoid" (as a rule, however, there is no parallel arrangement of the felspar plates). Further, the nepheline has a greenish or reddish elæolitic appearance, eudyalite is almost entirely absent, and sometimes the rock contains olivine. The microscope also shows differences in the character of the dark minerals, as will be discussed in more detail in the petrographic section. This foyaite sheet seems to have but little thickness.

The *pulaskite,* which covers the foyaite, forms a more considerable sheet, about 20—50 meters thick. This rock is white, coarse-grained, somewhat miarolitic, and consists mainly of white felspar in thick, plate-like crystals giving stout rectangular sections; between these are anhedra of dark-coloured minerals and iron-ore, sporadically also white, dull pseudomorphs which probably represent nepheline. Apart from the form of the felspar crystals the pulaskite has a good deal of outer resemblance to the earlier-mentioned augite-syenite; like the latter it crumbles easily and a rusty coating often covers the joint-planes.

In the locality south-west of Tupersuatsiak the sodalite-foyaite is covered by a 20—30 meters thick sheet of pulaskite. This can be followed southwards for a considerable distance, over which the surface gradually rises to a height of 320 meters. Near the northern end of the sheet there are several small, projecting cliffs of a light greenish, coarse-grained arfvedsonite-granite. Each of these masses is only some few meters in extent and is connected by a gradual transition with the pulaskite. From their mode of occurrence at this place one is inclined to consider them as local magmatic segregations of the pulaskite; but this is improbable when the conditions north of Tunugdliarfik Fjord are taken into account. As will be described in detail later, we find there a heavy sheet of arfvedsonite-granite which rests upon the sodalite-foyaite and as a transitional zone between them there is a sheet of this same pulaskite. It seems reasonable to conclude, therefore, that the sodalite-foyaite between Tunugdliarfik and Kangerdluarsuk has also originally been covered by a sheet of arfvedsonite-granite, and that the small arfvedsonite-granite masses south-west of Tupersuatsiak are the only remains, left by erosion, of this sheet.

## FROM TUPERSUATSIAK TO AGPAT.

But few lujavrite veins occur in the naujaite at Tupersuatsiak. Passing eastward from here over the coastal cliffs, the lujavrite veins become more numerous and broader (cf. Fig. 11, p. 68), and the naujaite is reduced to large lenses or fragments, which are quite surrounded by black arfvedsonite-lujavrite. These naujaite fragments are often as large as houses, more than 50 meters long and 10 meters high. The structure of this characteristic igneous breccia is best seen in the photograph Pl. XIII, Fig. 2, which represents a vertical cliff-wall facing the south, about two kilometers east of Tupersuatsiak.

Further to the east the naujaite fragments become rarer and the hills consist almost entirely of black and green lujavrite. This does not crumble so rapidly as the naujaite; the hills rise higher and more steeply, and there are many small lakes between them. Towards the fjord the lujavrite cliffs descend almost vertically into the sea and the waves have carved out many small caves. The easternmost lujavrite mass is the highest and steepest. It consists entirely of green ægirine-lujavrite and is called Agpat ("the auks"). It rises 300 meters from the sea as an unbroken, almost smooth wall with a slope of 75°.

At the eastern end of Agpat the sandstone appears in the coast-cliffs. Right down at the beach a little of the old granite shows under the sandstone. But the lujavrite is not in direct contact with the sandstone; between the two lies a kakortokite rich in eudialyte. This rock occurs here apparently as a regular dyke the direction of which is north to south and its breadth about 100 meters. The contact relations are here of a similar kind to those north of Laxefjæld (Fig. 8, p. 49), except that the augite-syenite is wanting at Agpat.

The kakortokite at Agpat is moderately coarse-grained; it does not show any differentiation into black and white sheets, but is throughout uniform. It is further remarkable in that it contains sodalite in idiomorphic crystals. It has tabular felspar crystals without any tendency towards parallel arrangement. There is no decrease in the size of grain, neither at the contact with the lujavrite nor at the contact with the sandstone, but near the latter contact the kakortokite contains numerous pegmatitic veins, which are parallel to the contact-plane. This pegmatite consists of felspar, nepheline, sodalite, ainigmatite and arfvedsonite.

The sandstone bordering on the nepheline-syenite just east of Agpat is white, quartzitic and distinctly stratified; the beds dip about 25° towards the south-west. Along the coast-line the sandstone only extends for about 100 meters and it can be followed upwards to a height of some few hundred meters. So far as could be seen, this sandstone is only a large fragment and has obtained its present position in consequence of faulting. East of this sandstone body there is a breccia of granite and smaller sandstone fragments. It is only at a distance of about 150 meters from the border of the nepheline-syenite that we meet with the unbrecciated and uniform Algonkian granite in the coast-cliffs.

The character of the landscape changes at the boundary of the nepheline-syenite. East of Agpat the naked, strongly coloured cliffs and the large rubbish-covered plains without vegetation disappear and are replaced by dark, lichen-covered hills of hard granite, and in the valleys a comparative abundance of birch and willow copses make their appearance.

## NORTH COAST OF TUNUGDLIARFIK.

On the north coast of Tunugdliarfik Fjord we have higher and steeper mountains than on the south coast and thus gain a more complete insight into the structure of the stratiform abyssal complex. Pl. VI, Fig. 1, gives a picture of the most instructive part of this coast. The highest peaks of Ilimausak are composed of porphyries, which originally formed the roof of the subterranean magma-reservoir. Under this roof the abyssal rocks are exposed to view from an altitude of about 1100 meters down to the surface of the sea. In the following description the more important localities on this coast will be dealt with in order from north-east to south-west.

### NUNASARNAK.

Nunasarnak (Pl. XIV) is a mountain ridge with a flat top, which forms a peninsula on the north side of Tunugdliarfik Fjord. It reaches a height of 620 meters above the level of the sea. The sides are steep and the ridge can only be ascended from the north-eastern end. The whole mountain consists of alternating beds of sandstone and sills of diabase and porphyrite. The bedding-planes are on the whole slightly inclined towards the south-west.

The south-west point of Nunasarnak consists of nepheline-syenite, and the junction of the abyssal rock with the stratified main body of Nunasarnak is finely exposed (Fig. 12). Just at the contact a slight depression runs transversely across the peninsula, and south-west of the depression the nepheline-syenite rises as a small elevation about 300 meters high[1].

The nepheline-syenite of Nunasarnak is a naujaite which is broken up into a large number of lens-shaped masses separated by a network of arfvedsonite-lujavrite veins. Petrographically the naujaite is extremely variable. Besides the typical naujaite described above, we find here varieties in which the sodalite crystals are so abundant, that the other mineral constituents are quantitatively of quite subordinate importance and the

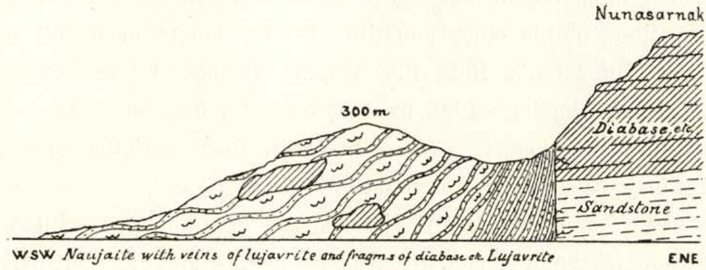

Fig. 12. Junction of nepheline-syenite and stratified rocks. South-west point of Nunasarnak.

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[1] Steenstrup (Meddelelser om Grønland II. 1881, Pl. I) called this locality *Kumerngit* (perhaps a corruption of "Kingmernat" ("bilberries"), a plant which is very common here). This name does not seem to be known any longer by the Greenlanders. — In 1888 Steenstrup found here a variety of nepheline-syenite of a foyaitic structure and with small brown crystals of eudialyte, which on microscopic examination proved to be partially transformed to catapleïite (see N. V. Ussing, Meddelelser om Grønland XIV, p. 167); the earlier described. sodium-free microcline was found in pegmatitic segregations in this rock (Meddelelser om Grønland XIV, p. 12).

rock may be characterised as "sodalitite" or "sodalitgestein"[1]. On freshly broken surfaces of these varieties the above-mentioned, violet-red colour is very finely displayed, but it disappears quickly under the influence of the light. The sodalite is everywhere perfectly fresh and more or less transparent; when the red colour has disappeared the mineral appears greenish or colourless. Some naujaite varieties of Nunasarnak are relatively fine-grained: while the poikilitic sodalite crystals in the typical rock are as a rule about half a centimeter in thickness, we find here varieties in which the crystals have an average diameter of only one millimeter. In such cases the dimensions of the other constituents are also reduced but not to such an extent; thus the felspar crystals are seldom less than 1·5 centimeters thick by 4 or 5 centimeters long. In comparison with other rock-types, however, these varieties of naujaite may be called very coarse-grained[2].

The main interest of Nunasarnak is connected with the junction of the lujavrite with the sandstone and the porphyrite (Fig. 12, p. 73). The lujavrite is of the black, arfvedsonite variety, often with green veins of the ægirine variety; the flow-structure is exceedingly well-marked and gives the rock a pronounced schistosity or fissility. The fissility-planes become steeper and steeper as we approach the contact. At a distance of 100 meters from the latter they have a dip of 60° towards the south-west, and still nearer the contact they are vertical and parallel to the contact-plane. The endomorphic contact-modification has a breadth varying from 10 to 20 meters; it is more or less close-grained, and often of a somewhat chert-like appearance. At many places it is distinctly banded, parallel to the contact-plane; the bands are a few centimeters in breadth

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[1] Meddelelser om Grønland XIV, p. 130. — H. Rosenbusch, Mikroskopische Physiographie II, 1 (1907), p. 240.

[2] Similar comparatively fine-grained varieties of naujaite are met with north of Nunarsuatsiak and in the district between Tupersuatsiak and Agpat.

and are alternately white and black (or green). The white bands consist of a saccharoidal aggregate of felspar, sometimes with dots of green ægirine 2—5 millimeters in diameter. The colour of the black and green bands is due to arfvedsonite and ægirine. At several places near the contact the lujavrite is traversed by pegmatitic veins, which consist mainly of large arfvedsonite prisms and felspar. The border-modification of the lujavrite sends out numerous apophyses, sometimes over 20 meters long, into the adjacent stratified rocks.

The sandstone bordering on the lujavrite is white with a somewhat quartzitic appearance. The igneous sheet which covers this sandstone consists of a porphyrite with numerous phenocrysts of felspar; the latter show distinct twin lamellation and appear in the form of plates about 1 millimeter thick by 1 or 2 centimeters long. At many places the phenocrysts have a fluxional arrangement, and the direction of the flow-structure is almost at right angles to the contact-plane with the nepheline-syenite. As shown in Fig. 12, several detached fragments of porphyrite, some hundreds of meters in length, are found in the nepheline-syenite; around these fragments the lujavrite shows the same contact-facies as described above. With regard to the exomorphic contact-effects in the porphyrite, these can hardly be seen with the naked eye where the adjacent lujavrite has a dense structure; only at a few places, where the lujavrite is fine-grained at the contact, the porphyrite is distinctly contact-metamorphosed and contains innumerable, small flakes of brown mica.

## NUNARSUATSIAK.

The south-west point of Nunasarnak is separated from the Ilimausak Mountains by the Tunuarmiut Inlet. At the foot of Ilimausak, on the north shore of the inlet, lies the small isolated hill Nunarsuatsiak which reaches a height of about 160 meters. This hill is seen in the photograph Pl. XV. It consists of naujaite with broad, irregular veins of arfvedsonite-lujavrite and a little ægirine-lujavrite; it is of interest chiefly as a mineral locality. At the top there is an irregular pegmatitic segregation, probably the coarsest-grained pegmatite in the whole region. It contains plate-shaped crystals of felspar[1], the thickness of which may be up to 30 centimeters, while the length is nearly one meter, and between the felspar plates lie allotriomorphic anhedra of arfvedsonite of similar dimensions. In the less coarse-grained portion of this pegmatite there also occur sodalite and nepheline, as well as a little ægirine and polylithionite.

In 1900 a new mineral was found in the low coastal cliffs below Nunarsuatsiak, the yellow erikite, which has been described by O. B. Böggild[2].

North of Nunarsuatsiak the country for a short distance is flat and covered with gravel; behind this level part rises the south-east slope of Ilimausak. At the foot of the slope the rock is a fine-grained arfvedsonite-lujavrite with almost horizontal, flat lenses of naujaite.

From Nunarsuatsiak towards the north-east the naujaite lenses become gradually more scarce, until at last the cliffs consist of a uniform lujavrite, which here belongs to the green variety (ægirine-lujavrite). At the same time the dip of the parting planes increases, and a little more than a kilometer north-east of Nunarsuatsiak the ægirine-lujavrite borders on the diabase sheets (Pl. VI, Fig. 1 and Pl. XV). The ægirine-lujavrite shows here a well-marked contact-facies, assuming the form of dense, green rock, speckled with black, short needles of arfvedsonite.

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[1] A complete description of this felspar, which is a microline-microperthite, is given in "Meddelelser om Grønland" XIV, pp. 22—28 (1894), where this locality is called "Serrarsuit". G. Flink mentions the same locality under the name "Nunarsiuatiak" (Meddelelser om Grønland XIV, p. 246 (1898)).

[2] Meddelelser om Grønland XXVI, p. 93, (1903).

## ENVIRONS OF NORTH SIORARSUIT.

From the heights of Ilimausak two mountain-torrents rush down towards the Tunugdliarfik Fjord (Pl. VI, Fig. 1 and Pl. X, Fig. 1). At a height of a little more than 200 meters above the sea the torrents unite in a narrow gully, at the mouth of which they have deposited a crescent-shaped alluvial cone or fan which is known as North Siorarsuit. Even in dry summers the brook which flows out over the alluvial plain is of quite a respectable size.

*The mountain slope north of N. Siorarsuit* consists of naujaite with veins of lujavrite. The veins have on an average a dip of 20°—40° towards the south. This mountain slope is traversed by a peculiar red-coloured band which is conspicuous even at a distance of many kilometers (Fig. 13) and indicates a local metamorphism due to pneumatolytical action. Where the alteration is but slight, the structure of the original rock is well-preserved, but the colour has become brick-red; upon closer examination it is seen that the rock has been filled with ferric oxide and violet fluorite, and the original mineral constituents are altered to a varying degree. The felspar remains relatively unaltered, but sodalite and nepheline are converted, sometimes to red spreustein, sometimes to pale-green gieseckite-like pseudomorphs; arfvedsonite and ægirine are replaced by chlorite. Where the alteration is more intense, the original structure can no longer be detected, and the rock is throughout transformed to zeolitic aggregates, which are filled with fine micaceous hæmatite and with fluorite. The metamorphism is on the whole of a similar character to that observed at S. Siorarsuit (p. 63), but at N. Siorarsuit ilvaite and epidote are wanting, and the rock has become intensely red. What is specially instructive at N. Siorarsuit, is the regular form of the red zone (Fig. 13); it extends almost like a dyke in the direction W. S. W. to E. N. E., thus intersecting the lujavrite bands of the naujaite at an oblique angle. The red zone thins out towards the west-southwest and disappears a little to the west of the place where it cuts across the brook at a height of about 230 meters. Following it from here upwards the zone gradually becomes broader; at a height of 420 meters it is almost 100 meters broad, but further to the E. N. E. the alteration is less intense and there is a gradual transition to the unaltered rock. It is evident from the mode of occurrence that the transformation has proceeded from a vertical fissure; through this there was first an emanation of gases containing fluorine and iron, which saturated the rock with fluorite and hæmatite; later, with decreasing temperature, water vapour and hot water have found a way through the fissure and led to the formation of zeolites.

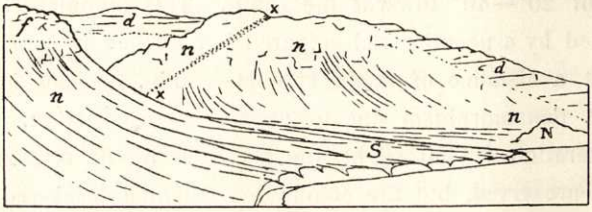

Fig. 13. North Siorarsuit, seen from the west.

*S*, gravel plain of N. Siorarsuit; *N*, Nunarsuatsiak; *f*, sodalite-foyaite; *n*, naujaite and lujavrite; *xx*, zone of red-coloured naujaite and lujavrite; *d*, diabase.

*The mountain slopes west of N. Siorarsuit.* — At the foot of the mountain west of the gravel-plain the naujaite is exposed. At an altitude of about 140 meters this is overlain by the sodalite-foyaite, in quite the same manner as south of the fjord (p. 68). The sodalite-foyaite is cut by a considerable number of tinguaitic dykes, which are dark-green or bluish green and of a dense structure, but have only a slight breadth. The largest tinguaite dyke observed here was 70 centimeters broad. Between the naujaite and the sodalite-foyaite there is a gradual transition. The transitional zone is not quite horizontal, but rises from N. Siorarsuit both towards the north and west; on the whole it is parallel to the direction of the partings in both rocks. The thickness of the sodalite-foyaite at this place amounts to about 200 meters. To the north and west the thickness decreases; two and a half kilometers west of North Siorarsuit it is reduced to some few meters.

In the upper parts the sodalite-foyaite gradually becomes poorer in sodalite and passes into a foyaite, which contains olivine and is of the same composition as the foyaite south of Tunugdliarfik (p. 69). As the transition is very slow I am unable to give the exact thickness of the olivine-bearing foyaite; probably it does not exceed ten meters.

*Transition from foyaite to arfvedsonite-granite.* — A considerable body of arfvedsonite-granite rests upon the foyaite (see Pl. VI, Fig, 1 and Map Pl. III), and the two rocks are connected by a gradual transition. This interesting transition from a nepheline-syenite to an alkali-granite was more closely studied in the mountain slope facing the east, just over the head of the alluvial fan of North Siorarsuit. Here the following series of coarse-grained rocks was found (in descending order):

Arfvedsonite-granite
Quartz-syenite, red (ca. 16 meters)
Pulaskite, red (ca. 4 meters)
Pulaskite, white (ca. 5 meters)
Pulaskite, white, with pegmatite (ca. 1 meter)
Foyaite

These rocks lie as almost horizontal strata above one another without any sharply defined contact between them. Inspecting the cliff from below upwards we observe, at an altitude of about 370 meters, that the foyaite passes into a coarse-grained pulaskite without showing any variation in the size of grain. The pulaskite is of quite the same composition as the pulaskite south of Tunugdliarfik (p. 69). The lowest bed of pulaskite, which is about a meter thick, contains grains of a reddish spreustein which indicate the original presence of nepheline in small amount; it also contains two or three horizontal pegmatitic veins, but a few centimeters broad, which consist of felspar and nepheline. The upper beds of the pulaskite, with a total thickness of about nine meters, are devoid of nepheline. In the lower beds of the quartz-syenite, quartz is only present in very small amount and is only seen under the microscope; in the upper beds quartz is easily seen with the naked eye. The quartz-syenite has a thickness of about 16 meters and is covered by the arfvedsonite-granite, which is rich in quartz. Nearest the quartz-syenite the granite is of a light grayish-red colour and a little variable in size of grain, coarse-grained and medium-grained varieties alternating in indistinct, horizontal bands.

As indicated in the above scheme, the upper part of the transition-series is of a red colour. This is due to an alteration of a similar kind to that in the red zone in the mountain north of N. Siorarsuit (p. 78); but in the transition-zone the process has not been carried so far and has everywhere left the felspar unchanged.

The junction of the nepheline-syenite with the superincumbent arfvedsonite-granite has proved to be of the same character at the other places where it has been closely investigated, but the thicknesses of the different transition-sheets are variable. A second example of the transition series may be given, as found about two and a half kilometers W. S. W. of the place just described, at an altitude of about 600 meters near Igdlunguak. Here the transition-sheets have a dip of almost 20° towards the north or north-west and the succession is the following:

Arfvedsonite-granite, light greenish;
Pulaskite, white, 10—15 meters;
Not exposed, 2 meters;
Sodalite-foyaite, ca. 1 meter;
Naujaite.

The transition from the arfvedsonite-granite to the pulaskite was finely exposed to view and proved perfectly gradual.

*The arfvedsonite-granite.* — The colour of this rock exhibits considerable variations. At some places it is light greenish, at others white, gray or grayish brown; locally also reddish or intensely red varieties are found. But apart from this the composition of the granite is very uniform in the whole district north-west of North Siorarsuit. The rock is more or less coarse-grained, the size of grain being frequently over 3—4 millimeters; it has a typical granitic structure, indicating that felspar and quartz have crystallised simultaneously on a large scale; there is no trace of parallel arrangement of the constituents, nor of porphyritic or rapakivi-like structures. The quartz is grayish clear and occurs abundantly as rounded or irregular grains. The felspar grains often have a form which gives broad, rectangular sections, but most of them are more or less equidimensional and do not show any good crystal outlines except where they are bounded by arfvedsonite. The latter is as a rule the only dark-coloured mineral which can be seen with the naked eye; it occurs in two different forms: on the one hand as elongated prisms (1—2 millimeters broad and 5—10 millimeters long), on the other hand as broad allotriomorphic anhedra which do not exceed 5 millimeters. At some places the arvedsonite is mainly of the latter form, at others the columnar form is predominant and the granite has then a very different appearance from ordinary granite. From the form of the arfvedsonite we can thus distinguish between two varieties of this rock, but they seem to occur quite irregularly together and transitional forms are very frequent. As regards colour, the light greenish varieties represent the rock in its freshest condition, and the granite is often uniformly of this colour over large distances. Most of the red portions of the granite do not seem to have obtained this colour from ordinary weathering, but from pneumatolytical action of a similar kind to that mentioned above (p. 78), though of less intensity. The whole lower portion of the arfvedsonite-granite body which is exposed at a height of 300--500 meters in the mountain slope to the west of North Siorarsuit, is so distinctly red that the colour is conspicuous at a distance of several kilometers; we also find red patches of large extent in the northern part of the arfvedsonite-granite area.

## IGDLUNGUAK AND TUGTUP AGTAKÔRFIA.

West of the alluvial fan of North Siorarsuit the side of the mountain descends more or less abruptly towards the fjord, and in front there is only a narrow, rocky beach. This part of the coast has only been investigated cursorily in geological regards but does not seem to offer features in any essential way different from those on the opposite side of the fjord. Some few words only will be devoted to the two mineral localities, Igdlunguak and Tugtup Agtakôrfia know from Dr. Flink's Expedition of 1897[1].

Igdlunguak lies on the north side of Tunugdliarfik right opposite Naujakasik (see Map Pl. III) and but a short distance west of North Siorarsuit. At this place the coast-line forms two small projecting points, which are built up of arfvedsonite-lujavrite and naujaite. On the point to the east the lujavrite exhibits a peculiar kind of orbicular structure, containing numerous spheroids of 2—20 centimeters in diameter, which are frequently somewhat flattened parallel to the schistosity of the rock. The spheroids have essentially the same composition as the surrounding rock, but they are somewhat more liable to

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[1] The localities were first described by G. Flink in Meddelelser om Grønland XIV (1898), pp. 256 and 258 under the names Agdlunguak and Tutop Agdlerkofia. The minerals from these places were described by J. C. Moberg in Meddelelser om Grønland XX (1898), p. 245, and O. B. Böggild and Chr. Winther in Meddelelser om Grønland XXIV (1899), p. 181.

decay, and the surface is thus full of circular holes. Round each spheroid there is usually a light-brown zone of about a centimeter in breadth. On examination with the microscope we find, that the light-brown zone consists of ordinary lujavrite of similar composition to the surroundings, but with the arfvedsonite replaced by acmite; the light-coloured minerals have partially been converted to analcime, and this alteration has advanced further in the spheroids than in the main body of the lujavrite. Furthest out on the western of the two points we find some few veins, up to half a meter broad, which contain an abundance of steenstrupine crystals and of transparent green natrolite.

At the coast about two kilometers W. S. W. of Igdlunguak there is a small projecting cliff called Tugtup Agtakôrfia. At this locality the rock is an ægirine-bearing arfvedsonite-lujavrite which contains numerous fragments and lenses of naujaite. The mountain which rises above Tugtup Agtakôrfia has the same structure up to about 300 meters, but higher up there is uniform gray naujaite (Pl. X, Fig. 2). In the lujavrite of the rocky shore there are several irregular veins up to half a meter in breadth, which mainly consist of a white, fine-grained albite or at other places of coarse-grained analcime. In these veins we find steenstrupine in beautiful crystals, schizolite and epistolite; further a number of other, less rare, minerals in well-developed crystals, such as arfvedsonite, eudialyte, albite, analcime and natrolite; sphalerite occurs in compact masses.

## ILIMAUSAK.

As will be seen from the geological map, Pl. III, the mountain group of Ilimausak is crowned by a snow-covered plateau, 1200 to 1300 meters high. The plateau is not very large and its flanks everywhere bear the mark of intense erosion, due to a recent local glaciation. With its vertical walls, its deeply notched ridges and small glaciers Ilimausak in its higher parts presents a fragment of magnificent Alpine scenery.

Over the plateau and near its southern margin rise two isolated peaks, Mount Steenstrup ("Steenstrup's Fjæld" 1370 meters) and the highest point of Ilimausak which is about 1450 meters high (see Pl. VI, Fig. 2). So far as known, the latter has never been ascended by any traveller. Between the two peaks a small glacier descends towards the W. S. W. (Pl. XIII, Fig. 1). The glacier fills the uppermost part of a broad U-shaped valley which in its whole length bears the mark of glacier sculpture. Only below each of the numerous water-falls the river has excavated small ravines after the glacier has retreated to its present position.

South and south-east of the two highest points there is a row of three peaks of less height running in east to west direction; these are outliers of the plateau, separated from it by a number of partially confluent cirques. The central peak of these three, "Hatten", has a distinctly hat-like form and commands the whole view of the mountain-group when seen from Tunugdliarfik (Pl. X, Fig. 1). In the two cirques which meet behind "Hatten" and no longer contain any glacier, rise the two earlier-mentioned brooks, which flow down towards the south and south-east to North Siorarsuit.

The principal features in the geological structure of the Ilimausak mountains are as follows. The plateau as also the two highest peaks are built up in part of effusive, in part of intrusive sheets of porphyries, porphyrites and diabases, which are inclined slightly towards the south; they are older than the underlying, abyssal complex. The latter is stratified, but the abyssal sheets are strongly and somewhat irregularly inclined. The arfvedsonite-granite is the uppermost sheet and under this come the quartz-syenite, the pulaskite and the nepheline-syenites.

The greater part of Ilimausak is readily accessible. But the great differences in the heights and the necessity of returning each evening to the tent on the shore of the fjord meant a considerable loss of time, and as but few days were available for the investigation of this region in 1900, the work was of a more cursory nature than in the case of the regions hitherto dealt with. When the author visited the district in 1908 at the end of July, the moutains were covered with snow from 500 meters upwards and no geological investigations were possible.

## ABYSSAL ROCKS OF ILIMAUSAK.

*The nepheline-syenites* are mainly represented by naujaite and lujavrite in the upper parts of Ilimausak. The sheets rise rather rapidly from North Siorarsuit towards the west and north and are exposed to view over a ring-shaped area round about the arfvedsonite-granite. This ring of nepheline-syenite is narrowest close to the south of Mount Steenstrup, where the nepheline-syenites are partially covered by the Narsak Glacier.

Ascending from North Siorarsuit towards the west and following the western part of the nepheline-syenite belt, we reach the watershed above Igdlunguak at a little below 600 meters; close to the west of the watershed lies a lake (Tasek), whose surface is about 500 meters above the sea. The larger, eastern part of the lake is surrounded by naujaite with very few veins of lujavrite. To the west the naujaite borders upon almost horizontal sheets of porphyrite, which are older than the naujaite; but the junction is not well exposed, the plateau being to some extent covered with morainic material. At one place near the boundary a white augite-syenite is observed, probably a continuation of the augite-syenite zone between Nunasarnausak and South Siorarsuit. North-west of the lake, at a height of only 520 meters, we come across another watershed, from which we have a view down into a broad valley which extends from the Narsak Glacier towards the W. S. W. Naujaite forms a great part of the mountain slope on the west side of the valley, but it contains many and broad veins of arfvedsonite-lujavrite and down by the river the lujavrite prevails. On the right side of the glacier-river the lujavrite extends towards the north up the mountain slope and reaches here its northernmost point about four kilometers north of Tasek. Naujaite and lujavrite continue along the river right up to the glacier, and the terminal moraine mainly consists of naujaite boulders.

The uppermost sheet of the nepheline-syenite complex, the sodalite-foyaite, which at North Siorarsuit is about two hundred meters thick, becomes gradually thinner towards the west (see p. 79). No investigation was made on the mountain side north-east of Tasek, to see whether it was present there or not, but further to the north, on the south side of the glacier valley, the foyaite is exposed in a zone of considerable thickness between the naujaite and the granite at a height of about 700 meters.

The eastern part of the naujaite and lujavrite area extends from North Siorarsuit northwards and east of Hatten, then bends round towards the west and culminates at a little over 1100 meters in the narrow ridge, which separates the Narsak Glacier from the cirque behind Hatten. Towards the east and north the nepheline-syenite area borders upon the diabase and porphyry sheets. At the junction the nepheline-syenite is usually represented by lujavrite; east of Hatten, however, the naujaite comes into direct contact with the diabase. At the contact the size of grain of the naujaite is somewhat smaller than usual (the sodalite crystals average about 1·5 millimeter in diameter and the felspar shows rectangular sections of about 5 centimeters by 1 centimeter); the diabase is intensely metamorphosed, being filled with very small, dark-brown scales of biotite. North of this place the naujaite is separated from the porphyrite sheets by a zone of white augite-syenite with numerous fragments of porphyrite and porphyry. The highest part of the naujaite that forms the above-mentioned ridge south of the Narsak Glacier, is remarkable for its brick-red colour, which is conspicuous even at a long distance. The original structure is usually well-preserved in this red naujaite, but the dark-coloured minerals and the sodalite are replaced by soapstone-like or chloritic aggregates, and the felspar is filled with ferric oxide and frequently zeolitised. Thus, we have here a similar local alteration to that found N. W. of Nunarsuatsiak.

*The arfvedsonite-granite* forms a sheet of considerable thickness above the nepheline-syenites. It occupies an area of irregular but roughly circular form, a little more than four kilometers in diameter. As mentioned earlier (p. 70), it has originally extended over an area several times larger, namely, right over to the other side of the Tunugdliarfik Fjord. At North Siorarsuit the transitional zone between the arfvedsonite-granite and the underlying nepheline-syenite lies at a height of about 400 meters; from here it rises towards the north and close to the south of the Narsak Glacier reaches a height of almost 1100 meters. This corresponds to an average inclination of about 11° towards the south, but in reality the transitional zone is bowl-shaped and the inclination is steepest in the northern part. The thickness of the arfvedsonite-granite sheet can be estimated at about 300 meters.

The general appearance of the arfvedsonite-granite has been described above (p. 81). The colour of the granite in the higher part of the region is usually light-greenish, but reddish varieties have a considerable extension; at a few places (in the narrow ridge south of the Narsak Glacier at a height of 1000—1100 meters and close to the south-west of Hatten at 760 meters) there is found a variety of a strong red colour; this variety is filled with secondary fluorite and micaceous hæmatite.

Within the area shown on the map (Pl. III) as arfvedsonite-granite, syenite has been observed at two places. The one place lies almost in the centre of the granite area, at a height of 650—720 meters south-west of Hatten; here a white syenite is found, in part very closely related to the augite-syenite of Kangerdluarsuk. The second place is on the south and south-west side of the high mountain between Tasek and the glacier, where a white, rapidly decaying syenite is observed in the steep cliff-wall; at this place the syenite sheet is apparently over 100 meters thick and rests upon the arfvedsonite-granite; above it lie the porphyry sheets.

On the south-east side of the mountain between Tasek and the Narsak Glacier, the arfvedsonite-granite is directly covered by the porphyry sheets, and the same is the case in Hatten. The junction is on the whole more or less horizontal, but on closer inspection the contact line proves very irregular and indented. In the vicinity of the porphyry the granite becomes banded with alternating fine-grained and coarse-grained "schlieren", then follows a fine-grained contact-facies of one or two meters in breadth and above this the porphyry, which has been greatly modified by contact-metamorphism. Numerous apophyses of fine-grained granite penetrate into the porphyry; most of them are only a few centimeters broad but several meters long.

## PORPHYRITIC ROCKS OF ILIMAUSAK.

A glance at the sections, Pl. VI, will show, that the Ilimausak Mountains have preserved considerable portions of the roof which covered the abyssal complex at the time when the latter was in a molten condition. These remnants of the roof consist of a series of more or less horizontal sheets of porphyries and diabases with a total thickness of about one kilometer; yet we must suppose, that what has escaped erosion is only a small remnant of the original mass. The series is built up of a large number of sheets, partly intrusive, partly effusive. As mentioned, the whole mountain region has only been cursorily investigated, and it cannot be said with certainty which of the sheets are effusive and which intrusive. Intrusive sheets are very common in the sandstone, and it is probable, therefore, that they also occur in abundance in the volcanic series.

On the other hand the occurrences, even if few, of volcanic agglomerates tell in favour of the view that some of the sheets are ordinary lava-flows. On the west side of Mount Steenstrup at 1220 meters above the sea a rock greatly modified by contact metamorphism was found, which consists of sharp-edged fragments of diabase and porphyry, some few centimeters in size and imbedded in an extremely fine-grained matrix of garnet and epidote. A similar rock was found as a boulder on the south-east side of Ilimausak above Nunarsuatsiak. Another boulder, found on the plateau above Narsak, consists of porphyry fragments imbedded in a matrix of minute felspar fragments with some garnet and epidote, thus probably a somewhat altered porphyry-tuff.

According to their macroscopic appearance the rocks of the volcanic series of Ilimausak may be classified provisionally as diabase, porphyrite, porphyry and quartz-porphyry. Most of these rocks exhibit very marked effects of contact-metamorphism. Microscopic examination has not succeeded in showing the presence of nepheline in them, but from the chemical analyses there can be no doubt, that they are effusive forms of magmas of the alkali group and must be referred to trachydolerite, alkali-trachyte, comendite etc. Without doubt they are genetically connected with the nepheline-syenites and the other rocks of the abyssal complex, although the latter at the junction always appear to be younger than the volcanic series.

As mentioned, it has not been possible to make a separation of the effusive from the intrusive sheets, nor has it been possible to determine with certainty the chronological sequence of the several rock-types. We may take it as not improbable, however, that the order of eruption corresponds with increasing acidity, since diabases and porphyrites are predominant in the lowermost part, while the porphyries form the highest part of the series; the quartz porphyries, which are only known as dykes, are distinctly younger than the porphyries.

A brief description may be given of the macroscopic appearance of the main types with notes on their occurrences.

The diabases of Ilimausak are much like those of Nunasarnausak (p. 56). A dense, dark-gray diabase, rich in secondary epidote, was found north of Tunuarmiut, at a height of about 300 meters. Other varieties with fine-grained or medium-grained structure make up the uppermost part of Mount Steenstrup; these varieties are unusually rich in large, macroscopic grains of magnetite and needles of apatite; they have been very intensely modified by contact-metamorphism and are filled with flakes of a brown biotite. The exceptional intensity of the contact-metamorphism here is doubtless connected with the fact, that the mountain is traversed by very numerous dykes of arfvedsonite granite.

The porphyrites are the most widely distributed rocks of the whole series. They have a dense, greatly altered groundmass of dark brownish, greenish or grayish-violet colour. The felspar phenocrysts show twin-striation; they are of a thin tabular form, usually $^1/_2$—$1^1/_2$ millimeter thick and 15—25 millimeters long. As a rule they show a well pronounced fluxional arrangement.

The porphyrites have been observed as sheets at the following places: on the mountain 760 meters high south-west of Tasek; on Nunasarnak above the nepheline-syenites; at Tunuarmiut; at a height of 800 meters above Tunuarmiut; on the west side of Mount Steenstrup at heights of 1000 meters and 1140 meters; at a height of about 750 meters on the unnamed mountain lying to the west of Mount Steenstrup.

The name "Ilimausak porphyries" may be given to a number of porphyries, probably effusive, which are found especially in the highest parts of the series and form a well-defined group in their macroscopic appearance. Their ground-mass is absolutely dense and of a dark bluish-black or brownish-black colour; it contains felspar phenocrysts to a varying amount. The latter have a light reddish colour, are comparatively small (about $^1/_2$ centimeter) and of varying forms giving short-rectangular or roundish sections. Superficially the Ilimausak porphyries have a resemblance to certain of the porphyries from Dalarne in Sweden, especially the so-called Klittberg porphyry, but in chemical and mineralogical composition they are very different from this; chemically they are related to the rhomb-porphyries of the Christiania district.

These porphyries rest on the arfvedsonite-granite in the mountain Hatten; they also occur in the high mountain west of Hatten, and in Narsap Kakâ west of the principal mass of Ilimausak; lastly, a sheet of Ilimausak porphyry has been observed at a height of about 1320 meters on the west side of Mount Steenstrup.

A remarkable variety was found at a height of 1100 meters west of Hatten. It has phenocrysts and ground-mass like the ordinary Ilimausak porphyries, but it contains innumerable, small sandstone fragments. These are more or less rounded and vary in size from the same dimensions as the felspar phenocrysts down to 1 millimeter and less. The rock resembles quartz porphyry and its true nature is first seen on microscopic examination.

A number of other types, as a rule of a more acid character than those just mentioned, are found scattered about the whole region. Thus, in the scree under Hatten, a dark-gray, much decayed porphyry was found with white, rhomboidal phenocrysts; and pebbles of the same rock are common in the alluvial fan of North Siorarsuit; the rock is interesting from its striking resemblance to certain varieties of the Norwegian rhomb-porphyry. A green porphyry, which occurs as a sheet of considerable thickness on the plateau south of Tasek Lake, at a height of about 600 meters, has some resemblance to grorudite but contains no quartz. It has small, light-reddish felspar phenocrysts of rectangular form. — The reddish-gray syenite-porphyry, which is very common as dyke-rock in the whole region, also occurs as sills; thus on the west side of Mount Steenstrup, at a height of 540 meters and also nearer the top. At the former place the rock contains a little quartz.

*Dykes cutting the volcanic series.* — The volcanic series of Ilimausak is cut by a large number of dykes. Most of them are strictly vertical and run in a direction corresponding to the main direction of the fjords (about N. 60° E.); as a rule they do not penetrate into the abyssal complex.

The commonest dykes are composed of a bluish-gray or reddish-gray syenite-porphyry; their ground-mass is fine-grained and usually (not always) devoid of quartz; the phenocrysts are light-gray or reddish crystals of felspar, which have in some cases rhomboidal, in others short-rectangular or irregular outlines. One of these dykes (1250 meters above the sea, on the west side of Mount Steenstrup) contains numerous fragments of sandstone, about the size of peas. The syenite-porphyry dykes hold their course for long distances and are frequently over ten meters in width.

Quartz-porphyry dykes are not quite so common, they are from two to ten meters in width and their direction is N. E.-S. W. or E. N. E.-W. S. W. The most frequent variety has a grayish-red or grayish-violet ground-mass of dense or extremely fine-grained structure; as phenocrysts occur both felspar (broad, rectangular sections, 3—8 millimeters in length) and quartz; the latter is in well-developed crystals of 1—2 millimeters in length. This type was met with on the plateau west of the mountain Hatten and on the west side of Mount Steenstrup. In several of the quartz-porphyry dykes the ground-mass is crowded with dark dots of the size of a pin's head, which proved to be spherulites on microscopical examination. A divergent variety of quartz-porphyry is common among the pebbles in the large alluvial fan of North Siorarsuit; it has the same colour and general habit as the Ilimausak porphyry, but differs from this in containing numerous phenocrysts of well-developed, bipyramidal form.

Other dyke-rocks are more restricted in their occurrence. Thus the uppermost part of Mount Steenstrup contains a number of dykes which consist of a red, coarse-grained granite and are probably connected with the underlying arfvedsonite-granite; they have an irregular course and are from one to ten meters in width. They cut through the above-mentioned dykes and sills of syenite-porphyry and contain fragments of these. One of the arfvedsonite-granite dykes passes through the very top of Mount Steenstrup. — A dyke of grorudite, one meter wide, of a very fine-grained structure and light grayish-green colour, occurs east of Kakarsuak at a height of about 600 meters. A dyke of a similar grayish-green rock, but containing no quartz, cuts the porphyrite of the mountain south-west of Tasek (about 750 meters above the sea). This dyke is only half a meter in width and is remarkable for its fine spherulitic structure, with densely packed spherulites, which are from 4 to 8 millimeters in diameter and consist of radiating fibres of felspar and ægirine.

It may be mentioned, lastly, that a vein containing a little copper-glance, bornite, malachite, brown garnet and albite, has been observed in the porphyrite above Tunuarmiut at a height of about 800 meters[1].

## NARSAK DISTRICT.

The Narsak District referred to here embraces the outermost (south-western) part of the peninsula between Sermilik and Tunugdliarfik Fjords, including Mount Kakarsuak and the coastal stretch lying to the south and west of this.

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[1] O. B. Bøggild, Mineralogia Groenlandica p. 56 (Meddelelser om Grønland XXXII, 1905).

Narsak is a pleasant little hamlet, situated at the western foot of Kakarsuak on a small plain covered with vegetation; it is one of the few places in Greenland where cows can be kept. Owing to the alluvial deposits and vegetation which conceal the rocks, the geological investigations are more difficult here than at the places mentioned hitherto. In addition, the geological structure is extremely complicated and the following description can therefore only be regarded as an account of the most conspicuous features.

## BASEMENT GRANITE AND SANDSTONE AT NUGARSUK.

Nugarsuk is the name of the low peninsula about two kilometers south-east of Narsak. The rock furthest out on the peninsula is Algonkian granite (Julianehaab granite) of a white or reddish-gray colour. In the northern part of the peninsula the granite is covered by arkose, and this in turn by the sandstone; the lowermost sandstone-beds are of a red colour but the upper beds are white and quartzitic. The bedding planes have a slight inclination towards the north or north-west. The main features of the geological structure are thus similar to those on the south coast of Tunugdliarfik Fjord (p. 62), but the arkose at Nugarsuk shows a much greater development.

The rocks are best exposed on the small peninsula close to the north-west of Nugarsuk. Here the arkose covering the granite has a thickness of 10—15 meters; it is very compact and on a cursory view may be mistaken for granite. The lowermost portions of the arkose are of a greenish-white colour, the main body brownish-red. It consists of large and small grains of quartz and felspar, intermingled with a microcrystallinic aggregate of felspar and epidote, which seems to have originated by conversion of the original felspar. The quartz is frequently of a milky appearance and the felspar is not very fresh. The red varieties of the arkose are filled with minute flakes of ferric oxide, and small metallic hæmatite crystals may sometimes be seen in them. The sandstone above the arkose is dark violet-red, very fine-grained and regularly bedded. Higher up and nearer the newer igneous rocks the sandstone has been discoloured.

The sandstone on Nugarsuk and in its vicinity forms a belt running west to east with a breadth of half a kilometer. To the north this belt borders upon the newer abyssal rocks (granite and nordmarkite). The junction is excellently exposed on the rocky shore north-east of Nugarsuk: the sandstone is in contact with a light-gray or reddish, medium-grained arfvedsonite-granite and is traversed by a network of small apophyses of arfvedsonite-granite, which are more coarse-grained than the main body of the granite.

To the west of this locality the northern boundary of the sandstone belt is covered by alluvial deposits and vegetation. On the geological map the sandstone area borders directly on the nordmarkite of Kakarsuak, but in reality there seems to be a narrow zone of a diabase filled with sandstone fragments between the two rocks.

## THE ESSEXITE.

*Distribution.* — The houses in Narsak are built on this rock, which likewise composes the low cliffs round the harbour and the northern part of the island outside. From here the essexite continues about three kilometers along the coast to the bay at Panernak, and it is again found at one small spot on the north side of the bay (see Pl. III).

The essexite is thus exposed within quite a restricted area, but since it reappears at Sigsardlugtok on the east side of the island Tugtutok, about seven kilometers west of Narsak (see Pl. II), it probably occupies a considerable area below the sea. At Sigsardlugtok the essexite occurs as two or three large dykes which continue for a distance of several kilometers towards the W. S. W. The essexite is also found at two places without any apparent connection with these localities, namely, six kilometers north-east of Narsak within a small area on the southern side of the valley which leads from the Narsak Glacier to Panernak Bay, and secondly about 23 kilometers north-east of Narsak on Kangerdluak Fjord (Pl. III), where the Algonkian granite is cut by a dyke of essexite several hundred meters wide.

*General appearance.* — The essexite decays so rapidly that it gives rise to rubbish-covered areas quite bare of vegetation, whose uniformly gray colour makes them conspicuous even at a distance. The rock is coarse-grained and of a well-pronounced ophitic structure. The main constituents are a felspar with conspicuous twin-lamellation and tabular form; the length of the crystals is usually 20—30 millimeters, the thickness about 2 millimeters. Its colour is clear grayish or with incipient weathering white. Black allotriomorphic augite, brown biotite, and magnetite occupy the interspaces between the felspar crystals, and in most varieties olivine is detected with the help of the lens. Epidote is commonly present as an alteration-product.

As a rule the felspar tables are not arranged in any definite order; in some cases, however, they show a strong tendency towards parallel disposition, as a result of fluctional movements of the magma before the final consolidation. Here and there we find very coarse-grained portions of 10—30 meters in extent, where the felspar crystals reach up to 6 centimeters in length and 6 millimeters in thickness. Judging from their size of grain we might be inclined to consider these portions as essexite-pegmatite, but in most cases they look like large clots and often consist almost entirely of felspar; it is probable, therefore, that they represent early segregations of the magma. In some of these very coarse-grained portions the dark minerals have been dissolved and in the cavities thus formed beautiful crystals of epidote 3—4 millimeters long are found. A true vein of essexite-pegmatite, half a meter wide, was found in the essexite cliffs near Panernak Bay; it is composed of felspar and pyroxene in crystals often exceeding 10 centimeters.

*Contact relations.* — The junction of the essexite and sandstone is exposed in the low cliffs of the coast, about one kilometer south-east of Narsak. The essexite shows a well-marked contact-facies almost 12 meters broad. This is a porphyritic rock crowded with large, white phenocrysts of felspar, while the ground-mass is a medium-grained essexite; the felspar phenocrysts are up to 14 centimeters in length and 2—3 centimeters in thickness. Immediately at the junction with the sandstone the rock changes to a dark-green, serpentine-like, decayed mass without phenocrysts. The contact-plane is not vertical but has an inclination of 20—30° towards the south-east; the essexite is thus partially covered by the sandstone. — At Sigsardlugtok (7 kilometers west of Narsak) the essexite shows a gradual decrease in size of grain towards the adjoining Algonkian granite.

*Magnetite-pyroxenite.* — Two kilometers north-west of Narsak a narrow point runs out towards the N. W., separating Panernak Bay from the sea. On the outer side of this point the essexite contains a small mass of black, fine-grained magnetite-pyroxenite, not very different in appearance from the well-known magnetite-olivinite from Taberg in Sweden. This mass extends for at least 40 meters from N.W. to S.E. and at least 15 meters at right angles to this direction. The contact between this rock and the surrounding essexite was not investigated.

*Dykes cutting the essexite.* — The essexite is traversed by a number of dykes which may be briefly mentioned at this place.

(1) Two dykes of a syenite-porphyry (or sölvsbergite) occur

close south-west of Narsak. Their ground-mass is fine-grained and of a gray colour; it is speckled with moderately small phenocrysts of a reddish-white felspar with broad rectangular outlines. One of these dykes is five meters wide and runs in the direction north-south, the other, two or three meters wide, running in the direction north-east to south-west.

(2) A dyke 17 centimeters wide of a light-coloured, fine-grained arfvedsonite-granite was found in 1888 by Dr. Steenstrup on the north side of the harbour at Narsak. This dyke is remarkable for its coarse-grained border-zones.

(3) Gray, fine-grained, bostonite-like dykes of about half a meter in width and irregular sinuous course occur at several places in the neighbourhood of the harbour.

(4) Perhaps the commonest of all the dykes are composed of a peculiar, jasper-like rock of bluish-black or greenish-black colour. These dykes are only 0·1 meter in width. Their border zones are of a glassy or pitchstone-like appearance and contain spherulites of a few millimeters in diameter with a fluxional arrangement. The central zone of the dykes consists almost entirely of spherulites, which may reach one centimeter in diameter, and here also some few small phenocrysts occur of a transparent felspar, without twinning. Under the microscope the spherulites appear turbid and brown or brownish-green; they consist of radiating, extremely fine fibres. They seem to have originated through devitrification after the rock had solidified. These dykes cut those mentioned under (1).

## THE NORDMARKITE AND THE ROCKS OF KAKARSUAK.

*The nordmarkite.* — This rock occupies the north-eastern part of the plain around Narsak and composes the slope of Mount Kakarsuak which faces Narsak. Towards the north-west the nordmarkite extends across Panernak Bay to Nungmiut where it bends round towards the north-east along the south coast of Sermilik Fjord. At the higher levels it is everywhere covered by the volcanic series.

The nordmarkite is a reddish-gray, coarse-grained syenite, which in outer habit shows a certain amount of resemblance to Brøgger's typical nordmarkite from the Christiania district. The main constituents are felspar, which is in part light-gray and fresh, in part light-reddish and weathered; frequently the central parts of the crystals are pure gray, changing to a more reddish colour towards the periphery. These colour-shadowings give the rock a characteristic, mottled appearance. The form of the felspar crystals is irregular, most being elongated, one or two centimeters in length by half a centimeter broad. In some varieties of the nordmarkite the felspars show distinctly rectangular outlines. The dark-coloured minerals are hornblende, pyroxene and biotite. Quartz is frequently present but only in very small amount.

At Panernak, about 2 kilometers north-west of Narsak, where the junction of the nordmarkite and the essexite can be studied in the cliffs along the shore, we find that the nordmarkite is younger than the essexite. The contact-plane is almost vertical and the difference in age of the two rocks is manifest from the following observations.

(1) The essexite has a marked flow-structure, which is cut across transversely by the nordmarkite.

(2) The essexite has a uniform, coarse grain right up to the contact, while the nordmarkite shows extreme variations in size of grain in a zone about 20 meters broad along the contact, due to the alternation of coarse pegmatite-like and fine-grained bands and patches.

(3) A fragment of essexite (two or three square meters large) was found in the nordmarkite near the contact.

The junction between the nordmarkite and the porphyritic rocks is finely exposed above Narsak on the south-west slope of Mount Kakarsuak, where the nordmarkite is covered by the characteristic Kakarsuak porphyrite to be described below. The nordmarkite exhibits here a well developed contact-facies with a fine-grained ground-mass and large felspar phenocrysts, which in places show rectangular, but more usually rhomboidal outline. This contact-modification has a breadth of some few meters. The same structure, though usually an even more fine-grained ground-mass, is shown in the numerous apophyses which enter the overlying rock.

At the southern foot of Kakarsuak, the map would indicate that the nordmarkite borders upon sandstone, but the contact has not been observed here.

*Occurrence of fluorite at Panernak.* — In the immediate vicinity of Narsak the land is very low and swampy, but about two kilometers N. N. W. of the town some low heights called Panernak ("the dry place") rise over the marshy plain. The rock is a red granite, or facies of nordmarkite rich in quartz, and contains here a system of quartz veins running side by side as a rule, though branching, the main direction being E. 10° N.—W. 10° S. There is a large number of veins, 10—20 may be counted within a distance of ten meters; the veins vary in width from one to 30 centimeters. Besides quartz the veins contain fluorite in cubes and coarsely crystalline aggregates of a white or light greenish colour. The largest fluorite masses seen in 1908 had a length of 0·3 meters, but these are only the remains of originally much larger masses. The Greenlanders are very fond of the fluorite, which they use as snuff, and they have removed most of what could be got at easily; in consequence a hole has been made here about half a meter deep and three meters long. This is the most extensive occurrence of fluorite which has hitherto been found in Greenland; but it is not sufficiently large to be of economical importance; a brief account of it has first been given by Dr. STEENSTRUP[1].

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[1] Meddelelser om Grønland II, p. 35 (1881).

*Dykes cutting the nordmarkite.* — The commonest dykes are composed of a red or reddish-brown arfvedsonite-granite; they have a south-westerly direction and a width of 3—10 meters. In appearance and character they are very similar to the large masses of arfvedsonite-granite north and east of Narsak; probably they are offshoots from the latter and thus indicate, that the consolidation of the granite has occurred later than that of the nordmarkite. Similar granite-dykes are observed in considerable numbers at Nungmiut, about seven kilometers N. N. W. of Narsak. Above Narsak a reddish-gray, bostonite-like dyke is found; it is ten meters wide and the direction is W. S. W. —E. N. E. At Narsak and at the south coast of Panernak Bay a few narrow (0·1—0·25 meters) and irregular dykes occur of the same black spherulitic rock-type, which forms dykes in the essexite (p. 98). A dyke of diabase is observed in the nordmarkite at Nungmiut; this is remarkable for the vasicular structure of its border-zones. It is two meters wide and the direction is W. S. W.—E. N. E.

*The rocks of Kakarsuak.* — The top of Kakarsuak consists of essexite-porphyrite, which directly covers the nordmarkite. The "Kakarsuak porphyrite", as the rock was called during the fieldwork, is greatly altered by contact-metamorphism and is remarkable for its large and numerous felspar phenocrysts, which are packed so thickly together that the dark ground-mass is reduced to a very small amount filling the interspaces between them. These phenocrysts show twin-lamellation and usually have a form which gives broad rectangular sections; in size they are very varying (1—10 centimeters) and they are of a dull greenish white appearance. The essexite-porphyrite is a minor intrusion of irregular shape, which has been intruded among the bedded porphyries. It has a great resemblance to the above-mentioned border-facies of the essexite.

The essexite-porphyrite is cut by numerous dykes of red arfvedsonite-granite; the width of these dykes is from 0·1 meter up to 30 meters and their direction is almost N. 60° E.—S. 60° W. They are probably connected with the extensive intrusive mass of red arfvedsonite-granite, which is met with a short distance east of the top of Kakarsuak. North-east of this intrusive mass, which is only a few hundred meters broad, we again come across the essexite-porphyrite, here filled with numerous fragments of sandstone. Following the plateau further towards the north-east, the essexite-porphyrite soon joins the ordinary porphyries, which lie in distinct sheets and have been described above (p. 88).

## SOUTH COAST OF SERMILIK.

### GENERAL FEATURES.

The south coast of Sermilik offers a magnificent, geological section (see Pl VI, Fig. 2). The cliffs rise almost vertically out of the water like a straight wall 1000—1200 meters high, and above the wall extends the snow-covered Ilimausak plateau deeply notched by picturesque glacier-filled cirques and surmounted by the two highest peaks of Ilimausak. The eastern part of this imposing wall, which is about 20 kilometers in length, is built up of the red sandstone, and as the surface of the cliffs is not covered by any vegetation, the dark red colour of the sandstone is conspicuous at a long distance. The sandstone formation is traversed by numerous dykes and sills of diabase and porphyry; as the dykes run almost parallel with the coast, they appear often like the sills as horizontal, dark bands in the cliff-wall. In the middle part of the section the sandstone is covered by the dark masses of the volcanic series. In the western part the cliffs are somewhat lower and from the sea upwards to about 600 meters consist of nordmarkite, over which the volcanic rocks form a cover.

## JUNCTION OF THF NORDMARKITE AND SANDSTONE.

In Sermilik Fjord the junction of the nordmarkite and sandstone is finely exposed just under Mount Steenstrup. The plane of contact is almost vertical and at a right angle to the shore-line. Towards the contact the nordmarkite becomes fine-grained and porphyritic; about one meter from the sandstone it passes into a quartz-bearing syenite-porphyry consisting of a brownish-gray, fine-grained, ground-mass with thick, tabular felspar phenocrysts about one centimeter long. Still closer to the sandstone the rock becomes so rich in quartz that it must be characterized as a granite; the structure here is medium-grained and the colour light-brown. Microscopic examination shows, that the quartz-grains of this contact-facies are not sandstone fragments, but have crystallised together with the other constituents. Thus, the syenite magma appears to have absorbed a very considerable quantity of silica from the sandstone, in a zone along the contact about one meter broad.

At the contact with the nordmarkite the sandstone exhibits distinct effects of contact-metamorphism: it has become quartzite-like and the red colour has disappeared. Under the microscope the interstitial matter of the sandstone is seen to have entirely disappeared and the rock consists of clear interlocking quartz grains. The white quartzite-like contact-zone has a breadth of some meters.

## TOTAL THICKNESS OF THE RED SANDSTONE AND OF THE VOLCANIC SERIES.

The natural section exposed on the south side of Sermilik Fjord gives us a means of forming a fairly trustworthy estimate of the thickness of the red sandstone. The beds have a very regular inclination of about 2° on the average towards S. S. W. At the head of the small side-fjord Kangerdluak (furthest to the left in the section Pl. VI, Fig. 2), the basement rock appears under the sandstone; it is a coarse-grained, light-reddish biotite-granite, and just as on Nugarsuk (p. 94) the lowermost sheets of the sandstone formation consist of arkose. From here up to the top of Nasanguak, the most easterly peak of Ilimausak, the mountain is built up entirely of the sandstone formation, and the numerous intrusive sheets in this show that no fault of any considerable amount of throw cuts the sandstone formation between Kangerdluak and Nasanguak. As can be seen from the section (Pl. VI, Fig. 2), the top of Nasanguak corresponds very closely to the upper boundary of the sandstone. As this mountain has a height of about 1050 meters according to measurements made by Dr. Steenstrup, the total thickness of the sandstone formation, taking the inclination into account, is about 1200 meters. The original thickness of the sandstone has not been quite so much as this, since the intruded diabase sheets have considerably added to the thickness of the formation. The lower half of the sandstone contains but few and thin sills, but in the upper half these are extremely numerous and thick: one of them has been estimated to be over 100 meters thick, and the total thickness of the sills probably amounts to about 300 meters, though the latter estimate is admittedly a rough one.

*The volcanic series* which covers the red sandstone, reaches an altitude of almost 1450 meters in the highest point of Ilimausak. From this we may calculate that the actual thickness of the series amounts to about 1000 meters, regard being taken of the inclination of the sheets towards the S. S. W. But since this, the uppermost formation, has undoubtedly been exposed to denudation through an enormous stretch of time, the original thickness of the volcanic series must have been very much greater, probably several thousands of meters.

This conclusion gains in probability from the fact, that the porphyries in Hatten and in the highest peak of Ilimausak, that is, the uppermost part of the volcanic series still preserved, only form a relatively thin cover from 200 to 300 meters in thickness over abyssal rocks, which have consolidated later than the porphyries. We can hardly assume that abyssal rocks have crystallised at a depth of but 200 to 300 meters under the earth-surface, and from this point of view we must conclude, therefore, that the volcanic rocks now existing must originally have been covered by igneous, or sedimentary, sheets of very considerable thickness. A still more direct proof is found in the numerous, large and regular dykes which traverse the whole of the still existing part of the volcanic series, showing that volcanic rocks must have composed at least an important part of the masses which have been entirely removed by erosion. We are thus led to the conclusion, that the red sandstone in the Ilimausak region has originally been covered by a series of volcanic sheets with a total thickness which probably amounted to several kilometers, but of the whole of this formation only a very small part has escaped destruction by erosion, the part, namely, which has been altered by contact-metamorphism round the abyssal rocks and has thus gained a special power of resistance.

# CHAPTER IV.

# PETROGRAPHY OF THE IGNEOUS ROCKS OF THE ILIMAUSAK REGION.

## INTRODUCTORY.

The igneous complex of Ilimausak comprises a great diversity of rocks which prove genetically connected. Furthermore the whole complex is dissected in such a way by the deep fjords that the arrangement of the rock-bodies, and their geological relations on the whole, are exceptionally plainly revealed. The complex is therefore of prominent interest from a petrological point of view. As moreover a great part of the rocks differs considerably from what is known from other places, a complete petrographic description would not be inappropriate. For practical reasons, however, only the leading types will here be described.

The petrographical examination of rocks from the region considered in this place was based to begin with on the collections made by Dr. K. J. V. Steenstrup during his various visits to the district of Julianehaab. A number of specimens from these collections was studied during a stay at Heidelberg in the winter of 1888—89, and the author is under great obligation to Professor Rosenbusch for many valuable suggestions at the commencement of the work. That its continuation has been greatly promoted by the excellent text-books of Professor Rosenbusch need hardly be pointed out to the petrographical reader.

In 1892 and 1894 the author obtained a subvention from the Carlsberg Fund for mineralogical and petrographical investigations of the nepheline-syenites of South Greenland, and in the latter year a monograph on the principal constituent minerals of these rocks was published[1]. The geological surveying of the district of Julianehaab during the summers of 1900 and 1908 has greatly augmented the collections available for the petrographical investigations whose results are stated in the following pages.

## ABYSSAL ROCKS: CLASSIFICATION.

From a geological point of view the igneous rocks of the Ilimausak complex may be divided into three main divisions. One division comprises the rocks of what may be called the 'stratified batholite', i. e. the central and north-eastern parts of the abyssal complex within which the rocks are arranged in almost horizontal sheets one upon the other. These rocks enumerated from the top downwards are as follows: —

*arfvedsonite-granite*
*quartz-syenite*
*pulaskite*
*foyaite*
*sodalite-foyaite*
*naujaite*
*lujavrite* and *kakortokite.*

The second division comprises a number of more independently occurring abyssal rocks which compose the western and

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[1] Mineralogisk-petrografiske Undersøgelser af Grønlandske Nefelinsyeniter. Meddelelser om Grønland XIV. — Some temporary results concerning the petrography of these rocks have been published in the section about nepheline-syenite in the 3rd edition of Mr. Rosenbusch's Mikroskopische Physiographie II (1896) and in his Elemente der Gesteinslehre (1898).

southern parts of the Ilimausak complex. The following types are here represented: —

*arfvedsonite-granite*
*augite-syenite*
*nordmarkite*
*essexite.*

The third division comprises the *volcanic rocks* of Ilimausak. During the field work these were classified as diabases, porphyrites, porphyries, and quartz-porphyries. For convenience the same headings will be used here; it should, however, be borne in mind that these rocks in reality belong to the alkali-group.

In the following description the rocks will be mentioned in the order given above with the exception that the description of the arfvedsonite-granite of the second division is given in connection with that of the corresponding rock of the first division.

## GRANITES.

The granites of the Ilimausak complex are alkali-granites and as a rule they are arfvedsonite-bearing. The principal granite-body belongs to the 'stratified' batholite and will be described as the 'arfvedsonite-granite of Ilimausak'. In the western unstratified part of the abyssal complex a closely related rock occurs which will be described under the head of 'arfvedsonite-granite of Narsak'. A third variety of granite which will also be mentioned in this place is the 'soda-granite of Iviangusat'. This, however, is no independent abyssal rock but occurs under peculiar conditions as subordinate masses in the augite-syenite and is intimately connected with the presence of sandstone-fragments.

## ARFVEDSONITE-GRANITE OF ILIMAUSAK.

The arfvedsonite-granite of Ilimausak covers an area of about 16 $km^2$, south of the highest summits of Ilimausak (see map, Pl. III). This granite-body has the form of a heavy sheet or stratum, 150 to 400 meters thick. It is overlain by the porphyry-sheets which are older than the granite, and it rests upon pulaskite and nepheline-syenite which are about contemporaneous with it. South of Tunugdliarfik Fjord erosion has only left a small remnant of arfvedsonite-granite which rests on the nepheline-syenite near Tupersuatsiak. This remnant is of interest because it indicates that the granite has originally extended southward across the fjord and has covered the nepheline-syenites round Tupersuatsiak in the same manner as it still covers those at Ilimausak.

*Macroscopic appearance.* — The arfvedsonite-granite, when fresh, is a light greenish coarse-grained rock the main constituents of which are easily detected with the naked eye. The diameter of the felspar-grains varies from 2 to 4 millimeters, the quartz-grains are a little smaller, while the arfvedsonite-anhedra may sometimes attain a length of 10 or 15 millimeters. As a result of alteration-processes the rock has assumed a light brown colour in some places and a reddish or violet-red colour in others. A fuller description of the local variations of the outer habit has been given in the preceeding chapter (see p. 81).

*Microscopic characters.* — Under the microscope the rock is seen to be made up of the following minerals: alkali-felspar, quartz, arfvedsonite, ainigmatite, and a little ægirine. Occasionally zircon, pyrochlore (?), and elpidite (?) are found. In those varieties which have undergone alteration processes there are found several secondary products viz. magnetite (or titano-magnetite), fluorite, hæmatite, ferric hydrates, and calcite.

The felspar is in more or less equidimensional grains, sometimes also in imperfect crystals giving broad rectangular sections. It is a microperthite made up of intimately intergrown potash-felspar and plagioclase; sometimes a rather high power is required to make out the structure. Between crossed nicols the sections exhibit a mosaic-like or reticular appearance, yet both felspars show a marked tendency to form veinlets parallel to *b* (010), or, in other specimens of the rock, perpendicular to *b* (010). The potash felspar is a microcline without cross-hatching but showing a quite irregular twin-structure, one individual of the twin forming numerous dots or stains within the other; in some felspar-sections only one microcline-individual is seen. In the more decomposed varieties of the rock the potash-felspar is turbid and has the appearance of orthoclase. — The plagioclase of the microperthite shows a fine twin-lamellation according to the albite-law; when examined after Becke's method it proves in all positions less highly refringent than quartz. The examination of a number of sections showing symmetrical extinction of the twin-lamellæ gave for the plagioclase a maximum angle of extinction amounting to 15° or 16°, while the microcline in the same sections gave values varying from 0° to 9°. As to the microcline the maximum angle of extinction in symmetrical sections was found to be about 19°, and the extinction-angle of the plagioclase of the same sections was 9° or 11°. This proves that the plagioclase is almost pure albite. The felspar of this rock, then, is a *perthitic microcline-albite.*

The relative proportion of microcline and albite varies somewhat, yet as a rule the albite is predominant. The marginal zones of the felspar consist sometimes of pure albite, less frequently crystals are found consisting entirely of this mineral.

The greenish colour of the fresh felspar is due to minute prisms or slender needles of ægirine imbedded in the felspar. In some cases the felspar also encloses small patches of arfvedsonite. In the red varieties of the rock the felspar contains numerous minute scales of yellowish red hæmatite or other iron oxydes.

*Quartz* occurs very abundantly in rounded or irregular grains rarely showing a slightly undulating extinction. It contains numerous minute fluid-cavities with a mobile bubble. In some cases these cavities have the form of negative crystals (dihexahedral pyramids).

The *Arfvedsonite* is in large irregular anhedra or in elongated prismoids with irregular outlines. In sections parallel to the plane of symmetry (010) the angle of extinction $c : \mathfrak{a}$ is 7 to 12°; the intense absorption and the strong dispersion of the axes of optic elasticity prohibit a closer determination of this angle. The optic axes are parallel to the plane of symmetry. The absorption-scheme is: —

| | |
|---|---|
| $\mathfrak{a}$ | dark indigo-blue or Prussian blue |
| $\mathfrak{b}$ | grayish blue |
| $\mathfrak{c}$ | light grayish green |

These characters indicate that the mineral is very closely related to the typical arfvedsonite occurring in the nepheline-syenites of the same igneous complex, yet with a slight tendency towards the riebeckite, as mentioned on a previous occasion[1].

In some varieties of this rock the central part of each arfvedsonite-anhedron is of a lighter and more brownish colour with gradual transition to the blue arfvedsonite of the marginal zone. In such cases the angle of extinction $c : \mathfrak{a}$ augments from the margin towards the interior where it may reach 30°. The central parts of these crystals, therefore, may be characterised as catophorite.

Small prisms of *ægirine* are sometimes enclosed within the arfvedsonite-anhedra. More often ægirine occurs as a marginal

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[1] Meddelelser om Grønland XIV, p. 197 (1894).

zone of very varying width surrounding the arfvedsonite; the ægirine in this case encloses irregular patches of arfvedsonite showing the same optic orientation as the main individual. The appearance of this intergrowth is such as to suggest a conversion of arfvedsonite into ægirine having occurred towards the final stages of the consolidation of the rock. Sometimes ægirine is also found in independent crystals; on the whole, however, this mineral occurs very sparingly in the typical arfvedsonite-granite. It is a little more abundant in those varieties where the arfvedsonite contains a catophorite-like nucleus.

*Ainigmatite* has been found in almost all specimens of arfvedsonite-granite from Ilimausak and also in the specimens from Tupersuatsiak. It occurs as irregular or elongated grains of rather small dimensions (less than one millimeter). The mineral is easily recognisable by its cleavage and by its deep brownish red or black absorption-tints. As a rule it is associated with the arfvedsonite, and it is often enclosed within this mineral. Sometimes it is partly converted into a black metallic substance, probably titano-magnetite; a titanite-like alteration product is rarely seen.

*Zircon* has only been found in one specimen. Small yellow *pyrochlore*-like crystals (optically isotropic) are somewhat commoner. In one specimen of greenish arfvedsonite-granite collected at an altitude of 830 meters, above N. Siorarsuit, a fibrous, light brick-red mineral is found rather abundantly. Owing to the finely fibrous structure no goniometric measurements could be obtained, but the mineral agrees, both macroscopically and microscopically, with *elpidite.*[1]

Among the secondary minerals of the arfvedsonite-granite *fluorite* is the most common, especially in the red varieties of the rock. *Calcite* has only been found in quite inconsiderable

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[1] I am informed by Professor Brögger, that he has found elpidite as an accessory in the soda-granites N. of Christiania.

quantities. Probably it is an alteration-product of the dark-coloured minerals of the rock.

*Structure.* — The structure of the arfvedsonite-granite is hypidiomorphic-granular without any tendency to parallel arrangement of the elongated mineral-components. A characteristic feature is the almost complete absence of minor accessories (apatite, zircon, and iron ores) among the first crystallised minerals of the rock. If the ægirine-microlites are left out of consideration the felspar is the most idiomorphic and the arfvedsonite the least idiomorphic constituent. A marked idiomorphism of the felspar, however, is only observed in a few varieties of the rock; in such cases the felspar sections are broad and rectangular while quartz and arfvedsonite fill the interspaces between them. More commonly the structure points to a simultaneous crystallisation of felspar and quartz the grains of the latter mineral being more or less rounded. Micropegmatitic intergrowths of felspar and quartz are also observed, though not very often. The arfvedsonite is always allotriomorphic when bounded by felspar, and as a rule the same holds true when it borders upon quartz. The ainigmatite is older than the arfvedsonite but its age in relation to the other minerals is unknown.

*Chemical composition.* — A chemical analysis of this rock has been made by Dr. Winther with the results given in **1** of the following table. The specimens selected for analysis were of a fresh-looking, light grayish-brown variety collected at an altitude of 450 meters, above North Siorarsuit. From this analysis we may reckon that the rock has the following approximate mineral composition: —

| | Per cent |
|---|---|
| Felspar | 64 |
| Quartz | 24 |
| Ainigmatite | 3 |
| Arfvedsonite | 9 |
| | 100 |

*Analyses of arfvedsonite-granite and related rocks.*

| | 1 | 2 | A |
|---|---|---|---|
| $SiO_2$ | 70·59 | 71·24 | 71·65 |
| $TiO_2$ | ·44 | ·68 | trace |
| $ZrO_2$ | — | | |
| $Al_2O_3$ | 12·38 | 13·78 | 13·04 |
| $Fe_2O_3$ | 1·61 | 1·30 | 2·79 |
| $FeO$ | 3·33 | 2·83 | 1·80 |
| $MnO$ | ·08 | ·15 | |
| $MgO$ | none | trace | trace |
| $CaO$ | ·93 | ·38 | trace |
| $Na_2O$ | 6·95 | 5·32 | 6·30 |
| $K_2O$ | 3·74 | 5·10 | 3·98 |
| $H_2O$ above 110° | ·21 | | 1·10 |
| $H_2O$ at 110° | ·20 | | |
| Cl | none | | |
| $P_2O_5$ | trace | | |
| Total | 100·46 | 100·78 | 100·66 |
| Sp. gr. | 2·657 | 2·64[1] | |

**1.** Arfvedsonite-granite, Ilimausak, S. Greenland. C. Winther, analyst.

**2.** Soda-granite, Iviangusat, Kangerdluarsuk, S. Greenland, C. Detlefsen, analyst.

A. Soda-granite, Hougnatten, Lougendal, Norway. L. Schmelck, analyst (W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes I 1894, p. 127).

About one third of the felspar is potash-felspar, the rest is soda-felspar.

Pure arfvedsonite-granites like the one described here —

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[1] Determination by Dr. K. J. V. Steenstrup.

that is to say a granite in which arfvedsonite is largely predominant among the dark minerals — appear to be very uncommon rocks. As instances of closely related rocks may be cited the arfvedsonite-bearing soda-granites from the district south of Kongsberg in Norway as described by **Brögger** (see analysis A in the above table), and those from Madagascar described by **Lacroix**[1]. From a chemical point of view the arfvedsonite-granite of Ilimausak shows a close relation to the grorudites of many regions, and a somewhat less pronounced analogy to the Icelandic liparites and obsidians described by **Bäckström**[2].

## ARFVEDSONITE-GRANITE OF NARSAK.

In the vicinity of Narsak arfvedsonite-granite covers three small areas separated from the arfvedsonite-granite of Ilimausak by a zone, 5 kilometers broad, of nepheline-syenites and porphyrites. Although belonging to the western part of the igneous complex the Narsak granite will be described in this place on account of its near analogy to the Ilimausak rock.

The arfvedsonite-granite of Narsak is a coarse- or medium-grained rock. As a rule it is of a strong red colour, locally also grayish white varieties are found. Under the microscope the main constituents are seen to be felspar, quartz, arfvedsonite and ægirine; apatite and magnetite commonly occur as minor accessories. The felspar is a perthitic microcline-albite of the same kind as that of the Ilimausak granite; as a rule it is somewhat more idiomorphic in the Narsak granite. Micropegmatitic intergrowths of felspar and quartz occur rather abundantly. The quartz is of the usual character. The principal difference from the Ilimausak granite appears in the dark-coloured minerals: in the Narsak granite no ainigmatite has been found and the arfvedsonite is accompanied by a

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[1] A. **Lacroix**, Matériaux pour la minéralogie de Madagascar. Nouvelles Archives du Museum (4) I, p. 82, Paris 1902.

[2] Geologiska Föreningens i Stockholm Förhandlingar, XIII, 1891.

considerable amount of other minerals of the pyroxene- and amphibole-groups. Only in certain varieties of the rock the prevalent dark mineral is arfvedsonite, in others both ægirine and a catophorite-like hornblende are also present. The ægirine is partly in independent crystals or anhedra, partly it is in parallel intergrowth with the arfvedsonite; in the latter case the ægirine most frequently makes up the peripheral parts of the anhedra enveloping an irregular nucleus of arfvedsonite. The catophorite-like hornblende shows brown, green, and bluish-green absorption-tints; in sections parallel to the plane of symmetry (010) the angle of extinction $c:\mathfrak{a}$ varies from 20° to 70°. A narrow marginal zone of arvedsonite commonly surrounds the hornblende. A fibrous, crocidolite-like mineral in small protuberances projecting from the arfvedsonite is observed in several specimens. A colourless augite has only been found in one specimen.

## SODA-GRANITE OF IVIANGUSAT.

At the foot of Iviangusat, on the south side of Kangerdluarsuk, the augite-syenite contains numerous fragments of sandstone, and each of these fragments is surrounded by a zone of soda-granite. The width of the zones is from one half to two meters. The detailed description of the mode of occurrence has been given in the preceding chapter (see p. 53), and it has been shown that this soda-granite must have originated by a process of resorption the augite-syenitic magna having dissolved sandstone. The interest connected with this occurrence is greatly added to by the fact that the rock, both mineralogically and chemically, bears a close resemblance to the arfvedsonite-granite of Ilimausak and Narsak. Macroscopically the simularity is almost complete, as the dark mineral of the Iviangusat rock strongly resembles arfvedsonite; upon closer inspection, however, it proves to be ægirine-augite and catophorite.

As already mentioned in the geological section the soda-granite of Iviangusat is of a rather varying size of grain. Coarse-grained and pegmatitic portions alternate irregularly or in stripes with medium-grained or fine-grained portions. The colour of the rock as a rule is light gray or yellowish.

*Microscopic characters.* — In a thin section the main constituents are seen to be the following: felspar, quartz, catophorite-like hornblende, and ægirine-augite; a little ægirine is usually associated with the latter mineral. Small crystals of zircon (sometimes with zonary banding) and others of magnetite are always present. Apatite is rare. An intensely yellow-coloured mineral occurs rather sparingly in small prisms and fibrous aggregates; it is optically biaxial and probably titaniferous; it is accompanied by a leucoxene-like decomposition-product.

The felspar is a perthitic microcline-albite of a rather fine lamellar structure. The lamellæ are of a tolerably regular shape and perpendicular to *b* (010) as in ordinary orthoclase-microperthite. The microcline is irregularly twinned. In many felspar-sections the majority of the microcline-areas belongs to one individual. The albite shows a fine twin-striation parallel to *b* (010); its indices of refraction are in all sections found to be lower than those of the adjoining quartz. The felspar is rather idiomorphic and of a thick-tabular habit.

The quartz has fluid-cavities with a mobile bubble. It is quite allotriomorphic and often occurs in relatively large anhedra each of which encloses a considerable number of felspar crystals. This structural feature may even be observed in the vicinity of the contact with the sandstone. But immediately at the contact it changes into the reverse: here the felspar becomes allotriomorphic and is seen to enclose isolated quartz-grains and send out off-shoots between the quartz-grains of the adjoining sandstone.

A catophorite-like hornblende is the most abundant ferromagnesian mineral. It occurs in allotriomorphic anhedra which are somewhat unevenly coloured. In sections parallel to the plane of symmetry (010) the absorption-tints are: —

$\mathfrak{c}$ (or $\mathfrak{b}$) rather dark dirty-brown or greenish-brown
$\mathfrak{a}$ light brown or sometimes reddish-brown.

In cross-sections the absorption-tint for $\mathfrak{b}$ (or $\mathfrak{c}$) is found to be dark grayish-brown. The angle of extinction $c : \mathfrak{a}$ varies from 60° to 70°, it is distinctly larger for green than for red light. This hornblende has a dark blue marginal zone with the characters of arfvedsonite ($c : \mathfrak{a} =$ ca. 10°), and there is a gradual transition from the greenish-brown core to the blue marginal zone. The angle between the $\mathfrak{a}$-axes of the two hornblendes is 50° to 60°. The directions of the cleavage are the same in the nucleus and in the marginal zone. Indistinctly bounded dark blue patches may also be found in the interior of the greenish-brown hornblende.

The ægirine-augite occurs in varying amounts and is sometimes entirely wanting. It is of the ordinary intense green colour. In sections parallel to $b$ (010) the angle of extinction $c : \mathfrak{a}$ is about 30°; in the central portions, however, the colour is lighter and the extinction-angle $c : \mathfrak{a}$ is greater. This mineral occurs in parallel intergrowths with the catophorite-like hornblende. It is especially abundant within a narrow zone immediately surrounding the sandstone-fragments.

*Chemical compositon.* — A typical light-gray, rather fine-grained specimen (without ægirine-augite) was selected for the chemical analysis. This was made by Mr. C. Detlefsen with the results given in No. **2** in the table p. 114. It will be seen that the composition closely agrees with that of the Ilimausak granite, and that the only remarkable difference is the very low amount of lime.

## TRANSITION-ROCK BETWEEN ARFVEDSONITE-GRANITE AND PULASKITE: THE QUARTZ-SYENITE.

The arfvedsonite-granite of Ilimausak rests, as previously mentioned (see p. 79), on a relatively thin sheet of quartz-syenite and this in turn is underlain by the pulaskite. The thickness of the quartz-syenite-sheet varies from 0 to about 20 meters. It is connected by gradual transitions both with the arfvedsonite-granite and with the pulaskite, and it may be regarded, either as a lower border facies of the granite characterised by a relatively low content of quartz, or as an upper quartz-bearing border facies of the pulaskite.

The quartz-syenite sheet reaches its maximum thickness in the mountain slopes above North Siorarsuit. It is here — together with the lowermost part of the granite and the uppermost part of the pulaskite — intensely red-coloured. The size of the grain is most frequently about the same as that of the granite but irregular bands of a somewhat less coarse-grained structure are also found.

The felspar or the quartz-syenite is a perthitic microcline-albite closely agreeing with that of the arfvedsonite-granite of Ilimausak. It shows a very slight tendency to idiomorphism against the quartz. This latter mineral occurs rather abundantly in the uppermost portion of the sheet but downwards the amount gradually decreases. In the middle part of the sheet only very little quartz is visible to the naked eye. Under the microscope a somewhat larger number of quartz-grains are detected; as a rule they are much smaller than the felspar-grains and are often associated in groups of four, five, or more grains. In the lowermost portion of the sheet quartz is only present in a very small amount.

The original dark minerals of this rock have been entirely converted into fine-grained aggregates of iron oxides and hydrous iron oxides intermingled with abundant fluorite and a little dark-brown mica. This conversion is intimately connected with the intense red colouring of the rock and is probably due to pneumatolytical actions. Of this rock no chemical analysis has been made, but the characters observed of the salic minerals show that the rock, chemically, may be characterised as an alkali-syenite rich in silica.

## PULASKITE.

The pulaskite constitutes a sheet of varying thickness (from 10 to 30 meters or more) which covers the uppermost sheets of the nepheline-syenitic complex. It occurs both south and north of Tunugdliarfik. North of this fjord it is overlain by the arfvedsonite-granite just mentioned. South of the fjord erosion has only left a very small remnant of the arfvedsonite-granite (near Tupersuatsiak) and the pulaskite, therefore, is as a rule uncovered.

As to outer habit the pulaskite may be described as a coarse-grained rock in most cases of white colour consisting of rather thick tabular felspar crystals and dark minerals filling out the interspaces between the felspars. Chemically this rock is closely related to the syenites of the unstratified, western and southern parts of the batholite (augite-syenite and nordmarkite).

*Microscopic characters.* — Under the microscope the following minerals are seen: felspar, arfvedsonite, ægirine, ægirine-augite, biotite; in small quantities also magnetite and fluorite; zeolites and a mineral that is probably catapleiite occur as secondary products. The original presence of scarce grains of nepheline, ainigmatite, and eudialyte is indicated by pseudomorphs observed in some specimens of the rock.

The *felspar* crystals are of a form giving rectangular sections e. g. 6 millimeters long by 1·5 millimeter broad. They are made up of a microperthitic intergrowth of microcline and albite; within each crystal the two kinds of felspar alternate in short and irregularly bounded lamellæ which are most frequently elongated parallel to *b* (010). The microcline shows a very fine and irregular twin-structure producing a moire-like appearance of the sections; one of the individuals of the microcline-twins is not infrequently reduced to a number of minute areas dotting the other individual. The moire-like twinning prevents an exact determination of the extinction-angles; it therefore remains uncertain whether the microcline is soda-bearing or not. The albite is finely twinned parallel to (010). The perthitic felspar crystals are sometimes surrounded by a marginal zone of pure albite; small tabular crystals of albite without microcline-inclusions may also be found. In one specimen of the rock some of the angular interspaces between the felspar crystals are filled with a clear und coarsely twinned albite of the same optic orientation as the albite of the adjacent perthitic crystals.

The felspar contains minute needles of ægirine and sometimes also of arfvedsonite. It is always somewhat clouded with kaolin-like decomposition products, and the microcline always proves more affected by this decomposition than the albite.

In some specimens of this rock a few, dull white or reddish pseudomorphs are seen which are probably derived from *nepheline*. They consist of zeolites (spreustein).

The dark-coloured minerals of the pulaskite are always allotriomorphic. As a rule both arfvedsonite, ægirine, ægirine-augite, and biotite are present, but the relative amounts of these minerals show quite irregular variations, although the rock, as to outer habit, keeps very constant. In some specimens from Tupersuatsiak and Nunasarnausak the prevalent dark mineral is an *arfvedsonite* closely agreeing with the typical variety found in the nepheline-syenites both as to absorption-colours and as to optic orientation ($c : \mathfrak{a} =$ ca. 14°). It has often been partially converted into ægirine of the same crystallographic orientation. This alteration-process begins along the margin of the anhedra, and the arfvedsonite may at last become reduced to a number of isolated lapped remnants enclosed within the ægirine. As the conversion has been effected without any separation of iron-oxides and as the alteration-product is not an aggregate but a single crystal of ægirine the process has probably taken place before the final consolidation of the rock.

In some specimens from North Siorarsuit *ægirine* is present in considerable amount. Some of the ægirine-individuals are surrounded by a narrow and irregular rim of arfvedsonite in parallel position. The arrangement in this case is the converse of that mentioned above. In other specimens from North Siorarsuit the prevailing dark mineral is *ægirine-augite.* The angle of extinction $c : \mathfrak{a}$ of this mineral varies from 30° or more, in the core, to 14° in the outer zone. This indicates a zonary banding due to an admixture of ægirine molecules in the outer zone, a feature which is frequently observed with ægirine-augite. The pleochroism is as follows: —

$\mathfrak{a}$ deep green
$\mathfrak{b}$ a little lighter green
$\mathfrak{c}$ light brownish green.

A deep brown and strongly pleochroic *biotite* is observed in most of the slices and is sometimes relatively abundant. It is always associated with arfvedsonite and magnetite. Fresh *ainigmatite* has not been found, but in several specimens from North Siorarsuit pseudomorphs are seen which have probably been derived from this mineral. The pseudomorphs are enclosed in the arfvedsonite. They consist of an aggregate of magnetite (or titano-magnetite) and brown mica. Another kind of pseudomorphs supposed to represent *eudialyte* are found sporadically in some specimens of the rock. They consist of an aggregate of colourless tabular crystals with hexagonal outlines and with the optical properties of catapleiite. These pseudomorphs are allotriomorphic against the felspar.

*Fluorite* is not uncommon in some specimens but very scarce in others. It belongs apparently to the primary constituents of the rock, for it is commonly inclosed within the dark minerals. Thus, the arfvedsonite and the ægirine-augite are frequently so filled with small rounded fluorite crystals that they get a sponge-like appearance. — A little *analcime* is also present filling small interstices between the felspar crystals.

*Chemical analysis.* — An analysis of this type was made by Dr. C. Winther with the results given in the following table. The specimen selected for analysis was taken at North Siorarsuit in the transition-zone from granite to foyaite, about three meters above the upper boundary of the foyaite (see p. 79). As shown by the analysis the rock must belong to that group of alkali-syenites which comprises the rocks commonly termed nordmarkites, pulaskites, and umptekites according to the character of their dark minerals. For the sake of comparison Washington's analysis of the original pulaskite of J. F. Williams is given in A. The Greenlandic rock differs from the typical pulaskite in so far as arfvedsonite or ægirine-augite in many specimens of the rock is more abundant than the biotite, but it agrees with typical pulaskite in all essentials and also as to outer habit.

It many other kinds of rocks, as is well known, the nature of the femic constituents is of systematic significance, but with rocks of the alkali series the distinction between mica-, amphibole-, and pyroxene-bearing types is of very little value from a systematical point of view, and the above described rock furnishes a striking example of this fact. The pulaskite of the Ilimausak complex is of a well defined type, nevertheless it contains mica, amphibole, and pyroxene in irregularly varying relative amounts so that very often two slices of the same rock-specimen should be classed into different groups if the nature

*Analyses of pulaskites.*

| | 3 | A |
|---|---|---|
| $SiO_2$ .......... | 57·88 | 60·20 |
| $TiO_2$ .......... | 1·23 | ·14 |
| $ZrO_2$ .......... | none | none |
| $Al_2O_3$ ........ | 14·80 | 20·40 |
| $Fe_2O_3$ ........ | 5·86 | 1·74 |
| FeO .......... | 3·71 | 1·88 |
| MnO .......... | ·15 | trace |
| MgO .......... | none | 1·04 |
| CaO .......... | 2·71 | 2·00 |
| $Na_2O$ ......... | 9·12 | 6·30 |
| $K_2O$ .......... | 3·06 | 6·07 |
| $H_2O$ above 110° . . | ·90 | ·23 |
| $H_2O$ at 110° .... | ·23 | ·10 |
| Cl ............ | none | ·09 |
| $SO_3$ .......... | none | ·13 |
| $P_2O_5$ ......... | trace | ·15 |
| Total... | 99·65 | 100·47 |
| Sp. gr.... | 2·772 | |

**3.** Pulaskite, 3 meters above uppermost foyaite-bench, North Siorarsuit, S. Greenland, C. WINTHER, analyst.

A. Pulaskite, Fourche Mt., Arkansas. H. S. WASHINGTON, analyst (Journal of Geology, IX, 1901, p. 609).

of the prevalent dark mineral was used as a basis of classification.

## NEPHELINE-SYENITES.

The family of nepheline-syenites in the usual sense of the word comprises both leucocratic types, as the ordinary foyaites, and melanocratic ones, as most lujavrites. From a systematic point of view it would perhaps be more convenient to class the melanocratic types as a separate family; in the present description, however, the term nepheline-syenite is used in the ordinary wide sense. The bulk of the Ilimausak batholite consists of melanocratic nepheline-syenites, leucocratic types are also represented though mainly by a very peculiar variety. The different types are here described under the following heads: —

Foyaite
Sodalite-foyaite
Naujaite
Lujavrite
Kakortokite.

As mentioned in the preceding chapter the geological arrangement of these rocks is generally spoken that of tolerably flat sheets or bowls placed one upon the other, and the succession given in the above enumeration corresponds with the actual succession of the sheets. The only exception is that the kakortokite is not only overlain by lujavrite but also underlain by this rock. It is, however, not improbable that the kakortokite was originally the lowermost layer of the whole complex since the actual arrangement and shape of the sheets has been modified by movements occurring during the final stages of the consolidation.

The uppermost sheet, *the foyaite*, is quantitatively very subordinate. As to outer habit and general character this type may be compared with the well-known rocks from Foya. It is especially noteworthy that the dark-coloured constituents are ægirine-augite and catophorite-like hornblende while ægirine and arfvedsonite are the characteristic dark minerals of all the other nepheline-syenites of Ilimausak.

*The sodalite-foyaite* is a very coarse-grained rock with thick tabular felspar-crystals and a considerable amount of sodalite. The name which was given during the field work has been retained in this report for practical reasons. It should, however, only be regarded as a provisional name, for the rock, upon closer examination, has proved to belong to the melanocratic division of the nepheline-syenites.

*The naujaite* is still more coarse-grained. It is characterised by a very high amount of sodalite and a peculiar poikilitic structure. Since it differs considerably from any other known rock and since it is of wide distribution within the Ilimausak region it may be regarded as the most characteristic rock of this complex.

*The lujavrites* of Ilimausak are more or less fine-grained, melanocratic rocks rich in needle-shaped ægirine or arfvedsonite. Some varieties of the ægirine-lujavrite of this locality are much like the original lujavrite from Kola as described by W. Ramsay. The extension of the lujavrite-group to comprise all the varieties which are described as lujavrites in this report is in accordance with the remarks of Ramsay as to the use of this term which was originally introduced by Brögger[1].

*The kakortokite* is structurally related to the foyaites, chemically to the lujavrites. The main body of this rock is moreover characterised by a most extraordinary banded structure.

## FOYAITE.

The pulaskite-sheet of the Ilimausak batholite passes downwards into the coarse-grained foyaite which constitutes the uppermost sheet of the nepheline-syenitic complex. The foyaite in turn is connected by insensible gradations with the underlying sodalite-foyaite. For this reason it is impossible to indicate the accurate thickness of the foyaite-sheet. As far as observations go the approximate thickness varies between 0 and 10 meters,

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[1] W. Ramsay, Das Nephelinsyenitgebiet auf der Halbinsel Kola II. Fennia XV, Nr. 2, 1898, p. 4.

but the latter figure may perhaps be erroneous as no attention was given to the difference between the foyaite and the sodalite-foyaite during the first part of the field work.

*Macroscopic appearance.* — The outer habit of this rock is that of an ordinary coarse-grained foyaite with rather thin tabular felspar-crystals averaging 1 or $1^1/_2$ centimeters in length while the thickness seldom exceeds one-tenth of the length. The interspaces between the felspars are filled with a grayish, greenish, or reddish translucent nepheline and with black minerals. As a rule there is no law of arrangement of the felspar-crystals, sometimes, however, they show a very marked parallel disposition. Variations in size of grains are observed in some cases.

*Microscopic characters.* — The main constituents of this rock are felspar, nepheline and a dark mineral which is commonly ægirine-augite but in some cases catophorite-like hornblende. Subordinate constituents occurring in varying amounts, or sometimes wanting, are: sodalite, biotite, ægirine, arfvedsonite, ainigmatite, olivine, eudialyte. Apatite and iron ore are constantly present though in very small quantities. Catapleiite, cancrinite, spreustein, and analcime occur as secondary products.

The *apatite* which occurs in small prisms is often enclosed in the felspar and in the nepheline, sometimes also associated with the dark minerals. The constant presence of apatite in this rock is noteworthy because apatite is absent or almost absent from all the other nepheline-syenites of Ilimausak. The *iron ore* is in rounded grains and occurs sparingly enclosed within the dark minerals.

The *felspar* is in tabular crystals. It is a microperthite consisting of microcline and albite. The latter is present in somewhat greater amount than the microcline, and the outer boundary of the crystals is frequently pure albite. The microperthitic structure is of the same type as in the pulaskite

(p. 121), but it is somewhat coarser and the microscopic appearance of the felspar therefore approaches that observed in the sodalite-foyaite (see below). While in some specimens the felspar is fresh and clear, in others it is clouded with kaolin-like decomposition products; in the unfresh crystals the twin-structure of the microcline is indistinct or invisible.

*Nepheline* occurs rather abundantly. It is idiomorphic when bounded by the dark-coloured minerals, but allotriomorphic against the felspar crystals. It is of elæolitic habit. In some specimens it is partly converted into radiating or irregular aggregates of cancrinite, in others it has been changed to spreustein or analcime.

*Sodalite* occurs sparingly in this rock, and in some specimens it is entirely absent; these specimens, however, are rich in spreustein and it is possible that some of the spreustein-aggregates may have originated from sodalite. One portion of the sodalite is in tolerably idiomorphic crystals, another portion is interstitial between the felspar crystals. As most specimens also contain interstitial analcime the sodalite was identified by treating the slices with nitric acid and nitrate of silver.

*Ægirine-augite* in allotriomorphic anhedra occurs abundantly in most specimens of the rock. The absorption-tints are the same as in the pulaskite (p. 122). In sections parallel to the plane of symmetry (010) the extinction-angle $c:\mathfrak{a}$ averages 30° or 40°. This angle has its maximum value (sometimes exceeding 50°) in the central part of each crystal and decreases gradually towards the outer boundary where it may be less than 10°. The central portions with large angle of extinction are of a rather pale green colour, the marginal zone is intensely green. In those portions of the ægirine-augite which are characterised by an extinction-angle of about 30° a strong dispersion of the axes of optic elasticity is observed: the angle $c:\mathfrak{a}$

is larger for green than for red light. — The ægirine-augite has not infrequently been converted into an aggregate of fine scales of brown biotite.

The catophorite-like *hornblende* shows the characters mentioned in the description of the soda-granite (p. 111); it is often surrounded by a dark bluish-green marginal zone resembling arfvedsonite. Ægirine and arfvedsonite are found in small amounts in most specimens of the rock; they are in rather large allotriomorphic anhedra which fill the interspaces between the felspar crystals. Ainigmatite and brown biotite occur in the same manner but only in a few rock-specimens; small scales of brown biotite, however, are not rare in the resorption-bands mentioned below.

*Olivine* is so abundant in some specimens of the foyaite that it must be regarded as one of the main components, in other specimens, however, it is entirely absent. It is in irregular grains sometimes reaching a length of 3 millimeters. In thin sections it appears colourless or slightly yellowish. The grains are surrounded by a zone of black metallic iron ore which also occurs along the cracks of the olivine. This alteration-zone has often a spongy appearance, the iron ore being intermingled with some biotite and hydrous iron oxide. These characters indicate that the olivine is of a variety rich in iron, perhaps fayalite.

*Eudialyte* in allotriomorphic anhedra is only seldom observed in the foyaite. In some specimens it is replaced by pseudomorphs consisting of an aggregate of catapleiite crystals.

*Sequence of crystallization.* — As already mentioned the felspar of this rock is idiomorphic against the nepheline, and this in turn is idiomorphic against the dark-coloured minerals. The latter show rather irregular variations in their mutual relation and succession, which may be illustrated by a few examples.

In one specimen — the same of which a chemical analysis is given below — the prevailing dark-coloured minerals are catophorite-like hornblende, ægirine, and ainigmatite. The ainigmatite has been partially converted into an aggregate of iron ore and biotite; besides, it is often surrounded by a zone or fringe which consists of an ægirine-aggregate of irregular columnar structure. Where the ainigmatite has altered, this ægirine-zone follows the original contours of the mineral. Ægirine is also found in large anhedra. Some of these are homogeneous; more commonly, however, each ægirine anhedron only forms an outer shell enveloping a pseudomorph. These pseudomorphs are of three kinds: some consist entirely of an aggregate of catophorite-like hornblende; others are aggregates of brown biotite; others, again, contain both hornblende and biotite. It is probable that these pseudomorphs have originated from ægirine-augite by a resorption-process. The catophorite-like hornblende also occurs separately as large anhedra which are sometimes surrounded by a narrow fringe of columnar ægirine.

Another specimen, taken directly below the pulaskite-sheet near North Siorarsuit, contains abundant olivine which is surrounded by the above-mentioned rim of iron ore with some biotite. Ægirine-augite, too, occurs abundantly; this as usual has an outer zone of intensely green ægirine. Both olivine and ægirine-augite are frequently enveloped by large anhedra of catophorite-like hornblende with a dark-coloured, arfvedsonite-like outer margin around which a last resorption-band is found, consisting of fine-grained ægirine with some biotite. In so far the sequence of crystallization is well marked. But in the same slices a few grains of ainigmatite are also found, and these are only surrounded by a zone of fine-grained ægirine. Finally ordinary ægirine and arfvedsonite are present in large anhedra bounded only by light-coloured minerals so that their age in relation to the other dark minerals is not evident from direct observation. Probably they are the latest crystallized minerals of the rock since they fill out even the narrowest interstices between the felspar crystals.

From what has been said above it will be seen that the sequence of crystallization of the dark-coloured minerals broadly speaking is as follows: —

First, scarce crystals of iron-ore; next, olivine, biotite, ainigmatite, and ægirine-augite; after this, under partial resorption of the minerals first enumerated, magnetite, biotite in scaly aggregates, catophorite-like hornblende, and ægirine, and finally, during the last phase of the consolidation, only ægirine and arfvedsonite. It is further to be noted that the ægirine here, as in most other nepheline-syenites, has crystallized during the entire epoch of consolidation: (1) it is found as minute prisms enclosed in the felspars; (2) it occurs, though very sparingly, as a little larger crystals which are idiomorphic against the felspar; (3) it surrounds the ægirine-augite and is present in some of the resorption bands mentioned above; (4) it appears as one of the latest crystallized minerals of the rock. The arfvedsonite has a similar wide range of crystallization. On the other hand, the structure of the rock proves with certainty that the greater part of the ægirine and of the arfvedsonite has crystallized during the latest stage of the consolidation-process.

*Chemical composition.* — A specimen of the foyaite, taken on the mountain-plateau above Naujakasik, has been analysed by Mr. C. Detlefsen with the results given in No. **4** in the table p. 132. The composition on the whole is not very different from that of the most common type of nepheline-syenites. The closest related rocks outside of Greenland are found within the igneous complexes of Kola and of the Los Islands. Two analyses of rocks from these localities are quoted for comparison (A and B). Considering the analogy between the South Greenlandic igneous complexes and those of the Christiania

*Analyses of foyaites and related rocks.*

| | 4 | A | B | C |
|---|---|---|---|---|
| $SiO_2$ | 56·31 | 56·40 | 56·10 | 54·55 |
| $TiO_2$ | 2·82 | ·84 | ·21 | 1·40 |
| $ZrO_2$ | | | ·31 | |
| $Al_2O_3$ | 20·11 | 21·36 | 21·80 | 19·07 |
| $Fe_2O_3$ | 3·93 | 2·96 | 2·26 | 2·41 |
| FeO | 1·45 | 2·39 | ·87 | 3·12 |
| MnO | ·60 | ·49 | ·58 | ·17 |
| MgO | ·36 | ·90 | ·83 | 1·98 |
| CaO | ·62 | 1·81 | ·88 | 3·15 |
| $Na_2O$ | 8·76 | 8·57 | 9·85 | 7·67 |
| $K_2O$ | 4·65 | 4·83 | 4·35 | 4·84 |
| $H_2O$ | 1·13 | ·01[1] | 1·66[1] | ·72[1] |
| Cl | ·15 | | ·45 | |
| $P_2O_5$ | ·13 | | | ·74 |
| | 101·02 | | 100·15 | |
| Cl = O | ·03 | | ·10 | |
| Total... | 100·99 | 100·56 | 100·05 | 99·82 |
| Sp. gr.... | 2·67[2] | | | |

**4.** Foyaite, Naujakasik, S. Greenland. C. Detlefsen, analyst.

A. Nepheline-syenite, Poutelitschorr, Umptek, Kola. F. Eichleiter, analyst (V. Hackmann, Der Nephelinsyenit des Umptek. Fennia XI, 1884, p. 139).

B. Nepheline-syenite, ægirine-bearing, Ruma, Los Islands. Pisani, analyst (A. Lacroix, Les syénites néphéliniques des îles de Los. Comptes rendus CXLI, 1905, p. 988).

C. Lardalite, main type, Löve, Lougendal, Norway. V. Schmelck, analyst, (W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes, III, 1898, p. 19).

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[1] Loss on ignition. [2] Determination by Dr. Steenstrup.

district it is also of interest to note that one of the analyses of lardalite, given by Brögger and quoted in C in the table, is pretty similar to the analysis of the foyaite of Naujakasik; it differs, however, in containing a somewhat greater amount of lime.

## SODALITE-FOYAITE.

*Occurrence.* — The sodalite-foyaite occurs as a heavy sheet underlying the foyaite described above and resting on the naujaite. It occupies two areas separated by the Tunugdliarfik Fjord. The area north of the fjord may be estimated at about 20 $km^2$ and that south of the fjord at about 8 $km^2$. In the former area the sodalite-foyaite is covered by the arfvedsonite-granite and the transition rocks mentioned in the preceding pages, and it is only visible in a narrow zone of approximately circular form. South of the fjord this rock is for the most part uncovered. Both areas have evidently been considerably reduced by the effects of erosion, and there is no doubt that the sodalite-foyaite originally formed one continuous sheet extending from the high mountains of Ilimausak to Kangerdluarsuk and covering an area of about 50 $km^2$. The thickness of the sheet varies from 2 to more than 150 meters; yet the mean thickness cannot be estimated at less than about 100 meters. Thus the total volume of sodalite-foyaite originally present within the Ilimausak complex probably amounts to about 5 $km^3$.

*Macroscopic appearance.* — When seen at some distance this rock is a medium gray owing to the freshness of the felspathic constituents and the considerable amount of dark minerals. In hand specimens the appearance is mottled in consequence of the very large size of grain. The structural habit on the whole is conditioned by the tabular felspar crystals arranged without any law or tendency to parallelism. Their thickness averages two or three millimeters, the breadth and the length are from

5 to 10 times as great as the thickness. Between the felspar crystals abundant nepheline and sodalite occur in grains or imperfect crystals measuring 5 to 10 millimeters across; both these and the felspars are translucent and of a grayish or slightly greenish colour. The dark-coloured minerals, ægirine and arfvedsonite, are in large allotriomorphic anhedra which fill the angular interspaces between the felspathic constituents. Eudialyte, of the typical bluish-red variety, occurs abundantly in many specimens; it is allotriomorphic against the felspar.

*Microscopic characters.* — The main components of this rock are the following: alkali-felspar, nepheline, sodalite, arfvedsonite, ægirine, ainigmatite, and locally also eudialyte. The number of minor accessories is rather considerable: magnetite, biotite, ægirine-augite, astrophyllite, rinkite, steenstrupine, polylithionite (?), and fluorite. Catapleiite, analcime, and spreustein occur as secondary products.

The *felspar* crystals are microcline-microperthite, as proved by their optical properties. They are developed tabular on *b* (010) and very often twinned according to the Carlsbad law. Between crossed nicols they show a microperthitic structure which is considerably coarser than that of the microperthites of the rocks described above. In sections parallel to *c* (001), see Fig. 14, the bands of microcline and albite are elongated parallel to the plane of symmetry (010). In sections parallel to *b* (010) the microperthitic structure is of the usual habit with lamellæ at an angle of about 72° with the direction of the cleavage. The microcline is twinned according to the albite- (or pericline?) law; it never shows cross-hatching but the two individuals penetrate one another in a very irregular manner (see Fig. 14). The twin-structure of the albite is of the usual fine lamellar kind. On the whole the structure is similar to that characterizing the felspar of certain foyaitic pegmatites belonging to the same complex and described in detail in another place[1].

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[1] Meddelelser om Grønland XIV, p. 21 and Pl. I (1894).

There is, however, some difference as to the relative amounts of microcline and albite: in the sodalite-foyaite the latter prevails or both felspars are present in about equal amounts, while microcline predominates in the microperthite of the pegmatites.

The felspar crystals of the sodalite-foyaite inclose numerous minute needles of ægirine and occasionally also of arfvedsonite. A peculiar transformation into analcime is observed in one specimen of the rock: here the microcline is intact but the albite-areas of the perthitic crystals are replaced by analcime with the exception of a few small remnants now lying entirely imbedded in the newly formed analcime. This analcime shows the 'eudnophitic' double refraction and a distinct cubic cleavage. — The felspar crystals are as a rule uninfluenced by ordinary weathering; only in a few specimens a slight kaolinization is seen, and this has only affected the albite while the microcline has remained clear.

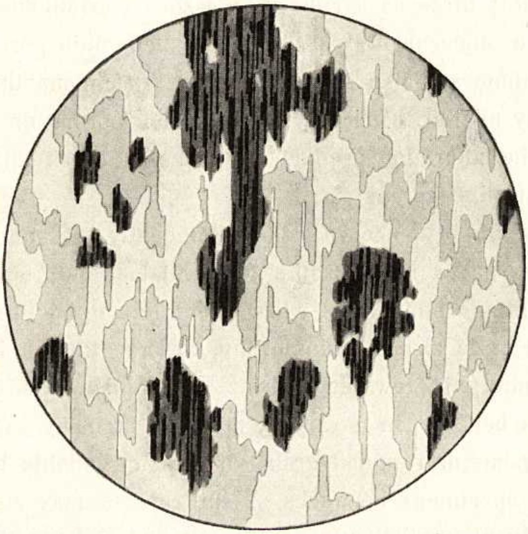

Fig. 14. Microcline-microperthite of the sodalite-foyaite.
Section parallel to *c* (001); crossed nicols; × 150. — The black and the heavy shadowed lamellæ are albite; the white and the light shadowed areas are microcline.

*Sodalite* occurs abundantly though in varying amount in the different specimens of the rock. Sometimes it is in dodecahedra enclosed in felspar crystals; more often it is allotriomorphic towards the felspar but at the same time idiomorphic where it borders upon the eudialyte or the dark-coloured minerals; in other cases, again, it is interstitial. Between crossed nicols it proves perfectly isotropic. It is always sprinkled with a large number of minute short prisms of ægirine and arfvedsonite; these as a rule show a zonary arrangement parallel to the dodecahedral faces. Rounded fluid-pores with a mobile bubble are also found. In most specimens the sodalite is partially altered, especially at the outer border or along the cracks; the alteration-product is in some cases analcime in others natrolite (spreustein)[1].

*Nepheline* also occurs rather abundantly. It often fills angular interspaces between the felspar tables and never shows crystallographic boundaries when it borders upon this mineral. As a rule it is also allotriomorphic towards the eudialyte, but it is idiomorphic towards ægirine and ainigmatite. Towards sodalite it behaves in a varying manner: in many cases it encloses crystals or rounded grains of primary sodalite but within the same specimens instances of the reverse may also be observed. In contradistinction to felspar and sodalite the nepheline is very poor in ægirine microlites. Alterations to zeolitic matter are common; sometimes also the nepheline is of a cloudy appearance, probably in consequence of ordinary weathering.

*Eudialyte* occurs in greatly varying amount. As a rule it is fresh, showing distinct double refraction. Locally it has been converted into an aggregate of catapleiite and light green ægirine. This alteration has not the character of a resorption process, for the original outlines of the eudialyte have been

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[1] For a fuller description of the alteration-processes of the sodalite of this rock and of the naujaite, see 'Meddelelser om Grønland' XIV, p. 135 (1894).

preserved in most cases; on the other hand observations show that the catapleiite has formed prior to the analcime, and the transformation of the eudialyte must accordingly have occurred before the cooling down of the rock[1].

*Ægirine* and *arfvedsonite* showing the typical characters[2] are present in great amounts. They occur in large allotriomorphic anhedra, sometimes in parallel intergrowth with one another, filling the interspaces between the other minerals. The ægirine is not only a primary constituent of the rock, but it is also found as an alteration product of arfvedsonite. In the latter case it occurs as very light coloured, fibrous aggregates and the majority of the fibres are parallel to the vertical axis of the original arfvedsonite. Interspersed in this ægirine-aggregate numerous minute scales of a strongly pleochroic mineral showing deep reddish brown and light grayish brown absorption-tints are commonly found; the direction of maximum absorption in some sections is parallel to, and in others perpendicular to, the direction of elongation of the scales; the mineral is probably hydrous iron oxide.

This alteration of the arfvedsonite begins at the margin and proceeds along the cleavage craks; as a rule it affects only small portions of each arfvedsonite-anhedron. Locally, however, the arfvedsonite has been completely converted into such fibrous aggregates of light-coloured or colourless ægirine, and this will apply to all the arfvedsonite-bearing rocks of Ilimausak. Nice pseudomorphs of this kind have already been found by the earliest explorers of the Ilimausak region. The existence of the pseudomorphs has no doubt contributed to the uncertainty about the chemical composition of arfvedsonite which prevailed until J. Lorenzen cleared up the question[3].

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[1] The conversion of eudialyte into catapleiite has been described in 'Meddelelser om Grønland' XIV, p. 164 and Pl. VI (1894).

[2] Ibidem, p. 176 and p. 191.

[3] Meddelelser om Grønland II, 1881, p. 147, and Mineral. Magaz. V, p. 50.

In some pseudomorphs the hydrous iron oxides mentioned above are wanting, in others they are replaced by micaceous hæmatite, while the ægirine is always of the same acmite-like habit and fibrous structure. A fuller description has been given in another place[1]; here, the analysis of them is quoted together with analyses of arfvedsonite and ægirine in order to show the general character of the alteration process.

| | *Arfvedsonite* (Lorenzen) | *Arfvedsonite-pseudomorphs* (Detlefsen) | *Ægirine* (Lorenzen) |
|---|---|---|---|
| $SiO_2$ ......... | 43·85 | 44·19 | 49·04 |
| $Al_2O_3$ ........ | 4·45 | 4·63 | 1·80 |
| $Fe_2O_3$ ........ | 3·80 | 34·67 | 29·54 |
| FeO .......... | 33·43 | 1·16 | 4·82 |
| MnO ......... | ·45 | ·45 | tr. |
| MgO ......... | ·81 | ·18 | tr. |
| CaO .......... | 4·65 | 2·35 | 2·70 |
| $Na_2O$ ......... | 8·15 | 11·61 | 13·31 |
| $K_2O$ .......... | 1·06 | ·13 | tr. |
| $H_2O$ .......... | ·15[2] | ·30 | — |
| | 100·80 | 99·67 | 101·21 |
| Sp. gr.... | 3·44 | 3·57 | 3·63 |

This alteration of the arfvedsonite no doubt belongs to the pneumatolytic phase; it is of special interest because it indicates the presence of an excess of oxygen during this phase. It is probable that the process is contemporaneous with, and partly due to the same agencies as, the conversion, mentioned above, of eudialyte into catapleiite; for in the specimens where the arfvedsonite is highly altered the same holds good of the eudialyte too.

*Ainigmatite* occurs in the sodalite-foyaite in varying but as a rule small amounts; it is in allotriomorphic anhedra. Micrographic intergrowths with arfvedsonite or ægirine are not uncommon.

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[1] Meddelelser om Grønland XIV, p. 195 (1894).

[2] Loss on ignition.

With regard to the minor accessories the *iron ore* is very limited in amount and sometimes entirely wanting. The *biotite* also is very scarce; it has a strong pleochroism varying between a very dark brownish green and a light yellow-brown. *Ægirine-augite* is rare; it has only been observed in two specimens where it occurs in rounded grains with the usual marginal zone of ægirine and is surrounded by arfvedsonite in a parallel position. *Astrophyllite* has only been observed in one specimen; it is in groups of irregularly arranged laths less than 0·8 millimeters long. This mineral has previously been found in somewhat larger crystals in different localities within the Julianehaab region[1]. The *rinkite* is rather common in this rock; it is often visible to the naked eye. In thin sections it is almost colourless and shows a polysynthetic twinning parallel to the cleavage; the extinction-angles of the lamellæ are very small. *Steenstrupine* in well defined crystals, reaching 0·5 millimeters in length, occurs very sparingly. Between crossed nicols it shows the peculiar microstructure described by Böggild as pertaining to the crystals of his second type[2]. It is associated with colourless flakes of a mica which is supposed to be *polylithionite* because this mineral is an almost constant companion of the steenstrupine in the pegmatitic veins. Small crystals of *fluorite* are not uncommon in the sodalite-foyaite; they are perfectly isotropic and colourless. Their index of refraction is perceptibly lower than that of sodalite, and this feature in connexion with the characteristic cleavage has been used for the identification of the mineral. It occurs in crystals, seldom more than 0·1 millimeter across, enclosed within the dark-coloured minerals.

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[1] J. Lorenzen, Untersuchung einiger Mineralien aus Kangerdluarsuk. Zeitschrift für Krystallographie IX, p. 253 (1884). O. B. Böggild, On some Minerals from Narsarsuk (Meddelelser om Grønland XXXIII, 1906, p. 103) and Mineralogia Groenlandica (ibidem XXXII, 1905, p. 351).

[2] O. B. Böggild, New examinations of Steenstrupite. Meddelelser om Grønland XXIV, 1900, p. 208.

*Analcime* very commonly fills narrow interstices between the other minerals. The interstitial analcime is of the same habit as that occurring as an alteration product of the light-coloured minerals, and both kinds of analcime often belong to the same crystallographic individuals. For this reason the interstitial analcime is not reckoned among the primary constituents of the rock. It is, however, decidedly older than the natrolite.

*Sequence of crystallization.* — From the above description it will be seen that the order of crystallization of the main components is as follows: first felspar, next nepheline, and finally ægirine and arfvedsonite. The sodalite shows a very wide range of crystallization, since one portion of it is older, and another portion of it later, than felspar. Eudialyte as a rule is later than felspar and older than nepheline. This order of crystallization is of interest because the naujaite, though closely related to the sodalite-foyaite, shows a different order. Only the place of the ægirine and the arfvedsonite at the end of the succession is common to both rocks and also to many other nepheline-syenites of related composition. This feature which is opposed to the general rule, that the sequence of crystallization corresponds with decreasing basicity, has been noted long ago in the descriptions of ægirine- and arfvedsonite-bearing nepheline-syenites from several localities[1]. It is true that the crystallization of the dark-coloured minerals in the sodalite-foyaite may be said to have commenced at a very early stage of the consolidation process because minute needles of ægirine and arfvedsonite are enclosed within the felspar, but this portion of the dark coloured minerals is quantitatively quite insignificant as compared with the large anhedra; and since individuals of intermediate size are relatively rare there is no doubt that the bulk of the ægirine and of the arfvedsonite has

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[1] V. Hackman, Petrographische Beschreibung des Nephelinsyenites von Umptek. Tennia XI, No. 2, p. 101 and 131 (1894).

*Analyses of sodalite-foyaite and tavite.*

| | 5 | A |
|---|---|---|
| $SiO_2$ .......... | 49·38 | 47·29 |
| $TiO_2$ .......... | ·63 | |
| $ZrO_2$ .......... | ·61 | |
| $Al_2O_3$ ......... | 17·31 | 15·46 |
| $Fe_2O_3$ ........ | 4·20 | 12·00 |
| FeO .......... | 5·25 | 2·35 |
| MnO .......... | ·08 | trace |
| MgO .......... | ·53 | 1·32 |
| CaO .......... | 2·23 | 1·61 |
| $Na_2O$ ......... | 13·87 | 14·74 |
| $K_2O$ .......... | 2·55 | 1·23 |
| $H_2O$ above 110° . . | 1·30 | 1·85[1] |
| $H_2O$ at 110° .... | ·16 | |
| Cl ............ | 1·68 | n. d. |
| $SO_3$ .......... | none | trace |
| $P_2O_5$ ......... | none | |
| | 99·78 | |
| Cl = O ........ | ·38 | |
| Total... | 99·40 | 97·85 |
| Sp. gr.... | 2·653 | |

**5.** Sodalite-foyaite, Tupersuatsiak, S. Greenland. C. Winther, analyst.

A. Tavite, Lujavr-Urt, Kola. H. Blankett, analyst (W. Ramsay, Das Nephelinsyenitgebiet auf der Halbinsel Kola II. Fennia XV, No. 2, 1899, p. 24).

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[1] Loss on ignition.

actually crystallized later than the main mass of the other constituents of the rock.

*Chemical composition.* — A chemical analysis of specimens of this rock, taken at Tupersuatsiak, has been made by Dr. C. Winther, with the results given in No. 5 of the above table. If this analysis is compared with the analyses of other nepheline-syenites it will be found to differ considerably from most of them. Among the rocks of Lujavr-Urt, Kola Peninsula, however, a closely related type occurs, namely the tavite of Ramsay (see above, analysis A). The analysis of the tavite is incomplete, chlorine not having been determined, but as a variety of sodalite (hackmanite) is a main constituent of the rock it is probable that a more complete analysis would show a still greater agreement with the analysis of the Greenlandic rock. On the other hand it deserves notice that the tavite as to structure is much more similar to the Greenlandic naujaite than to the sodalite-foyaite.

From the chemical analysis the mineral composition of the sodalite-foyaite of Tupersuatsiak is found to be approximately:

| | Per cent. |
|---|---|
| microcline | 16 |
| albite | 20 |
| sodalite | 22 |
| nepheline | 5 |
| eudialyte | 4 |
| ægirine | 12 |
| arfvedsonite | 6 |
| ainigmatite | 7 |
| zeolites (analcime and natrolite) | 6 |
| fluorite, rinkite etc. | 2 |
| | 100 |

In calculating these figures it has been assumed that the eudialyte, the ægirine, and the arfvedsonite are of the same composition as those of the pegmatites as analysed by J. Lorenzen. Likewise the analysis of nepheline by Clarke and that of ainigmatite by **Forsberg** have been used. But as the actual composition of all these minerals in the rock may be more or less different from that given in these analyses the above calculation is only likely to give a very approximate idea of the relative amounts of the mineral components.

## NAUJAÏTE.

The naujaite may be regarded as the most charateristic rock of the Ilimausak region. It covers a larger area than any other nepheline-syenite of this complex, and it is exceptional as to mineral composition and structure. It appears in the coast cliffs at most of the landing-places used by travellers going in search of rare minerals, and it has therefore long ago attracted attention. As a separate rock-type it was first described by Dr. **Steenstrup** who termed it 'sodalite-syenite'[1].

The naujaite may be defined as an extremely coarse-grained nepheline-syenite, characterized by a very high content of sodalite and by a peculiar poikilitic structure.

*Occurrence.* — The naujaite reaches its maximum thickness, about 600 meters, at the inner end of Kangerdluarsuk. From this place it extends northward and northeastward all the way to Tunugdliarfik; north of this fjord it reappears and covers a considerable area around and below the arfvedsonite-granite. The total area where the naujaite is exposed to view may be estimated at about 24 $km^2$. To this may be added the areas where it is covered by the other rocks or by the sea, as well as those from which it has been removed by erosion. In this way it is found that the original extension amounts to about 60 $km^2$. As the mean thickness is estimated at 300 meters the total volume of this rock originally present within the

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[1] Meddelelser om Grønland II, 1881, p. 35. — The term 'sodalite-syenite' is also used in later publications by **Steenstrup**, **Lorentzen**, **Böggild**, **Ussing** and others. The reasons for the introduction of a new name have been given in the preceding chapter (p. 32).

Ilimausak complex amounts to 20 $km^3$ or a little less. These figures, however, are only to be regarded as approximate.

The general shape of the naujaite-body is that of a tolerably flat or slightly concave sheet. In the higher parts of the mountains it is overlain by the sodalite-foyaite. It rests upon lujavrite. Between the naujaite and the sodalite-foyaite there is always a gradual transition; towards the lujavrite the contact as a rule is well marked though transitional forms are found in some places.

*Colour.* — The colour of the naujaite cliffs when seen at some distance is light gray; upon closer inspection or in hand specimens the rock has a conspicuously motley appearance owing to the large dimensions of the individual white, greenish, red, and black crystals and anhedra. On freshly broken surfaces the sodalite exhibits a magnificent, deep bluish-red colour which rapidly disappears when the surface is exposed to the light (p. 33)

*Mineralogical characters.* — The main constituents are sodalite, nepheline, alkali-felspar, ægirine, arfvedsonite, and eudialyte, the latter in varying and sometimes in very small amount. As minor accessories the following minerals have been detected: ainigmatite, rinkite, rosenbuschite, molybdenite, sphalerite, biotite, polylithionite, and apatite. The microscope also reveals the presence of analcime and natrolite (spreustein) occurring as secondary minerals in the same manner as in the sodalite-foyaite. A little interstitial analcime is often observed.

The *sodalite* is very abundant in vell developed dodecahedra. It is the most idiomorphic constituent of this rock; only where it borders upon nepheline it does not show any distinct idiomorphic form. The dodecahedral cleavage is well developed. The crystals are isodiametric or slightly elongated parallel to a trigonal axis. The diameter commonly varies between 3 and 5 millimeters; exceptionally very elongated crystals may reach a length of 1 or 2 centimeters. As a rule the sodalite is quite fresh, translucent, and of a greenish colour (rarely colourless). In polarized light it proves strictly isotropic. Lorenzen's analysis of this sodalite is here quoted:

*Analysis of sodalite-crystals of naujaite*[1].

| | |
|---|---|
| $SiO_2$ | 36·50 |
| $Al_2O_3$ | 31·53 |
| $Fe_2O_3$ | ·19 |
| CaO | ·25 |
| $Na_2O$ | 26·30 |
| $K_2O$ | ·18 |
| Cl | 7·30 |
| | 102·25 |
| Cl = O | 1·65 |
| Total | 100·60 |
| Sp. gr. | 2·31 |

The sodalite-crystals contain innumerable minute needles or microlites of arfvedsonite and ægirine which are responsible for the greenish colour of the crystals. As a rule the arfvedsonite-needles are more abundant than the ægirine-needles. Their dimensions are very small, exceptionally they may reach a length of 0·05 millimeters and a thickness of 0·01 millimeters. Most of them lie parallel to the cleavage directions, but they do not show any zonary arrangement, with the exception that the marginal zone of the sodalite-crystals in some cases is free from microlites. Minute fluid-inclusions with a mobile bubble occur in large number; these are at least partly of secondary origin, for they are often arranged in long rows stretching across several crystals. The sodalite is sometimes found to be partially converted into analcime, but the commonest alteration-product is natrolite-spreustein. Even in the freshest rock-specimens the microscope reveals the presence of small patches of natrolite at the margin of the sodalite-crystals; these patches appear just at the boundary between

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[1] Meddelelser om Grønland II, p. 59 (1881).

sodalite and felspar, and the alteration-process attacks both minerals simultaneously. It is therefore probable that the formation of spreustein in this case begins according to the equation

$$\overset{\textit{sodalite}}{\mathrm{Na_4Al_3ClSi_3O_{12}}} + \overset{\textit{albite}}{\mathrm{NaAlSi_3O_8}} + \mathrm{4H_2O} = \overset{\textit{natrolite}}{\mathrm{2(Na_2Al_2Si_3O_{10} \,.\, 2H_2O)}} + \mathrm{NaCl}.$$

Next to the sodalite *nepheline* is the most idiomorpic mineral of the naujaite. It occurs in hexagonal, short prisms, one or two centimeters across. The crystals as a rule are fresh, white or slightly grayish, and translucent. Under the microscope many of them are quite clear while others contain fluid-pores and minute prisms of arfvedsonite (rarely ægirine); these prisms are of considerably larger dimensions than the microlites contained in the sodalite, but they are not very numerous.

The mutual relations of nepheline and sodalite are somewhat intricate. Very often the larger nepheline crystals enclose crystals of sodalite in a poikilitic manner, but within the same slices also micrographic intergrowths of both minerals may be observed as well as instances where the nepheline has been partially converted into sodalite. In the latter case sodalite has formed not only round the margin of the nepheline but also in irregular patches in the interior, and at a more advanced stage of conversion the nepheline is reduced to isolated lapped areas enclosed in the sodalite. The sodalite replacing nepheline in this manner is of the same microstructure as the marginal zone without microlites that surrounds some of the idiomorphic sodalite-crystals as mentioned above. This seems to indicate that the transformation of the nepheline has occurred before the final consolidation of the rock. There are, however, found indications that a conversion of nepheline into sodalite has also taken place after the consolidation, for in some cases the outer zone of the nepheline-crystals has been changed into a sodalite showing convex or mammillary surfaces towards the remaining portion of the nepheline; in this sodalite no cleavage is visible, and its structure is probably fine-grained or spherulitic. Thus, while the greater part of the sodalite in the naujaite has crystallized prior to the nepheline, sodalite in minor quantities has formed at the expense of nepheline both before and after the consolidation of the rock. This is in harmony with the well-known experiences in regard to the artificial production of sodalite[1]. Another less common alteration of the nepheline of this rock is the conversion to spreustein; this process is always posterior to the 'sodalitisation'.

In comparison with the crystals of sodalite and nepheline those of *felspar* are of gigantic dimensions: their length varies from 3 to 25 centimeters and averages about one decimeter. They are of thick tabular habit, the thickness amounting to about one fourth or one third of the length. Each felspar-crystal encloses a large number of sodalite-crystals poikilitically; the cleavage surfaces for this reason are of a peculiar, coarsely dotted appearance. The clinopinacoidal crystal-faces (010) are well developed, sometimes also prismatic faces (110) are seen where the felspar is bounded by arfvedsonite. The crystals are very fresh, translucent, and of a light greenish or grayish colour.

Under the microscope the felspar is seen to be a microcline-microperthite. The perthitic structure as well as the twin-structure of the microcline is very different from any of the ordinary types represented by the felspars of common granitic and syenitic rocks, but both structures are of the same types as those characterizing the felspar of the sodalite-foyaite (see Fig. 14, p. 135). A still closer arrangement is found between the felspar of the naujaite and that of the pegmatitic veins. The latter has been described on a previous occasion[2]; the chemical analysis is here quoted:

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[1] H. Rosenbusch, Mikroskopische Physiographie I, 2, p. 40 (1905).

[2] Meddelelser om Grønland XIV, p. 21 and Pl. I (1894).

*Analysis of microcline-microperthite of naujaite-pegmatite.*

| | I | II | III | IV |
|---|---|---|---|---|
| $SiO_2$ | 65·62 | ·77 | 65·86 | 65·80 |
| $Al_2O_3$ | 18·50 | ·03 | 18·76 | 18·75 |
| $Fe_2O_3$ | ·55 | ·55 | — | — |
| MgO | tr. | — | — | — |
| $Na_2O$ | 3·50 | ·21 | 3·34 | 3·36 |
| $K_2O$ | 11·86 | — | 12·04 | 12·09 |
| Loss on ignition | ·38 | — | — | — |
| Total | 100·41 | 1·56 | 100·00 | 100·00 |
| Sp. gr. | 2·58 | | | |

I. Microcline-microperthite of naujaite-pegmatite, Nunarsuatsiak. Analysis by C. Detlefsen.
II. Deduction for ægirine-inclusions.
III. Calculated composition of the felspar after deducting 1·56 per cent of ægirine.
IV. Theoretical composition of a felspar containing 71·61 per cent. $KAlSi_3O_8$ and 28·39 per cent. $NaAlSi_3O_8$.

In the felspar-crystals of the naujaite, microcline as a rule dominates over albite; very often, however, the central part of each crystal is relatively rich in albite while microcline becomes gradually more prevalent as we approach the margin.

As it has been pointed out in the earlier description of these felspars[1] their structure is no doubt due to a *primary intergrowth* of microcline and albite. This is indicated by the fact that the composition surfaces of microcline and albite show a pronounced tendency to assume a direction parallel to *b* (010) which is the predominant crystal face. This feature is common to most of the perthites of the Ilimausak nepheline-syenites (and it has also been noticed elsewhere in rocks of similar composition) while it is opposed to the behaviour of the perthitic structure in most other rocks in which the perthitic composition planes do not follow the direction of any crystal face[2]. J. H. L. Vogt in his interesting study of the crystallization of the

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[1] loc. cit. p. 33.
[2] loc. cit. p. 86.

felspars in magmas[1] has expressed a somewhat different opinion. He supposes that the felspar of which the chemical composition has been given above has formed as a homogeneous crystal of potash-felspar containing the highest admixture possible of albite-silicate (according to his theory about 28 per cent.), and that the perthitic structure has originated by recrystallization when the solid crystal adjusted itself to another state of equilibrium at a lower temperature. It deserves notice, therefore, that the structural feature mentioned above is not the only fact telling against the view of Professor Vogt. Thus, the microscopical examination of the rock indicates the presence of all gradations connecting the perthites in which albite dominates with those containing prevalent microcline; and the naujaite itself with its perthitic felspars is connected by gradual transitions with the lujavrites in which microcline and albite occur in separate crystals of widely varying relative amounts[2].

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[1] J. H. L. Vogt, Physikalisch-chemische Gesetze der Krystallisationsfolge in Eruptivgesteinen. Tschermak's Mineralogische und Petrographische Mitteilungen XXIV, p. 533 (1906).

[2] Another hypothesis set forth by Professor Vogt (loc. cit p. 522) and relating to the same question, viz. that the cryptoperthites of certain augite-syenites (larvikites) represent the eutectic mixture of soda- and potash-felspar also seems open to some doubt. As a matter of fact the augite-syenites in question in many localities occur in connection with nepheline-syenites containing perthitic alkali-felspars of a chemical composition which differs considerably from that of the cryptoperthites, and for geological reasons it seems very unlikely, if not impossible, that the felspars of the augite-syenite have crystallized at a lower temperature than the other felspars. At Ilimausak the naujaite-pegmatite has evidently crystallized at a lower temperature than the naujaite itself, and this in turn has crystallized at a lower temperature than the augite-syenite which is of the Larvik type. Accordingly it might be expected that the eutectic alkali-felspar was to be found in the pegmatite rather than in the augite-syenite. But in the hypothesis of Professor Vogt the reverse is assumed: the pegmatitic felspar mentioned above is quoted as an instance of an originally homogeneous soda-bearing potash-felspar, and the felspar of the augite-syenite is interpreted as an eutectic intergrowth. To the present writer the assumption seems more likely that the augite-syenitic cryptoperthites in most cases have crystallized at a relatively high temperature as originally homo-

Minute prisms of æginine and of arfvedsonite are always found included in the felspar of the naujaite. They are, however, neither so numerous nor so small as in the sodalite of this rock. Another difference is that, among inclusions in the felspar, ægirine is predominant, while, in the sodalite, arfvedsonite-prisms prevail. The commonest alteration of the felspar in this rock results in the formation of analcime.

The felspar of the naujaite has often been partially converted into analcime. Among the slices of one single hand-specimen some may afford marked instances of this conversion while in others the felspar is quite intact. The transformation always begins from the margin and from a few cracks, and the analcime formed in this way is very coarsely crystalline, showing distinct cleavage and the usual anomalous double refraction. Curiously enough in many cases only the microcline has been altered to analcime while the albite is unaltered; instances of the reverse, however, are not uncommon.

The principal dark-coloured minerals of the naujaite are *ægirine* and *arfvedsonite*. The former is predominant in some places and the latter in others, but these variations are quite irregular and specimens containing ægirine and arfvedsonite in about equal amounts are also rather commonly found. Both minerals occur as large allotriomorphic anhedra often reaching a length of 20 or 30 centimeters. Each anhedron encloses a large number of sodalite-crystals poikilitically (sometimes several hundred). Upon closer inspection ægirine proves a little more idiomorphic than the arfvedsonite: while the latter is always interstitial and never shows any trace of external crystal faces

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geneous mixed crystals; while the primary perthitic felspars found in the Ilimausak pegmatites, in the naujaite, and in many other rocks, have crystallized at a lower temperature than the inversion temperature at which the felspars are transformed into non-isomorphous forms. The latter view of course depends on the assumption which has not yet been strictly proved, that the alkali-felspars are isomorphous at high temperatures.

(the minute prisms enclosed in the sodalite etc. are here left out of consideration) the ægirine, though mainly interstitial, shows traces of idiomorphism towards the felspar. At their mutual boundaries neither ægirine nor arfvedsonite shows idiomorphic outlines. The optical character of the ægirine and the arfvedsonite of this rock indicate that both are typical representatives of these mineral species. The well-known analyses of ægirine and arfvedsonite from 'Kangerdluarsuk' by Lorenzen, Doelter, and Berwerth refer to specimens from the pegmatites of the naujaite.

The *eudialyte* is present in widely varying amount in this rock: in some places it is abundant, in others it occurs as a very subordinate constituent. It is in fresh red crystals of similar large dimensions as the felspar, and as a rule it is a little more idiomorphic than the latter mineral. It is always closely dotted with sodalite-crystals, while inclusions of other kinds are very rare. Optically it agrees with the typical variety of eudialyte found in the pegmatites of the naujaite[1] and analysed by Lorenzen and Rammelsberg.

As mentioned above the number of minor accessories occurring in the naujaite is rather considerable but most of them are very rare. It deserves notice that iron-ore is entirely absent. Also *apatite* is extraordinarily scarce; only in a few slices three or four minute prisms have been observed, imbedded in sodalite or nepheline. Small scales of brown *biotite* occur rather commonly as a thin coating on those nepheline-crystals which are imbedded in the arfvedsonite. *Sphalerite* has been found in small grains, enclosed in ægirine, and in crystals surrounded by analcime; in thin slices it is of a yellowish brown colour. Among the other accessories, mentioned above (p. 144), only the *rosenbuschite* needs a more detailed description as this mineral has not been found previously in Green-

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[1] Meddelelser om Grønland XIV, p. 147 (1894).

land. It is present in a specimen of naujaite from Nunasarnak in colourless (or slightly yellowish) needles and slender prisms reaching a maximum length of 2 millimeters. Most of them are included in the outer zone of the sodalite-crystals. The needles are monoclinic and elongated parallel to the *b*-axis. There is a very distinct longitudinal cleavage. The optic axial angle is large. The refractive power, the birefringence, and the general habit agree with those of the rosenbuschite from Langesund. In several slices of the naujaite a few small crystals are observed showing characters agreeing with those of *schizolite*, a mineral which has been found in the pegmatites of the naujaite[1]; no exact determination, however, could be made of these crystals.

*Structure.* — The photograph, Pl. XVIII, showing the surface of a naujaite cliff near the inner end of Kangerdluarsuk Fjord, will give a general idea of the peculiar poikilitic structure of this rock. The rock may be said to be made up of a hypidiomorphic aggregate of felspar, nepheline, eudialyte, ægirine, and arfvedsonite. This aggregate is exceedingly coarse-grained (the length of the individual crystals with exception of the nephelines commonly exceeds 10 centimeters), and all crystals of the aggregate are closely and uniformly dotted with dodecahedra of sodalite averaging half a centimeter across or a little less. This contrast as to size between the sodalite and the other constituents is always very conspicuous: the sodalite-crystals never show the slightest tendency to attain dimensions comparable with those of the other minerals[2]. The bearing of this structure on the question of the origin of the naujaite will be discussed in the last chapter.

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[1] O. B. Böggild, On some minerals etc. Meddelelser om Grønland XXVI, 1903, p. 121.

[2] This refers exclusively to the naujaite itself: in the pegmatitic veins of the naujaite the same minerals may be present and the sequence of crystallization may be the same as in the naujaite but the structure is entirely different (p. 65).

The sequence of crystallization when only the main constituents are considered is as follows:

I. Sodalite
II. Nepheline and eudialyte
III. Felspar
IV. Ægirine, and finally arfvedsonite.

This applies to the time of crystallization of the bulk of each constituent. But it will be evident from what has been said above that the periods of growth of the different minerals largely overlap one another. Thus, the main portion of the sodalite which is rich in inclusions is no doubt older than the nepheline, but the crystallization of sodalite has slowly continued contemporaneously with that of nepheline and far beyond the time when felspar began to crystallize. On the other hand there are no indications whatever that sodalite or nepheline crystallized later than felspar, and this is a very noticeable difference from the sodalite-foyaite where felspar is the most idiomorphic mineral. As to the ægirine and the arfvedsonite their behaviour is the same as in sodalite-foyaite (see p. 137).

*Chemical composition.* — Owing to the extremely large size of grains of the naujaite great care was needed in the selection of specimens for the purpose of chemical examination. Two analyses have been made with the results shown in the table on the next page. The first analysis (No. **6**) was made on specimens collected as typical representatives of the naujaite as it appears at Kangerdluarsuk. For the second analysis (No. **7**) typical specimens were taken at Nunasarnak, on the northern side of Tunugdliarfik.

From the chemical analyses the mineral composition is approximately found to be the following[1]: —

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[1] With regard to the chemical composition of the minerals the same assumption have been made here as in the calculation of the sodalite-foyaite (p. 142).

*Analyses of naujaite and related rocks.*

| | 6 | 7 | A | B | C |
|---|---|---|---|---|---|
| $SiO_2$ | 49·46 | 43·39 | 45·28[1] | 48·10 | 48·35 |
| $TiO_2$ | ·16 | ·20 | | ·13 | ·45 |
| $ZrO_2$ | ·38 | ·27 | | trace | |
| $Al_2O_3$ | 23·53 | 23·13 | 27·37 | 24·20 | 23·10 |
| $Fe_2O_3$ | 3·04 | 3·62 | 3·56 | 1·11 | 2·48 |
| FeO | 1·02 | 3·24 | ·49 | 2·47 | 1·89 |
| MnO | ·17 | trace | ·19 | ·48 | |
| MgO | trace | none | ·33 | ·51 | ·89 |
| CaO | ·80 | ·56 | 1·22 | ·45 | 2·51 |
| $Na_2O$ | 14·71 | 19·68 | 17·29 | 15·20 | 13·20 |
| $K_2O$ | 4·34 | 1·51 | 3·51 | 3·00 | 3·58 |
| $H_2O$ above 110° | 1·38 | 1·36 | ·40[2] | 1·20 | 2·91[2] |
| $H_2O$ at 110° | | ·21 | | | |
| Cl | 2·25 | 3·63 | | 2·80 | 1·49 |
| $SO_3$ | none | none | | | |
| $P_2O_5$ | none | none | | | |
| | 101·24 | 100·80 | | 99·65[3] | 100·85 |
| Cl = O | ·51 | ·82 | | ·63 | ·34 |
| Total... | 100·73 | 99·98 | 99·53 | 99·02 | 100·51 |
| Sp. gr.... | 2·53 | 2·545 | | | |

**6.** Naujaite, Kangerdluarsuk, S. Greenland. N. V. Ussing, analyst[4].

**7.** Naujaite, Nunasarnak, S. Greenland. C. Winther, analyst.

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[1] Including "ca. 2 per cent. $TiO_2$".

[2] Loss on ignition.

[3] In the original the sum is given as 99·45.

[4] This analysis has previously been published in H. Rosenbusch, Elemente der Gesteinslehre, 1898, p. 126. As given above the analysis has been completed by the determination of $TiO_2$, made by Dr. Winther.

A. Urtite, Lujavr-Urt, Kola. A. Zilliacus, analyst (W. Ramsay, Das Nephelinsyenitgebiet auf der Halbinsel Kola II. Fennia XV, No 2, 1899, p. 22).

B. Nepheline-syenite, rich in sodalite, Los Isles. F. Pisani, analyst (A. Lacroix, Sur les facies de variation de certaines syénites néphéliniques des îles di Los. Comptes rendus CXLII, 1906, p. 684).

C. Nepheline-syenite, rich in sodalite, Zeekoegat, Transwaal. F. Pisani, analyst (H. A. Brouwer, Transwaalsche Nephelien-syenieten. s'Gravenhage 1910, p. 42).

| | *Naujaite* analysis No. 6 Kangerdluarsuk Per cent. | *Naujaite* analysis No. 7 Nunasarnak Per cent. |
|---|---|---|
| sodalite | 31 | 54 |
| nepheline | 18 | 5 |
| eudialyte | 3 | 2 |
| microcline | 20 | 6 |
| albite | 10 | — |
| ainigmatite | — | 2 |
| ægirine | 10 | 12 |
| arfvedsonite | 1 | 5 |
| analcime | 7 | 14 |
| | 100 | 100 |

The figures given in this table at once show that the salient feature of this rock is the extraordinarily high amount of sodalite. They also show that the naujaite of Nunasarnak is still richer in sodalite than the Kangerdluarsuk variety while on the other hand felspar and nepheline are considerably lower in the former rock. These differences in as far as sodalite and nepheline are concerned express an original variation in the composition. As to the amounts of felspar, however, the original difference is much inferior to that indicated by the analyses. The microscopical examination shows that the large amount of analcime found in the Nunasarnak naujaite has formed mainly at the expense of felspar, while the zeolitic matter in the Kangerdluarsuk rock is not only present in smaller amount but it has here formed at the expence of all the salic minerals.

The chemical type represented in the naujaite is of rarer occurrence. The writer is only aware of three other localities where similar rocks have been found (see analyses quoted in the table p. 154). At Lujavr-Urt in the peninsula of Kola the rock-type which is termed urtite has a chemical composition fairly analogous to that of the naujaite. The similarity, however, does not extend to the mineral composition, for the urtite as described by Ramsay is not sodalite-bearing. Nevertheless the chemical agreement is of great interest from a theoretical point of view, because both the urtite and the naujaite are associated with lujavritic rocks. A still closer agreement is manifest between the naujaite and certain sodalite-bearing nepheline-syenites from the Los Isles and from Transvaal (see analyses B and C, p. 154). These rocks, too, occur in connection with lujavrites.

### *Sodalitite.*

The description given in the preceding pages refers to the bulk of the naujaite. A peculiar variety with exceptionally small and numerous sodalite-crystals has been mentioned in the geological chapter (p. 74). Another more divergent variety is the 'sodalitite' found at Nunasarnak in subordinate masses in the naujaite. It is almost exclusively made up of sodalite exhibiting the same microstructure and occurring in grains of the same size as in the naujaite. Small amounts of ægirine, felspar, and eudialyte are also present in the sodalitite.

## LUJAVRITES.

As previously mentioned the naujaite of the Ilimausak batholite rests upon lujavrites. As a rule the lower part of the naujaite-body has been split up into huge fragments or lenses separated by a framework of lujavrite-veins. The veins increase downwards in number and thickness, and thus the breccia-zone passes into the more uniform lujavrite-body. In some places, however, a gradual transition from naujaite to lujavrite is observed.

The lujavrites are dark-coloured and rather fine-grained rocks showing a thin platy parting and a corresponding fissility parallel to the thick platy parting of the superincumbent naujaite and parallel, too, to the upper surface of the lujavrite-body. Since the latter surface is not quite horizontal but on a large scale cup-shaped, the lujavrites are exposed in a tolerably circular zone which surrounds the naujaite area and reaches its maximum width, about two kilometers, in the southeastern part of the complex. It is probable that the general form of the lujavrite-mass is similar to that of the naujaite, but no substratum is exposed to view and it is, therefore, not possible to indicate the actual thickness of the lujavrite-body. In the southeastern part of the batholite, between Laxe-Elv and Agpat, the visible thickness, measured perpendicularly to the direction of the parting, exceeds 600 meters. Roughly estimated, the volume of that part of the lujavrite-body which is above sea-level is about equal to the total volume of the naujaite and the sodalite-foyaite taken together, and as the lujavrites no doubt extend far below the sea-level they are, quantitatively, the most important rocks of the batholite.

The lujavrites occur in two varieties; the green ægirine-lujavrite and the black arfvedsonite-lujavrite. Transitional forms are also found, though they are not common. On the whole both varieties are present in about equal amounts, but their mutual distribution is rather irregular. The veins in the lowermost portion of the naujaite as a rule consist of arfvedsonite-lujavrite. Some veins have been found, however, the marginal zones of which are of the arfvedsonite variety while the interior is ægirine-lujavrite. As to the main body of the lujavrite the uppermost sheets, immediately below the breccia-zone, are as a rule arfvedsonite-lujavrite. Farther downwards the ægirine variety dominates and is here exposed in cliffs several hundred meters high and of an uniform green colour. In the lowermost visible sheets of the complex, at the mouth of Laxe-Elv, the arfvedsonite variety again prevails.

### *Ægirine-lujavrite.*

*Macroscopic appearance.* — This rock is as a rule of a rather fine-grained structure and there is a very conspicuous parallel arrangement of the minerals producing a marked fissility or schistosity. The surfaces along which the rock splits up are somewhat uneven and often exhibit an almost silky lustre. This, as well as the peculiar grass-green or dark green colour, is due to the ægirine occurring abundantly in slender needles. On a fresh fractured surface parallel to the fissile structure ægirine is often the only visible constituent. Most of the needles lie parallel to the surface and not unfrequently they show a slight tendency to parallel arrangement in one direction. On the cross fracture felspar, nepheline, and eudialyte may be detected with the naked eye. The felspar is in very fresh and clear, small crystals of thin tabular habit, arranged parallel to the schistose structure. The nepheline commonly appears as small white crystals of short rectangular or rounded outline; and the eudialyte crystals, when fresh, are of a clear brown colour and as a rule of much smaller dimensions than the nepheline-crystals.

A very conspicuous feature of most varieties of the ægirine-lujavrite is the presence of relatively large (1—3 centimeters) black patches of arfvedsonite producing a porphyritic appearance. In some places these arfvedsonite-patches are of quite irregular shape, in others they are prismatic and the prisms are sometimes arranged in radiate groups. These crystals and anhedra of arfvedsonite are not ordinary phenocrysts:

upon closer inspection they are seen to enclose poikilitically all the other constituents of the rock with the exception of the ægirine.

*Microscopic characters.* — Under the microscope the rock is seen to be made up of the following main constituents; felspar, nepheline, eudialyte, ægirine, and arfvedsonite. Analcime is present in very varying amount but this mineral is apparently always of secondary origin. Locally the rock contains large icositetrahedral phenocrysts of analcime which perhaps indicate the original presence of leucite (?). Primary sodalite is not common. Minor accessories are often entirely absent; only in a few instances fluorite, sphalerite, biotite, and astrophyllite have been observed. Besides analcime also catapleiite, sodalite, hydronephelite, and natrolite occur as secondary products.

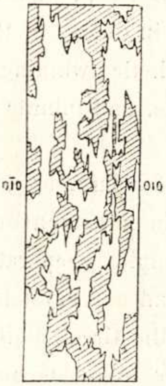

Fig. 15. Microcline in lujavrite, basic section (× 70).

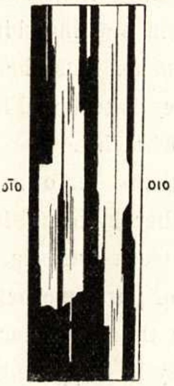

Fig. 16. Albite in lujavrite, basic section (× 120).

The *felspars* of the ægirine-lujavrite are microcline and albite. The crystals are of tabular habit parallel to *b* (010) and slightly elongated parallel to the *a*-axis. The length averages 3 or 4 millimeters (varying between 1 and 6 millimeters), and the mean thickness is about 0·4 millimeter (0·1—0·7 millimeter). The mode of crystallization of the alkali-felspars of this rock offers a peculiar interest. *Perthitic intergrowths are entirely wanting:* on optical examination some of the crystals prove to be pure microcline while others are pure albite; both kinds may be found in the same rock-slices and very often lie side by side. In some specimens of the rock microcline-crystals and albite-crystals are present in about equal amounts, in others the former are predominant, in others again albite-crystals prevail. These variations are not connected with any kind of variation in the outer habit of the rock.

Between crossed nicols the microcline shows an irregular twin-structure (Fig. 15) of the same type as in the naujaite; not seldom one individual of the twin is in excess of the other. The albite exhibits the ordinary polysynthetic twinning according to the albite-law (Fig. 16). Fluid-cavities and minute included needles of ægirine are not rare.

In almost all other rocks the alkali-felspars, as is known, occur either in perthitic intergrowth or in homogeneous mixed crystals (soda-orthoclase etc.). The complete separation into crystals of pure microcline on the one hand and crystals of pure albite on the other hand, characterising the Greenlandic lujavrites[1], may be supposed to result from the following conditions: — (1) Movements of the magma during the crystallisation are indicated by the structure of the rock. (2) An uncommonly high degree of liquidity of the magma is probable for reasons inferred from the chemical composition of the rock and from the peculiar character of the differentiation-processes which will be considered more fully in the final chapter. (3) A relatively low temperature of consolidation probably also characterises the lujavrites. The latter assumption is supported by the

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[1] Meddelelser om Grønland XIV, p. 93 (1994). — In the lujavrites of Kola and of Transvaal a similar behaviour of the alkali-felspars may sometimes be observed (W. Ramsay, Fennia XV, No. 2, p. 7, 1899; H. A. Brouwer, Oorsprong en samenstelling der Transwaalsche nephelien-syenieten. s'Gravenhage 1910, p. 120.

geological relations which indicate that the lujavritic magma — though present within the batholitic chamber at the same time as the magmas of most of the other rocks now constituting the batholite — has been the last to crystallize. That the two first-mentioned conditions would favour the formation of pure crystals of non-isomorphous minerals is evident. As to the influence of the temperature the experimental data are insufficient in order to settle the question[1]; in the writer's opinion, however, geological observations on the whole support the view, held by many authors[2], that the homogeneous mixed crystals containing considerable amounts of both kinds of alkali-felspars only form at high temperatures and that a low temperature of crystallization favours the separation.

The felspars of the ægirine-lujavrite also in other respects differ from those of the rocks described in the preceding pages: very often the larger among them are influenced by mechanical stresses. Thus many of the crystals are traversed by cracks or even bent, and not seldom strain-shadows may be observed. The latter phenomenon is especially common with the larger albite-crystals in which also the distribution of the twin-lamellæ has been influenced by the formation of the cracks. The dynamic effects on the microcline crystals are as a rule manifest only in the development of cracks and of small mutual displacements of the fragments.

In the ægirine-lujavrite the felspars have been converted into analcime on a large scale. Only in a few specimens both microcline and albite have been found quite unaltered, in most cases they are partly replaced by analcime and sometimes the felspar-substance has entirely disappeared. Even in the latter

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[1] A. L. Day and E. T. Allen, The Isomorphism and Thermal Properties of the Feldspars. Carnegie Inst. Washington, Publ. No. 31 (1905).

[2] N. S. Kurnakow und S. F. Žemčužnyi, Isomorphismus der Kalium- und Natriumverbindungen. Zeitschr. f. anorgan. Chemie, LII, p. 186 (1907). — Comp. also p. 149, above.

case the original shape of the crystals is easily discernible because most of them are surrounded by ægirine-needles which are uninfluenced by the zeolitization[1]. In different slices of one single hand-specimen instances of all stages of conversion may not infrequently be found. The analcime formed in this way shows a low birefringence with an irregular and often finely lamelar distribution of the doubly refracting areas. It also exhibits a distinct cubic cleavage, and the directions of the cleavage-cracks indicate that the crystallographic orientation of the analcime very often keeps constant throughout each pseudomorph and not seldom in the adjoining pseudomorphs also. The same holds good in those cases, too, where the original crystals have been bent or broken. Hence it follows that the transformation of the felspars into analcime is subsequent to the dynamical effects.

*Nepheline* occurs rather abundantly in crystals giving square or hexagonal sections, commonly 1 or 2 millimeters across. It does not show any sign of mechanical deformation, but the crystals have been more or less rounded by magmatic resorption. The ends of the felspar-laths sometimes project into the nepheline and not seldom small crystals of felspar and eudialyte are entirely included within it; besides, it contains numerous minute prisms of arfvedsonite and ægirine.

A marginal zone of sodalite, probably due to some kind of resorption-process, has been observed surrounding the nepheline in some specimens of the ægirine-lujavrite. The sodalite was tested according to the method of Lamberg[2]. More commonly the nepheline has been transformed into analcime. This process, too, commences at the margin of the crystals, and it

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[1] The conversion of felspar into analcime has been described in Meddelelser om Grønland XIV, p. 105 and Pl. V (1894). — A similar extensive formation of analcime at the expense of felspar and other salic minerals also characterizes some of the Transvaal lujavrites (H. A. Brouwer, Op. cit. pp. 130, 147).

Zeitschrift der deutschen geologischen Gesellschaft, XLII p. 737 (1890).

is later than the sodalitization. In many cases an inner core of the original nepheline has remained unaltered, but instances of complete alteration are also very common. The analcime shows the same characters as that replacing the felspars. As a rule the nepheline is more altered than the felspar: in such specimens where only a small amount of nepheline has been converted into analcime the felspar is intact. — Another common alteration of the nepheline is that into radiating zeolitic aggregates known by the name of spreustein[1]. This alteration-process is later than the formation of analcime; in several specimens it has affected the entire quantity of nepheline which has escaped the conversion into analcime. The nepheline-spreustein as a rule consists of hydronephelite as shown by the optical characters of the mineral; it is uniaxial with positive double refraction. In a few cases, however, nepheline-pseudomorphs of a somewhat different appearance have been observed which upon optical examination prove to be natrolite.

*Eudialyte* is present in varying amount and in some specimens it is abundant. It is in idiomorphic crystals of the ordinary form, $^1/_2$ or 1 millimeter broad. Occasionally, minute prisms of arfvedsonite and ægirine are found as inclusions. In hand-specimens the colour is brown, never red, and in thin sections it is clear and colourless or slightly brownish. Between crossed nicols a zonary banding is sometimes seen. The birefringence is often abnormally low; as a rule it is positive, but the outer zone of the crystals sometimes show a very low negative birefringence, and irregular patches of the same character may be found along the cracks. Occasionally small displacements along the latter indicate that the crystals have been slightly acted upon by mechanical forces. — In several specimens the eudialyte is replaced by pseudomorphs consisting of aggregates of catapleiite-crystals with some analcime[2].

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[1] Compare Meddelelser om Grønland XIV, Pl. VI, Fig. 1 (1894).

[2] Ibidem, Pl. VI, Fig. 5 and 6.

*Ægirine* is always very abundant in green needles showing the usual characters and arranged parallel to the rock. The needles are usually from 0·01 up to 0·20 millimeters thick by 1 or 2 millimeters long. As a rule they are well crystallized and bounded by the faces (100) and (110) in the prismatic zone; less frequently terminations are seen. The needles are often found broken or curved round the light coloured minerals.

*Arfvedsonite* appears in scattered anhedra or prisms of relatively large dimensions (1—3 centimeters) poikilitically enclosing a very great number of crystals of felspar, nepheline, and eudialyte. In many specimens it has been entirely converted into aggregates of acmite-grains or -prisms of the usual kind (see p. 137).

*Sodalite* as already mentioned is found as an alteration-product of nepheline. In a few specimens it has also been observed in independent crystals of about the same dimensions as the nephelines. The sections of the sodalite-crystals are roughly hexagonal though the crystal form is hardly developed.

*Analcime* is much more abundant in this rock than in those previously described. As far as it has been ascertained it is always a secondary product replacing the light-coloured minerals in the manner described in the preceding pages. The amount of analcime present varies within wide limits; of two rock-specimens, externally alike and taken in the same place, one may prove nearly unaltered while the other has been so strongly influenced that analcime replaces almost the entire amount of light-coloured minerals.

In a few cases the analcime occurs in a very peculiar manner building large icositetrahedra sometimes attaining 12 centimeters in diameter and appearing as big knots in the schistose rock. The icositetrahedra have been analyzed by Dr. Jul. Petersen with the following results:

*Analysis of pseudo-leucite (?) of ægirine-lujavrite.*

| | Per cent. |
|---|---|
| $SiO_2$ | 51·4 |
| $Al_2O_3$ | 25.1 |
| $Na_2O$ | 14.3 |
| $K_2O$ | tr. |
| $H_2O$ | 8·7 |
| | 99.5 |

The composition is that of an ordinary, slightly altered analcime. Between crossed nicols this analcime shows the usual 'eudnophitic' birefringence. It contains numerous minute needles of ægirine and arfvedsonite crowded in the central part of the crystals. Dr. Steenstrup who, in 1888, observed the icositetrahedra in the lujavrite in several places both on the northern and on the southern side of Tunugdliarfik held them to be leucite or altered leucite. Indeed, as they behave like phenocrysts it seems very unlikely that they are primary analcime-crystals, though the crystallographic orientation as indicated by the cleavage corresponds with the icositetrahedral form. It is probable, therefore, that they are pseudomorphs replacing original phenocrysts of leucite or some unknown mineral.

*Structure.* — Although the ægirine-lujavrite as shown by the mode of occurrence has crystallized under abyssal conditions its structure is very different from that of ordinary abyssal rocks. The accompanying microdrawing (Fig. 17) will give a general idea of the principal features. In the first place it is to be noticed that the minerals of this rock do not show the pronounced sequence of crystallization characterizing the typical abyssal rocks: with the exception of the large poikilitic pseudo-phenocrysts of arfvedsonite, which have evidently been the last to crystallize, all the other minerals exhibit a marked tendency towards idiomorphic development. The most peculiar structural features, however, are the schistosity of the rock and the relatively small size of grain. It is true that varieties are also found which are almost devoid of schistosity; in such cases the size of the grain is invariably much greater than in the common variety of the rock: the ægirine-prisms attain a length of 5 or 10 millimeters and a thickness of 2 or 3 millimeters. But such more or less massive varieties are of rare occurrence and are always very subordinate: the ordinary ægirine-lujavrite of the Ilimausak batholite is a rather uniformly fine-grained and schistose rock. That the schistosity has not been superimposed upon the lujavrite by mechanical movements after the consolidation, is shown by the large arfvedsonite-anhedra being entirely uninfluenced and the schistose structure, therefore, is essentially a flow-structure produced by fluxional movements operating during the earlier stages of the consolidation-process but ceasing before the rock had entirely solidified. The question connected with the origin of this structure will be considered more fully in the last chapter of this report.

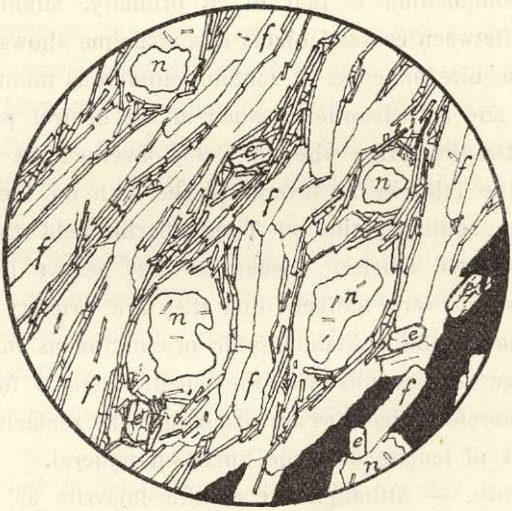

Fig. 17. Ægirine-lujavrite, × 20.

Showing felspar *(f)*, eudialyte *(e)*, and nepheline *(n)*, imbedded in a felt-like aggregate of ægirine-needles. The white areas surrounding the nepheline are analcime; the black area on the right is a portion of a poikilitic anhedron of arfvedsonite. The felspars are microcline and albite in separate crystals.

*Chemical composition.* — Three varieties of the ægirine-lujavrite have been selected for examination. The results are given in the table on the following page. The first analysis (No. **8**) refers to a specimen of which the only felspathic constituent is microcline (as far as observed in the slices); it is possible, however, that the rock may locally contain albite and that the absence of this mineral in the slices may be casual or due to its conversion into analcime. The total amount of analcime in this rock is small and the relatively high content of water is mainly due to the fact that hydronephelite largely replaces the nepheline.

The specimen of which an analysis is given in No. **9** differs from the preceding in the proportion of felspars, albite being the dominant felspar while microcline occurs subordinately. Arfvedsonite is rather scarce and has partly been converted into acmite. Analcime is almost absent, but the outer zone of the nepheline-crystals has been transformed into sodalite, and the interior has partly changed into hydronephelite.

The analysis No. **10** shows the composition of an ægirine-lujavrite in an advanced state of zeolitization. The ægirine is intact but the great majority of the light-coloured minerals has been replaced by analcime. In each slice there may be found areas where only ægirine and analcime are seen within the field of the microscope. Such areas at first sight give the impression that the ægirine-needles are imbedded in a colourless base. Upon closer inspection, however, the contours of the original crystals of felspar, nepheline, and eudialyte are seen to be indicated by the arrangement of the ægirine-needles, and in other parts of the same slices remnants of these minerals may be found.

A comparison of the figures given in the table will show that the analyzed varieties are all of the same chemical type. The differences in the proportion between soda and potash, in

*Analyses of ægirine-lujavrites.*

| | 8 | 9 | 10 | A | B | C | D |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 53·74 | 53·44 | 50·72 | 53·50 | 53·68 | 52·35 | 51·35 |
| $TiO_2$ | ·50[1] | ·30 | 2·84 | ·86 | 1·35 | ·59 | 2·75 |
| $ZrO_2$ | 1·63 | 1·00 | | none | | ·39 | ·54 |
| $Al_2O_3$ | 14·02 | 18·64 | 15·45 | 16·44 | 18·42 | 14·11 | 11·45 |
| $Fe_2O_3$ | 10·63 | 9·38 | 11·82 | 8·72 | 5·91 | 7·98 | 9·40 |
| $FeO$ | 1·71 | ·86 | ·80 | 1·48 | 2·57 | 2·17 | 2·41 |
| $MnO$ | ·36 | ·10 | ·31 | ·47 | ·75 | ·62 | 1·25 |
| $MgO$ | trace | none | ·13 | 1·05 | ·88 | ·66 | ·54 |
| $CaO$ | 1·18 | ·79 | ·14 | 1·50 | 2·05 | 4·65 | 3·27 |
| $Na_2O$ | 9·02 | 12·10 | 10·83 | 9·98 | 9·46 | 9·30 | 10·80 |
| $K_2O$ | 4·77 | 2·43 | 2·94 | 4·58 | 4·92 | 2·78 | 2·52 |
| $H_2O$ above 110° | 3·40 | 1·12 | 4·66 | 1·76 | ·89 | 3·20 | 3·20 |
| $H_2O$ at 110° | | ·34 | | | | | |
| Cl | | ·12 | | | | | |
| $P_2O_5$ | none | none | none | | | | |
| | | 100·62 | | | | | |
| Cl = O | | ·03 | | | | | |
| Total | 100·96 | 100·59 | 100·64 | 100·34 | 100·90 | 100·30[2] | 99·48 |
| Sp. gr. | 2·67[3] | 2·834 | 2·70[3] | | | | |

**8.** Ægirine-lujavrite, Laxefjæld, Kangerdluarsuk, S. Greenland. N. V. Ussing, analyst.

**9.** Ægirine-lujavrite, Tupersuatsiak, S. Greenland. C. Winther, analyst.

**10.** Ægirine-lujavrite, S. Siorarsuit, S. Greenland. C. Detlefsen, analyst.

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[1] Determination by Dr. C. Winther.

[2] Including 1·50 per cent. $CO_2$.

[3] Determinations by Dr. K. J. V. Steenstrup.

A. Lujavrite, rich in ægirine, Angwundas, Lujavr-Urt, Kola. Z. Zilliacus, analyst.[1]

B. Eudialyte-lujavrite, Tsutsknjun, Lujavr-Urt, Kola. W. Petersson, analyst[1].

C and D. Lujavrite, Pilandsberg, Transvaal. F. Pisani, analyst[2].

the content of water etc. agree with the results of the microscopical examination. The very low amount of lime proves that the ægirine and the eudialyte of this rock are much poorer in lime than the varieties of ægirine and eudialyte which have been analyzed hitherto. Indeed it must be supposed that the ægirine of this rock has a composition which approaches that of the pure acmite-silicate $NaFeSi_2O_6$. On this assumption it is found by calculation that the Greenlandic lujavrites, of which the composition is given in No.s **8**, **9**, and **10** of the table, contain respectively 31, 27, and 34 per cent. of ægirine. The rock, thus, has a pronounced melanocratic character.

For the sake of comparison a number of analyses of other typical lujavrites, two from Kola and two from Transvaal, are included in the table and it will be seen that they are all very much like the Greenlandic rock.

*Contact-facies of ægirine lujavrite.* — As before mentioned the ægirine-lujavrite has a distinctly marked endomorphic contact-facies where it borders upon the rocks of the volcanic series. Specimens of this contact-modification, taken in the mountain-slope northeast of Nunarsuatsiak, about 300 meters above the sea-level, are of a grayish-green dense appearance and dotted with numerous small prisms of arfvedsonite which attain dimensions of 3 millimeters by 0·5 millimeters. As proved by the microscopical examination this rock may be characterized

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[1] W. Ramsay, Das Nephelinsyenitgebiet auf der Halbinsel Kola II. Fennia XV, No. 2, p. 16 (1899).

[2] H. A. Brouwer, Sur certaines lujavrites du Pilandsberg. Comptes rendus, nov. 29th, 1909.

as an exceedingly fine-grained variety of ægirine-lujavrite: in the contact-modification the ægirine-needles reach a length of not more than 0·2 millimeters. In the specimens examined the light-coloured minerals are entirely replaced by analcime, but the contours of the original crystals of felspar and nepheline are clearly indicated by the arrangement of the ægirine-needles.

Contact phenomena of another kind pointing to a much slower rate of cooling are seen at the eastern boundary of the lujavrite, between Agpat and Kitdlavat. Here the ægirine-lujavrite borders upon Algonkian granite, the contact-plane is vertical, and the size of grain is seen to keep constant or even to increase on approaching the granite. Nearest to the contact the lujavrite is traversed by a large number of pegmatitic veins.

### *Arfvedsonite-lujavrite.*

This rock appears dark grayish-black; it has a moderately fine grain and a somewhat schistose structure. With the naked eye or with the lens it is seen to consist of arfvedsonite, felspar, nepheline, and eudialyte. The arfvedsonite is the chief constituent and occurs in small glittering black needles or prisms arranged parallel to the schistose structure. The light-coloured minerals are of the same general habit as in the ægirine-lujavrite. In contradistinction from the latter rock the arfvedsonite-lujavrite is tolerably even-grained and never shows a porphyritic or pseudo-porphyritic appearance.

*Microscopic characters.* — Under the microscope the main constituents are seen to be arfvedsonite, microcline, albite, nepheline, and eudialyte. Ægirine and sodalite are present in some specimens but in others one of these minerals or both may he entirely absent. Locally analcime is very abundant as a secondary product replacing felspar and nepheline, not unfrequently spreustein is also present. The number of occasional accessories is considerably greater than in the ægirine-lujavrite; they will be mentioned below.

The *felspars* are microcline and albite in separate crystals similar to those of the ægirine-lujavrite. Perthitic intergrowths do not occur. In some specimens of the rock both kinds of felspar-crystals are present in about equal amounts, other specimens abound in microcline, others again contain chiefly albite. The felspars are in many cases fresh and transparent, in others they have partly been altered to analcime.

The *nepheline* and the *eudialyte* of this rock are quite similar to those of the ægirine-lujavrite and show the same alterations. *Sodalite* when present as a primary constituent, is in rounded grains of the same size as the nepheline-crystals. *Ægirine* in needles similar to those of the ægirine-lujavrite is seen in many specimens.

The *arfvedsonite* of the arfvedsonite-lujavrite is in elongated prisms averaging about one millimeter in length. They do not show any good crystal outlines but are mostly allotriomorphic. Ortopinacoidal twinning is often observed. The absorption-tints are slightly more greenish than those of the typical arfvedsonite. The pleochroism-scheme is as follows: —

$\mathfrak{a}$ very dark bluish green,
$\mathfrak{b}$ deep bluish green (with a faint grayish tone),
$\mathfrak{c}$ light brownish green.

In sections parallel to $b$ (010) the angle of extinction $c : \mathfrak{a}$ is found to be 10 or 12 degrees[1]. Not unfrequently the arfvedsonite has been partly altered to acmite as described above (see p. 137).

A considerable number of occasional accessories have been detected in the arvedsonite-lujavrite, but most of them are present only in a few and small crystals, A dark brown *biotite,* small crystals or grains of *sphalerite* and *fluorite,* and small cubes of *pyrochlore* (?) are not seldom seen, but their

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[1] Meddelelser om Grønland XIV, p. 196 (1894).

occurring offers nothing of special interest. *Schizolite* is found in several rock-specimens from Kangerdluarsuk and Tugup Agtakôrfia. This mineral is in colourless crystals less than one millimeter long. It is more idiomorphic than the arfvedsonite and less idiomorphic than the felspar. It has been identified by the following observations. The crystals are of prismatic habit and without terminations. There are two distinct cleavages parallel to the direction of elongation of the crystals, and the axis of minimum optic elasticity 𝔠 coincides with (or is very near to) the intersection of the cleavages. In cross-sections the angle between the cleavage-traces is found to be about 85°. The bisectrix 𝔞 lies in the obtuse angle between the cleavage-planes and is 15° or 20° from one of them. The 𝔠-axis is acute bisectrix, and the apparent optic axial angle is about 90°. All these characters agree with those of the schizolite[1]. — *Ainigmatite* is very rarely seen in the arfvedsonite-lujavrite; it is in short prisms. More frequently minute crystals of an unknown, deep brownish red mineral are found; this is strongly pleochroic and bears some resemblance to the rhönite of SOLGER[2] but it differs in the absorption-tints. — *Erikite* has been observed in specimens of arfvedsonite-lujavrite from South Siorarsuit. This substance as described by BÖGGILD[3] occurs in large well-defined crystals in the pegmatite veins of the arfvedsonite-lujavrite in several places near Nunarsuatsiak. In thin slices it is seen to be a pseudomorph consisting of an intergrowth of a yellow mineral in minute grains and a zeolite (hydronephelite). In the rock-slices from S. Siorarsuit the erikite-crystals only attain half a millimeter in diameter but their micro-structure is identical with that of the large crystals. The yellow mineral of these pseudomorphs resembles *monazite*,

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[1] O. B. BØGGILD, On some minerals etc. (Erikite and Schizolite). Meddelelser om Grønland XXVI. p. 121 (1903).

[2] Neues Jahrbuch für Mineralogie, Beilage-Band XXIV, 1907, p. 475.

[3] Meddelelser om Grønland XXVI, p. 93 (1881).

but owing to the very small dimensions of the grains I have not been able to identify them with certainty[1]. — The slices of the specimens from Lille Elv (the same specimens of which a chemical analysis is given below) contain grains of a somewhat altered mineral which bears some resemblance to the olivine when in an advanced state of serpentinization (with mesh-structure'); the mean index of refraction, however, seems to be a little lower than that of olivine. — Finally it may be mentioned that *zircon* has been observed in one specimen of this rock (from Nunasarnak); it is in minute grains crowded in

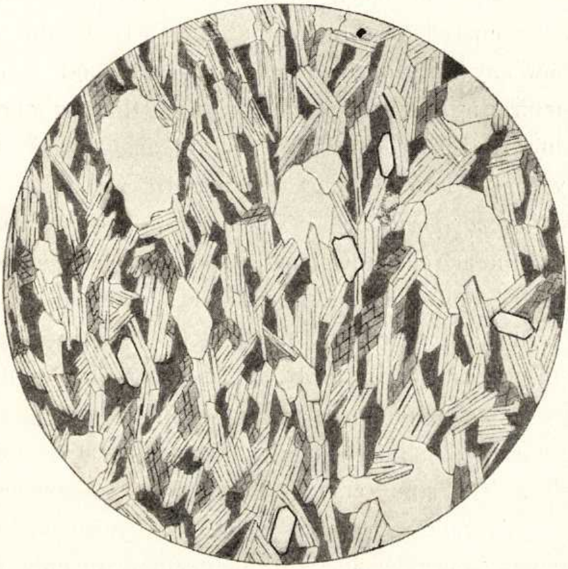

Fig. 18. **Arfvedsonite-lujavrite, Nunasarnak**; × 20.
Showing nepheline (white), felspar (light gray), eudialyte (small and well-defined crystals), and arfvedsonite (longitudinal sections black and transverse sections dark gray).

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[1] The chemical composition of the erikite (Meddeleser om Grønland XXVI, p. 104) is approximately that of a mixture of two thirds of monazite and one third of hydronephelite.

small lumps which have probably originated by magmatic resorption of eudialyte[1].

*Structure.* — The structure of the arfvedsonite lujavrite (see Fig. 18) is of the trachytoid type owing to the bath-like form of the felspar, and there is a more or less pronounced tendency toward panidiomorphic development. The typical varieties of this rock show a conspicuous flow-structure and a corresponding schistosity. The felspar-crystals are not seldom seen to be curved or broken but the arfvedsonite columns never show any sign of deformation. On the other hand the flow-structure is not so pronounced as that of the typical ægirine-lujavrite described above, and in many places the rock gradually passes into more or less massive varieties.

*Chemical composition.* — To illustrate the chemical composition of the arfvedsonite-lujavrite two typical specimens have been analyzed and the results are shown below in columns **11** and **12**. The first specimen, of which an analysis is given in **11**, has been taken at Lille Elv, Kangerdluarsuk. In the slices the mineral composition is seen to be the following: arfvedsonite, ægirine, albite, microcline, nepheline, sodalite, and minor accessories. The albite-crystals are present in greater amount than the microcline-crystals; ægirine is relatively abundant while zeolites (analcime and hydronephelite) are only found in small quantities. The second analysis (**12**) is of a specimen from Nunasarnak. Externally both specimens are alike, but upon microscopical examination the latter specimen proves richer in arfvedsonite and poorer in ægirine.

For purposes of comparison the mean composition of the analyses of the Greenlandic ægirine-lujavrite (analyses No. 8, 9, and 10, see p. 168) is given in **A**, and it will be seen that the chemical composition of the arfvedsonite-lujavrite is of the same general character as that of the ægirine-lujavrite but

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[1] Meddelelser om Grønland XIV, p. 172 (1894).

*Analyses of arfvedsonite-lujavrite and ægirine-lujavrite.*

| | 11 | 12 | A |
|---|---|---|---|
| $SiO_2$ | 53·01 | 56·64 | 52.63 |
| $TiO_2$ | ·33 | ·30 | 2·09 |
| $ZrO_2$ | ·65 | — | |
| $Al_2O_3$ | 15·33 | 16·10 | 16·04 |
| $Fe_2O_3$ | 9·14 | 4·90 | 10·61 |
| $FeO$ | 4·44 | 6·86 | 1·12 |
| $MnO$ | ·13 | ·57 | ·26 |
| $MgO$ | ·10 | none | ·04 |
| $CaO$ | ·67 | ·39 | ·70 |
| $Na_2O$ | 11·86 | 11·50 | 10·61 |
| $K_2O$ | 2·60 | 1·00 | 3·38 |
| $H_2O$ above 110° | 1·88 | 1·54 | 3·17 |
| $H_2O$ at 110° | ·20 | ·04 | |
| Cl | ·23 | trace | ·12 |
| $SO_3$ | none | none | none |
| $P_2O_5$ | trace | none | none |
| | 100·57 | | 100·77 |
| Cl = O | ·05 | | ·03 |
| Total | 100·52 | 100·29 [1] | 100·74 |
| Sp. gr. | 2·844 | 2·79 [2] | 2·73 [2] |

**11.** Arfvedsonite-lujavrite, Lille Elv, Kangerdluarsuk, S. Greenland. C. Winther, analyst.

**12.** Arfvedsonite-lujavrite, Nunasarnak, Tunugdliarfik, S. Greenland. Chr. Christensen, analyst.

A. Ægirine-lujavrite, S. Greenland. Mean of analyses No.s 8, 9, and 10 (see p. 168).

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[1] Including 0·45 $Nb_2O_5$.

[2] Determintaions by Dr. K. J. V. Steenstrup.

that the latter rock has a higher ferric oxide and lower ferrous oxide.

*Contact facies of arfvedsonite-lujavrite.* — At Nunasarnak the arfvedsonite-lujavrite passes into a peculiar contact modification directly bordering on the sandstone. This contact facies is a very fine-grained or dense rock of a conspicuous banded and spotted appearance as described p. 74. Upon microscopical examination it proves to be of a more acid character than the typical lujavrite: nepheline occurs only in small amount and in many specimens it is entirely absent while small allotriomorphic anhedra of quartz fill the interstices between the felspar-laths. The white bands of this contact rock are almost exclusively made up of lath-shaped crystals of albite, sometimes intermingled with microcline-laths, and there is a pronounced parallel arrangement of the crystals. The green spots are large anhedra of ægirine which enclose a great number of felspar-crystals in a poikilitical manner. The black bands of the contact rock have the composition and structure of a very fine-grained arfvedsonite-lujavrite devoid of nepheline, and in some cases they are quartz-bearing. Minute patches of a yellowish red mineral, probably an iron-oxide, are frequently found in all varieties of this rock. Schizolite has been observed in one (nepheline-bearing) specimen. Of special interest is the occurrence of a mineral, which is probably corundum, in an apophysis in the sandstone. This apophysis is of the white variety with green spots described above. The mineral which is supposed to be corundum is in small columns without distinct crystallographic form and about 0·5 millimeter long by 0·1 millimeter broad. They are colourless and optically uniaxial with a low birefringence of negative character; the mean index of refraction is like that of ægirine.

## KAKORTOKITE.

The rock-type which has here been termed kakortokite is much like lujavrite in chemical as well as in mineral composition, but it differs in the structure which is coarse-grained and of the 'foyaitic' (W. C. Brögger) or 'trachytoid' type. The felspar-crystals are of tabular habit and as a rule they show a conspicuous parallel arrangement; the black minerals are developed in broad anhedra or in stout prisms which are not of very good crystal form. A noteworthy peculiarity of this rock is the abundance of eudialyte in idiomorphic crystals, But the most striking feature is the strong tendency to differentiation in bands or sheets of different colour and composition.

The kakortokite composes the mountain plateau of Kringlerne (see Plate IX). It attains its maximum thickness, about 400 meters, in the southern and southwestern parts of the plateau. Towards the northeast the kakortokite-body becomes gradually thinner and north of Laksefjæld it disappears. It is underlain by the lujavrite, and at its northern end it is also covered by this rock. The macroscopic appearance of the alternating white, red, and black kakortokite-sheets has been described in the preceding chapter (see p. 43).

*Microscopic characters.* — The minerals composing this rock are: eudialyte, alkali-felspar, nepheline, arfvedsonite, and ægirine. In many specimens there is a small amount of sodalite present. Other occasional accessories are ainigmatite, biotite, rinkite, fluorite, and rarely epistolite; zeolites occur as secondary products. The different sheets of the kakortokite are all alike in qualitative mineral composition the difference being in the relative amounts of the main constituents.

*Eudialyte* in idiomorphic crystals of the usual form is abundantly present in all varieties of the kakortokite. In the red kakortokite its amount is even greater than that of any other constituent. The diameter of the crystals averages about two millimeters. Macroscopically they are of a bright red colour, but in thin slices they are almost colourless. Between crossed nicols the crystal-sections frequently show an irregular 'hour-glass structure' or more rarely a zonary banding due to the alternation of moderately birefringent areas with others of a very weak birefringence.

While in many specimens of the kakortokite the eudialyte-crystals are clear and unaltered, in others a partial or complete conversion has taken place giving rise to pseudomorphs of a dull brown appearance. Under the microscope the pseudomorphs are seen to consist of an aggregate of catapleiite, acmite, and zeolites; sometimes also felspar and a little green mica are present. This conversion of the eudialyte is probably due to pneumatolytical effects.

*Felspar* is the chief constituent of the 'white' variety of the kakortokite and is abundantly present in the other varieties too. It is in tolerably idiomorphic crystals of rather thin tabular habit parallel to *b* (010). There are two kinds: large ones and small ones. The latter are qualitatively quite subordinate and are sometimes entirely absent. *The large felspar-crystals* average about one millimeter in thickness (varying from 0·5 to 1·7 millimeter), while the length is about ten times the thickness. They are often twinned according to the Carlsbad law. When examined between crossed nicols they are seen to be of a microperthitic structure and to consist of microcline and albite; the general appearance is much like that of the felspars of the sodalite-foyaite (see Fig. 14, p. 135). In some specimens of the kakortokite the felspar crystals contain a greater amount of microcline than of albite, in others the albite prevails. Very often the marginal portion of each crystal consists of pure albite. The most common inclusions in the felspar are minute needles of ægirine; besides, the crystals are generally a little clouded with kaolin. — *The small felspar-crystals* attain a length of only one-fourth or half a millimeter. They never show perthitic intergrowths, but the majority of them are pure albite while a few are pure microcline. As a rule they are heaped together in small clusters or are arranged in definite short trails; very often they are enclosed within the arfvedsonite-anhedra.

*Nepheline* is very abundant in clear crystals or grains of the usual form, averaging two millimeters in diameter. It is a little less idiomorphic than the felspar. As a rule it contains numerous fluid-pores and flakes of arfvedsonite; less frequently ægirine-needles occur as inclusions. In many cases the nepheline has been partially converted into sodalite.

*Ægirine* and *arfvedsonite* are usually present in about equal amounts and are always very abundant, all varieties of the kakortokite showing a melanocratic character. In the black sheets of this rock the total amount of ægirine and arfvedsonite is 65 per cent. In the white variety of the kakortokite and in the red one both minerals are allotriomorphic and largely interstitial between the light-coloured constituents. In the black kakortokite, too, they are less idiomorphic than the eudialyte, the felspar, and the nepheline; nevertheless both ægirine and arfvedsonite show a strong tendency towards idiomorphic development in stout prisms, which attain a length of one or two centimeters. In several cases the arfvedsonite has been partially converted into acmite-aggregates of the usual appearance (see p. 137).

*Sodalite* rarely occurs in rough dodecahedral crystals. More frequently it appears in formless masses filling small interstices between the felspar-crystals. As shown by the direction of the cleavage-cracks this interstitial sodalite often belongs to the same crystallographic individuals as the sodalite occurring as an alteration-product of the nepheline. It is probable therefore that the conversion of nepheline into sodalite has taken place during the final stages of the consolidation-process.

A brown *biotite* has been observed in almost all the slices; it is in scattered small scales or more rarely in elongated small prisms, and its total amount is very small. *Ainigmatite* is sometimes rather abundant, but in many specimens it is entirely absent. It has not been found in the black variety of the rock. *Rinkite* which is always accompanied by *fluorite* often occurs in small amount. *Epistolite*[1] has been observed in the slices of the analyzed specimen of the red kakortokite (analysis No. 14). It is in aggregates of small scales not exceeding 0·1 millimeter in length. This mineral is colourless and resembles muscovite but differs in the angle of extinction ($a : \mathfrak{c} =$ ca. 7°). *Analcime* is rare; only in the black variety of the rock it has occasionally been found in noteworthy amount filling small interstices between the other minerals. *Hydronephelite* and *natrolite* are common alteration-products of nepheline and sodalite.

*Structure.* — As set forth more fully in the preceding chapter the entire kakortokite-mass consists of a large number of sheets of alternating white (or gray), red, and black colour. In the 'white' sheets the prevailing minerals are felspar and nepheline, in the red sheets the eudialyte is the chief constituent, and the black ones abound in ægirine and arfvedsonite. All the sheets are coarse-grained, markedly miarolitic, and of a pronounced foyaitic structure due to the tabular form of the felspar crystals. A less conspicuous, though very peculiar, feature is the frequent occurrence of a subordinate amount of very small felspar-crystals which are not connected with the ordinary large felspar-crystals by any kind of transitional forms. These small felspar-crystals are commonly included in the large arfvedsonite-anhedra, and their formation, accordingly is prior to the final consolidation of the rock. Perhaps they must be regarded as fragments detached from the large felspars by

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[1] See O. B. Böggild, Meddelelser om Grønland XXIV, p. 187 (1900).

some kind of mechanical or chemical process, perhaps also they represent a second generation of felspar. The first assumption is supported by their mode of occurrence since they are commonly found in small clusters which are abundantly present in some slices (see Fig. 19) but are absent in others. It is true that the large crystals are of a perthitic structure while as a rule the small ones are pure albite. But this, apparently, is no serious objection since the large felspar-crystals often have an outer coating of albite. Moreover it is found that the boundary of the large felspar-crystals is very irregular where the albite-coating is wanting, and not seldom crystals are observed showing a half-detached albite-shell, a small stripe of arfvedsonite being intercalated between the perthitic nucleus and the albite-coating.

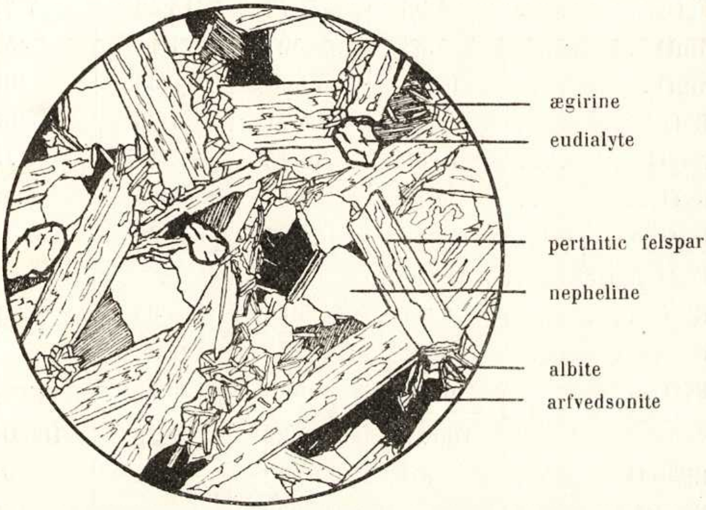

Fig. 19. Kakortokite ('white' variety). Kringlerne. × 8.

While in the white variety of the kakortokite the black minerals are interstitial and have evidently crystallized later than the light-coloured ones, the black kakortokite does not show any marked sequence of crystallization but all the con-

*Analyses of kakortokites.*

| | 13 | 14 | 15 | A |
|---|---|---|---|---|
| $SiO_2$ . . . . . . . . . . | 51·62 | 49·39 | 48·90 | 51·82 |
| $TiO_2$ . . . . . . . . . . | ·44 | ·49 | n. d. | ·35 |
| $ZrO_2$ . . . . . . . . . . | 1·70 | 4·89 | 1·96[1] | 2·05 |
| $Al_2O_3$ . . . . . . . . . | 15·63 | 10·39 | 7·85 | 13·68 |
| $Fe_2O_3$ . . . . . . . . . | 6·06 | 4·31 | 11·46 | 7·32 |
| FeO . . . . . . . . . . . | 4·98 | 7·72 | 13·32 | 7·27 |
| MnO . . . . . . . . . . . | .33 | ·97 | 1·11 | ·57 |
| MgO . . . . . . . . . . . | trace | none | ·38 | ·09 |
| CaO . . . . . . . . . . . | 3·13 | 5·11 | 1·95 | 3·06 |
| $Na_2O$ . . . . . . . . . | 10·09 | 11·45 | 7·40 | 9·75 |
| $K_2O$ . . . . . . . . . . | 4·19 | 2·62 | 3·23 | 3·92 |
| $H_2O$ above 110° . . | 2·12 | 1·24 | 1·80 | — |
| $H_2O$ at 110° . . . . | — | ·22 | — | — |
| Cl . . . . . . . . . . . . | ·17 | ·51 | ·03 | ·16 |
| F . . . . . . . . . . . . . | n. d. | ·75 | n. d. | — |
| $P_2O_5$ . . . . . . . . . | none | none | none | — |
| | 100·46 | 100·36[2] | 99·39 | 100.04 |
| Cl = O . . . . . . . . | ·04 | ·12 | ·01 | ·04 |
| F = O . . . . . . . . | — | ·32 | — | — |
| Total . . . | 100·42 | 99·92[2] | 99·38 | 100·00 |
| Sp. gr. . . . | 2·76[3] | 2·85[3] | 3·12[3] | |

**13.** Kakortokite, white sheet. Kringlerne, Kangerdluarsuk, S. Greenland. N. V. Ussing, analyst[4].

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[1] $ZrO_2 + TiO_2$. Probably titanic acid is very low since no ainigmatite is found in the specimen.

[2] Including 0·30 $Nb_2O_5$.

[3] Determinations by Dr. Steenstrup.

[4] The analysis No. 13 has previously been published by H. Rosenbusch (Elemente der Gesteinslehre, 1898, p. 126). As given above the percentage of CaO has been corrected, and determinations of $TiO_2$ and Cl have been added. For the latter determinations the author is indebted to Dr. Winther.

**14.** Kakortokite, red sheet, Kringlerne, Kangerdluarsuk, S. Greenland. Chr. Christensen, analyst.

**15.** Kakortokite, black sheet, Kringlerne, Kangerdluarsuk, S. Greenland. C. Detlefsen, analyst.

A. Calculated mean composition of kakortokite (see p. 184).

stituent minerals of this rock show a strong tendency towards idiomorphic development.

*Chemical composition.* — The analyses which have been made of the different varieties of the kakortokite are given in the above table (see p. 182). No. **13** shows the composition of a specimen of the white sheets; No. **14** refers to a specimen of the red sheets; and No. **15** to one of the black sheets. It will be seen on comparison that the composition of the white sheets of the kakortokite is much like that of the lujavrites (see analyses No.s 11 and 12, p. 175). The red and black sheets show a chemical composition which is very different from that of other known rocks. The salient feature of the red kakortokite (No. **14**) is the extraordinarily high zirconia which indicates that eudialyte makes up about one-third of this rock. The distinctive characters of the black kakortokite (No. **15**) are the very high iron combined with high alkalies and low alumina; this combination is the chemical expression of the peculiar fact that in spite of its extremely melanocratic character the rock is entirely devoid of iron-ore.

As shown by the analyses the white, red, and black sheets of the kakortokite are so different in chemical composition that they would have to be classified under very different heads in any quantitative system of rock-classification. Moreover, since the individual sheets are of a large areal extention and of no inconsiderable thickness, some of them even exceeding ten meters in thickness, and since each of them shows a tolerably constant structure and mineral composition throughout its entire mass, they cannot be regarded as 'Schlieren' but have the character of true rocks. It might, therefore, be natural to give to each of the three kinds of sheets a distinct name of its own. The reasons why it has here been preferred to introduce one term comprising all the sheets are the following: — (1) The entire series of about one hundred white, red, and black sheets constitutes a rock-body which must, for geological reasons, be regarded as a unit and needs a name of its own. (2) There are no indications whatever that three kinds of magma corresponding with the three kinds of kakortokite-sheets have existed at any time. As it will be shown in the last chapter it must be assumed that there has been only one kakortokitic magma which was differentiated in place during the process of crystallization. (3) As previously mentioned the sheeted kakortokite-body passes into an unsheeted kakortokite both at its upper boundary and at the northeastern end, and this undifferentiated kakortokite is of a mineral composition which is intermediate between the three kinds of sheets.

In A of the above table (p. 182) is given the supposed mean composition of the kakortokite. In order to obtain this the three analyses of kakortokites have been calculated to 100 per cent. omitting $H_2O$, F, and $Nb_2O_5$ (see table at the end of the summary). From the figures obtained in this way the mean composition has been calculated under the assumption that the total thickness of the white sheets is three times as great as the total thickness of the black sheets, and nine times as great as that of the red ones. This assumption, however, is somewhat arbitrary since the observations relating to the thicknesses of the sheets are very incomplete (see p. 46).

# AUGITE-SYENITE.

The augite-syenite of the Ilimausak region is an alkali-syenite related to the Larvik-type of the Christiania district[1]. It appears as a zone, only a few hundred meters wide, along the southwestern, southern, and southeastern margins of the igneous complex.

In general appearance the rock shows only very small local variations. It is a coarse- or medium-grained, somewhat weathered rock of grayish-white colour in which the dark-coloured minerals form conspicuous spots sometimes attaining a diameter of 1 centimeter. There are no traces of a parallel arrangement of the constituent minerals. The main component, the white felspar, does not show the lenticular form characteristic of the felspar of the Larvik-type but occurs in irregular grains without any definite shape or elongation; in some cases, however, it shows a strong tendency towards a thick tabular development. The common variety of the rock occurs irregularly intermingled with the type containing the tabular felspars and connected with it by transitions.

*Microscopic characters.* — Under the microscope the mineral composition proves somewhat variable. In the variety which is here considered as typical and is found represented by specimens from all the chief localities, the main components are as follows: felspar (soda-orthoclase), augite of pale violet-brown colour, and olivine. In smaller amount the rock contains: nepheline, green hornblende, brown hornblende (barkevikite), biotite, iron-ore, and apatite. In other varieties of the rock some of these minerals may be absent while others may

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[1] W. C. Brögger, Die silurischen Etagen 2 und 3. Kristiania 1882, p. 256, aud Zeitschrift für Krystallographie XVI, 1890, p. 30. — There is also a noteworthy agreement between the Ilimausak augite-syenite and the 'larvikite, type II' from Madagascar (see A. Lacroix, Les roches alcalines, 1902, p. 103).

occur, viz: zircon, ainigmatite (?), ægirine-augite, catophorite-like hornblende, arfvedsonite, cryptoperthite, microperthite, and quartz.

The *apatite*, which is almost entirely wanting in the nepheline-syenites and lujavrites of this region, occurs invariably and in relative abundance in the augite-syenite, partly as small and slender prisms enclosed in the augite, partly in larger grains and stout crystals that may attain a diameter of one millimeter and are irregularly dispersed in the rock. Iron-ore is a constant component; it is rather frequent, in crystals and irregular laps. It is sometimes accompanied by small titanite-like grains and seems to be highly titan-bearing. An ainigmatite-like mineral has been found as a subordinate constituent in only two specimens of olivine-bearing augite-syenite.

*Olivine* is abundant in the main type of the rock but in other varieties it may be entirely absent. It is quite fresh and has the form of grains or very imperfect crystals that may attain a diameter of $^1/_2$ centimeter. In thin slices the mineral is colourless or of a faint yellowish-green. Sometimes it is filled with close-lying black lines due to linear-shaped inclusions imbedded parallel to (100) and elongated parallel to the crystallographic $b$-axis. These inclusions are metallic and, where they are very thin, brownish and translucent. Probably they consist of ilmenite. They produce a schiller-structure of similar but much coarser kind than that observed in the pyroxenes.

*Biotite* is an almost constant but quite subordinate constituent. It is strongly pleochroic with absorption-tints from pale yellow to almost black.

The commonest pyroxene in the augite-syenite is a faintly coloured augite characterized by an extinction-angle $c : \mathfrak{c}$ of about 42°. The pleochroism is not very pronounced the absorption-tints varying from quite pale brownish-violet to somewhat strong brown-violet, less frequently the mineral is faintly greenish without pleochroism. Locally it may be filled with extremely fine and close-lying short, black lines arranged in two directions in the usual manner (parallel to (100) and (001)). The augite grains are quite allotriomorphic and of a similar or somewhat larger size than the olivine. Many of them show a narrow green marginal zone connected with the interior by even transition. In the green marginal zone the extinction angle $c:\mathfrak{c}$ increases to about 50°, indicating a transition to ægirine-augite. In several specimens of the augite-syenite the light-coloured augite has been replaced by a more or less strongly green ægirine-augite with extinction angle $c:\mathfrak{a} = 35°$ to 40°. The value of this angle is as usual somewhat greater in the central parts of the crystals than in the marginal zone. The ægirine-augite is especially frequent in those varieties of the rock in which the felspar shows a tendency towards the tabular form. Only rarely it is observed in the same specimens of the rock as the light-coloured augite.

Together with the augite one or several members of the hornblende-group can usually be found as subordinate constituents. In the typical variety of the rock both green and brown hornblende are found, often both in parallel intergrowth with the augite. In sections about parallel with the plane of symmetry (010) the green hornblende shows an extinction angle $c:\mathfrak{c}$ of about 20° and the pleochroism-scheme is as follows: —

$\mathfrak{a}$ light yellowish green
$\mathfrak{b}$ dark brown-green
$\mathfrak{c}$ dark green

The brown hornblende has the same extinction angle and absorption-tints as barkevikite. In other specimens of the augite-syenite a brown or blue-gray catophorite-like hornblende has been found, with varying extinction angle, and together with it a few anhedra of arfvedsonite.

The *felspar* of the typical augite-syenite is a soda-orthoclase. The grains show traces of crystallographic development where they touch augite, hornblende, nepheline, or quartz, but as a rule they are of quite irregular form. The maximum diameter is mostly only 2 or 3 millimeters. The extinction angle in sections perpendicular to the obtuse bisectrix (and thus parallel to (010)) is about 12°. In the same sections the homogeneity is often broken by narrow bands of microperthitic structure extended about parallel to the vertical axis[1]. Other felspar-grains in the same slices show a more or less plain crypto- or microperthitic structure throughout, with the orthoclase and plagioclase areas quite irregularly dispersed in dots or patches. The latter seem to belong to an oligoclase-albite. A closer inspection is rendered difficult by the felspars being usually rather weathered. The degree of weathering seems to bear a certain proportion to the degree of differentiation which the felspars have undergone: the fresher the felspars, the more the structure approaches the homogeneous soda-orthoclase. — In the variety of augite-syenite where the felspar-crystals show a tendency to the tabular shape, their dimensions are as a rule greater (length ½ to 1 centimeter) and the structure more variable: in some cases soda-orthoclase, in others chiefly cryptoperthite, in others again microperthite with fine and irregularly dotted structure or with a tendency to a banded structure parallel to (801).

*Nepheline* is only present in very scant degree in this rock so that in each slice only a few, rather weathered anhedra are seen filling angular interspaces between the felspars. In the specimens of augite-syenite with tabular felspar nepheline is as a rule quite absent.

*Quartz* is found sporadically in a few specimens of the coarse-grained augite-syenite and occurs abundantly in a contact-

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[1] Described in Meddelelser om Grønland XIV (1894), p. 63 and table V, fig. 1.

facies described below. In both cases it is no doubt derived from the absorption of sandstone or granite.

*Structure.* — The most peculiar structural feature is the agglomeration of the femic ferromagnesian minerals which is essentially of the same kind as in the Larvik-type. The pyroxenes and amphiboles are generally arranged like a cover, round a core, consisting now of a single crystal of iron-ore or olivine, now of a small aggregate of crystals of both these minerals and apatite. The augite is generally found nearest the core and surrounded by hornblende in parallel position. The barkevikite is sometimes seen as a narrow band between the iron-ore and the augite, and aggregates of biotite-crystals as a rule surround those areas of iron-ore which are not intergrown with the augite.

*Chemical composition.* — A specimen of the typical augite-syenite, taken at the foot of the Nunasarnausak, on the north coast of Kangerdluarsuk, has been analyzed by Dr. Winther with the following results (No. **16**). For the sake of comparison two analyses of the original Larvik-type from Norway have also been given. As will be seen by the figures the conformity is not as great as might be expected from the similarity in mineral composition, the Greenlandic rock differing from the Norwegian in alumina, ferrous oxide, and alkalies. On the other hand, if the analysis of the augite-syenite is compared with that of the pulaskite (analysis No. 3, see p. 124), a very close conformity between these two rocks will be discovered.

### *Contact facies of augite-syenite.*

*Normal contact facies.* — Where the augite-syenite borders on the old granite, it often shows an endomorphic contact modification which may be characterized as a fine-grained and sometimes rather porphyritic variety of the common augite-syenite. At the immediate contact the rock is in some places — e. g. at the foot of Iviangusat — richer in dark-coloured

*Analyses of augite-syenites.*

| | **16** | A | B |
|---|---|---|---|
| $SiO_2$ | 55·79 | 56·85 | 57·12 |
| $TiO_2$ | 1·81 | — | — |
| $ZrO_2$ | — | — | — |
| $Al_2O_3$ | 15·76 | 21·56 | 21·69 |
| $Fe_2O_3$ | 1·60 | 3·44 | 1·63 |
| $FeO$ | 7·56 | 1·14 | 3·65 |
| $MnO$ | ·14 | — | — |
| $MgO$ | ·41 | ·85 | 1·55 |
| $CaO$ | 3·70 | 5·26 | 4·03 |
| $Na_2O$ | 7·72 | 6·07 | 5·93 |
| $K_2O$ | 4·34 | 3·66 | 3·48 |
| $H_2O$ above 110° | ·18 | ·52 | ·58 |
| $H_2O$ at 110° | ·34 | | |
| Cl | none | | |
| $P_2O_5$ | ·36 | | |
| Total | 99·71 | 99·35 | 99·66 |
| Sp. gr. | 2·766 | | |

**16.** Augite-syenite, N. coast of Kangerdluarsuk, S. Greenland. C. Winther, analyst.

A. Larvikite, Nötterö, Norway. G. Forsberg, analyst[1].

B. Larvikite, Frederiksværn, Norway. G. Forsberg. analyst[1].

minerals and of a rather peculiar structure. It consists of a fine-grained allotriomorphic aggregate of soda-orthoclase with numerous rounded crystals or anhedra of olivine, light gray augite and a little barkevikite; the iron-ore is scattered in small grains throughout the mass so that every crystal of

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[1] W. C. Brögger, Zeitschrift für Krystallographie XVI, 1890, p. 30.

augite or felspar often contains several of the black metallic grains. A dark brown biotite often surrounds the iron-ore grains, and apatite in minute crystals is abundantly dispersed throughout. At the contact with the diabase at Nunasarnausak a fine-grained contact modification of augite-syenite containing the same mineral constituents as the main type of the rock, has also been observed.

*Quartz-bearing contact facies.* — Where the augite-syenite borders on sandstone, as at Nunasarnausak, its border facies, on microscopical examination, invariably proves quartz bearing and often contains this mineral in considerable quantity. The same applies to the apophyses which the angite-syenite sends into the sandstone. The size of grain in the quartz bearing augite-syenite is often rather coarse right up to the contact with the sandstone. When the quartz is only present in smaller quantity it is always interstitial between the felspar crystals and when the rock contains more quartz it also occurs in micrographic intergrowth with the felspar. The other minerals are generally the same as in the normal augite-syenite, with the exception that olivine and barkevikite are always wanting. In one specimen, however, from the southern side of Nunasarnausak, no augitic mineral was found, but a very light brown-green hornblende with a fibrous (uralitic) structure. Here a uralitization of the augite seems to have taken place through the influence of the acid magma[1].

As the augite-syenite only becomes quartz-bearing when in touch with sandstone and not by the contact with granite and diabase, there can be no doubt that augite-syenitic magma has dissolved silica from sandstone. This process has reached its maximum development round the huge sandstone fragments in the augite-syenite at the foot of Iviangusat where the

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[1] Cfr. L. Duparc, Sur l'ouralitisation du pyroxène. Comptes rendus 1907, Nov. 4.

magma has become so completely altered that it has consolidated as a true soda-granite. The occurrence is described in p. 53 and p. 116.

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## NORDMARKITE.

The nordmarkite covers an area of about 12 $km^2$ in the extreme west of the peninsula between Sermilik Fjord and Tunugdliarfik Fjord. It is a coarse-grained, flesh-coloured or grayish-red alkali-syenite. In habit it shows considerable likeness to Brögger's original nordmarkite from the district of Christiania. The macroscopic description is given p. 98.

*Microscopic characters.* — In thin sections under the microscope the minerals seen are apatite, iron-ore, biotite, augite, ægirine-augite, hornblende, felspar, and frequently quartz. Ægirine, arfvedsonite, and ainigmatite have been observed in some specimens of this rock, fluorite only in one specimen. Calcite and brown or black ferruginous material are not seldom found as alteration-products of the ferromagnesian minerals.

*Apatite* is abundantly present in small prisms. *Iron-ore*, in more or less irregular grains is not so abundant as in the augite-syenite. It is mostly magnetite (or titano-magnetite) but small crystals of pyrite may sometimes be found. Where the rock contains quartz in greater quantity, the amount of apatite and iron-ore is diminished.

The *biotite* is strongly pleochroic, the absorption tints varying from a very dark red-brown or greenish-brown to quite pale yellow. It often surrounds the iron-ore and occurs in greatly varying quantities.

*Augite* in rounded grains or allotriomorphic anhedra is rather abundant in some specimens, in others it is scant or absent. It is colourless, pale gray or greenish. In sections parallel to the plane of symmetry (010) the angle of extinction

$c:\mathfrak{c}$ is 42°. It only seldom shows inclusions of the black microlites so common in the augite of the augite-syenite. Sometimes it is accompanied by ægirine-augite. Less frequently ægirine occurs in the nordmarkite and when such is the case the augite is wanting.

*Hornblende* in large quite allotriomorphic anhedra is commonly the predominant dark mineral. In sections parallel to the plane of symmetry (010) the angle of extinction $c:\mathfrak{c}$ has been found to be from 15 to 25°, somewhat different in the different specimens. The absorption tints are rather varying with $\mathfrak{a}$ light brown or yellowish green, while $\mathfrak{b}$ and $\mathfrak{c}$ show dark green, brown or sometimes bluish brown colours. A thin blue marginal zone, in which the angle of extinction $c:\mathfrak{c}$ is a little greater than in the interior, is often seen. In varieties of the rock which are richer in quartz the usual hornblende may be replaced by arfvedsonite. Ainigmatite has only been observed as an occasional, subordinate component.

The *felspar* is chiefly an alkali-felspar of complicated perthitic structure and shows a somewhat varying form and habit in the different specimens. The size of grain averages about half a centimeter and the shape is rather irregular, often tending to a form that gives broadly tabular sections, or in other specimens with a tendency to a more elongated, rhomboidal form. In the latter case the felspar-crystals may attain a length of 3 centimeters.

In the varieties of the rock where quartz is almost entirely absent, the felspar is a soda orthoclase in microperthitic intergrowth with oligoclase. In sections parallel to *b* (010) the main portion is optically homogeneous with an extinction angle of + 9°. Locally, however, a very fine cryptoperthitic lamellation, under an angle of 72 or 73° with the cleavage-traces, is seen under high magnification. This is due to an alternation of lamellæ of only slightly different index of refraction and the lamellation is best seen in non-polarized light. In the more or less homogeneous main portion are included numerous areas of oligoclase showing an extinction angle of about + 4°. These areas have the form of an irregular oval and are elongated parallel to the direction of the cryptoperthitic lamellation. In sections perpendicular to (010) the oligoclase areas show an imperfect rectangular form and are slightly elongated parallel to the trace of (010); the twin lamellation is not easily perceptible. The cryptoperthitic lamellation is also observed in these sections and its direction is perpendicular to (010).

In other varieties of the rock, containing more quartz, the felspars consist of orthoclase and albite in very irregular spotty and dotted microperthitic intergrowth. Sometimes the boundary of the crystals consists of pure albite and sometimes pure albite is observed in separate crystals. In a specimen of nordmarkite from Nungmiut, north-west of Narsak, the felspar is rather peculiar. In this specimen larger, scattered crystals of oligoclase are found, while most of the felspars consist of microperthitic microcline-albite and this microcline shows a very marked cross-hatching. It is otherwise extremely rare to find cross-hatched microcline in the post-Devonian igneous rocks from this area.

The felspar is generally a little weathered and under the microscope proves more or less turbid. In the perthitic crystals the orthoclase is always more weathered than the plagioclase.

*Quartz* commonly occurs as a subordinate component, sometimes, however, it is almost entirely wanting. It fills angular interspaces between the felspars and the other minerals.

The *structure* is a typical hypidiomorphic-granular one without any tendency to a parallel arrangement of the constituents. Apatite and after that iron-ore and augite are the most idiomorphic components, next comes felspar. The other dark-coloured minerals are as a rule less idiomorphic than the felspar, while the quartz appears as the mineral last crystallized.

*Chemical composition.* — For the chemical analysis specimens were taken of a tolerably fresh rock from a spot on the west side of Kakarsuak near Narsak. The rock in this place is, howerer, not quite typical in so far as it is practically free from quartz. The mineral composition is as follows: soda-orthoclase with some oligoclase, green and brown hornblende, colourless or grayish augite, some biotite, iron-ore and apatite, finally a little hydrous iron oxide, arisen from decomposition of the ferromagnesian minerals.

The result of the analysis which was carried out by Dr. Winther has been given in No. **17** of the table on the next page. For comparison two analyses of the typical nordmarkite (B and C) have also been given. These show a somewhat greater content of silica and alumina and a slightly lower content of lime, while the amount of alkali is equal in the Greenlandic and Norwegian nordmarkite. The Narsak rock shows a still greater conformity with the pulaskite from North Siorarsuit (analysis No. 3, p. 124), from which it chiefly differs by a lower content of iron and a slightly higher content of alumina, lime, and phosporic pentoxide. From a purely chemical point of view the analyzed nordmarkite variety from Narsak might be supposed to be a pulaskite variety, but from a geological point of view it belongs to a well characterized nordmarkite-mass and its low percentage of silica is accounted for by the fact that the material for the analysis was accidentally taken in a place where the rock was exceptionally poor in quartz.

Rock-types that are closely related to the one here described occur pretty frequently all over the globe. In this place the very close agreement in chemical composition with the nordmarkite from Cabo Frio, described and analyzed by F. E. Wright, is especially pointed out. The analysis of this rock has been given for comparison (in A). A comparison with the

*Analyses of nordmarkite and related rocks.*

| | 17 | A | B | C | D |
|---|---|---|---|---|---|
| $SiO_2$ | 58·17 | 58·46 | 60·45 | 63·20 | 63·71 |
| $TiO_2$ | 2·09 | ·28 | — | ·46 | ·86 |
| $Al_2O_3$ | 16·07 | 16·56 | 20·14 | 17·45 | 16·59 |
| $Fe_2O_3$ | 1·30 | 5·69 | 3·80 | 3·60 | 2·92 |
| $FeO$ | 5·04 | 2·59 | | | ·66 |
| $MnO$ | ·07 | trace | — | — | ·20 |
| $MgO$ | 1·20 | ·62 | 1·27 | ·75 | ·90 |
| $CaO$ | 3·42 | 2·61 | 1·68 | 1·40 | 3·11 |
| $Na_2O$ | 7·41 | 6·23 | 7·23 | 6·90 | 8·26 |
| $K_2O$ | 4·65 | 5·44 | 5·12 | 5·88 | 2·79 |
| $H_2O$ above 110° | ·41 | 1·21 | ·71 | ·50 | ·19 |
| $H_2O$ at 110° | ·19 | | | | |
| $Cl$ | none | — | — | — | — |
| $SO_3$ | none | trace | — | — | — |
| $P_2O_5$ | ·42 | ·23 | — | — | — |
| $CO_2$ | none | ·04 | — | — | — |
| Total... | 100·44 | 99·96 | 100·40 | 100·14 | 100·19 |
| Sp. gr.... | 2·74 | 2·674 | | | |

**17.** Nordmarkite, W. of Kakarsuak, Narsak, S. Greenland. C. Winther, analyst.

A. Nordmarkite, Cabo Frio, Rio de Janeiro. F. E. Wright, analyst (Tschermak's mineralog. u. petrog. Mitteilungen XX, 1901, p. 233.

B. Nordmarkite, Aueröd, S. Norway. G. Forsberg, analyst (W. C. Brögger, Zeitschrift für Krystallographie XVI, 1890, p. 54).

C. Nordmarkite, Tonsen Aas, Christiania. G. Forsberg, analyst (W. C. Brögger loc. cit.).

D. Umptekite, Umpjavr, Kola. W. Petersson, analyst (W. Ramsay, Fennia IX, 1894, p. 205).

Umptekite of Kola (D in the above table) is also of interest as this rock appears as part of a rock assosiation similar to the Narsak-nordmarkite.

### *Contact Facies of Nordmarkite.*

*Normal contact facies.* — As mentioned in the geological section (p. 100) the nordmarkite has a distinctly marked endomorphic contact facies where it borders on the superincumbent rocks of the volcanic series. This contact facies may be characterized as a nordmarkite-phorphyry containing the same mineral components as the main type of rock. The phenocrysts are felspars consisting chiefly of soda-orthoclase; the angle of extinction in sections parallel to (010) is about + 9°. They are remarkable by their form which gives a lozenge shaped section as in the Norwegian rhomb-porphyries. They are much less pure than the felspars in the coarse-grained nordmarkite as they enclose small rounded crystals of augite, hornblende and iron-ore. The ground-mass consists of soda-orthoclase with perthitically imbedded albite, green hornblende, sometimes also a little augite and biotite, further iron-ore and apatite, and finally interstitial quartz which is a constant but very subordinate component. The felspars of the ground-mass have the form of laths, seldom more than 0·1 millimeter wide, and the structure is a typical trachytoid flow-structure.

*Granitic contact facies.* — At the contact with the sandstone on the south coast of Sermilic Fjord (p. 103) the nordmarkite has dissolved silica from the sandstone, and in a zone, one half to one meter wide, nearest the sandstone the rock is a medium-grained granite. This contact-rock consists of felspar and quartz with some ægirine, arfvedsonite and ainigmatite. The felspar-crystals have a shape giving imperfect tabular sections, and consist of microcline-microperthite. The twin structure of the microcline is irregularly granular or finely dotted, and the perthitic structure is finely lamellar with somewhat irregular lamellæ arranged in the same manner as in an ordinary orthoclase-microperthite. The quartz is allotriomorphic and is present in about the same proportion as the felspar. The anhedra are of considerably smaller dimensions in this granite than in the adjoining quartzitic sandstone. The arfvedsonite is, apparently by magmatic resorption, very extensively altered to ægirine with numerous inclusions of black ferruginous material.

## ESSEXITE.

The essexite covers a small area of almost two square kilometers along the coast by the Narsak settlement. On the opposite coast it appears again at Sigsardlugtok, about seven kilometers west of Narsak and in Sermilik Fjord it is found at Kangerdluak. It is a coarse-grained dark gray rock whose main component, a plagioclase, is developed in large tabular crystals. The occurrence of the rock and the variations in its appearance have been described at length in a former chapter (p. 95).

*Microscopic characters.* — Under the microscope the minerals seen are: apatite, iron-ore, olivine, augite, hornblende, biotite, labradorite, orthoclase and secondary products. Nepheline has not been observed.

The apatite is relatively abundant in prisms of the usual form. The crystals may reach a length of 5 millimeters and a thickness of 0·5 millimeter. The iron-ore occurs in considerable amount; it is in crystals and irregular grains sometimes measuring several millimeters across. It is titaniferous and gives rise to secondary titanite. In the pseudomorphs a framework of unaltered iron-ore indicates that the original ore had a lamellar structure[1]. It is usually bordered by a fringe of scaly biotite.

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[1] The pseudomorphs agree with those figured by Rosenbusch (Mikrosk. Physiogr. I, 2, Pl. II, 6 (1905)).

*Olivine* is always present in considerable amount. It occurs in rounded crystals or grains, one or two millimeters or more in diameter. It is mostly fresh and sometimes clear, sometimes filled with minute black microlites producing a "schiller" structure. In many specimens of the rock the olivine shows prominent resorption-phenomena: along the margin and cracks it is changed to a black metallic matter — probably magnetite — with irregular boundaries. Sometimes a whole olivine crystal has been changed in this manner with the exception of a few small, separated remnants. The outer part of the black zone contains numerous needles and bunches of actinolite which is sometimes accompanied by colourless augite in slight quantity. Round this zone of magnetite-actinolite is found an outer fringe of finely scaled, colourless or faint greenish mica sometimes containing half discoloured remains of brown biotite. In other cases the olivine may be immediately surrounded by fresh brown biotite. In less fresh specimens of the essexite the olivine is often surrounded by a margin of serpentine, or it may be quite serpentinized.

*Augite* of a more or less pronounced violet tint, and therefore probably titaniferous, is a constant component of the essexite. It occurs in about the same amount as the olivine. It is as a rule quite allotriomorphic and often contains the usual black microlites, these, however, are not uniformly dispersed in the augite but concentrated in patches. The extinction angle *c* : c is large and exceeds 40°. Locally a little pale green uralite may be found in the margin of the augite-anhedra. In the more decomposed varieties of the rock the augite together with the other ferromagnesian minerals has changed to aggregates of serpentine, chlorite, epidote, calcite etc.

A brown hornblende with the absorption-tints and optic orientation of the barkevikite is found in small amount in most of the essexite-specimens. It occurs in small short prisms or shapeless grains mixed with the biotite-aggregates; sometimes also as a thin outer zone surrounding the augite and parallel with it.

*Biotite* of a brown colour is found in rather considerable amount. It occurs as aggregates of small scales or plates round the iron-ore, sometimes also in large, tabular crystals surrounded by felspar. It is strongly pleochroic, the absorption-tints varying from deep chocolate colour to quite pale yellow.

A *labradorite* in rather idiomorphic, tabular crystals is the main component of the essexite. The crystals are often several centimeters long. They are always twinned according to the albite-law, locally also pericline-lamellæ are seen and Carlsbad-twins are tolerably common. Upon optical examination the main part of each crystal proves tolerably homogeneous but in an outer shell of varying thickness a decrease of basicity takes place. This zonary banding is as a rule very pronounced. For a more exact determination of the plagioclase, measurement was employed of the angles of extinction in symmetrical sections of Carlsbad-twins and in sections parallel to *b* (010). The main portion of each crystal was in this way found to consist of a labradorite the composition of which varied in the different specimens of the rock from $Ab_3An_4$ to $Ab_1An_2$. In the outer part of the crystals the extinction-angles decrease and attain values characterizing an andesine $Ab_2An_1$, and sometimes the outermost zone is oligoclase.

In some specimens of the essexite the plagioclase is quite clear and fresh, in others it is filled with minute dust-like inclusions. When the felspar contains small enclosed biotite crystals the dust is often wanting in the immediate vicinity of these[1]. In many cases the plagioclase is more or less altered and the crystals are filled with small scales of a colourless

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[1] A similar micro-structure of the labradorite has also been observed in essexites from other localities (ROSENBUSCH, Mikrosk. Physiogr. 1907, II, 1, p. 392).

mica-like substance; where the transformation has progressed farther, epidote in rather large crystals also occurs.

*Orthoclase* occurs in the fresh specimens of the essexite in greatly varying amount, and in some of them it seems to be entirely absent. It must be emphasized that even where the orthoclase is wanting the mineral composition is for the rest unaltered and typically essexitic. In the more decomposed varieties of the rock the orthoclase cannot be identified. It is always the mineral last crystallized; it partly forms an outer covering of the plagioclase crystals and is partly interstitial. In the specimens from Sigsardlugtok where it only occurs very sparingly it appears to be a normal orthoclase with an angle of extinction on (010) of about + 4°. But in the specimens from the Islands at Narsak and from Kangerdluak the mineral is more abundant and proves to be a *soda-orthoclase* with an angle of extinction on (010) of about + 8°. This soda-orthoclase shows a more or less plain cryptoperthitic striation that in sections perpendicular to (010) follows a direction parallel with the *b*-axis, and in sections parallel with *b* (010) is orientated under an angle of about + 71° with the *a*-axis. It is often, but not always, more cloudy than the plagioclase.

*Structure.* — As already mentioned the plagioclase in this rock is developed in large and rather idiomorphic, tabular crystals and the dark-coloured minerals fill up the interspaces between them. Apatite is always the earliest mineral. After this comes iron-ore and olivine. Plagioclase and augite have perhaps to a great extent crystallized simultaneously but the crystallization of the augite has continued longest and augite-anhedra have grown out so that they fill even narrow interstices between the plagioclase-crystals. Sometimes also the biotite aggregates take part in this filling up of the interstices. When orthoclase is present it is of even later date than the augite. Usually each anhedron of augite fills only one interstice and in no place the augite-anhedra are large enough to mould several felspar-crystals. The structure may therefore perhaps best be characterized as sub-ophitic.

The order of succession of the dark-coloured minerals is very pronounced: iron-ore and olivine are in separate grains but both are embraced by augite, and very often a single augite-anhedron contains several grains of the two minerals first mentioned. Biotite mixed with' more or less barkevikite surrounds the augite and is found as a 'corona' round the iron-grains outside the augite. This tendency in the dark-coloured minerals to embrace one another in regular succession is common to the normal varieties of the essexite and the augite-syenite (p. 189), and in both rocks the fine-grained border varieties show a more even-grained development of the minerals.

Mechanical phenomena are as a rule absent in the essexite, in those varieties, however, that show a marked flow-structure the labradorite crystals are at times somewhat bent or broken. But the mechanical phenomena do not affect the augite and orthoclase and must therefore have been produced while the rock was as yet semi-fluid.

*Chemical composition.* — It will be seen from the preceding sections that the mineral composition and structure of the rock described is tolerably typical of essexite and the same holds good from a chemical point of view as it will appear from the subjoined analysis (No. **18**). The specimens analyzed have been collected at Panernak Bay, northwest of Narsak where the rock had a very fresh appearance. For purposes of comparison I give a number of analyses of essexite from various parts of the world where the essexite occurs in a somewhat similar association of igneous rocks as in South Greenland. The agreement especially with the essexite of Essex is very conspicuous. As the igneous rocks of the Ilimausak area are on the whole distinguished by a high content of iron in proportion to the regions mentioned in the table on the next page

*Analyses of essexites.*

| | 18 | A | B | C | D |
|---|---|---|---|---|---|
| $SiO_2$ | 46·10 | 46.99 | 48·59 | 43·66 | 47·90 |
| $TiO_2$ | 3·34 | 2·92 | 2·71 | 1·21 | 1·91 |
| $ZrO_2$ | — | — | — | — | — |
| $Al_2O_3$ | 18·59 | 17·94 | 17·91 | 17·35 | 16·55 |
| $Fe_2O_3$ | 2·63 | 2·56 | 3·09 | 7·88 | 5·67 |
| FeO | 6·68 | 7·56 | 6·41 | 5·40 | 7·50 |
| MnO | ·05 | trace | ·15 | — | ·60 |
| MgO | 3·23 | 3·22 | 3·06 | 4·27 | 4·44 |
| CaO | 9·86 | 7·85 | 7·30 | 9·39 | 9·35 |
| $Na_2O$ | 6·22 | 6·35 | 5·95 | 5·12 | 3·23 |
| $K_2O$ | ·63 | 2·62 | 2·56 | 2·07 | 2·08 |
| $H_2O$ above 110° | ·80 | ·65 | ·95 | 1·99 | ·20 |
| $H_2O$ at 110° | ·11 | — | | | |
| Cl | none | — | n. d. | — | — |
| $P_2O_5$ | 1·41 | ·94 | 1·11 | 1·32 | ·32 |
| $CO_2$ | none | — | [·13][1] | — | — |
| Total | 99·65 | 99·60 | 99·92 | 99·66 | 99·75 |
| Sp. gr. | 2·895 | 2·919 | | | |

**18.** Essexite, Panernak Bay, Narsak, S. Greenland. C. Winther, analyst.

A. Essexite, Salem Neck, Essex Co., Massachusetts. H. S. Washington, analyst (Journal of Geology VII, 1899, p. 57).

B. Essexite, Mount Johnson, Quebeck. M. F. Connor, analyst (F. D. Adams, The Monteregian Hills. Journal of Geology XI, 1903, p. 265).

C. Essexite, Cabo Frio, Rio de Janeiro. M. Dittrich, analyst (H. Rosenbusch, Elemente der Gesteinslehre 1898, p. 172).

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[1] BaO 0·08 and NiO + CoO 0·05.

D. Essexite, Tofteholmen, Holmestrand, Norway. V. Schmelck, analyst (W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes III, 1898, p. 83).

one might have expected that the analysis would have given particularly high figures for this element. But as a comparison will show, this is not the case, even if it is taken into consideration that the iron may be supposed to be partly replaced by titanium. It is of interest to note this circumstance as the magma of the Narsak essexite must be presumed originally to have contained a surplus of iron, a surplus which has been laid down in the magnetite-pyroxenite mentioned below.

Another interesting feature is the very low percentage of potash in the analyzed specimens of essexite from Narsak. This figure is the only one deviating considerably from what must be counted as typical. Nevertheless it cannot be taken as a sign of any essential difference between the Narsak type and the ordinary essexite type, for as already mentioned the potash-felspar content of the Narsak-essexite is locally variable: in thin slices of the analyzed specimens I have not been able to detect any orthoclase, whereas this mineral has been found in no inconsiderable amount in the essexite-specimens from various other localities (the island at Narsak, Sigsardlugtok, Kangerdluak) where the rock does not otherwise show any deviations from the analyzed variety.

## MAGNETITE-PYROXENITE.

The magnetite-pyroxenite occurs within the essexite area at a locality about 2 kilometers north-west of Narsak (p. 97). It is a fine-grained rock of black colour. It is strongly magnetic and sometimes possesses polarity. Under the microscope it is seen to be made up of pyroxene, iron-ore, olivine and biotite. All these minerals form more or less isometric grains

*Analyses of magnetite-pyroxenite.*
*and related rocks.*

| | 19 | A | B |
|---|---|---|---|
| $SiO_2$ .......... | 31·77 | 38·38 | 45·05 |
| $TiO_2$ .......... | 12·97 | 4·32 | 2·65 |
| $Al_2O_3$ ........ | none | 6·15 | 6·50 |
| $Fe_2O_3$ ........ | 12·97 | 11·70 | 3·83 |
| FeO .......... | 10·23 | 8·14 | 7·69 |
| MnO .......... | trace | ·16 | — |
| MgO .......... | 15·77 | 11·47 | 12·07 |
| CaO .......... | 12·20 | 18·60 | 18·66 |
| $Na_2O$ ........ | 2·69 | ·78 | ·94 |
| $K_2O$ .......... | ·54 | ·13 | ·78 |
| $H_2O$ above 110° .. | ·60 | ·54 | 2·40 |
| $H_2O$ at 110° .... | ·05 | ·18 | |
| $P_2O_5$ ......... | trace | ·17 | ·31[1] |
| Total... | 99·79 | 100·72 | 100·88 |
| Sp. gr.... | 3·561 | | |

**19.** Magnetite-pyroxenite, Narsak, S. Greenland. C. Winther, analyst.

A. Jacupirangit, Jacupiranga, Brazil. H. S. Washington, analyst (The Foyaite-Ijolite Series of Magnet Cove. Journal of Geology IX, 1901, p. 620).

B. Pyroxenite, Brandberget, Gran, Norway. L. Schmelck analyst (W. C. Brögger, The Basic Eruptive Rocks of Gran. Quart. Journ. Geol. Soc. L, 1894, p. 31).

of tolerably uniform size, their diameter varying only from 0·07 to 0·3 millimeters.

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[1] $Ca_3P_2O_8$.

The pyroxene is of a light brown (not violet) colour and constitutes almost half of the rock. It is of the diopsidic type; the extinction angle $c : c$ is 38°. The iron-ore forms black metallic grains. To judge from the chemical analysis of the rock it must be highly titaniferous. No pyrite is seen. The olivine is quite colourless and contains small fluid cavities. It occurs in about the same quantity as the iron-ore. The biotite is less abundant. It is in irregular grains and is the least idiomorphic constituent of the rock. It is strongly pleochroic with absorption-tints varying from dark yellowish-brown to quite pale brownish. It contains innumerable minute needles; these are arranged in three systems intersecting each other at angles of 60° and all lying in the plane of cleavage. All the constituents are fresh and decomposition products are entirely wanting.

The chemical composition of this rock is shown in the above table. The most striking feature is the very high figure for titanic acid, in which respect the rock calls to mind the ilmenite-norite of West Norway, and the absence of alumina. Apart from this the rock shows evident affinities with the jacupirangite from Brazil, Magnet Cove, and other places. This rock is a differentiation-product of foyaitic magmas, whereas the Narsak-rock is to be classed with the essexite. As far as I am aware no exactly similar differentiation-products from essexitic magmas are known elsewhere, but the pyroxenite from Gran, quoted in the table for comparison, appears as a facies of essexite and may be cited as an example of a differentiation which to a certain degree goes in the same direction as that which has produced the magnetite-pyroxenite of Narsak.

## ESSEXITE-PORPHYRITE.

This rock composes the upper part of the Kakarsuak Mountain at Narsak. It is a minor intrusive body of irregular shape. It is older than the nordmarkite but is itself intrusive in the sheeted diabases and porphyries which comprise the bulk of the volcanic series. On the geological map the essexite-porphyrite is not shown separately but included in the volcanic series.

The rock in question is porphyritic in appearance, characterized by very numerous and large plagioclase-phenocrysts imbedded in a scant ground-mass of very fine grain and of greenish-black colour. The phenocrysts are of a shape giving broadly tabular or rounded sections and sometimes they are broken. In the variety of which an analysis is given below they seldom exceed 1 centimeter in length whereas otherwise they often reach a length of 10 centimeters. They are greenish of colour, the cleavage planes are often dull.

Upon microscopic examination the rock proves greatly altered by contact-metamorphism and the original structure of the ground-mass is quite effaced. The felspar-phenocrysts where they are fresh, are twinned according to the albite-law, sometimes also according to the Carlsbad-law. They are labradorites of about the composition $Ab_3An_4$. The smaller phenocrysts have often a coating of orthoclase. The crystals are partially, and many of them throughout, converted to a colourless, nonhomogeneous aggregate of extremely fine structure. The main constituent of this aggregate has about the same refractive index and interference-tints as scapolite and it is mixed with minute grains of a somewhat more highly refracting mineral, probably epidote.

The ground-mass has a structure indicating intense contact-metamorphism. Its original structure was probably less fine-grained than the actual structure. It consists of small irregular grains and scales of colourless minerals finely dotted with innumerable small black grains. The minerals are: plagioclase, orthoclase, augite, iron-ore, and apatite. Plagioclase is the predominant constituent, the sections are sometimes elongated and may attain a length of 0·2 millimeters. It is sometimes

*Analysis of essexite-porphyrite.*

| | **20** |
|---|---|
| $SiO_2$ | 50·98 |
| $TiO_2$ | 1·38 |
| $Al_2O_3$ | 22·15 |
| $Fe_2O_3$ | 1·04 |
| FeO | 4·25 |
| MnO | trace |
| MgO | ·79 |
| CaO | 7·90 |
| $Na_2O$ | 6·84 |
| $K_2O$ | 2·71 |
| $H_2O$ above 110° | 1·22 |
| $H_2O$ at 110° | ·12 |
| Cl | trace |
| $P_2O_5$ | ·38 |
| $CO_2$ | trace |
| Total | 99·76 |
| Sp. gr. | 2·82 |

**20.** Essexite-porphyrite, 450 meters above sea-level, Kakarsuak near Narsak, S. Greenland. C. Winther, analyst.

twinned and sometimes twinning is wanting. The larger grains are often altered in the same way as the phenocrysts. The maximum value of the extinction-angle in sections perpendicular to (010) is 38° in the central part of the crystals. This indicates a labradorite of almost the same composition as the phenocrysts. The extinction-angle decreases towards the margin of the grains and they are surrounded by a zone of orthoclase (or soda-orthoclase). This mineral is also found as interstitial grains. Augite is abundantly present in small rounded grains, 0·01—0·06 millimeter in diameter, evidently all formed by the metamorphism of the rock. The apatite is in small needles and the iron-ore in grains of varying size (0·005—0·1 millimeter) sometimes surrounded by a yellow biotite.

The chemical composition is given in the table above from which it will be seen that the composition is of essexitic type. A comparison with the analysis of the Narsak-essexite (p. 203) shows for the essexite-porphyrite more silica, alumina, and alkalies, and less titanic acid, iron oxides, and magnesia. This corresponds with the circumstance of the rock being extremely rich in felspar-phenocrysts and poor in ground-mass.

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## ROCKS OF THE VOLCANIC SERIES.

The volcanic formation rests on the red sandstone and is built up of a large number of sheets, some effusive, others intrusive. The total thickness is about one thousand meters. The original thickness was probably much greater, this formation being the uppermost in South Greenland .and having been exposed to erosion through enormous periods. It constitutes the highest snow- and icecovered part of the Ilimausak mountain group and only in very few places stretches down to the level of the sea. During the field work it has been impossible to subject this formation that is so difficult of access, to anything but a very cursory examination.

Rocks of quite similar character occur as dykes and sills in the red sandstone. They are here classed with the volcanic series.

In the following pages a few typical examples will be described, the aim being to give a general idea of the character of the rocks and to show the relationship or consanguinity with the rocks described in the foregoing chapter. According to their macroscopic appearance the rocks of the volcanic series have been mentioned in the geological chapter by the names of diabases, porphyrites, porphyries, and quartz-porphyries. From each of these groups a typical representative has been selected for description.

## DIABASE (TRACHYDOLERITE) OF NUNASARNAUSAK.

The diabase which forms the flat top of the Nunasarnausak mountain is the relic of an intrusive sheet in the sandstone. The thickness of the sheet is about 150 meters. The rock has an ordinary dolerite- or diabase-like appearance. Its colour is a greenish black or grayish black and its structure is ophitic and more or less fine-grained, the tabular felspar-crystals having an average length of about one millimeter. At the lower surface of the sheet as well as at the summit of the mountain the structure is almost dense and sometimes porphyritic; in some places a flow-structure is also seen here.

*Microscopic characters.* — Examined in thin slices under the microscope the rock proves greatly altered. The alterations are probably due to contact-metamorphism and in many respects recall those of the Tertiary basaltic lavas of Skye, as described by HARKER[1]. It can be established that the following minerals have constituted original components of the rock: apatite, iron-ore, olivine, augite, and plagioclase (labradorite). Judging from the chemical composition of the rock orthoclase and perhaps nepheline, brown hornblende, and mica have probably also been originally present, but the microscopical examination gives no downright proofs of this.

The *apatite* is comparatively abundant in slender prisms or needles. The *iron-ore* is in crystals and irregular grains, it probably consists of titano-magnetite.

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[1] A. HARKER, The Tertiary Igneous Rocks of Skye. Memoirs of the Geological Society of the United Kingdom, 1904, p. 50.

Fresh *olivine* has not been found, but the rock abounds in pseudomorphs which may with certainty be referred to this mineral, owing to the fact that the alteration has begun in the same way as in the essexite, viz. by the formation of a zone of iron-ore round the grains and along their cracks. The interior of these pseudomorphs consists of a greenish serpentine aggregate crowded with numerous small needles of actinolite.

The *augite* is partly fresh and of a pale reddish violet colour. The extinction-angle $c : \mathfrak{c}$ is about 45°; it is slightly greater for a blue than for a red light. The mineral is quite allotriomorphic, moulding the tabular felspar-crystals. It has originally been present in about the same amount as the olivine but the augite-anhedra have to a great extent been converted into a greenish fibrous hornblende whose fibres are about parallel to the vertical axis of the augite. This uralitic hornblende is rather impure being full of small grains of iron-ore and of a strongly refringent mineral with high interference tints, perhaps titanite. The conversion of the augite is no doubt due to contact-metamorphism; yet in the most intensely altered portions of the rock (viz. those nearest the augite-syenite) there is no uralite left, but the rock is full of small grains of newly formed augite and scaly yellowish brown mica.

The *felspar* is in tabular crystals giving sections of about 1 millimeter in length by 0·1 millimeter in breadth. The decomposition-product is a colourless muscovite-like aggregate. Those parts of the felspar-crystals that are not decomposed in this manner are perfectly clear and fresh, a sign that the alteration of the rock is not due to ordinary weathering. The clear felspar has a faint brownish tint which is not due to visible inclusions of any kind; the outer zone of the crystals is, however, usually colourless. The crystals are always twinned according to the albite-law and sometimes also pericline-lamellæ are seen, Carlsbad twins are frequent. In a number of sym-

*Analyses of diabase (trachydolerite) of Nunasarnausak and related rocks.*

| | 21 | A | B | C | D |
|---|---|---|---|---|---|
| $SiO_2$ | 45·27 | 45·61 | 44·16 | 45·55 | 45·75 |
| $TiO_2$ | 4·41 | 3·48 | 3·14 | 4·45 | 2·95 |
| $Al_2O_3$ | 15·03 | 15·70 | 15·94 | 15·40 | 13·40 |
| $Fe_2O_3$ | 4·04 | 6·17 | 2·61 | 2·43 | 8·21 |
| FeO | 9·10 | 7·29 | 9·75 | 9·12 | 6.35 |
| MnO | trace | trace | — | — | ·24 |
| MgO | 6·59 | 4·84 | 4·62 | 5·20 | 7·29 |
| CaO | 6·64 | 6·34 | 8·96 | 7·70 | 12·05 |
| $Na_2O$ | 5·07 | 5·06 | 5·13 | 4·54 | 1·33 |
| $K_2O$ | 1·08 | 2·67 | ·72 | 2·04 | |
| $H_2O$ above 110° | 1·85 | 2·34 | 2·88 | 2·35 | 1·75 |
| $H_2O$ at 110° | ·14 | | | | |
| Cl | sl. tr. | | | | |
| $SO_3$ | none | | ·24 | | |
| $P_2O_5$ | ·16 | | 1·50 | | |
| $CO_2$ | ·38 | | | 2·15 | |
| Total | 99·76 | 99·50 | 99·55 | 100·93 | 99·32 |
| Sp. gr. | 2·988 | 2·87 | | | |

**21.** Diabase (trachydolerite), Nunasarnausak, South Greenland. C. Winther, analyst.

A. Basalt (trachydolerite), Franklin Island, Antarctic. G. T. Prior, analyst (Mineralog. Mag. XII, 1899, p. 80).

B. Diabase (trachydolerite) Neuwerk an der Bode, Hartz, Germany (quoted in H. Rosenbusch, Elem. d. Gesteinslehre 1910, p. 440).

C. Camptonite, Hvinden, Gran, Norway. L. Schmelck, analyst (W. C. Brögger, Eruptivgesteine des Kristianiagebietes III, p. 60).

D. Essexite-melaphyre, Holmestrand, Norway. G. Särnström, analyst (W. C. Brögger, Zeitschr. f. Krystallograph. XVI, 1890, p. 27).

metrical sections of such twins the extinction-angles were measured. The values obtained indicate that felspar is a labradorite of about the composition $Ab_3An_4$. The extinction-angle in some cases slightly decreases from the middle towards the margin of the crystals. These statements refer to the brownish felspar which constitutes the main component of the rock. The outer colourless shell which covers many of the brownish labradorite-crystals, in sections perpendicular to (010) shows a fine twin-lamellation and very small extinction-angles. It has an index of refraction somewhat lower than that of the labradorite but higher than that of Canada balsam. The outer shell consequently consists of oligoclase.

Besides the crystals and pseudomorphs mentioned, numerous formless areas, consisting of aggregates of serpentine, muscovite, actinolite, and sometimes epidote and calcite, are seen in the slices.

*Chemical composition.* — For the chemical analysis specimens were taken in a spot at a height of 560 meters on the north side of Nunasarnausak, near the lower boundary of the sheet. The results of the analysis are given in No. **21** of the table above. The composition is evidently of an essexitic type and very similar to that of the essexite of Narsak given in A of the same table. According to the system of Rosenbusch the rock may be characterized as a trachydolerite related to nepheline-basanite. In the table the analyses of some other related rocks are quoted for comparison. It is of special interest to note that rocks approaching these in composition occur in the petrographical province of the Christiania district.

## PORPHYRITE (TRACHYDOLERITE) OF TASEK.

At the southwestern end of Lake Tasek and about 4 kilometers northeast of Narsak a mountain rises from the flat moraine-covered tableland to a height of 750 meters above the level of the sea. This mountain consists of a porphyrite here to be described by the name of the Tasek-porphyrite. The mountain is the relic, left by the erosion, of a thick sheet belonging to the volcanic series. The sheet is probably effusive as the rock contains vesicles, though not in any great number. The vesicles are mostly about 1 centimeter long and filled with felspar and epidote which have perhaps formed at the expense of an original filling of zeolites[1].

The rock contains numerous phenocrysts of felspar imbedded in a greenish-black, dense ground-mass. These felspar-crystals have a thin tabular shape and usually only measure 1 or 1$^1/_2$ millimeter in thickness while they may attain a length and breadth of 1 or 2 centimeters. Their colour is gray or greenish and the bright cleavage-planes parallel to (001) show a very distinct twin-striation. The crystals show a strong tendency to parallel disposition.

*Microscopic characters.* — Upon examination under the microscope the rock proves so highly affected by contact-metamorphism and subsequent alterations that none of the original minerals have remained unaltered with the exception perhaps of apatite and some grains of iron-ore. The *felspar-phenocrysts* are filled with innumerable minute scales of a green mica which also occurs in the ground-mass. Usually they also contain more irregularly distributed small grains of a mineral which from its refractive power and double refraction is supposed to be epidote. Neither the mica nor the epidote shows the faintest trace of crystallographic boundaries. The clear felspar substance in which these decomposition-products are imbedded is twinned according to the albite-law; it has a composition between that of an acid andesine and an almost pure albite, but on account of the impurity of the crystals an exact determination was impossible. The extinction-angles in symmetrical sections are small though in some cases they reach

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[1] Cfr. A. HARKER, The Tertiary Igneous Rocks of Skye, 1904, p. 50.

15°; they are larger along the margin than in the middle of the crystals, and the outer shell seems often to consist of pure albite. The mean index of refraction is a little lower than that of Canada balsam.

Pseudomorphs from another kind of phenocrysts occur in small number. They are smaller than the felspars and often show hexagonal outlines. They consist of a microcrystalline aggregate of colourless minerals dotted with iron-ore and mica scales.

The *ground-mass* is of the trachytoid type in regard to structure. It is in the main composed of felspar-laths and a felt-like aggregate of green biotite; moreover it contains apatite and iron-ore. The *apatite* is in stout prisms. The *iron-ore* occurs in grains and crystals sometimes reaching a diameter of 0·3 millimeter, but generally much smaller. Most of the iron-ore crystals are surrounded by a reaction rim consisting of an extremely fine-grained aggregate of a highly refringent and strongly birefringent mineral, probably titanite. Many iron-ore crystals are almost entirely altered, only a small nucleus being left, and in some cases the alteration is complete. The *felspar-laths* of the ground-mass average about 0·4 millimeter in length by 0·1 millimeter in breadth. They are simple or once twinned; more seldom they are polysynthetic. Their mean refraction index is slightly lower than that of Canada balsam. The maximum extinction-angle in sections at right angles to the albite-lamellæ is about 10°. The felspar-laths of the ground-mass thus consist of an acid oligoclase or nearly pure albite. It is possible that also other kinds of felspar or felspathoid minerals may be present in small amount. The colourless minerals of the ground-mass, with the exception of the augite, are filled with exceedingly small scales of brown biotite and of colourless or greenish needles giving hexagonal sections. The latter as a rule attain only 0·01 or 0·02 millimeter in length, they are rather highly refringent, but owing to the minuteness

*Analyses of porphyrite of Tasek and related rocks.*

| | 22 | A | B |
|---|---|---|---|
| $SiO_2$ | 47·79 | 46·10 | 52.78 |
| $TiO_2$ | 3·82 | 3·34 | 1·50 |
| $Al_2O_3$ | 16·88 | 18·59 | 19·08 |
| $Fe_2O_3$ | 4·66 | 2·63 | 3·63 |
| FeO | 5·92 | 6·68 | 3·79 |
| MnO | trace | ·05 | trace |
| MgO | 1·51 | 3·23 | 1·58 |
| CaO | 5·58 | 9·86 | 5·09 |
| $Na_2O$ | 7·76 | 6·22 | 7·95 |
| $K_2O$ | 3·26 | ·63 | 3·85 |
| $H_2O$ above 110° | 1·17 | ·80 | ·44 |
| $H_2O$ at 110° | ·14 | ·11 | |
| Cl | none | none | ·33 |
| $P_2O_5$ | ·76 | 1·41 | ·63 |
| $CO_2$ | none | none | ·10 |
| Total | 99·25 | 99·65 | 100·75 |
| Sp. gr. | 2·921 | 2·895 | |

**22.** Porphyrite (trachydolerite), Tasek, Narsak, South Greenland. C. Winther, analyst.

A. Essexite, Narsak, South Greenland (analysis No. 18, p. 203).

R. Trachydolerite (lava) Meru, East Africa. B. Mauritz, analyst Tschermak's petrogr. u. mineralog. Mitteilungen XXVII, 1908, p. 322).

of the needles no birefringence can be detected. Perhaps they may be actinolite. The *green biotite,* which quantitatively is the mineral next in importance to the felspar in the ground-mass, forms irregular scales seldom more than 0·1 millimeter, the absorption-tints for 𝔟 and 𝔠 are grayish-green or brownish-green (not very dark) and for a very pale greenish.[1]. The biotite is often mingled with small grains of iron-ore and irregular agglomerations of titanite-like grains.

*Chemical composition.* — The chemical composition is given in No. **22** of the above table. Upon a comparison with the analysis of the Narsak essexite (p. 203) it will be seen that the rock must be derived from an essexitic magma and may therefore according to the system of Rosenbusch be termed a trachydolerite. The main difference from the trachydolerite of Nunasarnausak above described (p. 210) is in the alkalies which are higher in the Tasek rock. In reality this later rock approaches the tephrites in chemical composition and it is probable that in fresh condition it has been nepheline-bearing. For comparison the analysis is given of a trachydoleritic lava from Meru which bears a close resemblance to the rock here described.

## ILIMAUSAK PORPHYRY.

The Ilimausak porphyry has a dense violet-black groundmass with rather small and sparse felspar-phenocrysts of a shape that gives square or short-tabular sections. It occurs in sheets of considerable thickness, probably effusive, in the highest parts of the Ilimausak mountains. The sheets are intensely altered by contact-metamorphism and owing to the extremely fine grain the microscopic examination gives rather unsatisfactory results.

The specimens to be described were taken at a height of

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[1] The brown, strongly pleochroic mica so frequent in contact-metamorphosed rocks is wanting in the Tasek-porphyrite but is otherwise very extensively spread in the igneous rocks of the Ilimausak region. In a diabase from the summit (1370 meters) of Mount Steenstrup the brown mica is partly converted into a more faintly coloured green mica of the same appearance as that of the Tasek-porphyrite. It is therefore probable that also the green mica of this rock is an alteration-product of brown mica.

about 800 meters, at North Siorarsuit in the talus at the foot of Mount Hatten and come from the upper part of this mountain[1].

*Microscopic characters.* — The reddish-white felspar-phenocrysts have varying forms. Most of them are rather isometric with short-tabular or square or rounded forms, a few are thick-tabular. Their greatest diameter seldom exceeds 5 millimeters and is in some cases parallel to the $a$-axis, in others parallel to the vertical axis. They are as a rule very impure, filled with minute brownish particles, small dots of iron-ore, and a little larger scales of colourless mica. Their index of refraction is a little lower than that of Canada balsam. The optic examination shows that the felspar-phenocrysts are of various kinds. *In sections parallel to (010)* some of the crystals show an extinction-angle of + 5° in their central part; in the marginal zone this angle is greater and may reach about + 10°. In other crystals the extinction-angle is considerably greater both in the central portion and the marginal zone, varying between + 14° and + 19°. In both kinds of crystal locally an indistinct cryptoperthitic striation is seen, making an angle of ÷ 66° to ÷ 70° with the cleavage-traces. *In sections perpendicular to (010)* the extinction-angles vary in the different sections from 0° to about 17°; some of the crystals show a fine and irregularly granular twin-structure and others a not very distinct twin-striation parallel to (010). In the latter case the extinction-angles are always very small. These observations show that the felspar-phenocrysts are alkali-felspars of the soda-microcline series (anorthoclase) with a composition

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[1] The upper part of this mountain is not accessible as it is too steep, but at a height of about 1090 meters specimens were taken from the wall of the rock immediately above the arfvedsonite-granite. These specimens agree with those taken among the fallen boulders in the talus with the exception that they are still more intensely metamorphosed.

ranging from that of an almost pure potash-felspar to that of albite.

Besides the felspar also apatite and iron-ore occur as phenocrysts. The apatite is rather abundant in stout prisms of 0·6 to 0·2 milimeter. The iron-ore, probably titano-magnetite, occurs in more isometric crystals partially changed to titanite.

The ground-mass consists mainly of small felspar-laths and shows a marked flow-structure. The felspar-laths have a length of 0·04 to 0·15 millimeter, while the thickness is one seventh or one tenth of this. Their index of refraction is a little fainter than that of Canada balsam. They show about parallel extinction or they are longitudinally once twinned with extinction-angles from 0° to 8°. Consequently they are alkali-felspar and probably anorthoclase. Besides felspar the ground-mass contains a great quantity of colourless needles, grains of titanite and scales of muscovite and the whole is finely dotted and splashed with innumerable minute grains of iron-ore. The colourless needles have a thickness of 0·001 to 0·002 millimeter and the length is about ten times as great; the axis of maximum optical elasticity apparently coincides with the long axis of the microlites.

*Chemical composition.* — A chemical analysis of the Ilimausak porphyry is given in No. **23** of the table below. The composition is rather peculiar. It may perhaps have been slightly modified by the alterations the rock has suffered, but it does not seem likely that it should differ greatly from the original composition. It is of a type related to the alkali-trachytes; on the other hand it shows analogies pointing towards phonolite and trachydolerite. There is a rather striking analogy with the mugearite of Skye an analysis of which is quoted for comparison. The main difference is in the alkalies which are higher in the Ilimausak rock. There is also some analogy with the rhomb-porphyry of South Norway (se analysis

*Analysis of Ilimausak porphyry and related rocks.*

| | 23 | A | B | C |
|---|---|---|---|---|
| $SiO_2$ | 49·64 | 49·24 | 53·12 | 54·0 |
| $TiO_2$ | 4·25 | 1·84 | ·25 | 2·0 |
| $Al_2O_3$ | 13·74 | 15·84 | 20·48 | 18·9 |
| $Fe_2O_3$ | 7·10 | 6·09 | 5·13 | 7·8 |
| $FeO$ | 4·97 | 7·18 | 1·50 | |
| $MnO$ | ·03 | ·29 | | ·4 |
| $MgO$ | 1·58 | 3·02 | 1·88 | ·7 |
| $BaO$ | ·21 | ·09 | | |
| $CaO$ | 4·88 | 5·26 | 4·29 | 3·8 |
| $Na_2O$ | 6·33 | 5·21 | 6·20 | 6·5 |
| $K_2O$ | 4·42 | 2·10 | 4·88 | 3·9 |
| $H_2O$ above 110° | ·81 | 1·61 | 2·25 | 2·3[3] |
| $H_2O$ at 110° | ·14 | 1·08 | | |
| $P_2O_5$ | 1·57 | 1·47 | ·43 | |
| Total | 99·67 | 100·46[1] | 100·83[2] | 100·3 |
| Sp. gr. | 2·892 | 2·79 | 2·684 | |

**23.** Ilimausak porphyry, Hatten, Ilimausak, South Greenland. C. Winther, analyst.

A. Mugearit, Druim na Criche, Skye. W. Pollard, analyst (A. Harker, Tertiary Igneous Rocks of Skye, 1904, p. 263).

B. Trachyte (tephritic), Columbretes Islands, Spain. R. Pfohl, analyst (F. Becke, Tschermak's mineral. u. petrogr. Mitteilungen XVI, 1896, p. 168).

C. Rhomb-porphyry, Brumun Valley, Norway. H. Bäckström, analyst (Bihang till K. Svenska Vetenskaps-Akad. Handl. XIV, II, No. 3, 1888, p. 11).

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[1] Including F 0·18 and S 0·03 but less 0·07 (O = F).

[2] Including Cl 0·28 and $SO_3$ 0·14.

[3] Loss on ignition.

C, p. 220). True rhomb-porphyries which cannot macroscopically be distinguished from the Norwegian ones are also found in the igneous complex of Ilimausak, but they are only found as erratics and have not been subjected to closer inspection. A peculiarity in the Ilimausak porphyry, which deserves pointing out, is its relatively high content of baryta. It is the only baryta-bearing igneous rock found in the Ilimausak region.

## QUARTZ-PORPHYRY (COMENDITE).

Quartz-porphyries are only found as dykes and intrusive sheets. But as they belong to the latest rocks in the volcanic series, and as the dykes are very numerous and large, it is not improbable that effusive rocks of the same composition may have been present in those parts of the volcanic series which have been entirely removed by erosion. The quartz-porphyries have not been so much altered by contact-metamorphism as the igneous rocks mentioned in the preceding chapters, still they have not quite escaped this influence.

The commonest type of quartz-porphyry in the Ilimausak region has a dense or extremely fine-grained ground-mass of grayish violet, grayish red or entirely red colour. There are phenocrysts of quartz as well as of felspar. Usually the felspar-phenocrysts are 2 or 3 millimeters, and have about the same colour as the ground-mass; they have shapes giving short-tabular sections and they sometimes occur in groups of 3 or 4 intergrown crystals. The quartz-phenocrysts are of somewhat smaller dimensions and are quite clear and fresh. They have the usual bipyramidal shape. Sometimes they are found in groups of 2—4 crystals.

*Microscopic characters.* — Under the microscope the felspar-phenocrysts are seen to be strongly clouded by weathering products. They consist of an irregular microperthitic intergrowth of potash-felspar and albite. The albite is less weathered than the potash-felspar and exhibits the usual twin-lamellation.

The potash-felspar, when clear, is seen to be microcline with a fine-grained twin-structure but, when turbid, it looks like orthoclase. In some specimens of quartz-porphyry the felspar-phenochrysts seem to be soda-orthoclase with only a few and small veinlets of albite perhaps of secondary origin.

The *quartz*-phenocrysts are sometimes sharp edged crystals, sometimes they are more or less corroded in the usual way. They contain fluid-pores and included portions of the ground-mass. Phenocrysts of ferromagnesian minerals now quite converted into iron oxides have been found in a few cases. They have the shape of long prisms and have perhaps originally consisted of soda-amphibole.

The *ground-mass* is micro-granitic or micro-pegmatitic. When tolerably unaltered it consists of potash-felspar, quartz, and a blue amphibole.

Among the specimens collected the least altered comes from a heavy dyke in the sandstone on the south coast of the Sermilik Fjord just below Mount Steenstrup. In this specimen the ground-mass is microgranitic, but small areas of micrographic intergrown felspar and quartz are seen with tolerable frequency in the slices. The size of the grain of the ground-mass is 0·05—0·2 millimeter. The quartz is very abundant and shows some tendency to crystallographic outlines. The felspar is in broad and short laths or grains. It is a microcline-microperthite. The blue amphibole is in small allotriomorphic anhedra which are mostly elongated parallel to the vertical axis. The extinction-angle $c:\mathfrak{a}$ is small but cannot be determined with exactness; the absorption-tint for $\mathfrak{a}$ and $\mathfrak{b}$ is a dark grayish blue, for $\mathfrak{c}$ a light grayish green. The mineral is thus probably a riebeckite.

Another specimen from a dyke in porphyrite 5 meters wide and from a locality east of the summit of the Ilimausak and about 830 meters above sea level, has almost the same structure but is more altered. There is no blue amphibole but in its place small dots and irregular laps of black iron oxide. The felspars of the ground-mass are more clouded and consist of orthoclase-microperthite mixed with crystals of pure albite. A few small grains of zircon were observed, also a little fluorite. Of this rock a chemical analysis is given below.

In a third specimen from the same locality as the last one, but from a dyke only two meters wide, the ground-mass has a micro-pegmatitic (granophyric) structure with a marked tendency to sphærulitic arrangements. The dark minerals are completely converted into iron oxides and the whole ground-mass is finely dotted with black iron-ore. Somewhat similar is a specimen taken at a height of 800 meters in the talus at the foot of a peak east of Hatten, in this rock, however, the sphærulitic structure is still more developed, the ground-mass consisting almost entirely of sphærulites with a diameter of about one millimeter. The sphærulites in this case contain not only felspar and quartz but also radiating needles of a mineral that has been completely converted into iron-ore. The sphærulites of this rock have therefore macroscopically the appearance of innumerable small dark spots in the ground-mass.

A somewhat different type of quartz-porphyry is rather common among the blocks in the large alluvial fan at North Siorarsuit and must be supposed to be from one of the high Ilimausak peaks. This rock macroscopically resembles the Ilimausak porphyry with the exception that its phenocrysts are both quartz and felspar. The quartz-phenocrysts have a sharply developed bipyramidal shape and the felspar-phenocrysts are microcline-microperthite. The ground-mass is bluish black and macroscopically looks homogeneous. Under the microscope it is seen to be full of small arfvedsonite-like prisms in tolerably parallel arrangement so that they produce a pronounced flow-structure. Their length varies about 0·05 millimeter, their thickness is only one tenth of this. The extinction-angle $c:\mathfrak{a}$ is small, and the absorption-tints are those of the arfvedsonite, *Analyses of comendites.*

| | **24** | A |
|---|---|---|
| $SiO_2$ | 73.68 | 74·76 |
| $TiO_2$ | ·57 | trace |
| $ZrO_2$ | ·24 | — |
| $Al_2O_3$ | 11·05 | 11·60 |
| $Fe_2O_3$ | 3·93 | 3·50 |
| FeO | 1·45 | ·19 |
| MnO | trace | — |
| MgO | none | ·18 |
| CaO | ·48 | ·07 |
| $Na_2O$ | 5·20 | 4·35 |
| $K_2O$ | 4·05 | 4·92 |
| $H_2O$ above 110° | ·08 | ·64 |
| $H_2O$ at 110° | ·17 | |
| Cl | trace | — |
| $P_2O_5$ | none | trace |
| Total | 100·90 | 100·21 |
| Sp. gr. | 2·694 | |

**24.** Quartz-porphyry (comendite), Ilimausak, South Greenland. C. Winther, analyst.

A. Comendite, Comende, San Pietro Island, Sardinia. M. Dittrich, analyst (H. Rosenbusch, Elemente der Gesteinslehre, 1898, p. 257).

varying from a very dark greenish blue (a and b) to a pale yellowish green (c). A few of the needles are partly converted into black iron oxide. This arfvedsonitic felt is imbedded in a very microcrystalline aggregate of felspar and quartz which seems to have been produced by divitrification as the boundaries between the quartz grains and the felspar grains take an irregular course which is quite independent of the presence of the arfvedsonite-like needles.

*Chemical composition.* — A specimen of the above mentioned quartz-porphyry from a dyke 5 meters wide, at a height of 830 meters, east of the summit of the Ilimausak, has been analyzed by Dr. **Winther**. The results have been given in No. **24** of the table above. The figures of the analysis and the microscopic characters agree in showing that the quartz-porphyry from the Ilimausak belongs to the alkali series and must accordingly, in the system of **Rosenbusch**, be referred to the comendites. For comparison an analysis of the comendite from Comende in Sardinia has been given in **A**.

# CHAPTER V.

# DESCRIPTIVE GEOLOGY AND PETROGRAPHY OF THE IGALIKO REGION.

## INTRODUCTORY.

The district to be described in this chapter extends round the eastern ramifications of the Tunugdliarfik and Igaliko Fjords. It includes the area shown on the index map (Fig. 20), and given on a larger scale (about 1 : 212000) on the geological map (Pl. IV).

From a topographic point of view the district offers considerable variation. The tracts lying west of the Tunugdliarfik Fjord and the area between this fjord and the inner end of the Igaliko Fjord are rather low, and consist mainly of sandstone plains on which grass grows more prolifically than is usually the case in Greenland. In the Middle Ages the Norse colonists had a principal settlement here, a number of ruins still standing as mementoes of that time. Later on the whole district was deserted for several centuries, until, a little more than a hundred years ago, a Dane, Anders Olsen by name, who had been a merchant at Julianehaab, took up his abode at Igaliko with his Greenland family and a small stock of cattle. The place is now inhabited by about twenty Greenlanders, descendants of Anders Olsen; they live by the rearing of cattle in connection with seal fishery. Low lands with grassy plains and luxuriant shrubberies of willow and birch trees and many Norse ruins are locally to be found also outside the sandstone tracts. Thus at Kagsiarsuk in the south eastern corner of the district here mentioned, and at Kiagtut farthest north.

Moreover the last mentioned place is famous as being able to show some of the tallest birches in Greenland (3—4 meters in height). The summer temperature in these innermost parts of the Tunugdliarfik and the Igaliko Fjords is higher than that at the outer coast, and residence in the inner fjords in summer would be most enjoyable if the mosquitoes and the violent Föhn winds were not there, but these annoyances reach their maximum in the Igaliko district.

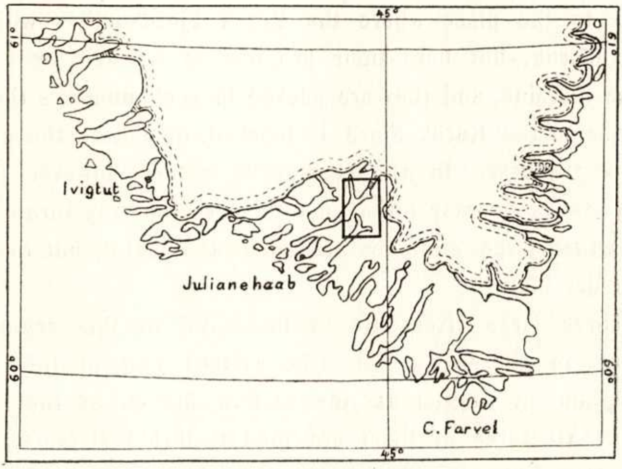

Fig. 20. Index map showing location of area represented on Pl. IV.

In contradistinction to the plains described just now a wild highland scenery is to be found in the eastern half of the area. The mountains south of the Korok Fjord with the high summit of the Igdlerfigsalik (1750 meters) are especially of a true Alpine type, and their upper parts have received their contour through the activity of local glaciers. The photograph

(Pl. XVI) gives a view of this enormous group of mountains seen at a great distance (40 kilometers) from the east, and the scenery is yet far more picturesque on the north eastern side, where four hanging glaciers are fed by the snow masses of the Igdlerfigsalik.

Only in one place does the inland ice extend to the area shown on the map (Plate IV), namely in the northern arm of the Korok Fjord. Here a rather narrow branch of the large mer-de-glace forces its way among the steep bluffs, and forms a large number of icebergs. By the wind these are quickly driven to the place where the Korok Fjord unites with the Tunugdliarfik, but here their progress is arrested by a submarine moraine, and they are packed in such numbers that the entrance to the Korok Fjord is blocked up during the greater part of the year. In August and September, however, it will nearly always be easy for a boat to make her way through the ice. Other large moraines are found at Kiagtut, but they are all on dry land.

Three large rivers are to be found in this region: at Kiagtut, in Giesecke's Dale (the eastern part of the Korok Fjord), and at Kagsiarsuk (the eastern branch of the Igaliko Fjord). All three of them are mighty, turbid streams, taking their rise from the outlet of the inland ice, and having formed large deltas at the mouths, where it is very difficult to land.

There are three rock formations in the Igaliko territory viz: basement rock, red sandstone, and newer abyssal rocks. The basement rock is a granite which is supposed to be of Algonkian age, and it is denoted here as the "Julianehaab granite". The red sandstone the "Igaliko sandstone" lies directly upon the granite. The sandstone formation is deposited in fairly horizontal strata. It contains numerous sills und dykes of dark coloured igneous rocks. Whilst the sandstone formation in the Ilimausak district is present in its original thickness and covered by the volcanic series, in the Igaliko district only the lower part of the sandstone is to be found, and the upper strata of sandstone as well as the whole volcanic series have been worn away by erosion. The newer abyssal rocks are exposed over an extensive area. They constitute the large "Igaliko batholite" which occupies one third of the area lying to the north east, as shown on the map (Plate III), and most probably it extends far beyond the limits of the map.

From a mineralogical point of view the Igaliko district presents a locality of the greatest interest, principally Narsarsuk at the western side of the foot of the Igdlerfigsalik mountain, where an unusually large number of rare minerals have been found.

In the following description we shall treat, firstly the batholite, its rocks (nepheline-syenite and augite-syenite), and conditions of contact, and seçondly the basement-granite and the sandstone areas.

## IGALIKO BATHOLITE.

The lofty mountains north, south, and east of the Korok Fjord belong to a large batholite which is indicated here as the "Igaliko batholite". It mainly consists of nepheline-syenite, but in places where the junction between the batholite and the early rocks has been examined, it has been found that the nepheline-syenite is bordered by a narrow zone of augite-syenite. The eastern parts of the district being difficult of approach have not been surveyed[1], thus it is impossible to indicate the extent of the nepheline-syenite area. The part of it which has been visited is the largest nepheline-syenite area in Greenland,

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[1] The author had but fourteen days at his disposal, of which he lost some on account of bad weather, for the geological surveying of the Igaliko district. Consequently the observations are incomplete in various respects.

and most probably it is one of the largest in the world, for as far as can be judged according to the topography and the aspect of the mountain slopes regarded from a distance, the nepheline-syenite is continued very far to the east, and in all likelihood it extends under the inland ice.

The general appearance of the Igaliko batholite mountains differs from that of the Ilimausak batholite. They are higher and steeper. Boldly and precipitously they tower above the sea, and attain to large altitudes, there being, as a rule, no beach. It is obvious from the shape of the mountains that we are here closer to the inland ice, so that the erosion which is due to the fjord-glaciers has been maintained until quite recently. The mechanical disintegration of most of the rocks in the Igaliko batholite is not as conspicuous as this phenomenon at Kangerdluarsuk and Ilimausak, and vegetation is frequently found on the lower part of the hills. Upon the whole, however, the decay of the Igaliko batholite must be characterized as relatively rapid, and in several places it determines the appearance of the mountain slopes. In this respect they differ considerably from the compact and hard sandstone rocks in the west, and the old granite north of the batholite. The contrast is less apparent at the south border, where, singularly enough, the old granite in the Tavdlorutit mountain is covered with screes to almost as great an extent as is the case with the syenite on the opposite side of the valley, and looked at from a distance the rocks might be supposed identical. Therefore earlier explorers have attributed to the syenite a larger extent than it really has.

## NEPHELINE-SYENITE OF THE IGALIKO BATHOLITE.

The bulk of the Igaliko batholite, as far as is known, consists of nepheline-syenite. Seen from a distance the colour of the rock is reddish; sometimes it is intensely red like that at Angmagsivik or grayish as in the southern part of the batholite. In most places where specimens have been collected the rock is not unlike the well known "foya type" although differing in petrographic details. This rock which is probably the main rock of the batholite will be described here as the „Korok type". An essentially different type the "Usuk type" has been found in the valley east of Usuk.

### *Korok type.*

*Macroscopic appearance.* — The foyaite of this type is a coarse-grained rock of a reddish-gray colour, less frequently brownish-red or gray. Among the thick tabular felspar crystals plenty of nepheline and dark-coloured minerals are to be seen. The felspar tables are of a very fresh, grayish appearance. On an average their thickness is 5 millimeters (varying from 1 to 8 millimeters in the different places), and their widest extent which is parallel to the $a$-axis is from five to ten times as large as their thickness. Frequently they are arranged in parallels. The nepheline is reddish and of an elæolithic habit. It is in grains and in short prisms of a diameter of one quarter of a centimeter to a centimeter. It is just a little less idiomorphic than felspar. The dark-coloured minerals to be seen with the naked eye are a black pyroxene (ægirine-augite) and a black mica.

In most places the foyaite is of a uniform size of grain. Considerable variations have only been observed in the western part of the foyaite area near the contact with the augite-syenite. Here both porphyritic and pegmatitic varieties are very common. The latter occur in veins and segregations of irregular form; locally they are extremely coarse-grained with felspar crystals which exceed half a meter in length. Rare minerals have not been found in these pegmatites.

*Microscopic characters.* — Under the microscope the rock is seen to be made up of the following minerals: apatite, iron ore, ægirine-augite, hornblende, biotite, felspar, nepheline, cancrinite, and alteration products (zeolites and calcite). Very small quantities of zircon, fluorite, and a rinkite-like mineral have been found in one specimen of the rock.

The apatite in stout prisms or grains is more abundant in this rock than in most other nepheline-syenites. The diameter of the prisms rarely exceeds 0·1 millimeter. The iron ore is in black metallic grains; it occurs in very small quantities and is entirely absent in some slices. It is sometimes associated with pyrite.

The principal dark-coloured mineral is ægirine-augite. This occurs in very imperfect crystals or allotriomorphic anhedra, several millimeters in diameter. It is intensely green with marked pleochroism. The extinction angle $c:\mathfrak{a}$ is large (30° to 40°) in some specimens, and small (about 20°) in others; within each crystal the angle has its maximum value in the central portion and decreases towards the margin, but the difference is only a few degrees. In one instance an anhedron of ægirine-augite has been observed which contained a nucleus consisting of colourless diopside with an extinction angle of about 45°.

Hornblende is entirely absent in some specimens, but others contain a considerable quantity of it. It is in allotriomorphic anhedra. The plane of the optic axis is parallel to (010), and the angle of extinction $c:\mathfrak{c}$ is about 22°; this angle is slightly higher in the boundary-zone of the crystals. The pleochroism is marked with $\mathfrak{c}$ dark green, $\mathfrak{b}$ brownish green, and $\mathfrak{a}$ light brown or greenish.

The biotite is intensely pleochroic; the absorption-tints vary from a very dark green (or in some specimens of the rock: greenish brown) to a light brownish yellow. It is in allotriomorphic plates or aggregates of thick scales. It is sometimes found in micrographic intergrowth with the ægirine-augite. As a rule it is in smaller quantities than the ægirine-augite, but in two specimens of this rock (from Niakornarsuk and from the mountain between Giesecke's Dale and Flink's Dale) it is the most abundant dark-coloured mineral.

Felspar is the main constituent of the rock. It occurs in large tolerably idiomorphic plates. The dimensions have been given above. Between crossed nicols it is seen to consist of a microperthite with a very fine perthitic structure, often graduating into cryptoperthite. In some cases the inner portion of a crystal is homogeneous or cryptoperthitic while the outer zone is perthitic. In sections parallel to (010) the perthitic bands are arranged in the ordinary manner at an angle of about 71° to the basal cleavage. In sections parallel to (001) the perthitic structure is of a reticular type: numerous veinlets of plagioclase follow a direction perpendicular to (010) and are connected with one another by ramifications. The structure in some respects recalls that described from the pegmatites of Narsarsuk[1]. As a rule the potash-felspar of these perthites is *orthoclase;* in some cases, however, an indistinct, gritty or moire twin-structure is observed, which indicates the presence of microcline. The plagioclase-veins show twin lamellation according to the albite law, the lamellæ are fine and the extinction angles small. A comparison of the refracting power with that of Canada balsam and of nepheline shows that the plagioclase is not pure albite, but an acid *oligoclase.* Roughly estimated the two felspars are present in about equal quantities, but the central portion of each crystal is richer in orthoclase while the oligoclase predominates in the peripheral portion, and a narrow zone of pure oligoclase often surrounds the crystal. More rarely crystals of pure oligoclase are found. In a specimen of foyaite from the mountain W. of Flink's Dale the perthitic structure differs from the above described type in being coarser with relatively large areas of orthoclase and oligoclase which are elongated parallel to (010).

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[1] Meddelelser om Grønland XIV, Pl. 4, Fig. 2 (1894).

In most specimens of the foyaite the felspar is very fresh and clear or only a little clouded, but in other specimens which apparently are no less fresh many of the felspar crystals are seen to contain small irregular grains or patches of clear calcite.

Nepheline occurs very abundantly. The crystals are fresh, or contain only a small quantity of secondary muscovite. At their border they have frequently been partially converted into natrolite. The nepheline is sometimes a little more and sometimes a little less idiomorphic than the felspar. Cancrinite is entirely absent in many specimens, but in others it is relatively abundant. It occurs in large lapped anhedra filling the interstices between the crystals of felspar and nepheline. Sodalite is another occasional constituent of the rock, but the quantity of it is never large. Sometimes it is interstitial, sometimes it occurs as a magmatic alteration product of the nepheline.

As to structural details observed under the microscope it may be noted that the dark-coloured minerals, though as a rule disseminated through the rock or occurring in irregular intergrowths, in some few specimens show a tendency towards concentric arrangement. This peculiarity is especially well developed in a medium-grained nepheline-syenite collected at the coast due N. of Igdlerfigsalik. In this rock the dark-coloured minerals are crowded together in patches which consist of an aggregate of ægirine-augite surrounded by hornblende which, in its turn, is surrounded by biotite.

*Chemical composition.* — The chemical analysis of the rock is given in the first column of the following table. The specimens selected for analysis were taken N. N. W. of Igdlerfigsalik at the south coast of the Korok Fjord. Mineralogically, they are of the ordinary type: ægirine-augite predominates among the dark minerals, and sodalite and cancrinite are present only in very small quantities. The structure shows some tendency towards the porphyritic.

*Analyses of foyaites and related rocks.*

| | 25 | A | B | C | D |
|---|---|---|---|---|---|
| $SiO_2$ | 53·53 | 53·68 | 52·25 | 53·71 | 53·73 |
| $TiO_2$ | ·44 | 1·35 | ·60 | 1·03 | ·09 |
| $ZrO_2$ | — | | — | — | — |
| $Al_2O_3$ | 19·69 | 18·42 | 22.24 | 21·82 | 20·35 |
| $Fe_2O_3$ | 5·09 | 5·91 | 2·42 | ·78 | 3·74 |
| FeO | 2·83 | 2·57 | 1·98 | 2·47 | 2·13 |
| MnO | ·24 | ·75 | ·53 | ·19 | ·51 |
| MgO | none | ·88 | ·96 | ·56 | ·47 |
| CaO | 1·87 | 2·05 | 1·54 | 1·90 | 2·72 |
| $Na_2O$ | 9·61 | 9·46 | 9·78 | 8·52 | 7·94 |
| $K_2O$ | 5·23 | 4·92 | 6·13 | 7·07 | 6·05 |
| $H_2O$ above 110° | ·34 | ·89 | ·73<br>(ign.) | 2·27 | 2·02 |
| $H_2O$ at 110° | ·25 | | | | |
| Cl | ·04 | | — | trace | ·23 |
| $P_2O_5$ | ·31 | | — | trace | — |
| $CO_2$ | ·40 | | — | — | — |
| Total | 99·87 | 100·88 | 99·16 | 100·32 | 99·98 |
| Sp. gr. | 2·751 | | | 2·578 | 2·580 |

**25.** Foyaite (Korok type), Korok, South Greenland. C. Winther, analyst.

A. Eudialyte-lujavrite, Tsutsknjun, Kola. W. Petersson, analyst (W. Ramsay, Fennia XV, No. 2, 1899, p. 16).

B. Foyaite (Chibinite), main type, Umptek, Kola. V. Hackmann analyst (Fennia XI, No. 2, 1894, p. 132).

C. Foyaite, Picota, Serra de Monchique, Portugal. P. Jannasch, analyst (Neues Jahrbuch für Mineralogie 1884, II, p. 13).

D. Foyaite, Renseburg, Transvaal. E. A. Wülfing, analyst (Neues Jahrbuch für Mineralogie 1888, II, p. 32).

The analysis and the mineralogical characters agree in showing that the rock belongs to a rather common type of nepheline-syenites. In most parts of the world, indeed, it is possible to find rocks which are closely related to the foyaite of Korok. It is also noteworthy that rare elements are almost entirely absent. On the other hand, if all foyaites of the commonest type be arranged according to the iron contents, the foyaite would be placed at that end which is richest in iron. Thus the rock may be regarded as a transitional type between the ordinary foyaites and the nepheline-syenites rich in iron which are represented in the Ilimausak batholite and in the lujavrites of a few other occurrences. To illustrate this relation an analysis of a lujavrite from Kola is quoted for comparison. Most lujavrites, however, and especially those of Ilimausak contain a still larger quantity of iron.

### *Usuk type.*

A different type of nepheline-syenite occurs in the large valley east of Usuk. The same type has been found as erratics on Mount Iganek. This rock, when fresh, is of a pure gray colour; on weathering it becomes reddish-gray. Structurally it differs from the Korok type in the size of grain and in the form of the felspar crystals. These are Carlsbad twins, developed in very thick plates; their thickness frequently exceeds one centimeter, while the length only attains three or four centimeters. The nepheline is in anhedra or imperfect crystals, one or two centimeters in diameter. The dark-coloured minerals are allotriomorphic.

The mineral constituents of the Usuk type are: felspar, nepheline, olivine, ainigmatite, ægirine-augite, hornblende, biotite, iron ore, and apatite; in one specimen a crystal of eudialyte, about five millimeters long, has also been observed. The felspar is a microperthite of the same kind as that of the Korok-type; more rarely a soda-orthoclase exhibiting a beautiful blue schiller has been observed.

It is not improbable that the Usuk type has a wide distribution in the upper part of the Igdlerfigsalik Mountain which has not been visited by the author. At the summit of the mountain Dr. Steenstrup, in 1888, has collected specimens of a weathered and red-coloured nepheline-syenite which belongs to the Usuk type.

### *Dykes cutting the nepheline-syenite.*

In the nepheline-syenite only a few dykes have been observed. They belong to the following types: fine-grained nepheline-syenite, tinguaite, and syenite-porphyry.

Two or three dykes of a fine-grained nepheline-syenite were found by Mr. Böggild in the large valley east of Usuk. These consist of a gray and somewhat weathered foyaite in which the prevalent dark-coloured minerals are a brown biotite and a diopside with a green marginal zone. One specimen is olivine bearing and of a porphyritic structure, showing phenocrysts of microperthite and nepheline which may attain a length of two or three centimeters.

In the coarse-grained foyaite of the mountain west of Flink's Dale in Korok two dykes of *tinguaite* have been observed. Each is about one meter wide and follows a curved course. The rock is dense and of a greenish-black colour. Under the microscope the main constituents are seen to be: alkali-felspar, biotite, ægirine, and analcime. The felspar is very abundant and appears in the slices as small laths, 0·01 millimeter thick by 0·03 millimeter long, sometimes arranged in radiating groups. Some of the laths are orthoclase, others consist of a plagioclase, probably albite. Perthitic intergrowths are also common; the combination-surfaces are irregular or partially parallel to (010). The analcime is not very abundant, it occupies small areas of irregular form and is partly interstitial between the other minerals. The biotite is present in large quantities. It is strongly pleochroic, showing light yellow and deep greenish-black absorption colours. The ægirine in small grains and rounded prisms is less abundant than the biotite. A cancrinite-like mineral occurs subordinately as small allotriomorphic anhedra. Needles of apatite are rare.

A dyke of *syenite-porphyry,* about ten meters in breadth, traverses the nepheline-syenite on the peninsula west of the Korok Fjord, near the northern end of the submarine moraine. This is a fresh-looking, grayish-brown rock with numerous phenocrysts of felspar (soda-orthoclase), about one centimeter long, which are of a form giving rhomboidal or broad rectangular sections. The ground-mass is fine-grained and of a trachytoid structure: it is mainly made up of felspar-laths which show a marked tendency to parallel disposition. The laths are rarely more than one millimeter long and consist of a very cloudy microperthite. Besides felspar the ground-mass contains allotriomorphic anhedra of a brownish-green hornblende with an angle of extinction $c:\mathfrak{c}$ varying from 15° to 25°. In small quantities the ground-mass also contains rounded prisms of a colourless pyroxene with large angles of extinction. Apatite and iron ore occur as minor accessories. This dyke is of particular interest because it is the only known instance of a syenitic dyke cutting the nepheline-syenites of the Julianehaab district.

## AUGITE-SYENITE OF THE IGALIKO BATHOLITE.

### *Occurrence.*

The augite-syenite covers a border about one kilometer wide along the western side of the foot of the Igdlerfigsalik mountain group, and north of the Korok Fjord it appears again in the coast rocks between Niakornarsuk and the mouth of the fjord.

To the east and north it abuts on the nepheline-syenite, to the west on the rocks of an older origin (vide map, Pl. IV).

The rock is very rapidly decaying, and consequently it has given rise to the formation of plains more or less level and covered with rubbish which contrast markedly with the more or less steep slopes of the abutting nepheline-syenite (Pl. XVII). As a rule these rubbish plains lack vegetation, but a certain break in the uniformity is produced by the presence of small rocks projecting through the rubbish on account of their greater power of resisting erosion. The augite-syenite in Korok's coast rocks forms an exception to this. The rock is here altogether fresh and compact, no doubt because the glacial erosion in the fjord has been so intense that the hardest parts of the rock only have been preserved.

### *Petrography.*

*Macroscopic appearance.* — In its outer appearance the augite-syenite of the Igaliko batholite shows a considerable likeness to that of the Ilimausak batholite, but still more striking is the likeness to the familiar larvikite from southern Norway. As will be seen from the following this likeness also extends to their microscopic characters and chemical composition. In its freshest state the rock is of a dark gray colour, but usually it is of a somewhat lighter gray or brownish-gray, and on the surface it can sometimes be reddish-gray. The structure is coarse-grained; an imperfect parallel arrangement of the oblong felspar crystals is found in some cases. Porphyric varieties have especially been found in the western part of the area near the junction of the sandstone. The main constituent of the rock is a gray, semi-transparent felspar which becomes whitish by weathering and very often shows a beautiful blue schiller. The crystallographic form of the felspar is badly developed, still, on fresh surfaces of fracture the rock exhibits felspar sections which evidently tend towards stout rectangular or rhomboidal outlines. Both forms are generally to be seen in each specimen. The length of the crystals is one or two centimeters. The width of the rhomboidal slices is a little less than half as large, whilst that of the rectangular slices is often one third of the width only. Dark-coloured minerals are present in no small quantity; augite and biotite are to be seen with the naked eye.

*Microscopic characters.* — Under the microscope the rock is seen to be built up of the following minerals: apatite, iron ore, augite, hornblende, biotite, and alkali-felspar. In addition to these a large quantity of olivine and nepheline has been found in some specimens, and only in very few cases and very sparingly ainigmatite, titanite, and zircon have been found.

As usual the apatite has been developed in stout prisms, and can be found imbedded in all the other minerals. The iron ore is in grains or in irregular anhedra sometimes as large as 2 millimeters in diameter. In reflected light it is black metallic and often shows distinct twin-lamellation.

Olivine occurs rather abundantly in some of the specimens from Niakornarsuk, but is lacking in those from Narsarsuk and Iganek. The size of the grains does not exceed 3 millimeters. In the slices it has a very faint yellowish colour, and often contains the very same streak-like inclusions mentioned on p. 199. The cracks are filled with black disintegration products, but on the whole the mineral is very fresh. It is often surrounded by a border zone of greenish augite.

The augite which is always the main ferromagnesian constituent forms allotriomorphic anhedra of a diameter of several millimeters. "Schiller" inclusions in two directions are often observed; as a rule, this structure affects only a small portion of each crystal. The colour of the augite in most of the specimens examined is quite light, grayish-green, but in the variety of the rock from Niakornarsuk which has been analyzed, the augite is grayish-violet and exhibits a slight pleochroism.

In both cases the extinction angle in section parallel to the symmetry plane (010) is about 45°, and likewise the augite has often a narrow green border zone in which the angle $c : \mathfrak{a}$ is somewhat smaller, indicating a slight admixture of the ægirine-molecule. In some specimens (both olivine-bearing and the opposite) the augite is accompanied by or replaced by an ægirine-augite with an extinction angle $c : \mathfrak{a}$ amounting to about 25°, and sometimes with a border zone of almost pure ægirine.

The hornblende in this rock is of a brown colour. The extinction angle $c : \mathfrak{c}$ is about 15—20° and the pleochroism-scheme is:

$\mathfrak{a}$ entirely light brown
$\mathfrak{b}$ dark brown
$\mathfrak{c}$ dark greenish-brown.

It is allotriomorphic and occurs in greatly varying quantities, in some specimens it is almost as plentiful as augite, in others it is very scarce. It is often found in parallel intergrowth with augite, thus, an augite crystal may enclose many small irregular areas of hornblende, and at the same time be surrounded by this mineral. Sometimes a narrow border of pale green augite surrounds the hornblende. Biotite flakes of a deep brown colour are usually present to a very small extent only; as a rule they are associated with iron ore.

Felspar, the chief constituent of the rock, is a soda-orthoclase. The extinction angle is about 11—13° in sections parallel to (010). Sometimes it is quite homogeneous, and in such a case vaguely defined specks may be found in the crystals which, among the crossed nicols, show an extremely fine cross-hatching indicating the presence of soda-microcline. More frequently the felspar among crossed nicols has a more or less irregular patchy or moire appearance due to variations in the chemical composition. As a rule the central portions of the crystals are richer in potash-felspar, whilst the peripheric portions approximate more to pure albite. A cryptoperthitic differentiation is also to be seen very frequently. Minute pulverous inclusions, giving a dark colour to the mineral, have been found in the felspar in some specimens of the augite-syenite from Niakornarsuk. In nearly all the specimens of this rock the felspar is fresh, or only a little clouded by reason of disintegration products.

Nepheline is entirely absent in some specimens, but generally it is present in considerable quantities. It is partially interstitial, and partially in micrographic intergrowth with the felspar. As a rule it is fresh; in some cases, however, it has partly changed to muscovite.

The structure of the rock is typical hypidiomorphic, and presents nothing very particular compared with the augite-syenite from other places. But it is worth mentioning that although the dark minerals are often grouped together as in other syenites of the Larvik type, this feature does not approximately come out so strongiy in this augite-syenite as in that of Kangerdluarsuk (p. 189).

*Chemical composition.* — Specimens were taken for analysis of the very fresh augite-syenite from Niakornarsuk on the north western side of the Korok Fjord. The minerals in this variety of the rock are felspar, violet augite, some olivine, and iron ore, and very small quantities of brown hornblende, biotite, and apatite. As most of the varieties of the Igaliko syenite differ from the specimen analyzed in not containing olivine, it is probable that the general composition of the rock is a little more acid than that of the variety analyzed. The result of the analysis is given in No. **26** in the table annexed. As a comparison is stated the analysis of the augite-syenite of Kangerdluarsuk and of a larvikite from Norway.

The Korok augite-syenite, as will be seen from the table, shows a rather close conformity to that of Kangerdluarsuk, and

*Analyses of augite-syenites.*

| | 26 | A | B |
|---|---|---|---|
| $SiO_2$ | 53·71 | 55·79 | 56·85 |
| $TiO_2$ | 3·40 | 1·81 | |
| $Al_2O_3$ | 15·37 | 15·76 | 21·56 |
| $Fe_2O_3$ | 3·28 | 1.60 | 3·44 |
| FeO | 5·72 | 7·56 | 1·14 |
| MnO | ·14 | ·14 | |
| MgO | 1·58 | ·41 | ·85 |
| CaO | 5·20 | 3·70 | 5·26 |
| $Na_2O$ | 6·84 | 7·72 | 6·07 |
| $K_2O$ | 4·11 | 4·34 | 3·66 |
| $H_2O$ above 110° | ·45 | ·18 | ·52 |
| $H_2O$ at 110° | ·33 | ·34 | |
| $P_2O_5$ | ·52 | ·36 | |
| Total | 100·65 | 99·71 | 99·35 |
| Sp. gr. | 2·697 | 2·766 | |

**26.** Augite-syenite, Niakornarsuk, Korok Fjord, S. Greenland. C. Winther, analyst.

A. Augite-syenite, Kangerdluarsuk, S. Greenland (= analysis No. 16, p. 190).

B. Augite-syenite (larvikite), Nötterö, Norway. G. Forsberg, analyst (W. C. Brögger, Zeitschrift für Krystallographie XVI, 1890, p. 30).

as both of the rocks, especially the last mentioned, in some degree show local variations in their chemical composition the idea is not excluded that the two rocks may be identical in their general composition. Still it would seem probable that the presence of lime in greater quantities in the analysis of the Korok rock; is not casual, but an expression of a general difference between the augite-syenite of the Igaliko batholite and that of the Ilimausak batholite. Furthermore it will be seen from the table that the Korok augite-syenite closely agrees with the larvikite from southern Norway, especially as far as the figures for lime and alkali are concerned. The main difference is in the iron oxides.

### *Border facies of augite-syenite.*

The augite-syenite, at its western border at the junction of the sandstone and the basement granite, shows a very marked endomorphic contact modification which, however, is only a few meters wide. Towards the point of contact the rock gradually becomes more fine-grained and often porphyritic. Sometimes a coarse-grained and a fine-grained rock alternate in "schlieren". Dense modifications, not seldom with well developed flow structure, have also been observed in the numerous apophyses penetrating the sandstone. Examined under the microscope this border facies essentially displays the same mineral composition as the main rock: it is made up of soda-orthoclase (in one specimen: microperthite) and augite with some iron ore, apatite, and often some brown hornblende and biotite. As a contrast to the main rock it must be mentioned that in all the specimens examined of the border rock olivine as well as nepheline are absent, whilst in some few cases, the more coarse-grained apophyses, quartz enters as an essential constituent; it is also worth mentioning that the dark minerals are not crowded together in specks, but are evenly distributed throughout the rock.

### *Occurrence of rare minerals on Narsarsuk.*

The rocks in the Igaliko batholite, the augite-syenite as well as the nepheline-syenite are altogether poor in rare minerals, whilst the case is the reverse as regards the rocks in the Ilimausak batholite. Still there is one exception and a very noteworthy one: Narsarsuk's mineral locality. Here the rare minerals occur in pegmatitic segregations belonging to the augite-syenite, and consequently their occurrence should be treated here.

The augite-syenite by its disintegration has formed a fairly level plain called *Narsarsuk* (Pl. XVII) at the western side of the foot of the Igdlerfigsalik Mountain. It is situated at an altitude of 250—300 meters and has an area of a few square kilometers. The plain is entirely denuded of vegetation, and is covered by coarse rubbish of decaying augite-syenite, the wind having carried away all fine material. In a closely defined area not more than a hundred meters in diameter an amazing number of rare and well crystallized minerals have been found, mostly loose in the rubbish, but belonging to the rock disintegrated on the spot. The mineral locality is about 270 meters above sea level, a little less than one kilometer south of the southern end of the moraine near the entrance to the Korok Fjord. The spot is marked by a cross on the geological map (Pl. IV).

The locality was not known until 1888 when the Greenlanders from Igaliko took Dr. STEENSTRUP to the place where the large ægirine crystals, which are now familiar to all collectors of minerals, were found. A few years later neptunite and other rare minerals were found by the Greenlanders, but a thorough mineralogical investigation of the locality was not undertaken until 1897 by Dr. G. FLINK who found a large number of new minerals[1].

Each year since then the Greenlanders from Igaliko have searched for minerals on the Narsarsuk, and several European mineralogists have visited the place, but only some few fresh discoveries have been made[2].

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[1] G. FLINK, Berättelse om en Mineralogisk Resa i Syd-Grönland 1897. Meddelelser om Grønland XIV, p. 223.

[2] O. B. BÖGGILD, On some minerals from Narsarsuk. Meddelelser om Grønland XXXIII, p. 97 (1906).

Dr. FLINK has written a memoir "On the Minerals from Narsarsuk" in which an exhaustive account of most of the minerals from this place is given, accompanied by a description and diagram of the place itself[1]. By undertaking a number of minor excavations he found that all the minerals in question originate in irregular pegmatitic segregations of syenite. In some of the specimens which FLINK has collected the pegmatite is in contact with a white quartziferous sandstone, probably occurring in fragments in the syenite. The pegmatitic rock mainly consists of felspar and ægirine with some quartz and a little eudialyte, and most of the rare minerals are found in small cavities in the pegmatite. As may be seen from the map (Pl. IV) the place is only a few hundred meters away from the point of contact between the augite-syenite and the sandstone to the westward of that which dips to the east at the junction. Consequently the pegmatites may be said to belong to the border facies of the augite-syenite, and with so much more reason as the augite-syenite itself has a somewhat porphyric structure in the mineral locality.

As to the minerals from this place the following are found in large crystals especially well developed: synchysite, epididymite, albite, ægirine, catapleiite, elpidite, and neptunite. A complete list is given in the table over-leaf. The entire list of minerals is also entered in the table for all the localities belonging to the Ilimausak batholite (i. e. the mineral localities which in mineral collections are usually indicated Kangerdluarsuk, Naujakasik, and Siorarsuit) because a comparison is of interest, considering the large geological differences between both batholites. In the list all such minerals have been omitted which are only identified by microscopic examination. The

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[1] G. FLINK, On the Minerals from Narsarsuk. Meddelelser om Grønland XXIV, 1899. In the diagram accompanying Dr. FLINK's treatise (Pl. IX) the sandstone west of the mineral locality has wrongly been indicated as granite.

### *List of the minerals found at Narsarsuk and of those found in the mineral localities of the Ilimausak batholite (Kangerdluarsuk etc.).*

| | Narsarsuk | Kangerdluarsuk etc. | | Narsarsuk | Kangerdluarsuk etc. |
|---|---|---|---|---|---|
| Graphite | × | × | *Stenstrupine* | | × |
| Molybdenite | | × | Leucophane | | × |
| Galenite | × | × | Nepheline | | × |
| Sphalerite | × | × | *Sodalite* | × | × |
| Fluorite | × | × | Garnet | | × |
| Quartz | × | × | Zircon | × | |
| Hæmatite | | × | Epidote | × | × |
| Magnetite | × | | Ilvaite | | × |
| Calcite | × | × | Analcime | × | × |
| Rhodochrosite | × | | Natrolite | × | × |
| *Cordylite* | × | | *Polylithionite* | × | × |
| *Synchysite* | × | | Biotite | × | × |
| *Ancylite* | × | | Chlorite | | × |
| Eudidymite | × | | *Spodiophyllite* | × | |
| *Epididymite* | × | | *Tæniolite* | × | |
| *Leucosphenite* | × | | Astrophyllite | × | × |
| Potash-felspar | × | × | *Neptunite* | × | |
| Albite | × | × | *Narsarsukite* | × | |
| Ægirine | × | × | *Lorenzenite* | × | |
| *Schizolite* | | × | *Rinkite* | | × |
| Hornblende | × | | Microlite | × | |
| Riebeckite | × | | *Chalcolamprite* | × | |
| Crocidolite | × | × | *Endeiolite* | × | |
| *Arfvedsonite* | × | × | *Epistolite* | | × |
| *Ainigmatite* | | × | *Erikite* | | × |
| *Eudialyte* | × | × | *Britholite* | | × |
| Catapleiite | × | | Apatite | × | × |
| *Elpidite* | × | × | | | |

names printed in italics indicate minerals which were new to science on being found in this region.

Narsarsuk's richness in rare minerals is characterized by the fact shown in the table that the number of previously unknown minerals, which, mainly through Dr. Flink's efforts, have been found in the very small area of the Narsarsuk locality, is no less than thirteen. Compared with this the Ilimausak batholite may be called relatively poor, as in the aggregate its numerous and much more thoroughly worked localities have only enriched science with eleven new mineral species, and some of these are even rather common minerals which by a mere chance were first described from Greenland.

When comparing the list of the Narsarsuk minerals on the one side, with that of the minerals occurring inside the Ilimausak batholite on the other, one's first impression is that of a rather considerable dissimilarity. The Narsarsuk list altogether comprises 41 mineral species, the other list 35, and of these only 21, or a little more than half of the number, are common to both of the lists. But on closer consideration the differences turn out to be of slight importance, when looked at from a theoretical point of view. Thus it deserves mention that the discrepancies would already be considerably smaller if the minerals which have only been observed under the microscope had been entered in the list. Greater importance must be attached to the fact that it does not seem possible out of the differences to derive definite rules for the division of the minerals in the two lists, but the differences have a rather chance character, whilst on the other hand there are important points of similarity, especially as regards the presence of less common elements. So that Narsarsuk as well as the localities in the Ilimausak batholite are characterized by the presence of minerals in large quantities rich in zirconium, titanium, niobium, and cerium metals, and by the occurrence in smaller quantities of beryllium and lithium compounds. Furthermore they unite in the absence of certain rare elements which may be found in other places in the pegmatite belonging to the rock of the alkali series. Thus boron is entirely absent, and tantalum is only present in extremely small quantities.

The table at foot will show more distinctly the analogies between the Narsarsuk mineral locality and that of the Ilimausak batholite (Kangerdluarsuk etc.) respecting the occurrence of minerals rich in zirconium, titanium, niobium, cerium metals, beryllium, and lithium.

| Minerals rich in | *Narsarsuk* | *Kangerdluarsuk etc.* |
|---|---|---|
| *Zirconium* | Eudialyte<br>Catapleiite<br>Elpidite<br>Zircon | Eudialyte<br><br>Elpidite |
| *Titanium* | Neptunite<br>Astrophyllite<br>Tæniolite<br>Narsarsukite<br>Lorenzenite<br>Leucosphenite | Ainigmatite<br>Astrophyllite |
| *Cerium metals* | Synchysite<br>Cordylite<br>Ancylite | Steenstrupine<br>Rinkite<br>Erikite<br>Britholite |
| *Niobium* | Chalcolamprite<br>Endeiolite | Epistolite |
| *Beryllium* | Epididymite<br>Eudidymite | Leucophane |
| *Lithium* | Polylithionite<br>Tæniolite | Polylithionite |

### *Dykes cutting the augite-syenite.*

Only some few dykes have been observed in the augite-syenite, but as the greater part of the syenite area is covered with rubbish, several dykes may have been overlooked. An aplitic dyke was found in the little valley north of the Iganek Mountain at a place lying about 250 meters above sea level. This dyke is only 1·3 meter wide; it is quartz-bearing and fine-grained, the colour being gray. A narrow marginal zone on each side consists of a black glassy material with phenocrysts of white felspar showing broadly rectangular sections of a length of 1 or 2 millimeters only.

A more peculiar dyke was found near the river south of the Narsarsuk Plateau a little above the water-fall made by this river where it falls on to the low granite area north of the Igaliko Fjord. The dyke is a tinguaite. It is five meters wide, and runs from E. N. E. to W. S. W., the same direction as most of the dykes in the sandstone territory. The rock is a grayish-green porphyry with a fine-grained ground mass; in the border facies the ground mass is dense and the colour a clearer green. This dyke is specially interesting as it contains scarce quartz-like grains 3—5 millimeters in size which are probably extraneous inclusions in the rock, and which on closer investigation proved to be cordierite. They have the appearance of milky quartz and are rich in minute inclusions which are needle-shaped and arranged parallel to the least axis of optic elasticity, whilst other inclusions consisting of small rounded pyroxene-like grains are arranged in rows at right angles to the former. The mineral is optic biaxial, and has a mean index of refraction slightly lower than that of the Canada balsam. The microscopic test which indicated the presence of large quantities of magnesium moreover proved the identity of the mineral with cordierite. The ordinary phenocrysts of the rock consist of a clear orthoclase in rather scarce large tables, about 10 millimeters by 3—5 millimeters. The extinction angle on (010) is 7° indicating the presence of albite silicate to a slight extent. A few ægirine-prisms also occur as phenocrysts. The ground mass consists of felspar, ægirine, analcime, and probably nepheline, besides small quantities of a reddish-brown strongly pleochroic biotite, a few small patches of a blue arfvedsonite-like mineral, and perhaps sodalite. The felspar of the ground mass occurs in laths about half a millimeter in length; they are twinned, and seem to be albite, but an exact determination was not possible on account of their richness in ægirine-microlites and other inclusions. The ægirine is very abundant, and shaped both like prisms and allotriomorphic anhedra. The analcime is also very abundant and is apparently quite secondary. It contains remnants of a stronger refractive mineral resembling nepheline.

## CONTACT RELATIONS OF THE IGALIKO BATHOLITE.

As may be seen from the geological map (Pl. IV) the boundaries of the Igaliko batholite are partially covered by alluvial deposits and by the sea, and partially they have not been explored. Only in the district between the Tunugdliarfik Fjord and the large valley north of Tavdlorutit in a tract of about seven kilometers the author had the opportunity to study the junction between the augite-syenite and the rocks of an older origin, which are represented here by red sandstone and granite.

The junctions are of a type far different from those met with near the Ilimausak batholite. The contact planes observed at the latter are in some places vertical, whilst in others the rocks of an older origin overlie the batholite; but at the part of the junction which has been examined the contact plane is nclined towards the augite-syenite, so that we may regard this as resting upon the said rocks at its junction, just as it, in its turn, has been covered by nepheline-syenite.

Sections almost at right angles to the horizontal border line have been observed in three places: on the Iganek Mountain, and at the southern and northern ends of the Narsarsuk Plateau. The augite-syenite at all three places is bounded by sandstone, and the sandstone beds dip to the east under the syenite (Figs. 21 and 22).

### *Mount Iganek.*

The mountain so called lies on the Igaliko Fjord opposite to Igaliko, and according to Steenstrup's measurements it has an altitude of 562 meters. Its upper part consists of a quartzitic sandstone greatly metamorphosed and very capable of resistance to erosion. It is presumable that the augite-syenite formerly covered the top, and that the hard quartzite now projects as a separate mountain on account of the rapid disintegration of the syenite.

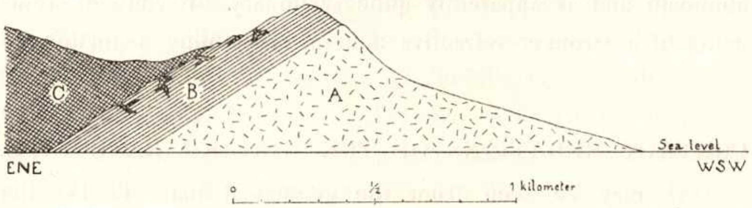

Fig. 21. ENE—WSW section of the northern part of Mt. Iganek showing junction of augite-syenite and sandstone. — A basement granite; B sandstone and hornfels; C augite-syenite.

Through a fault (Pl. IV) the mountain is divided into a southern and a northern half. The southern part consists of sandstone strata dipping at an angle of about 8° to N. N. W., but the contact between these strata and the augite-syenite to the east is not exposed to view. A rivulet running northward has excavated a small valley north of the fault, and on the left side the contact is well exposed (Fig. 21). The augite-syenite at the bottom of the valley is of the usual gray and coarse-grained type, but at the contact with the sandstone it becomes reddish and turns to a fine-grained and sometimes porphyritic border facies. It sends numerous apophyses into the sandstone. These are reddish, fine-grained or dense, more or less porphyritic, and sometimes they show a strongly-marked flow structure. Their course is somewhat irregular, but they mostly run parallel to the bedding planes of the sandstone (this fact is only imperfectly shown on the diagram). Directly at the point of contact the sandstone beds have a sharp and rather irregular dip in an eastern direction, but already at a short distance from that point they become very regular, with a uniform incline of 33° to the east and 10° to the north. The entire thickness of the sandstone in this place is less than 200 meters, and all the beds are greatly metamorphosed by contact, and consist of a white quartzitic rock with minor, but thick seams of a black hornfels rich in mica. The crest of the mountain is formed of white quartzite.

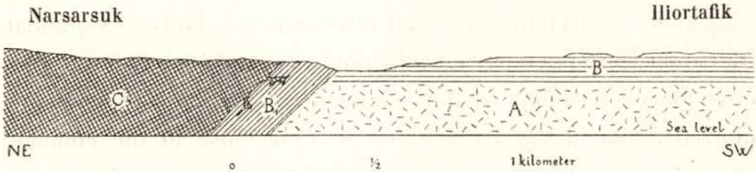

Fig. 22. NW—SE section of the plateau of Narsarsuk near the moraine at the entrance of Korok Fjord. — A basement granite; B sandstone; $B_1$ sandstone and hornfels; C augite-syenite.

During the field work it was thought that the sandstone was lying in its original position in proportion to the old granite which is to be seen under it on the western side of the mountain, and the junction between granite and sandstone was not closely examined. However, doubt may arise as to whether the sandstone in the northern half of the Iganek Mountain (Fig. 21) represents the lowest sandstone beds deposited on the granite. This will appear from a comparison of the order of the strata in the two halves of the mountain divided by the fault. In the southern half the succession in descending order is:

Alternating beds of white quartzite and black hornfels; about 200 meters;
Granite;

whilst the following succession was noted for the southern half during a cursory examination (the thicknesses have not been measured, but only estimated):

White quartzite, about 60 meters;
Black hornfels with subordinate quartzite beds, about 40 meters;
White quartzite and black hornfels, about 100 meters;
White quartzite with subordinate dark beds, about 200 meters;
White sandstone, about 100 meters;
Red sandstone, about 200 meters;
Granite.

This last section is of itself interesting as showing a gradual transition from the relatively unaltered red sandstone at the southern side of the foot of the mountain to the greatly metamorphosed strata in the crest which is quite close to the contact, and probably was at one time covered by augite-syenite. If the quartzite in the northern half of the Iganek Mountain (Fig. 21) had been lying in its original position in relation to the granite on which it now lies, it should correspond to the red sandstone in the southern part of the mountain, and the numerous thick hornfels beds in the quartzite north of the fault should be represented south of it by slate beds and diabase sheets wedged into the red sandstone. But this sandstone at the southern side of the foot of the Iganek Mountain, as far as has been observed, is very poor in diabase and shale. On the other hand there is a striking likeness between the strata directly covering the granite north of the fault and those south of it which lie several hundred meters above the granite. Consequently it does not seem unlikely that the sandstone mass delineated on Fig. 21 is only an isolated large fragment of sandstone which has gained its present position in relation to the granite through the disturbances which accompanied the intrusion of the abyssal rocks.

A more detailed investigation, however, will be necessary in order to decide the question.

### *Narsarsuk.*

The augite-syenite with its usual fine-grained contact facies north of the Iganek Mountain borders directly on the old granite, but the contact plane also inclines here towards the batholite, so that the margin of the augite-syenite lies upon granite. Sandstone appears again on the Narsarsuk Plateau. The sandstone beds at the direct contact plane incline towards the syenite at rather sharp angles (40°—50°). They are of a quartzitic nature, and alternate with beds of black hornfels rich in biotite, quite like the Iganek Mountain. But at a short distance west of the contact plane the sandstone strata are horizontal and of a more uniform nature, and they remain so for a long stretch to the westward. A good section of the junction between the sandstone and the augite-syenite is exposed in the steep wall at the north coast of the Narsarsuk Plateau (Fig. 22), and quite a similar section is to be seen at the southern end in the steep rocky wall dividing the plateau from the low granite tract north of the Igaliko Fjord. The total thickness of the inclined sandstone strata in both places was found to be less than 200 meters.

The occurrence of rare minerals attached to the border facies of the augite-syenite on the Narsarsuk Plateau is mentioned on p. 244.

### *Contact metamorphism of surrounding rocks.*

Where the wall of the batholite is made up of sandstone formations it has passed through an intense contact metamorphism. Rocks of this formation altered in a high degree are to be found along the margin of the batholite from the outlet of the Korok to the valley north of Tavdlorutit. The metamorphosed strata, especially on the Iganek Mountain, are splendidly exposed, the whole crest of the mountain consisting of such rocks of a total thickness of several hundred meters, whilst the red sandstone at the south western side of the foot of the mountain stands out with its usual characteristics as mentioned on p. 254.

On ascending the Iganek Mountain from the west, the first traces of the contact metamorphism already appear at an altitude of about 50 meters, the red colour of the sandstone disappearing, and the beds assuming a white or gray colour. The alteration is more intense higher up the mountain. The beds which consist of relatively pure quartz-sandstone are white and quartzitic, the impure beds appearing like dark gray, fine-grained seams. On microscopic examination these dark gray beds show the following peculiarities: the quartz grains have retained their rounded contours, but the cement has been re-crystallized to an aggregate of felspar and quartz grains, through which a number of other minerals are disseminated: granules of a colourless pyroxene, scales of biotite, minute specks of black iron ore, and groups of hornblende needles. These are in some cases blue and crocidolite-like, in others they resemble actinolite.

In the upper part of the mountain the operations of the contact metamorphism reach their maximum. The rocks are hornfels and white quartzite, the beds of the first mentioned being exeedingly numerous, varying in thickness from a few centimeters to about ten meters. The fissures in the rock are covered by crystals of garnet, epidote, actinolite, fluorite, and sometimes graphite. The hornfels beds are most frequently black or dark gray, but gray and pale green beds may be found too. All of them are of a massive not schistose structure, their size of grain being extremely small, irrespective of the large scales of black mica which are to be found in many of them. A large part of these hornfels rocks are no doubt alteration products of the diabases and other igneous rocks occurring as intrusive sheets in the sandstone, whilst another part has come into existence from subordinate beds of impure sandstone or argillaceous material. It is not impossible that in some cases a transference of matter from the magma to the sediments may have taken place. A circumstance pointing in this direction is the not unusual occurrence of fluorite and crystallized hæmatite in fissures in the sandstone, even far away from the line of contact. Some of the hornfels sheets may perhaps have been enriched with iron in this manner, and the graphite may perhaps be of pneumatolytic origin.

Under the microscope the hornfels beds appear to be of an extremely varying composition, and not two specimens have been found alike. The number of minerals to be seen in thin sections is very large, but on account of their small size of grain their identification is often difficult or impossible. We will only refer to a few instances here.

A specimen which seems to represent an entirely re-crystallized igneous sheet shows large scales (about 1 millimeter) of chocalate-brown biotite irregularly distributed over a very fine-grained mass. This consists of a micro-crystalline aggregate of twinned felspar grains mixed with a number of other minerals, among which a fibrous greenish hornblende and a colourless mineral having the qualities of the clinozoisite are most conspicuous. Apatite needles are tolerably abundant, iron ore only occurs in relatively large irregular grains surrounded by biotite. Small cracks in the rock are filled by analcime and a little fluorite.

In another specimen which is probably of similar origin, the biotite is of a brownish-green colour mixed with brown garnet, granules of iron ore, titanite, and a large quantity of pale green augite. The latter is partly in relatively large anhedra which seem to be remnants of the original augite of the rock, and partly in small rounded grains. Among these minerals lies a colourless aggregate of felspar and alteration products of same.

The third specimen is a dark gray, very fine-grained rock in which the microscope reveals the presence of granules of a green spinel, scales of biotite and muscovite, and quite small syenite-like grains, lying evenly distributed over a fine-grained aggregate of felspar, probably orthoclase.

A more divergent type is represented by a number of very heavy specimens of black hornfels. Felspar is usually absent here, and its component elements are small rounded grains of a colourless or greenish augite and of black iron ore, amalgamated with very small scales of brown biotite. Brown garnet and titanite often occur too, and sometimes the augite is replaced by a greenish-brown hornblende.

An andalusite hornfels has been found represented among a series of specimens collected by Dr. Steenstrup in 1888 on the Iganek. This rock is distinctly stratified of a rather dark reddish-gray colour, and speckled with scales of biotite about one millimeter in size. Under the microscope the biotite is seen to be of a light brown colour, its quantity being rather inconsiderable, as the rock is essentially made up of andalusite, quartz, felspar, muscovite, and small specks of iron ore. The andalusite is colourless; it occurs in anhedra several millimeters in extent entirely filled by granules of the other minerals. This rock has, no doubt, originated in an argillaceous bed, and the same is probably the case with a hornfels rich in biotite collected near the top of the mountain, and in which the colourless minerals are quite filled by very fine sillimanite-like needles.

## BASEMENT GRANITE AND SANDSTONE AREAS.

As will be seen from the geological map (Pl. IV) the country west and south of the Igaliko batholite is made up of basement rock, mainly granite and sandstone. The sandstone contains several intrusive sheets of igneous rock, and the former as well as the basement rock is traversed by hundreds of dykes. The sandstone areas in this region are upon the whole low lying, and in only very few places do they extend beyond 400 meters. The basement rocks often form mountains of an altitude of more than 800 meters, but even these appear low compared with the lofty and snow covered summits of the adjacent batholite. Also in other respects do the topographic features vary from those of the batholite, the basement rocks and the sandstone being relatively compact and capable of resisting weathering. The surface of the rock in higher altitudes is therefore most frequently dark and overgrown by lichen, and the lower areas are green with shrubs and grass, but we do not find such extensive surfaces without vegetation, such large screes and stone rivers like those which are so common within the domain of the batholite. An exception is mentioned on p. 230.

## CHARACTER AND DISTRIBUTION OF ROCKS.

*Basement rocks.* — The most widely spread basement rock in this region is the Julianehaab granite, the petrographic qualities of which have been mentioned in the first chapter. In the same place reasons are given which favour the belief that this rock is of Algonkian age.

Inside the granite territory subordinate masses of diorite (p. 12) have been found in several places, but these diorite areas are but small, and as their limits have not been minutely examined, they are not indicated on the map. The places where diorite has been found are the following: 1) Directly north of the Igaliko a quartz-diorite occurs in an area of less than two square kilometers. This diorite lies upon the granite near the coast, and at an altitude of about 50 meters it is covered by sandstone. 2) A diorite of quite a similar nature is to be found in the upper part of the Tavdlorutit Mountain east of

Igaliko. This diorite area is also rather small. On ascending the mountain from the north western side one observes that the lower part of it is a granite of the usual type partially red, partially gray; the diorite appears again at an altitude of a litttle more than 300 meters, and forms the western top (about 800 meters) of the mountain. But at a short distance, perhaps half a kilometer, east of the top it again gives place to the biotite-granite. 3) A dark diorite without quartz occurs near Sigsardlugtok on the western side of the Igaliko Fjord. On its eastern side opposite to Sigsardlugtok the granite contains dark coarse-grained inclusions or segregations, which in their outer appearance correspond to the diorite from Sigsardlugtok.

A rock, probably much older, is to be found near Kiagtut (on the northernmost part of the map, Pl. IV), namely a strongly-marked foliated and somewhat porphyritic gneiss or gneiss-granite of a greenish-gray colour.

*Igaliko sandstone.* — The Igaliko sandstone, no doubt, has originally covered large districts, but on account of dislocations accompanying or preceding the formation of the batholite and the long continued erosion, most of the sandstone has disappeared, and that which is now left covers four mutually separate areas (vide map, Pl. IV). One of these, the sandstone of the Iganek Mountain, has been mentioned previously (p. 253). The sandstone area stretching westward to the Tunugdliarfik Fjord from the Igaliko hamlet is considerably larger. To the south, on the mountain Nulup Kakâ, it is cut off by a fault, south of which the old granite rises to an altitude of 800 meters. The sandstone attains a considerable thickness, more than 500 meters, due north of the fault, but northward the surface sinks, and the lower surface rises so that the layer becomes flat, and in the low depression, Itivdlersuak, connecting the Tunugdliarfik Fjord with the inner end of the Igaliko Fjord north west of the hamlet, the sandstone has entirely crumbled away by erosion. The inclination of the sandstone beds in the environs of Igaliko is 0—5°, and runs, as a rule, in a southern direction, but just at the fault considerable disturbances are to be seen, and a steep dip to the north may often be observed here. The colour of the sandstone in this area is usually red, but at the direct contact with the dykes it is often discoloured.

In 1900 the author had only little opportunity of undertaking a closer investigation of the sandstone formations near Igaliko, but a number of observations from previous visits there have been reported by K. J. V. Steenstrup[1]. We learn from these that at least four diabase sheets, sometimes exhibiting a fine columnar structure, occur among the sandstone beds. Some of these igneous sheets are decidedly sills, but

Fig. 23. Sandstone cliffs near Igaliko.

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[1] Meddelelser om Grønland XXXIV, p. 119 (1909).

one of them, occurring about 50 meters above Igaliko, is in its upper part of a pronounced slaggy appearance. But pebbles of diabase have not been found anywhere in the sandstone beds which immediately cover the diabase sheets, and Dr. Steenstrup consequently regards it as being most probable that all the diabase sheets are intrusive. On the other hand the slaggy surfaces show that the rock cannot have been formed to any very considerable depth below the surface, and thus we come to the conclusion that Igaliko's slaggy diabase represents one of the oldest, if not the oldest, manifestation of the igneous activity which in its further development produced the batholites of Igaliko and Ilimausak.

The sandstone appears again north of the Itivdlersuak depression, and forms the Iliortafik Plateau which has only an altitude of 2—300 meters. Here the stratification is horizontal and the thickness of the sandstone stratum is very slight, so that the underlying granite is visible at the foot of the plateau on the north western as well as on the southern side (vide Fig. 22, p. 253). The sandstone on the Iliortafik Plateau is peculiar from the fact that the upper beds are white and quartzitic, whilst the sandstone strata are red some distance below the surface on the south western part of the plateau. It is likely that the quartzitic character of the upper beds is due to contact metamorphism, as the beds, which are now on the surface of the plateau, were at one time covered either by augite-syenite or some intrusive sheet of a considerable thickness.

The sandstone area which is to be seen on the map (Pl. IV) west of the Tunugdliarfik Fjord is the largest of all of them, and stretches westward towards the Ilimausak batholite. The sandstone in this area closely corresponds to that near Igaliko.

## FAULTS.

As we have mentioned (p. 260) the area inside which the red sandstone is to be found is limited, to the north as well as to the south, by large faults with a main direction E. N. E. to W. S. W. The exact position of the northern fault-line which lies entirely inside the granite territory is not known, but most likely it crosses the Tunugdliarfik Fjord somewhere near Kiagtut. The southern main fault runs about two kilometers south of Igaliko along the northern slope of the mountain Nulup Kakâ. This fault is most obvious when the mountain is looked at from the fjord or from the opposite coast. It is almost vertical, and strikes from W. 10° S. to E. 10° N. The vertical displacement amounts to 800 meters at least, this being the altitude to which the granite rises closely south of the fault, whilst on the northern side the basis of the sandstone is below sea level. Just north of the fault the sandstone beds dip abruptly in a northern direction, or in some places they lie irregularly, but within a short distance from this place they are nearly horizontal.

Faults have been observed also inside the sandstone area, but they are not very common, and, as a rule, the throw is only insignificant. The fault through the Iganek Mountain forms an exception (vide map Pl. IV and Fig. 24 on next page). The strike of this fault is about N. 60° E. and S. 60° W., the southern side has subsided, and the down-throw is about 400 meters. The sandstone strata in the southern part of the mountain are inclined at an angle of about 8° to N. N. W., whilst the highly contact metamorphosed beds covering the granite north of the fault dip about 33° E. 10° N. (vide Fig. 21, p. 252).

A fault, probably the continuation of the Iganek fault, is to be seen on the western side of the fjord a little north of Igaliko (vide map, Pl. IV). The extent of the vertical displace-

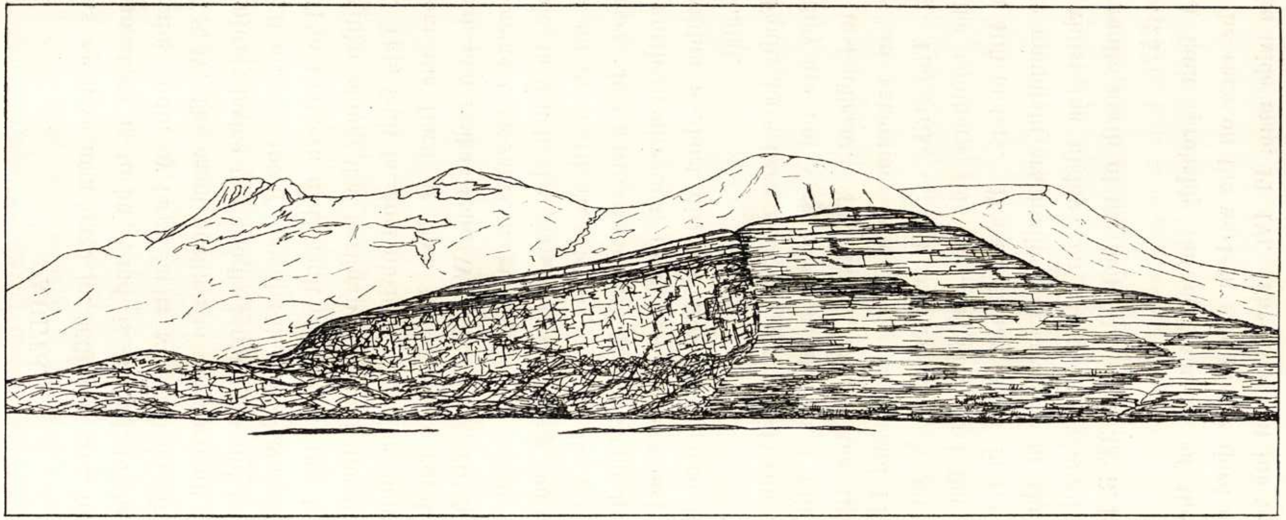

Fig. 24. Mount Iganek (562 meters) seen from Igaliko.

A fault divides the mountain into two parts. To the right of the fault: sandstone; to the left: basement granite overlain by sandstone. In the foreground are seen two flat sandstone islands. The lofty mountain masses in the background are nepheline-syenite: the peak on the left is Igdlerfigsalik (1750 meters).

ment is not known here, but most likely it is far less than on the Iganek.

## DYKES.

The perceptibleness and frequency of the dykes is one of the most striking peculiarities of the Igaliko region, as it appears to the explorer who visits the inner districts of the Tunugdliarfik and Igaliko Fjords for the first time. More or less parallel dark bands or lines are to be seen nearly everywhere on the surfaces of the basement granite and sandstone mountains, and it is often possible, whilst sitting in a boat on the fjord, to follow them with the eyes for a distance of several kilometers. Actually the Igaliko district offers a splendid opportunity of studying a large collection of genetically related dykes. The time we had at our disposal during the field work was, however, not sufficient for any systematic study of them, and here we will only give a short report of what seem to be the main features according to the observations at hand, and we will leave several questions open concerning the dykes.

*General features.* — The dykes in the basement granite and the sandstone of the Igaliko territory in their general relation show a considerable correspondence to those of the Ilimausak region. In both territories the most frequent type is a reddish-brown syenite-porphyry; the direction of the dykes is almost identical (N. E.—S. W.), and it is not impossible that some of the individual dykes, on subsequent investigations, will be found to extend in connection from one district to another. The dykes of the Igaliko region are much easier of approach than most of those in the Ilimausak territory. This is due to the fact that the fjords run in varying directions. In the Ilimausak district they run almost from N. E. to S. W. following the general rule as regards the fjords in this part of Greenland. Consequently the dykes are parallel to the coasts, and many of them are only to be looked for on the lofty plateaus, the débriscovered surface of which is most unfavourable to investigation. But in the Igaliko district we meet with quite exceptional directions of the fjords. Thus the main branch of the Tunugdliarfik Fjord here takes a direction N.—S., and the innermost end of the Igaliko Fjord even runs from N. W. to S. E. In this region, therefore, practically all dykes intersect the coast lines, and are well exposed in the naked coast cliffs.

All the dykes are almost vertical and very regular. The width of most of them varies from 5 to 10 meters, but numerous narrow as well as large dykes are to be found even up to a width of 50 meters. As we have already mentioned, the strike is about N. E. and S. W. varying between N. 25° E.—S. 25° W. and N. 65° E.—S. 65° W. As a rule the dykes are a little more liable to decay than is the case with the country rock, and not seldom have they been the cause of the formation of picturesque cliffs. Still there are many exceptions to this rule. Near the abyssal rocks most of the dykes are intensely contact metamorphosed.

*Rocks composing the dykes.* — On the preliminary examination of the dyke-rocks collected from the basement granite and the sandstone areas of the Igaliko district, the following types were found represented:

diabase,
monzonite-porphyry,
augite-syenite-porphyry,
hedrumite,
nepheline-porphyry,
sölvsbergite (?).

Also a few very small pitchstone dykes have been found in the neighbourhood of Igaliko.

When we compare this list with that of the type of dykes known from the Ilimausak territory, it will be noticed that quartz-porphyries which are so common in the last mentioned locality have not been found, whilst, on the other hand, the nepheline-porphyries have only been found in the Igaliko district. To some degree this difference may possibly be due to the incompleteness of the investigations.

The above list should only be regarded as preliminary. Many of the specimens collected are rocks which have undergone slight alterations, and only very few of them have been chemically analyzed. Consequently, the systematic position of these rocks is in several cases somewhat dubious. As already mentioned, moreover, the dykes have not been subjected to any systematic study during the field work, and many small areas have not been visited at all, not even those which from the boat could be seen to be extremely rich in dykes. It is therefore likely that the number of dyke-rocks will be increased considerably on future research.

*Diabase dykes.* — Dykes of a diabase-like appearance fine-grained or dense and of a greenish-black colour are commonly found both in the granite and the sandstone territories. As pointed out by Dr. Steenstrup[1] they are not as frequent as the red-coloured porphyry dykes mentioned below. They are nearly always of an altered or weathered appearance, and have not been subjected to closer investigation.

*Monzonite-porphyry.* — A few hundred meters north of the houses in Igaliko the sandstone is penetrated by a porphyry dyke 15—20 meters wide of a strike almost N. E.—S. W. Looked at from a distance, this dyke appears of a light gray or greenish colour, forming a sharp contrast to the surrounding dark red sandstone. As it, moreover, projects a little above the surface of the sandstone, it is easily perceptible even from the opposite side of the fjord. It was first mentioned by Dr. Pingel[2]. In hand specimens the rock is grayish-green. The

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[1] Meddelelser om Grønland XXXIV, 1909, p. 126. .

[2] Om den af Porphyrgange gennembrudte røde Sandsten. Videnskabernes Selskabs Skrifter 1843, p. 16.

phenocrysts, which are present in almost as large quantities as the ground mass, consist of a white or greenish felspar. They have a shape giving broad rectangular sections, their length is most frequently about one centimeter, but in some parts of the dyke they may attain five centimeters. On microscopic examination they appear to a large extent converted into a muscovite-like aggregate, whilst the still fresh parts consist of labradorite. The ground mass is greenish-gray and fine-grained, the size of grain averages 0·1—0·3 millimeter. It is made up of orthoclase and plagioclase with some augite, iron ore, apatite, and chlorite. In symmetrical sections the plagioclase shows extinction angles indicating a rather acid labradorite. The augite is light gray and is sometimes surrounded by a marginal zone of a green colour. The chlorite appears to replace biotite. As the rock is rather disintegrated and no chemical analysis has been made, it is difficult to say whether it is an essexite-porphyry or a monzonite-porphyry, but when we consider the large quantities of orthoclase in the ground mass, the latter supposition seems to be the more probable one.

Another dyke which most likely is also a monzonite-porphyry occurs at a short distance east of the Igaliko settlement. This dyke is about 10 meters wide, and strikes almost E. N. E. —W. S. W. It has numerous white felspar phenocrysts about one centimeter long, and of a shape giving broad rectangular sections. They are tolerably fresh, and consist of andesine with a rather thin marginal zone of orthoclase. Olivine is sometimes to be found in grains of a size of 1 or 2 millimeters. The ground mass is almost dense, and of a dark brownish-gray colour. It is essentially made up of short felspar laths partly orthoclase partly oligoclase, the former most frequently as a thick mantle round the latter. The ferromagnesian constituents are light grayish augite, brownish-green biotite, a little olivine, and iron ore. A small quantity of sodalite or analcime occurs in the interstices between the felspar laths. A similar but contact metamorphosed dyke has been found in the quartzitic sandstone on Mt. Iganek, it is perhaps a direct continuation of the former.

*Augite-syenite-porphyry.* — A common sort of dyke in this region has a dark reddish-brown ground mass of a fine-grained or almost dense structure and phenocrysts of white felspar. These are tabular and, as a rule, they do not exceed 1 centimeter. They consist of alkali-felspar, most often soda-orthoclase. The ground mass is of a trachytoid structure, and is mainly made up of small laths of orthoclase and albite; in some cases these laths are perthitic, in others the orthoclase forms the centre of the crystals, whilst the marginal zone is albite. The felspar is thoroughly saturated with red ferric oxides. The other constituents of the ground mass are: gray and green augite, green biotite, a little apatite, and tiny grains of iron ore. Chlorite, calcite, and brown iron oxides commonly occur as secondary products.

*Hedrumite.* — The recently described type of dyke rocks is by transitions connected with a type which may be characterized as hedrumite[1]. The dykes of this type are almost as common as are the augite-syenite-porphyries, and some of them are very wide. Thus one dyke north of the Igaliko houses is about 40 meters wide. The colour is dark brownish-red or gray, the structure is fine-grained and trachytoid. The parallel arrangement of the small felspar tables imparts to the rock a slight silky lustre when it is split parallel to the direction of the flow structure. Phenocrysts are absent. The main constituent is a perthitic alkali-felspar. Aggregates of muscovite replace the nepheline and are present in varying, but on the whole, small quantities. The ferromagnesian minerals are a light gray augite, ægirine-augite, ægirine, brownish-green biotite, and

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[1] W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes III (1898), p. 183.

dark brownish-green hornblende. A more complete description with chemical analysis of a dyke of this kind is given below (p. 278).

*Nepheline-porphyry.* — Dykes of this kind are found in different parts of the Igaliko region, but are not common. The petrographic description is given below (p. 274).

*Sölvsbergite(?).* — In the vicinity of the landing place at Igaliko two tinguaïtic dykes are found. One is 5 meters wide, and the other 8 meters. Both strike from E. N. E. to W. S. W. The ground mass is grayish-green, dense or very fine-grained. Under the microscope it shows a typical tinguaïtic structure. It consists of fine ægirine needles distributed evenly, but without parallel arrangement over an aggregate of salic mineral grains which are mainly microcline.

*Age of dykes.* — As far as observation goes, the dykes are later than the sandstone, and, as a rule, they are also younger than the sills between the sandstone beds, for the sills in a great many instances are seen to be cut by the dykes. Only once, as mentioned by Dr. Steenstrup[1], is a diabase sill seen to be in direct connection with a dyke of the same rock.

It is difficult at present to give a satisfactory answer to the questions as to the age of the different kind of dykes in relation to one another, and to the abyssal rocks of the Igaliko batholite. These questions are evidently of great importance from a theoretical point of view, but they will require much additional field work for their entire solution.

Still it is possible from the observations in hand to draw certain conclusions as regards the age of the different dykes. On the one hand it may be regarded as established that, whilst dykes are rather rare in the augite-syenite and the nepheline-syenite, they occur much more frequently in the closest abutting areas of basement granite and sandstone, as for instance

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[1] Meddelelser om Grønland XXXIV, 1909, p. 126.

on the Narsarsuk Plateau and Mt. Iganek. Furthermore, almost all the specimens of dyke rocks collected from these places are greatly contact metamorphosed. Thus we arrive at the conclusion that the majority of dykes are older than the batholite. But the diabase dykes and the numerous reddish-brown porphyry dykes in the environs of Igaliko must probably be reckoned among this older group.

As pointed out in the foregoing, on the other hand, dykes have been found which intersect the augite-syenite and the nepheline-syenite. A small number of the dykes are thus of later origin than the batholite. It is of interest that most of these younger dykes have the same direction as the older ones. The tinguaïtic dykes mentioned on p. 237 and p. 250, and most probably also the sölvsbergites mentioned above, belong to these younger dykes. It has been mentioned (p. 237) that the syenite-porphyries are also represented in the younger series. That diabase dykes of this series have not been found in the Igaliko territory is probably only due to the cursory nature of the field work undertaken. The existence of the younger series of dykes is of importance to the apprehension of the geological history of the district; it shows that we must look at it as not impossible, perhaps even probable, that the volcanic activity on the surface of the earth has continued as late as down to the time when a large part of the batholites became solidified, even if the main part of the volcanic phase be older than the batholite.

## PETROGRAPHY OF NEPHELINE-PORPHYRIES AND RELATED DYKE-ROCKS.

As already mentioned foyaitic dyke-rocks are of rather common occurrence in the Igaliko district. They belong to a number of different types, of which the most important will be described in the following pages.

### *Nepheline-porphyry: Fox Bay type.*

This rock, in a somewhat altered condition, is known under the name of *gieseckite-porphyry*[1]. It is the mother-rock of the pseudomorphs called gieseckite which formerly have been regarded as a particular mineral. The fresh rock was first found by Pingel 1828. Later, Tamnau, examining Pingel's collection, found that gieseckite in fresh condition is identical with elæolite[2]. The specimens to be described in the following lines have been collected by Dr. Steenstrup, in 1888. The exact locality is on the northern side of a small bay, Fox Bay, at Akuliarusek on the Igaliko Fjord.

*Mineralogical characters.* — The fresh rock is a porphyry with large phenocrysts of nepheline and felspar imbedded in a violet-brown, almost dense ground mass.

The nepheline-phenocrysts are present in large quantities. They are short hexagonal prisms showing the combination $(10\bar{1}0) \cdot (0001) \cdot (10\bar{1}1)$. The thickness of the prisms averages a little more than one centimeter, and the height is about the same. The general appearance is that of typical elæolite and its colour is green. In some cases an alteration to reddish aggregates of muscovite has taken place on the surface of the crystals and along cracks. The nepheline contains innumerable minute inclusions, partly fluid-cavities and partly minerals. Among the latter the most conspicuous are scales of a green biotite and small grains which apparently are ægirine, but the majority of the inclusions are in such small grains that no determination of their nature has been possible. In the central portion of each nepheline-crystal the inclusions are evenly scattered, in the peripheral portion they show a zonary arrangement.

The felspar-phenocrysts are less numerous than the nephe-

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[1] H. Rosenbusch, Mikroskopische Physiographie II, 1, p. 544 (1907).

[2] Poggendorff's Annalen der Physik, vol. 43, 1838, p. 149.

line-crystals. They are of a fresh reddish appearance and developed in thick tabular crystals which are often Carlsbad twins. The thickness of the tables, as a rule, is less than 0·5 centimeter while the length may exceed 2 centimeters. They consist of a soda-orthoclase sometimes stained with irregular patches or shreds of a clouded albite. In sections parallel to (010) the soda-orthoclase shows an angle of extinction amounting to about + 11°, while in the albite areas the corresponding angle is about 20°. In the same sections the soda-orthoclase upon closer examination sometimes shows an indistinct, broadly veined structure at an angle of 72° with (001) corresponding to the ordinary perthitic structure. The felspar phenocrysts often enclose a great number of small felspar laths of the same kind as those of the ground mass.

The original presence of a third kind of phenocrysts is indicated by dull greenish-black stains, less than 0·5 centimeter in diameter. They consist of an aggregate of green biotite scales, which are sometimes partially altered to chlorite. Remnants of a colourless augite have sometimes been found enclosed within these aggregates. The biotite aggregates, therefore, have probably originated from magmatic resorption of augite phenocrysts.

The prevailing constituent of the ground mass is an alkali-felspar which appears in laths of very irregular outlines. There is no tendency to parallel arrangement of the laths, but sometimes radiating groups are found. The length of the laths is 0·2—0·3 millimeter. Their refractive index is a little lower than that of Canada balsam. Many of them show twin lamellation with extinction angles indicating albite, others are heterogeneous: the border zone consists of albite while the nucleus apparently is a soda bearing orthoclase. Exceptionally an extremely fine and indistinct cross-hatched twin structure is observed.

Besides felspar the ground mass contains the following light coloured constituents: nepheline, sodalite, analcime, and small quantities of cancrinite and fluorite. They are all in very small grains or anhedra which are interstitial between the felspar laths.

The principal ferromagnesian mineral of the ground mass is a green biotite in scales or shreds averaging 0·2 millimeter in length. They are strongly pleochroic with absorption-tints varying from dark green to light yellow. A light green ægirine in imperfect prisms and rounded grains occurs in varying quantities. A colourless or light yellowish-green mineral with the same refractive power as ægirine, but differing in its being optically isotropic, is probably garnet. It occurs rather abundantly in groups of very small rounded grains sometimes showing roughly hexagonal contours. Iron ore is present in minute crystals and grains. Apatite is rare.

*Chemical composition.* — The chemical analysis of this type is shown in the first column (No. **27**) of the table on the next page. In the same table the composition of the following type (No. **28**) is also given. Both agree rather closely and are near related to the nepheline-syenite of Korok (analysis No. 25, p. 235). The same chemical type is rather common among the nepheline-porphyries and tinguaïtes from foreign localities. As examples are cited the analysis of a nepheline-porphyry from Predazzo and of a tinguaïte from the Christiania district.

### *Nepheline-porphyry: Nuk type.*

A nepheline-porphyry of a somewhat differing type has been found at Akuliarusek on the peninsula south of Fox Bay. This dyke strikes N. 35° E. Its width is 13 meters. It is a composite dyke, i. e. the middle portion is about 5 meters wide, and is flanked on either side by a sharply defined marginal zone of a somewhat different character.

*Central part of the dyke.* — The rock which makes up the central part of the dyke shows some resemblance to the

*Analyses of nepheline-porphyries and related rocks.*

| | **27** | **28** | **A** | **B** |
|---|---|---|---|---|
| $SiO_2$ | 51·31 | 54·58 | 53·19 | 55·65 |
| $TiO_2$ | 1·20 | ·62 | trace | |
| $Al_2O_3$ | 21·54 | 20·43 | 22·57 | 20·06 |
| $Fe_2O_3$ | 3·68 | 2·08 | 1·98 | 3·45 |
| FeO | 3·37 | 3·39 | 1·72 | 1·25 |
| MnO | .41 | trace | trace | |
| MgO | ·18 | trace | ·49 | ·78 |
| CaO | 1·39 | 1·56 | 2·55 | 1·45 |
| $Na_2O$ | 9·25 | 10·70 | 8·86 | 8·99 |
| $K_2O$ | 5·49 | 5·74 | 6·60 | 6·07 |
| $H_2O$ above 110° | ·84 | 1·02 | 1·47 | 1·51 |
| $H_2O$ at 110° | | ·12 | | |
| Cl | ·17[1] | — | ·37 | |
| $P_2O_5$ | trace | trace | trace | |
| $CO_2$ | .15[1] | — | ·11 | |
| | 98·98 | | 99·91 | |
| Cl = O | ·04 | | ·08 | |
| Total | 98·94 | 100·24 | 99·83 | 99·21 |
| Sp. gr. | 2·71[2] | 2·698 | — | |

**27.** Nepheline-porphyry, Fox Bay type, Akuliarusek, Igaliko Fjord, S. Greenland. C. Detlefsen, analyst.

**28.** Nepheline-porphyry, Nuk type, Akuliarusek, Igaliko Fjord, S. Greenland. C. Winther, analyst.

A. Nepheline-syenite porphyry, Val dei Coccoletti, Predazzo. M. Dittrich, analyst (C. Romberg, Sitzungsberichte der k. preuss. Akad. d. Wiss. 1902, p. 748).

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[1] Determinations by Dr. C. Winther.

[2] Determination by Dr. K. J. V. Steenstrup.

B. Ægirine-tinguaïte, Hedrum, Norway. V. Schmelck, analyst (W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes I, 1894, p. 191).

preceding type, but its outer appearance is duller and the rock is evidently somewhat altered.

The phenocrysts are very abundant. There are four kinds. The felspar phenocrysts are the most numerous; they are developed tabular on (010), measuring about 12 millimeters by 2 millimeters. The cleavage surfaces are dull, the colour is white or reddish. Under the microscope the large felspar tables are seen to be filled with a large number of small felspar crystals which apparently have originated by re-crystallization. The low index of refraction proves that the felspars are alkali-felspars. Sometimes an indistinct microperthitic structure may be observed, but as a rule the felspars are too turbid for a closer determination.

Fresh nepheline is not found as phenocrysts, but a number of pseudomorphs consisting of muscovite with some felspar must probably be derived from nepheline.

A third kind of phenocrysts consists of an unknown colourless mineral which shows some resemblance to cordierite, but differs in several respects. It occurs in rather equidimensional crystals, varying from 3 to 5 millimeters in diameter, which probably belong to the rhombic system. The crystals show a very marked lamellar structure in one direction, and two indistinct cleavages perpendicular to one another and to the lamellæ. Sections parallel to the lamellæ show tolerably hexagonal outlines, sections perpendicular to the lamellæ are rectangular. The hardness is about the same as that of nepheline, the specific gravity is 2·63. A negative optic bisectrix is perpendicular to the lamellæ; the plane of the optic axes is parallel to one of the cleavage directions; and the angle between the optic axes 2 E is 25—30°. The mean index of refraction is slightly inferior to that of Canada balsam, and the birefringence is about equal to that of felspar. Under the microscope the lamellar structure is seen to be due to rows of fluid-cavities; otherwise the mineral is perfectly transparent and fresh. It gelatinizes with hydrochloric acid and on microchemical test gives a strong reaction for sodium. The mineral could not be chemically analyzed for lack of material.

The fourth kind of phenocrysts is represented by relatively numerous, dull, greenish-black pseudomorphs, 1 or 2 millimeters in diameter. Under the microscope they are seen to be made up of a fibrous green hornblende surrounded by a reaction rim of green biotite and ægirine. The fibrous hornblende contains remnants of big crystals of a light grayish augite with large extinction angles and with numerous inclusions of apatite, zircon, and iron ore.

The ground mass has a trachytoid structure. It consists of felspar, nepheline and decomposition products of this mineral, ægirine, and green biotite. A gray augite with green margin and little grains of titanite are found in small quantities. The felspar of the ground mass is a lath-shaped microperthite, and there is a strong tendency to parallel arrangement of the laths. Their length is about 0·5 millimeter. A little analcime is often found among the felspar laths.

*Marginal zones of the dyke.* — A four meters broad zone on each side differs from the central part of the dyke. While the latter abounds in phenocrysts and has an almost dense ground mass the marginal zones are extremely poor in phenocrysts, and their ground mass is coarser and of a foyaitic structure. They consist of felspar, nepheline, and ægirine. The felspar is a microcline-microperthite of about the same type as in the naujaite (p. 147); it is in small plates showing a very marked parallel arrangement. The nepheline is very abundant and less idiomorphic than the felspar; it contains numerous ægirine-microlites, and has partially been converted into aggregates of a colourless mica. The ægirine is also abundant; it is allotriomorphic. The very few phenocrysts consist of a dull white felspar of the same kind as the felspar phenocrysts of the central part of the dyke.

*Chemical composition.* — According to the analysis by Dr. Winther, the central part of the dyke has the composition given in the above table (No. 28, see p. 275). The marginal zones have not been analyzed.

### *Hedrumite of Akuliarusek.*

Among the dykes of Akuliarusek on the Igaliko Fjord several instances of a type which may be characterized as hedrumite have been found (vide p. 269). These dykes probably represent transitional forms between the foyaitic and the syenitic dykes.

The rock to be described in the following lines constitutes a three meters wide dyke running from N. 40° E. to S. 40° W.; it was found at a little distance south of the last mentioned nepheline-porphyry. The rock is fine-grained and devoid of phenocrysts. The structure is trachytoid. The main constituent of the rock is a felspar which is developed in tabular crystals about 1 millimeter long with a fluxional arrangement. Under the microscope the felspar tables are seen to be made up of orthoclase and plagioclase in perthitic intergrowth. The composition surfaces of the two felspars are about parallel to (010). The orthoclase is a little clouded and locally it is microcline-like, showing an indistinct and irregular twin structure. The plagioclase has the optic characteristics of albite, or of an oligoclase-albite poor in lime. Between the felspars allotriomorphic aggregates of muscovite occur in rather small quantities. These aggregates are probably secondary replacing nepheline, but fresh nepheline has not been found. The femic minerals of this rock are the following: brownish-green hornblende ($c : \mathfrak{c}$ = ca. 16°), gray augite, ægirine, and green biotite, all in about equal quantities. Apatite and iron ore occur but sparingly.

*Analyses of Hedrumites.*

| | 29 | A | B |
|---|---|---|---|
| $SiO_2$ | 56.90 | 59·88 | 57·52 |
| $TiO_2$ | 1·09 | .85 | ·92 |
| $Al_2O_3$ | 16·34 | 17·87 | 18·46 |
| $Fe_2O_3$ | 3·61 | 2·67 | 2·23 |
| FeO | 5·72 | 1·50 | 2·44 |
| MnO | trace | trace | 1·20 |
| MgO | ·22 | 1·04 | 1·08 |
| CaO | 2.21 | 2·01 | 2·12 |
| $Na_2O$ | 8·10 | 7·96 | 7·58 |
| $K_2O$ | 4·96 | 5·69 | 4·08 |
| $H_2O$ above 110° | 1·10 | ·90[1] | 1·80[1] |
| $H_2O$ at 110° | ·08 | | |
| Cl | trace | | |
| $P_2O_5$ | ·17 | ·32 | ·21 |
| Total | 100·50 | 100·69 | 99·64 |
| Sp. gr. | 2·783 | | |

**29.** Hedrumite, Akuliarusek, Igaliko Fjord, S. Greenland. C. Winther, analyst.

A. Hedrumite, Sundet, Aasrum Lake, Norway. V. Schmelck, analyst (W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes III, 1898, p. 190).

B. Hedrumite, Skirstad Lake, Norway. V. Schmelck, analyst (W. C. Brögger, l. c.).

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[1] Loss on ignition.

The *chemical composition* of this rock is given in No. **29** in the table above. For comparison two analyses of typical hedrumites from southern Norway are cited in the same table. It deserves notice that the hedrumite is chemically closely related to the pulaskite of Ilimausak (vide analysis No. **3**, p. 124).

### *Tinguaïte-porphyry of Tavdlorutit.*

Tavdlorutit (about 800 meters above sea level) is the westernmost top of the mountain ridge which borders the southern side of the great nepheline-syenite area of Igdlerfigsalik. The country rock is a diorite at this place, but at a short distance east of Tavdlorutit the ridge consists of a red biotite-granite. At altitudes between 800 and 1000 meters this granite is cut by a number of tinguaïte-porphyry dykes which contain crystals of låvenite, a mineral which has not been found at other places in Greenland. The width of the several dykes are from half a meter to six meters, and their direction is from N. N. E. to S. S. W.

The tinguaïte-porphyry has a fine-grained or dense ground mass dotted with phenocrysts of felspar, nepheline, låvenite, sometimes also black mica, and a few grains of iron ore. The colour of the ground mass is greenish-gray or less frequently dark reddish-gray. When examined under the microscope the ground mass shows a typical tinguaïtic structure: it is made up of ægirine in rather short needle-shaped crystals which are imbedded in a hypidiomorphic aggregate of felspar and nepheline with some sodalite and fluorite. The felspar of the ground mass tends to assume a lath-shaped form, and consists of a more or less turbid microperthite; it is intermingled with abundant nepheline, partly converted into muscovite. The felspar phenocrysts are up to 5 millimeters long and of a tabular habit; they are soda-orthoclase. The nepheline phenocrysts are about 1 millimeter in diameter; most of them have been altered to muscovite.

The låvenite is in imperfect crystals of a brown colour, some few millimeters in diameter. As a rule they are more abundant than the felspar phenocrysts. In the slices the låvenite appears of irregular or rectangular outlines, and contains numerous inclusions of fluorite, felspar, and ægirine. The mineral has been identified by the following observations. The mean index of refraction is slightly inferior to that of ægirine. The birefringence is about the same as that of ægirine. The mineral is optically biaxial and negative with an axial angle 2 E exceeding 100°. The pleochroism is:

𝔞 light yellow, almost colourless,
𝔟 light yellow,
𝔠 deep orange-yellow.

Sections perpendicular to the optic 𝔟-axis show distinct cleavage cracks, and the angle between the 𝔞-axis and the direction of the cleavage is about 20°.

### *Liebenerite-porphyry.*

At several localities within the territory of the Igaliko sandstone dykes are found which on account of their outer appearance may be characterized as liebenerite-porphyry. They are always in a very unfresh condition, but deserve to be mentioned because of their close resemblance to the liebenerite-porphyry of Predazzo. Dr. Steenstrup, in 1875, found a dyke of this rock near Igaliko. According to his labels the dyke is 1·5 meter wide and the direction is from N. 26° E. to S. 26° W. In 1888 he found another, 3 meters wide, dyke of the same kind near the former. In 1900 a very wide dyke of liebenerite-porphyry was observed on the sea shore near Musartut on the western side of the Tunugdliarfik Fjord. It is, therefore, not improbable that these dykes, upon continued investigations, will prove to be rather common.

The Greenlandic liebenerite-porphyry contains numerous phenocrysts of felspar and liebenerite lying in a very fine-grained or dense ground mass of a brick-red or brownish-red colour. The felspar phenocrysts are light red and occur in well defined crystals which are tabular on (010). The thickness of the crystals is 1—3 millimeters, the length 1—2 centimeters. They are often Carlsbad twins. In the more weathered varieties of the rock they may sometimes be picked out of the ground mass without difficulty[1]. Under the microscope they are found to be considerably altered, filled with muscovite aggregates and dust. In most cases they are too turbid for optical determinations; occasionally, however, they are tolerably transparent in thin sections, and the structure then proves rather inconstant: sometimes they are soda-orthoclase, sometimes microperthite, and at other times microcline with a marginal zone of plagioclase.

The liebenerite is in well developed and tolerably equidimensional crystals of the ordinary form characteristic of nepheline. The crystals are seldom larger than 0·5 centimeter. The colour is greenish-gray. They consist entirely of a muscovite aggregate and no remnants of the original nepheline have been found. As shown by the microscopic examination dark minerals were originally represented among the phenocrysts of this rock, but they have been converted into aggregates of chlorite, calcite, and iron oxides.

The ground mass is always very decomposed. Its main constituent is an alkali-felspar in small laths. Flow structure is not observed.

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[1] The felspar crystals from the above mentioned 1·5 meter wide dyke have been described by O. B. Böggild (Meddelelser om Grønland XXXII, 1905, p. 440). They are twins, and the twin plane is parallel to $(20\bar{1})$. The forms observed are (010) · (001) · (110) · $(20\bar{1})$. In sections parallel to (010) I found the extinction angle to be + 10°; these crystals accordingly are soda-orthoclase.

# CHAPTER VI.

## SUMMARY AND CONCLUSIONS.

### OUTLINE OF THE GEOLOGICAL HISTORY OF THE COUNTRY AROUND JULIANEHAAB.

The records of past geological periods found in the regions here considered are extremely fragmentary. The only sedimentary formations which remain are Devonian sandstone and superficial deposits of Quaternary age. The igneous formations are quantitatively much more important. They belong to two distinct epochs of igneous activity: the one of Algonkian and the other of Devonian or post-Devonian age. From a geological point of view, the principal interest is connected with the igneous activity of the latter epoch.

The following pages contain a discussion of the nature of the igneous activity, but for better comprehension a brief summary will first be given of what is known of the general geological history of the country.

As mentioned in the second chapter the old Archæan rocks, which are widely distributed elsewhere in Greenland, do not occur in the country around Julianehaab. The oldest and most abundant rock in this part of Greenland is the *Julianehaab granite.* This rock is regarded as Algonkian; it is later than the latest folding which has affected southern Greenland.

During the early part of Palæozoic time continental conditions prevailed in South Greenland. Long continued erosion removed all the rocks which originally covered the Julianehaab granite, and the surface of the country gradually assumed the character of a peneplain. Probably in late Silurian (or Devonian) times the conditions were changed, a subsidence occurred, and the *Igaliko sandstone* was laid down upon the granite. That the condition of the surface, before the deposition of the sandstone, was at least partially that of a peneplain, is indicated by several facts: — (1) as far as has been observed, the upper sandstone covered surface of the granite is almost level and parallel to the bedding planes of the sandstone; (2) a layer of arkose generally of considerable thickness immediately overlies the granite; (3) the conglomerate beds of the sandstone are almost exclusively made up of sandstone pebbles.

The Igaliko sandstone for reasons given (p. 18) is supposed to be Devonian. Except where metamorphosed it is red stained throughout. Perhaps it is largely of æolian origin, but since conglomerate beds with large and well-rounded sandstone pebbles are intercalated at several horizons, wave action must at intervals have played an important part in its formation. The total thickness of the sandstone is about 1200 meters.

The sandstone is overlain conformably by a series of *volcanic sheets:* diabases, porphyrites, and porphyries. The question whether the volcanic activity immediately succeeded the formation of the sandstone, or not, has not been definitively settled. Certain observations mentioned in the second chapter tell in favour of the view that the conditions of sedimentation which gave rise to the red sandstone, continued after the beginning of the volcanic activity, and the second igneous epoch in South Greenland is for this reason believed to have commenced in late-Devonian times.

This period of igneous activity was no doubt a long one, and it showed considerable intensity. The total thickness of the volcanic series now existing at Ilimausak is about 1000 meters, but there is evidence that the original thickness was several times as great.

Volcanic sheets, sandstone, and basement granite alike have been invaded by Plutonic rocks which are now exposed in two separate areas. The *Ilimausak complex* of abyssal rocks is the westernmost of these areas, while the *Igaliko complex* is situated farther eastward and immediately adjoins the inland ice. The most conspicuous feature of both complexes is the presence of a great Plutonic rock-body of batholitic habit. The distance between the eastern margin of the Ilimausak batholite and the western margin of the Igaliko batholite is about 27 kilometers.

The consolidation of the batholites was later than the formation of any part of the volcanic series which now remains. But as the composition of the two suites of rocks is closely related, it is probable that both belong to the same cycle of igneous activity. Some observations suggest, too, that the abyssal rocks may have consolidated before the final cessation of lava outpourings at the surface. The geological age of the batholites, therefore, is also assumed to be late-Devonian. —

Of the long succession of geological periods which separate the close of this igneous activity from the Quaternary ice age no substantial records have been detected in southern Greenland. It is probable, therefore, that during late-Palæozoic, Mesozoic, and Tertiary periods the country has been elevated above sea level. During this time the greater part of the volcanic series has been removed, and only in the peninsula between Sermilik Fjord and Tunugdliarfik are the remnants still preserved. The reasons why remnants have escaped destruction there are, firstly, that they have been sheltered by local subsidence, and secondly, that they have been much altered by contact metamorphism, thus acquiring an augmented power to resist the ravages of erosion. The Igaliko sandstone, too, has for the most part disappeared in a similar way. At the close of the Mesozoic and perhaps also during the Tertiary period the surface of the country was for the second time reduced to a peneplain, surmounted here and there by a few isolated and smoothed monadnocks.

In the Quaternary period the country was entirely covered by thick inland ice. The ice removed all incoherent and weathered material from the surface, and dissected the peneplain into deep valleys and fjords. Later, the inland ice retired from the coast belt leaving local glaciers in the highest parts of the country, where local glaciation has produced an Alpine type of sculpture. Still later, the ice has contracted to its present boundaries.

The high mountains of Ilimausak and Igdlerfigsalik present typical examples of the Alpine topography, and here considerable remnants of the local glaciers are at work. At the foot of Igdlerfigsalik the ice stream of Korok, which has its origin in the inland ice, may be regarded as a small remnant of one of the large fjord glaciers of the ice age. The pre-Quaternary peneplain is believed to be represented by the ice smoothed plateau which can now be seen around Ilimausak at an altitude of 700—900 meters, and towards the inner part of the country their altitude increases. The fjords, as already mentioned, are thought to have been excavated by the ice, but the first beginning of their formation is probably much older than the Quaternary. In that respect it is worth mentioning that the main direction of the fjords coincides with the direction of the most important system of dykes which radiate from the Palæozoic Plutonic rocks.

The Quaternary sediments of the country around Julianehaab are but slight in bulk. A little morainic material often covers the plateau; relatively large screes are found on the slopes of the rapidly decaying batholitic rocks, and alluvial fans occur at the mouths of the rivers. Terminal moraines of noteworthy dimensions are seen only at Korok and at Kiagtut. —

After the retreat of the inland ice from the coast belt an upheaval occurred. According to some observations by Steenstrup and Jessen[1] the extent of this upheaval in the country around Julianehaab may be estimated at about 50 meters, and it increases gradually towards the north. Several explorers have expressed the opinion that the land is now-a-days slowly subsiding, and although the correctness of this view has not yet been definitely proved, there is no doubt that the post-glacial rising of the land has long ago ceased. This fact is of special interest, because the opposite coast of the Davis Strait is said to be still rising[2].

## GENERAL STRUCTURE OF THE COUNTRY.

As only a small part of the rock surface is covered by Quaternary deposits, and the steep sided fjords and valleys exhibit magnificent natural sections, the country affords excellent opportunities for the study of the geological structure. The lack of sufficiently detailed topographical maps and the limited time available for the field work, have made it impossible yet to accomplish a detailed investigation of all the phenomena. It is believed, however, that the observations mentioned in the preceding chapters will suffice to demonstrate some of the main features of the structure of the country.

The general structure is that of a plateau area which is traversed by faults, ranging as a rule from northeast to southwest or from E. N. E. to W. S. W. Folds and other

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[1] Meddelelser om Grønland XVI, p. 150 (1890).

[2] R. A. Daly, The Geology of the Northeast Coast of Labrador. Bull. Comp. Zool. Harvard XXXVIII, p. 261 (1902).

structural features, attributable to lateral thrust movements, are entirely absent.

*Faults.* — Two main faults are recognized (Fig. 25). The northern of them follows the south coast of Sermilik Fjord, north of the mountain group of Ilimausak, and farther to the northeast traverses the northern part of the peninsula between Sermilik and Tunugdliarfik, where it is apparently replaced by a number of smaller dislocations, which for the most part lie within the granite district, and cannot be located with accuracy. Farther eastward the fault-line follows the Kiagtut valley, but here it is concealed by the Quaternary deposits and the glacier. The southern main-fault may be traced from Kangerdluarsuk to the country south of Igaliko; its continuation east of the Igaliko Fjord is entirely covered by alluvial deposits. Minor faults are observed at several places within the sandstone territory (see Fig. 24, p. 264).

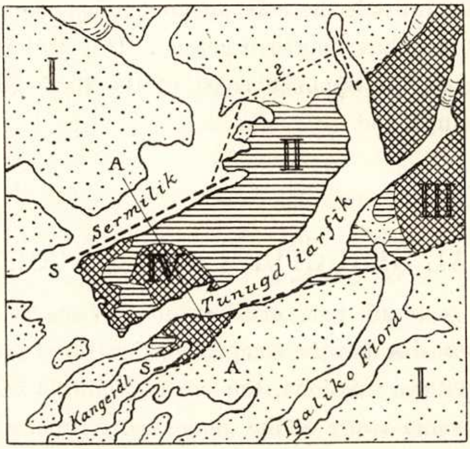

Fig. 25. Sketch-map of the country around Julianehaab, showing the distribution of the main faults (ss). — Scale about 1 : 1000000.

I Algonkian granite. II red sandstone and volcanic sheets. III Igaliko batholite. IV Ilimausak batholite. A—A line of section represented in Fig. 26.

The two main faults bound a sunken area which has its greatest length from W. S. W. to E. N. E., and *the sandstone, the volcanic sheets, and the newer Plutonic rocks are only preserved within this sunken area.*

That the sandstone formerly extended far beyond its present boundaries is evident from the distribution of the erratics, and from the phenomena seen along the great fault south and southwest of Igaliko (p. 260). The volcanic sheets must also once have extended over a large area; their feeder dykes occur abundantly, not only within the sunken area, but also in the areas adjoining, and everywhere maintain the same general character and have the same main direction from N. E. to S. W. or from E. N. E. to W. S. W.

Apart from minor irregularities, the sandstone strata in the larger northeastern part of the sunken area show a slight dip towards southwest or south, while the strata in the southwestern part of the area are inclined northeastward. If the original surface of the sunken area is reconstructed parallel to the stratification of the sandstone, this surface, though broken irregularly, will on the whole be trough-like, and its lowermost portion will lie in the south or southeast of the Ilimausak Mountains, over the central part of the Ilimausak batholite (Fig. 26).

Since the sandstone outside the sunken area has been entirely removed by erosion, the full extent of the vertical displacement cannot be acertained. At Nulup Kakâ, south of Igaliko, where the southern main fault is well exposed, the minimum amount of the down-throw must be 800 meters. At the southwestern end of Nunasarnak Mountain the uppermost sandstone beds outcrop about 300 meters above sea level, and as the sandstone has a fairly uniform thickness of about 1200 meters, and the old granite only seven kilometers south of this place attains an altitude of 1260 meters, the vertical displacement here must be at least 2000 meters. In that part of the area where the depression reaches its maximum, a subsidence amounting to about three kilometers may be postulated.

*Age of faults in relation to the Plutonic rocks.* — It is evident from direct observations that the main faults are younger than both the sandstone and the undestroyed part of the volcanic series. The absence of these formations outside the sunken area is easily explained as a consequence of the denudation. It is, however, a very remarkable fact that intruded abyssal rocks, which have risen to considerable heights within the area of subsidence, are nowhere visible in the adjacent tracts, and this notwithstanding that natural sections down to sea level are found in many parts of the district. This would seem to indicate that the main faulting is not later than the consolidation of the batholites, and a closer examination will corroborate this view[1].

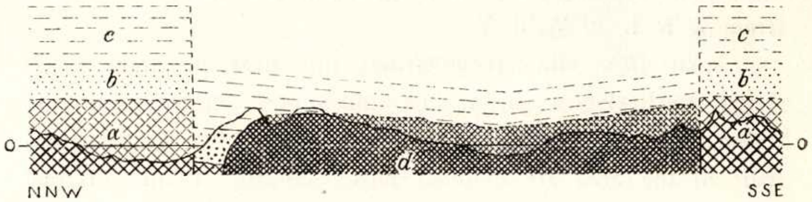

Fig. 26. Reconstructed cross-section of the Ilimausak batholite. Scale of lengths and heights 1 : 260000.

*a* Algonkian granite. — *b* sandstone. — *c* volcanic sheets. — *d* Plutonic rocks. (The position of the section is indicated on the sketch map, Fig. 25.

The relation of the faults to the batholitic rocks can be best studied along the great southern fault. This fault, as previously mentioned, is very conspicuous south and southwest

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[1] Here only the main faulting is considered. The first beginning of the crustal deformations may perhaps have preceded the first manifestations of the late Devonian igneous activity, but, as discussed in the description of the structure of the Ilimausak batholite, subsidence in some places may have continued after the consolidation of some of the batholitic rocks.

of Igaliko, where a vertical breccia zone separates the old granite from the sandstone formation. Farther to the west the fault for a distance runs under the sea (Tunugdliarfik Fjord), but near Agpat the breccia zone reappears in the coast cliffs. From this point the fault line (see Fig. 25) extends southwestward, between the mountain ridge of Kitdlavat, in which the Algonkian granite rises to 1260 meters, and Nunasarnausak where the sandstone is at sea level. But the area between these mountains is occupied by the batholite, and no fault is exposed to view. Since the granite rises abruptly and without brecciation at the southeastern border of the batholite, it is evident that the fault cannot intersect it, and since the peculiar stratification of the batholite proves the absence of any noteworthy dislocations in it, it cannot traverse the Plutonic rocks. Even along the boundary between the old granite and the batholite no fault is observable: but instead the abyssal rocks show an ordinary contact facies with apophyses running into the granite.

Hence the main faulting, though later than the formation of the sandstone and the oldest sheets of the volcanic series, is prior to the final consolidation of the batholites. It is scarcely possible to give any more precise determination of the age relations. At first sight it might seem probable that the faulting was directly connected with the intrusion of the batholites, but at this place it is only necessary to call attention to the fact that since the place of the Ilimausak batholite coincides with the area of maximum subsidence, the faulting cannot directly have forced the magma of the Ilimausak batholite into its present position.

*Comparison with the Christiania district.* — Although the connection of a local subsidence of the earth crust with the occurrence of large Plutonic bodies is by no means a general rule, yet it is possible to cite a great number of analogous cases from other plateau regions. It will suffice to quote here the instance of the Christiania district, where a similar connection was pointed out by **Brögger** in his classical investigations several years ago[1]. Without entering into a detailed comparison it may be mentioned that the subsidence connected with the igneous action is much more marked at Julianehaab than at Christiania; for, while tbe depressed strip at Julianehaab is only about half as broad as the corresponding belt at Christiania Fjord, the amplitude of the subsidence is as great or greater than at the former place. It is further worthy of mention that the original covering of the Plutonic rocks of Ilimausak had a decided concave or trough-like form, while in the Christiania district the stratified rocks originally overlying the Plutonic masses had a convex or arch-like surface, according to the reconstruction given by **Brögger**.

## MECHANISM OF INTRUSION OF THE BATHOLITES.

*Introductory.* — Owing to the world wide distribution of Plutonic rock bodies of batholitic habit the question of the processes by which these bodies have invaded the upper part of the earth crust is of great interest. Recent investigations by **Suess**, **Iddings**, **Barrois**, **Michel Lévy**, **Brögger**, **Daly**, and many others have added largely to our knowledge in this respect, but the question is in most cases unsettled, and the hypotheses which have been put forth are not generally accepted. The difficulties arise partly from the complex nature of the intrusion, but they are also partly due to the fact that the present shape of the batholites is commonly so modified by erosion, that the original form cannot be made out with certainty. Very often, too, the exposures are so inadequate, and do not give any clear idea of the character of the junction with the invaded rock.

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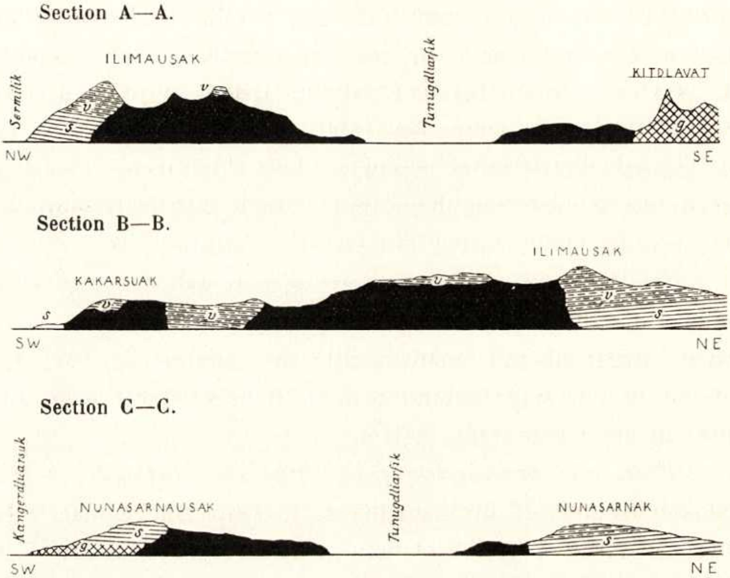
[1] W. C. **Brögger**, Ueber die Bildungsgeschichte des Kristianiafjords. Nyt Magazin for Naturvidenskaberne XXX, 1886. — *Idem*, Die Eruptivgesteine des Kristianiagebietes II, 1895, p. 133.

In the preceding chapters two batholites have been described. One of them — the large *Igaliko batholite* — is in a state of preservation which is very unfavourable to a study of any geological features which might lead to an interpretation of the mechanism of intrusion. In this case the original cover of the batholite has been entirely denuded, the junction with the country rock is only exposed in a few sections of inconsiderable height, and it is not possible to arrive at any definite conclusion as to the mode of formation of the batholite. It deserves mention that the position of the sandstone at Narsarsuk and Iganek (more than 1700 meters below the near top of the batholite) favours the supposition that invasion here has taken place under conditions quite like those which controlled the invasion of the batholite next to be mentioned.

The *Ilimausak batholite* is exceedingly well exposed for an inquiry into the mechanism of intrusion. The original cover is partly preserved, and junctions with the country rocks are disclosed in numerous natural sections from sea level to an altitude of more than 1100 meters.

*Form and boundaries of the Ilimausak batholite.* — The general features of the batholite as to shape and contact relation will appear from the sections given in Fig. 27 (see also Plate III, V, and VI). The plan of the mass is a rude ellipse, the maximum diameter being about 20 kilometers while the breadth is less than 15 kilometers. The boundaries are of two kinds: in some places they are more or less parallel to the stratification of the invaded rocks, while in others they are distinctly transgressive. Contact surfaces of the former kind are found in the two southernmost peaks of Ilimausak. There erosion has left two outliers of the cover resting horizontally upon the Plutonic rocks. On closer inspection this contact plane proves very irregular: but on the whole it is parallel to the stratification. At the periphery of the batholite the boundaries are transgressive and often vertical. In all cases the contact proves to be a primary igneous contact, and the Plutonic rock exhibits an ordinary border facies and sends out apophyses into the country rock. It is notable that the remnants of the flat roof consist entirely of volcanic sheets (porphyries) and that the batholite has not only traversed the entire sandstone formation but also penetrated a large part of the volcanic series.


Section A—A.

Section B—B.

Section C—C.

Fig. 27. Three cross-sections of the Ilimausak batholite.
Scale about 1 : 150000.

*g* Algonkian granite. — *s* sandstone. — *v* volcanic sheets. The rocks of the batholite are given in black. The position of the section is indicated on the map, Fig. 28.

To the reconstruction given in Fig. 26 (p. 290) it might be objected that we cannot know whether the upper contact has been, on the whole, of the same kind as that observed with the small remnants of the cover now constituting the two southernmost peaks of Ilimausak. This, of course, is true: but on the other hand the observed dip of the strata all round the batholite, and the regular sheeted structure of the batholite itself strongly support the view that the whole upper contact surface was tolerably flat, and that its position may be approximately indicated as suggested in Fig. 26.

*Hypotheses to explain the mechanism of intrusion.* — Since granitic and other abyssal rock bodies occupy a space which prior to the intrusion was occupied by the 'country rock', the intrusion must be preceded or accompanied by a removal of the latter rock. To explain this removal various hypotheses have been put forth. We will here discuss the question whether one or more of these hypotheses are applicable to the Ilimausak batholite.

(I.) In regions where mountain-making processes are going on, lateral thrust-movements may produce a subterranean cavity which is filled with magma concurrently with its formation (intrusion by folding)[1]. In the Ilimausak region no movements of this kind have occurred, and the hypothesis, consequently, may be left out of consideration in the present case.

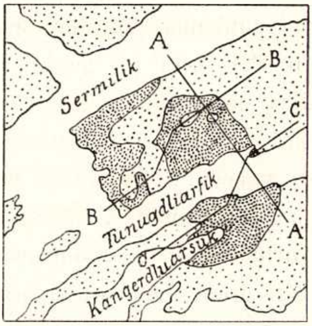


Fig. 28. Map of the Ilimausak region showing position of sections given in Fig. 27. — The closely dotted areas indicate the batholitic rocks.

(II.) An empty space in the earth crust may be produced by volcanic outbursts of an explosive character, and the cavity thus formed may be filled with magma. That this hypothesis which applies to a large number of 'volcanic stocks' is unable to account for the Ilimausak batholite, is shown by the form of the cover and the large dimensions of this batholite.

(III.) The pressure of the magma may have lifted the country rock from the space now occupied by the abyssal rock (laccolitic intrusion)[2]. Of late year several geologists have

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[1] E. Suess, das Antlitz der Erde I, p. 218 (1885).

[2] W. C. Brögger, die Eruptivgesteine des Kristianiagebietes II, p. 116 (1895).

endeavoured to apply this hypothesis to large granitic intrusions of irregular habit. Nevertheless the applicability of the hypothesis does not seem to be sufficiently proved in any such case, and in the present instance it is easy to see that we are not concerned with phenomena comparable to those which are exemplified in the laccolites. This is shown by the following facts: — (a) The strata of the country rock are cut off almost vertically by the batholite from sea level to an altitude of more than 1100 meters. If the intrusion was of the laccolitic kind the contact surfaces must as a rule be parallel to, and not perpendicular to, the bedding planes of the country rock. (b) The cover of the Ilimausak batholite is concave or troughlike, and occupies a sunken position in relation to the adjacent parts of the earth crust (see Fig. 26 and Fig. 27). The cover of a laccolite is convex or domed and is elevated in relation to the surroundings. It is to be concluded, therefore, that the intrusion of the Ilimausak batholite is due to processes different from those which produce laccolites.

(IV.) According to the assimilation hypothesis the magma is supposed to melt its way upward, and thus incorporate a large portion of the country rock[1].

This hypothesis is in accordance with the general form of the Ilimausak batholite, but it does not seem to be satisfactory from a chemical point of view. This is indicated by the fact that most of the abyssal rocks of Ilimausak are characterized by certain chemical peculiarities of composition — extremely large quantities of sodium and zirconium — which seem to preclude the assumption that the bulk of the batholite has originated from the assimilation by any magma of large portions of the country rock. Further the comparison of the Julianehaab district with that of Christiania furnishes an argument against the sup-

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[1] A. Michel Lévy, Contributions à l'étude du granite de Flamanville. Bull. des services de la carte géol. de la France V, No. 36, p. 35 (1893). A. Lacroix, Le granite des Pyrénées. Ibid. X, No. 64, p. 62 (1898).

position that sediments have been absorbed on a large scale in the upper part of the batholite. It is found that, although the Plutonic rocks of both districts, from a chemical point of view, belong to similar types (nepheline-syenites, soda-syenites, soda-granites), the sediments invaded are very different. Thus, while in the Christiania district the Plutonic masses are often bounded by limestones and shale, sediments of these kinds are entirely absent at Julianehaab[1]. Moreover, when the junction of the Ilimausak batholite with the country rock is studied in detail, it is found that indications of a marginal assimilation are entirely absent at many places. This applies to the whole contact surface between the arfvedsonite-granite and the overlying porphyry; probably it holds good also of the contact between the batholite and the Algonkian granite south of Tunugdliarfik.

It is easy to see, however, that these arguments do not suffice to refute the assimilation hypothesis. All that can be concluded is that the bulk of the visible part of the Ilimausak batholite is not an assimilation product, but consists of material which has originated from some unknown source in the interior of the earth, and that if assimilation has played any part in the mechanism of intrusion, it must have been accompanied by other processes. Now proofs are not wanting that a local assimilation of the invaded rock has actually taken place at Ilimausak. Thus, both the augite-syenite and the lujavrite pass

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[1] The complete absence of carbonate-rocks in the whole country around the very large nepheline-syenite areas of south Greenland is inconsistent with the hypothesis recently set forth by DALY relating to a genetic connection between carbonate-rocks and nepheline-syenites (Origin of the Alkaline Rocks. Bull. Geol. Soc. of America XXI, p. 87, 1910). The only carbonate bearing formation of South Greenland is the Arsuk group (p. 9). The possibility that dolomites of this group have once existed at Julianehaab cannot be denied. But the late-Algonkian igneous series (Julianehaab granite etc.) which is later than the Arsuk group consists of sub-Alkaline rocks. Thus, actual observations tell against the hypothesis in every way.

into quartz bearing contact modifications at the junction with the sandstone. Since assimilation is dependent upon the temperature, it must be assumed that it has operated on a larger scale in the deeper portions of the batholite which are not exposed to view. It must also be borne in mind that the effects of the assimilation may become concealed or obscured by subsequent differentiation of the magma.

The above considerations will show that, although the assimilation hypothesis does not suffice to account for the mechanism of intrusion of the Ilimausak batholite, yet it is probable that the intrusion has taken place with the co-operation of assimilation processes.

(V.) Finally we have to consider the hypothesis of batholitic invasion by subsidence of roof blocks. This hypothesis postulates a long continued breaking and sinking into the magma of fragments of the roof rock, and a corresponding rise of the magma to occupy the place of the sunken fragments. The hypothesis agrees with the assimilation hypothesis in assuming a passive and slow invasion from below, and the process does not necessarily imply any movements of the earth surface. It differs from the assimilation hypothesis in the assumption that the older rock is removed as fragments which pass down to unknown depths, leaving the chemical composition of the upper part of the magma uninfluenced. **Brögger** has drawn attention to the fact that roof blocks must in some cases have sunk through the magma[1]; but the theory that a process of this kind may be the main cause of batholite invasions was first set forth in a more elaborate form by **Daly** in 1903[2], who termed the process 'overhead stoping'. According

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[1] W. C. Brögger, Die Eruptivgesteine des Kristianiagebietes II, p. 145, (1895).

[2] R. A. Daly, Geology of the Ascutney Mountain. Un. St. Geol. Surv. Bull. No. 209, p. 93 (1903). — *Idem.* The Mechanics of Igneous Intrusions. Amer. Journ. of Science 4th series XV (1903), XVI (1904), and XXVI (1908).

to Daly it is extremely probable that all magmas, with exception of some of the basic ones, have a lower specific gravity than common rocks at the same temperature, and a sinking down of detached blocks is for that reason possible To account for the breaking free of the roof blocks, it is assumed that local heating of the roof rock by contact with the magma will produce local expansion, resulting in the formation of cracks and fissures into which the magma makes its way and thus progressively detaches one block after another.

A very striking instance of a batholite, the intrusion of which seems only to be intelligible on the basis of this hypothesis, is the Marysville batholite in Montana as described by Barrell[1], and in the opinion of the present writer the same may be said of the Ilimausak batholite[2].

*Evidence of subsidence of roof blocks at Ilimausak.* — A direct proof of the subsidence of roof blocks is found in the presence of numerous sandstone fragments, the largest of which exceeds 200000 cubic meters, in the augite-syenite at the foot of the Iviangusat Mountains, Kangerdluarsuk. This occurrence has been described in chapter III (p. 51), and it has been shown that the fragments can only be derived from above, and that they must have sunk down through more than 900 meters of magma. Another instance of roof blocks in the batholitic rock is observed at Nunasarnak (p. 75).

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[1] J. Barrell, Geology of the Marysville Mining District. Un. St. Geol. Surv., Professional Paper No. 57, 1907.

[2] The author on his first visit to the Ilimausak region, in 1900, arrived at the conclusion that the coming to place of this batholite was mainly due to subsidence of roof blocks, and in January 1902 expressed his view in a lecture in the Danish Geological Society. Shortly after this Daly published his paper on the mechanics of intrusion, and put forth the hypothesis in a much more elaborate form and on much broader grounds than the present author had intended, and the publication of the view was therefore deferred until the present full report.

*Subsidence of roof blocks probably was the chief cause of intrusion of the Ilimausak batholite.* — The premises from which this conclusion is drawn may be summarized thus: —

(1.) A strong evidence in favour of the hypothesis of intrusion by subsidence of roof blocks is shown by some of the general features of this batholite, viz. (a) the flat roof; (b) the more or less steep flanks abruptly cutting off the strata of the sandstone and the volcanic series from sea level to an altitude of 1100 meters; (c) the numerous reentrant angles and minor irregularities of walls and roof.

(2.) The direct evidence, mentioned above, of subsidence of roof blocks.

(3.) The results of the preceding discussion which shows that the other hypotheses are unable to constitute a satisfactory explanation.

Since a relatively low specific gravity of the magma is the condition of the subsidence of roof blocks, it might be objected to the applicability of the hypothesis in the present instance that some of the abyssal rocks of Ilimausak are heavy. Thus certain nepheline-syenites rich in iron attain a specific gravity of 3·1. These rocks, however, owe their large quantity of iron to differentiation processes operating after the intrusion of the magma, and the low specific gravity of the naujaite offers a full compensation. The mean specific gravity of the batholitic rocks, calculated from the figures given in the tables of analyses, is lower than that of the augite-syenite which envelops the sunken sandstone blocks mentioned above. Thus no difficulties to the hypothesis arise from the presence of subordinate masses of heavy rocks.

As Daly has pointed out the hypothesis of overhead stoping is not opposed to the assimilation hypothesis. The roof blocks which sink will gradually be subjected to higher temperatures, and it must be supposed, that at least some of them will melt, while marginal assimilation may be an important factor tending to enlarge the lower part of the batholite. Probably overhead stoping will not be possible on a larger scale without the co-operation of assimilation. Since the Ilimausak complex of abyssal rocks represents the uppermost portion of a batholite it is not to be expected that it will show more than relatively small and local instances of assimilation. As mentioned above, such have actually been observed both in connection with the detached fragments and at the walls.

*The subsidence of the orographic blocks was only indirectly connected with the invasion of the batholite.* — That there must be some kind of connection between the formation of the Ilimausak batholite and the faulting of the sandstone areas has been stated above, but it is also evident that the hypothesis suggested by Brögger for the Christiania district[1], viz. that the subsidence of orographic blocks was the direct cause of the intrusion, cannot hold good for a region like that of Ilimausak, where the place of the batholite coincides with the area of maximum subsidence of the earth surface. The most probable supposition appears to be that the subsidence of the orographic blocks was directly connected with the volcanic activity at the earth surface and the formation of dykes and sills, and that the faulting only influenced the batholitic invasion in so far as it facilitated and localized the processes by which the more acid portion of the magma slowly began to move upward. Another factor which contributed to determine the localization of the batholite at the region of most intense volcanic activity, was the heating of the earth crust produced by the volcanic materials themselves.

According to this view the batholitic invasion is in all essentials independent of the subsidence of the earth crust, while faulting, on the other hand, may have played some part

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[1] W. C. Brögger, die Eruptivgesteine des Kristianiagebietes II, 1895, p. 151.

in the localization of the intrusion. Nevertheless, at Ilimausak the latest subsidence of the overlying earth crust took place after the intrusion of the batholite, but this, as mentioned below, was a purely local subsidence, being probably caused by the diminution of volume of the magma during crystallization.

*The original thickness of the cover.* — When the igneous activity came to an end, the Ilimausak batholite had a cover consisting of tuffs, lava sheets, and sills, which probably had a considerable thickness. How great was this thickness cannot be acertained, for the quantity of rock material which has been removed from the surface during the long continued period of erosion which followed the volcanic activity is unknown. The remnants still remaining on the lofty peaks of Ilimausak doubtless represent only a small part of the cover which once existed. In the reconstructed section, Fig. 26 (p. 290), the cover has been given a thickness of a little more than one kilometer, but this is quite an arbitrary estimate.

The cover which existed at the time of cessation of the igneous activity is not, however, necessarily the original cover. It has been pointed out by several authors that the hypothesis here adopted to account for the mechanism of intrusion involves the *question of the maintenance of the cover.* This problem may be regarded from two different points of view.

From the statical point of view it is difficult to imagine how a batholitic magma of very large horizontal dimensions could support a cover consisting of a material heavier than itself. In the present instance, however, the horizontal dimensions are not so large that the cover would be in danger of foundering if stoping ceased at a distance of one kilometer or more from the surface, and as the question has been elaborately discussed by DALY[1] from a general point of view, it may here be left out of consideration.

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[1] Amer. Journ. of Science (4) XXVI, p. 30 (1908).

On the other hand the existence of the cover is directly endangered by the stoping process. How does the process come to an end before the earth surface is reached, and why does the magma 'never break through'? Barrel, discussing this difficulty, comes to the conclusion that 'although depending on many factors, the key to the permanence of the cover appears to lie in the difference in temperature between the cover and the magma, and in the viscous nature of the magma when cooled nearly to the point of solidification'[1]. Harker[2] speaks of the fact that batholites 'never break through' as an obvious difficulty when overhead stoping is considered as a more than subsidiary factor in the mechanics of intrusion.

In some respects, however, the correctness of these objections does not appear to be sufficiently borne out by observation. There is of course no question that overhead stoping does in some cases come to an end before the magma reaches the earth surface. Thus the Marysville batholite, as described by Barrell in the important monograph cited above, evidently had a permanent cover of sedimentary rocks, and the same may be true of several other batholites, but this fact cannot be considered as a grave objection to the hypothesis. Overhead stoping must, no doubt, be a very slow process. It requires a continual supply of heat from below, and when the magma nears the earth surface the consumption of heat will go on at a rapidly increasing rate, and the process, thus, will be more and more retarded. The escape of water vapour and other volatile substances through fissures will probably be the chief method by which heat is lost, and as soon as the loss of heat exceeds the supply from below, the magma will become more and more viscous, until the process gradually ceases. Since batholitic magmas are of acid or intermediate composition, loss

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[1] Un. St. Geol. Surv., Professional Paper No. 57, p. 174 (1907).

[2] Natural History of Igneous Rocks (1909), p. 86.

of water may perhaps also raise the temperature of consolidation, and the chilling effect will thus be increased.

The fact that batholitic magmas in several instances have failed to swallow up their cover is not, therefore, opposed to the hypothesis of intrusion by subsidence of roof blocks, and the value of the objection mentioned above, entirely depends on the correctness of the statement that batholitic magmas *never* break through. If, however, the possibility of overhead stoping be admitted, the 'never breaking through' cannot be considered as an established fact. Of course we cannot assume that an acid magma would appear at the earth surface as a lava lake like that of Kilauea. But when we do consider the probable result of a breaking through, it will be found that certain observed phenomena are not at all incompatible with the supposition that many batholitic magmas may have actually penetrated their cover, and some may perhaps have done this on more than one occasion.

Penetration of the cover would presumably lead to a volcanic outburst of catastrophic character with more or less heavy explosions, accompanied by the outpouring of heavy lava flows and the formation of a solid lava crust. The immense loss of heat, caused by such an outburst, would establish a period of quiescence, but after a time hot magma from below, being brought by convective currents into contact with the newly formed roof stoping, would be set up again. Thus interrupted, perhaps by repeated volcanic outbursts, the stoping process would continue until the dying away of the igneous activity. The final result would probably be a batholite under a relatively thin cover of its own lava, and at the contact the batholitic rock would present a fine-grained, marginal facies sending apophyses into the roof rock, without any direct evidence of the breaking through.

But in many cases the record of the breaking through might be yet more concealed. If volcanic action continued at neighbouring centres from which lavas were poured out over the roof of the batholite, the thickness of the lava cover would be materially augmented, and if stoping was still in progress the batholitic magma would invade this new part of the cover[1]. If processes going on within the batholitic chamber resulted in the formation of a magma different from that existing at the time of breaking through, a further complication obscuring the record of the breaking through might arise. The possibility of such a partial replacement of one batholitic rock by another must be allowed if the overhead stoping hypothesis be accepted; as Daly and others have pointed out there is a probability that such replacements have actually occurred in some cases, and this will also appear from the discussion given below of the internal structure of the Ilimausak batholite.

We thus conclude that if a batholitic magma on one or more occasions during its intrusion has penetrated its cover, the incident, as a rule, will be obliterated by the continuation of the stoping process. The presence of a sedimentary cover, as at Marysville, shows that outbursts from the batholitic magma can only have occurred through fissures in the cover, but batholites of this kind are relatively rare. More commonly the cover entirely consists of lavas belonging to the same cycle of igneous activity as does the batholite itself (e. g. Boulder batholite of Montana[2]), and several of the large Plutonic masses of the Christiania district, and of the west of Scotland etc. In such cases the observed phenomena are not, as a rule, inconsistent with the assumption that the batholitic magma has broken through, and has even taken part in the production of the very lava sheets into which the consolidated batholite is intrusive.

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[1] Of the porphyry covering the Ilimausak batholite it is not possible to decide, whether it is derived from Ilimausak or from Igaliko or from some other unknown centre.

[2] J. Barrell, Geology of the Marysville Mining District, 1907, p. 167.

The Ilimausak batholite is of the latter kind. Its cover is a porphyry — the Ilimausak porphyry — which is consanguineous with the batholitic rocks, and it is interesting to note that this porphyry, while chemically very different from the arfvedsonite-granite which now forms the uppermost part of the batholite, is very closely related to another batholitic rock, viz. the augite-syenite (compare analyses **16** and **23**), which for other reasons must be supposed to represent the composition of the batholitic magma during earlier stages of the intrusion. This of course does not *prove* that the cover has been produced by an outburst of the batholitic magma itself, but it indicates the possibility of a connection of this kind.

*Mechanism of intrusion in other parts of South Greenland.* As far as observation goes, the Ilimausak batholite is the only instance in South Greenland of a batholite with remnants of the cover still preserved. The Igaliko batholite is situated within the same area of subsidence, and is also in contact with the Devonian sandstone; but as it rises to greater heights its roof has been entirely removed by erosion. In other parts of South Greenland a great many Plutonic rock masses occur which are also younger than the Algonkian Julianehaab granite, and are probably contemporaneous with the batholites of Ilimausak and Igaliko. These, however, are situated within areas from which all Palæozoic sediments have been denuded, and their age relations cannot be determined with certainty. These for convenience, will be spoken of as the 'Palæozoic' intrusions. They are of great interest in discussing the question of methods of intrusion, and illustrate the occurrence of different kinds of intrusive rocks within a deeply dissected crystalline mountain plateau which is almost everywhere exposed as bare rock.

As a supplement to the evidence obtained from the Ilimausak and Igaliko batholites we give here a brief review of the general characters of the other occurrences. These, as will be seen from the following data, are in close agreement with DALY's theory of the mechanics of intrusion. They are also in accordance with the experience gained in other regions of similar geological structure, as for instance large districts of eastern Scandinavia.

The main features of the Palæozoic intrusions of South Greenland, outside the Julianehaab area, may be summarized as follows:

1. The Palæozoic Plutonic rocks of South Greenland are granites, syenites, nepheline-syenites, and gabbros (incl. essexites).

2. They have invaded the upper part of the earth crust at a time much later than that of the latest foldings of the country. At the time of the intrusion the country was probably a plateau; but this, during later periods, was deeply dissected by the agents of denudation. The encasing rocks now remaining are entirely crystalline (Algonkian and Archæan granites, gneisses and schists).

3. The intrusions have nowhere a laccolitic habit.

4. The heavy gabbroid rocks occur in innumerable vertical *dykes,* which are very coarse-grained and often more than 150 meters wide. Some few boss-like masses are also found, but their horizontal dimensions are small, and seldom exceed one or two kilometers. The original form of the boss-like occurrences has very often been obscured by later intrusions of more acid magmas.

5. The granites and the syenites occur as large *batholites* of more or less irregular shape. These batholites are indicated on the map, (Pl. I). Their minimum horizontal dimension amounts to 5—30 kilometers or more. Both granite and syenite are often found within one batholite. Nepheline-syenite has only been met with at one place outside the Julianehaab area, viz. east of Ivigtut. This occurrence is a small and elongated batholite, 9 kilometers long by 2 kilometers broad.

The junctions of the batholites with their encasing rocks are generally vertical, and the contact relations on the whole are analogous to those of the Ilimausak batholite, and thus indicate that the igneous masses have replaced corresponding portions of the invaded rocks. No indications of a pushing aside of the wall rocks have yet been found.

6. Fragments of crystalline rocks, identical with those of the surroundings, are sometimes found enclosed within the batholites, but these, on the whole, are rare. Although the surrounding rocks are entirely crystalline the batholite of Cape Desolation at some places encloses numerous sandstone fragments.

The salient feature is thus the contrast between the mode of occurrence of the dense gabbroid rocks and the specifically lighter, more acid rocks. The same contrast, as is well known, may also be observed in many other regions of similar geological structure. It is true that large gabbro batholites are found at several places in other countries, but there can be no doubt that the rule which is illustrated so conspicuously in southern Greenland, with its many and excellently exposed Plutonic rock bodies, is of more than local significance[1]. No theory of intrusion, therefore, can be regarded as satisfactory which fails to account for this difference in the typical mode of occurrence of the gabbroid and the other abyssal rocks. Perhaps both the assimilation theory and the theory of subsidence of roof blocks may to some extent meet this demand, but the insufficiency of the former theory is shown by the fact that the chemical composition of the batholitic rock is independent of the wall rock in South Greenland as elsewhere. In addition, direct support is given to the latter theory by the finding in the granite of Cape Desolation of sandstone fragments, which can only be derived from a sandstone layer formerly overlying the crystalline rocks, and which

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[1] Compare DALY, Amer. Journ. of science (4), vol. XXVI, 1908, p. 40.

must, accordingly, have sunk many hundred meters through the magma.

All the batholitic intrusions of southern Greenland, thus, are therefore believed to have mainly come to place by the subsidence of roof blocks, that is by the same process of intrusion which brought the Ilimausak batholite.

From the fact that dykes of ordinary granites and syenites are extremely rare, while batholites of these rocks are common, we may conclude that, as a rule, the batholitic magmas of this area did not possess the relatively high degree of liquidity which is necessary for dyke intrusions. This implies also that the process of magmatic stoping must have acted very slowly.

The question of the final fate of the sunken roof blocks has been hitherto entirely neglected. The Palæozoic batholites of South Greenland supply no information on this matter, for the blocks, with very few exceptions, have sunk down beyond the range of observation. Some indications may perhaps be obtained in another way. Within the immense areas of pre-Cambrian granites in South Greenland fragments of crystalline schists and gneisses of widely different sizes occur abundantly in many places. This may perhaps suggest that at greater depths some of the rock fragments, without necessarily being assimilated, may cease to sink.

In the general problem of the mechanics of igneous intrusions the distinction drawn by Harker[1], between intrusions which are connected with tangential pressures of the part of the earth crust which is invaded and those which are not, is no doubt of fundamental significance. It must, therefore, be borne in mind that the above discussion refers exclusively to intrusions of the latter kind, which occur under conditions allowing of the formation of a large number of massive vertical dykes.

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[1] Natural History of Igneous Rocks, 1909, p. 60.

The intrusions of South Greenland all belong to the category of plateau intrusions.

# CHRONOLOGICAL SEQUENCE OF INTRUSIVE ROCKS.

About twenty years ago **Brögger**, **Teall**, **Wadsworth**, and others found that in several petrographical provinces there is a definite order of succession of extensive Plutonic intrusions. The most basic rocks are the oldest, and they are followed by rocks more and more acid, but **Brögger** and **Wadsworth** have also indicated as a very common exception to this rule of 'decreasing basicity', that nepheline-syenites are younger than the syenites with which they are associated. More recent investigations in many parts of the world have, as a rule, confirmed these results[1].

The Palæozoic abyssal rocks of South Greenland conform to the general rule. Their order of succession is: first gabbros (incl. essexites), next syenites, and finally nepheline-syenites and granites.

The extrusive rocks and dykes, on the other hand, show a sequence which is much more complicated, and the results obtained from an examination of the succession of lava flows and dykes from different petrographical provinces apparently can-

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[1] W. C. Brögger, Ueber die Bildungsgeschichte des Kristianiafjords, 1886, p. 75. — J. J. H. Teall, On some Quartz-Felsites and Augite-Granites from the Cheviot District. Geol. Mag., dec. III, vol. II, 1885, p. 106. — J. R. Dakyns and J. J. H. Teall, On the Plutonic Rocks of Garabal Hill. Quart. Journ. Geol. Soc. vol. 48, 1892, p. 104. — M. E. Wadsworth, Syenite and Gabbro in Massachusetts. Geol. Mag., dec. III, vol. II, 1885, p. 207. — For fuller references see W. C. Brögger; Eruptivgesteine des Kristianiagebietes II, 1895, pp. 165—181, and III, 1898, pp. 345, 363.

not be summarized under any simple rule. In this connection it may suffice to make mention of the classical researches which have been made by Iddings in the western States of America, by A. Geikie in the British Isles, and by Brögger in the Christiania district[1].

Most authors agree, as is well known to every petrologist, that, wherever a regularity in the sequence of igneous rocks has been observed or inferred, the cause of the regularity must be sought for in the laws which control the processes of differentiation by which the individual rocks of the particular petrographical province are believed to have descended from a common parent magma. From the order of succession of the rocks conclusions, accordingly, are drawn as to the nature of the supposed processes of differentiation. From this point of view the different rules of chronological sequence are out of harmony, and various attempts, which in the opinion of the present writer are not quite satisfactory, have been made to reconcile them[2].

Harker[3] points out that when only large Plutonic masses are concerned the 'rule of decreasing basicity' is of world wide application, and this distinction is no doubt of great value in the treatment of the problem. The 'rule of decreasing basicity' may as in the Christiania district hold good in some cases also for extrusive rocks, but as a general law (with some exceptions) it is only applicable to abyssal rocks which belong to the same cycle of igneous activity. With this limitation the 'rule of

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[1] J. P. Iddings, The Origin of Igneous Rocks. Bull. Phil. Soc. Washington, vol. 12, 1892. — *Idem*, Journal of Geology, vol. I, 1893, p. 840. — *Idem*, Quart. Journ. Geol. Soc., vol. 52, 1896, p. 617. — A. Geikie, ibidem, vol. 52, 1896, Proceedings p. 178. — W. C. Brögger, Op. cit. — A. Harker, Natural History of Igneous Rocks 1909, pp. 110—146.

[2] W. C. Brögger, Eruptivgesteine des Kristianiagebietes III, 1898, p. 363. — A. Harker, Natural History of Igneous Rocks, 1909, pp. 112—117.

[3] Op. cit. p. 114. — Tertiary Igneous Rocks of Skye, 1904, p. 421.

decreasing basicity' must point to some universal and not to any local causes.

We may now consider the question whether one should seek the universal cause for the 'rule of decreasing basicity' in the processes of differentiation which belong to 'the first order'.

The age of an igneous rock, and its place in the chronological sequence, is assumed at the time of its consolidation, and the observations from which the relative age of two associated abyssal rocks can be inferred, are of the phenomena at the contact between the two rocks (apophyses, variations in size of grains, cutting off of structural planes etc). Hence it must follow that the sequence, found by observation, is really the *sequence of consolidation* and nothing more. This view was clearly enunciated in some of the earlier statements about chronological sequence of Plutonic rocks[1]. But in the later literature the sequence of consolidation is freely considered as synonymous with the *sequence of intrusion* or sequence of coming to place, which with abyssal rocks may be something very different. The sequence of intrusion in turn is by pure hypothesis often referred to a *sequence of differentiation* within the supposed common magma reservoir, and thus an apparent connection is postulated between the order of consolidation of contiguous abyssal rocks and the hypothetical differentiation processes which operate in the deeper portions of the earth crust.

It has already been observed by many petrologists that the differences between the age of associated abyssal rocks are often very small. Thus Dakyns and Teall, speaking of the

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[1] Dakyns and Teall, Quart. Journ. Geol. Soc., vol. 48, 1892, p. 106 ("Taking all facts into consideration, there seems no escape from the conclusion that we have in this area the record of a series of events connected with the *consolidation* of a vast subterranean reservoir of molten rock" [the italics are ours]).

rocks of Glen Tilt, say[1]: 'as a rule the one type passes gradually into the other — granite merges into diorite — but occasionally one rock veins the other, and when this takes place, the granite is always seen to be the younger of the two'. Brögger, discussing the relative age of larvikite and lardalite, mentions that in some places the former rock proves to be decidedly older than the latter, while in other places the contact relations are such as to suggest that both rocks may have been partly fluid (or viscous) at the same time[2]. In the batholites of South Greenland contact relations of this kind are very common.

Now, if the final consolidation of both rocks takes place after the intrusion of both rocks, the development of contact modifications etc. will depend upon the temperatures of consolidation: and the magma with the highest consolidation temperature will consolidate first, and perhaps become 'veined' by the other. The problem of the chronological sequence of abyssal rocks cannot, therefore, be solved without regard to the temperatures of consolidation of the different rocks.

Of these temperatures there are very few exact data. It must be taken for granted, that each rock has a considerable temperature-range of crystallization, and that the lower point of this range, especially in acid rocks, is very different from the melting point of the pure mineral, and is largely dependent upon pressure and the amount of volatile substances which they contain, and hence no precise statements can be given. There is, however, no doubt that under like conditions acid magmas crystallize, as a rule, at temperatures lower than those of basic magmas[3]. The most important exception to this rule is that magmas which are rich in alkalies and in iron must in many cases be assumed to crystallize at a lower temperature

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[1] Op. cit. p. 107.

[2] Erupt.-gest. d. Kristianiageb. III, p. 38.

[3] A. Harker, Natural History of Igneous Rocks, 1909, p. 186.

than other magmas of corresponding acidity. Thus nepheline-syenites often consolidate at a temperature lower than the syenites with which they are associated. It will be seen, therefore, that the usual order of succession of associated abyssal rocks — (1) gabbro, (2) syenite, (3) nepheline-syenite, and (4) granite — corresponds better with a law of decreasing temperature of consolidation than it does with a law of decreasing basicity.

For the closer study of the influence of the temperature of consolidation upon the relative age of associated abyssal rocks, we may consider some important cases separately. For the syenitic and granitic rock-bodies here discussed, the usual batholitic habit will be assumed and it will easily be seen that many of the results are also applicable to large laccolites.

*Gabbro and syenite* (or granite). — It can scarcely be doubted that large syenitic (and granitic) batholites may often remain more or less fluid during the whole period of intense igneous activity, and though intrusion may have commenced at an early date (p. 312), consolidation can only be expected when the igneous activity begins to decline. Even small batholites must remain fluid for a very long time. If we assume that a gabbroid magma is intruded into the upper earth crust during the same period of intense igneous activity, but *later* than a syenitic magma, the gabbro will probably not break through the unconsolidated syenite, but the magmas may perhaps come into contact somewhere along a more or less vertical surface along which, by reason of the viscousity of the syenite, they may not mix. In this case, as mentioned above, contact relations will entirely depend upon the order of consolidation; the syenitic magma, solidifying at the lowest temperature, in some places may send out apophyses into the gabbro; in other places it may encroach upon the gabbro by magmatic stoping and, if so, it will become fine-grained at the contact; in other places perhaps no signs of difference of age will be visible. Such in many places are the actually observed contact relations between associated gabbros and syenites, and it may be concluded that these relations, while justifying us in saying that the syenite is younger than the gabbro, do not settle the question of the original order of intrusion, and still less the order of their differentiation.

Contact relations which, on the other hand, show syenite younger than gabbro may, however, throw light upon the question of the sequence of intrusion. Thus, when syenite is overlain directly by a gabbro of earlier consolidation, we may with certainty conclude that the intrusion of the syenite is later than the consolidation of the gabbro. In this case since a heavy magma cannot rest upon a lighter one, the gabbro cannot have been fluid when in contact with the syenite. Nevertheless it may be quite doubtful whether or not the observed sequence agrees with the original sequence of intrusion. Syenite may be extremely slow in stoping its way through the overlying rocks, and may perhaps meet with solid gabbro sills or laccolites which have been intruded by a process of relatively rapid intrusion at a time later than that at which the syenitic magma began to invade the upper earth crust.

When the igneous activity decreases, the batholites will slowly consolidate. When they have done so, the igneous activity will often be near its final wane. Batholites are, therefore, in many cases traversed by but few independent dykes, and as basic dykes are the commonest of all dykes, the latest of these will probably be basic.

If after a long interruption igneous activity recommences the batholites will have attained a solid state. Syenites under these circumstances may be invaded by a gabbroid magma, and exceptions to the 'rule of decreasing basicity' will result. In such exceptions to the rule, the observed order of consolidation has a real bearing upon the original order of sequence of intrusion.

*Syenite and granite.* — The syenitic magmas are denser and generally solidify at a higher temperature than do the granitic ones. The contact relations between a syenite and a granite belonging to one cycle of igneous activity will, therefore, depend upon the same kinds of factors as are mentioned above for gabbro and syenite, and the granite will usually seem to be younger than or contemporaneous with the syenite, whatever the original order of intrusion may have been.

After the coming to place of the magmas, crystallization by reason of the difference as to chemical composition between crystals and magma, will involve 'secondary differentiation processes'. These processes will tend generally to accentuate the evidence that granite is younger than syenite, and the residual magma from the crystallization of the latter rock may give rise to the formation of quartz bearing dykes or veins within it.

*Summary.* — From the above discussion it will be seen that the sequence of eruption of associated igneous rocks may most safely be ascertained from the succession of lava flows, or from the intersections of their dykes and minor intrusions. Studies of this kind have been pursued even since the beginning of the science of field petrology, and their importance has been emphasized by v. Richthofen, Iddings, and many others. Of late years attention has been paid to abyssal rocks and the phenomena of their mutual contacts have been observed. For these rocks a sequence corresponding to decreasing basicity has proved to be the usual rule, and it has been assumed that this rule indicates the sequence of intrusion, and with it perhaps also the sequence of differentiation. The interpretation, however, of the contact relations of large abyssal rock bodies involves special difficulties which appear to have been to some extent overlooked. For lavas and dyke-rocks sequence of consolidation of course is identical with sequence of protrusion, but with abyssal rocks no such connection needs necessarily exist. Even in cases where magmatic stoping can be neglected, the consolidation of abyssal rocks may have taken place much later than their intrusion. With batholites in which the contact relations are largely determined by the effects of stoping, the contact phenomena will depend rather upon the final stages of the process, than upon the original sequence of intrusion.

For this reason the magma reservoirs from which superficial lavas have originated may present themselves as apparently later intrusions into their own lavas (p. 305), and for the same reason the oft-discussed regular sequence of abyssal rocks obeying the 'rule of decreasing basicity', is in most cases simply a consequence of the fact, that basic magmas as a rule crystallize at a higher temperature than acid magmas, and is not necessarily an expression of the original sequence of intrusion. The 'rule of decreasing basicity' is in fact essentially a rule of decreasing temperature of consolidation.

We may express the above statement from another point of view thus: — when the contact relations of abyssal rocks indicate a sequence of consolidation which agrees with the rule of decreasing temperature of consolidation, the evidence is insufficient to settle the question of the original sequence of intrusion; but when the contact relations are at variance with that rule (e. g. gabbro veining granite) we may conclude that they express not only the sequence of consolidation, but also the sequence of intrusion.

The Palæozoic abyssal rocks in the south of Greenland agree with the rule of succession according to decreasing temperature of consolidation (gabbro — syenite — nepheline-syenite and granite). This fact in connection with the scarcity of basic dykes cutting the acid and intermediate batholites seems to show that all belong to one uninterrupted cycle of igneous activity.

## STRUCTURE OF THE ILIMAUSAK BATHOLITE.

While the great batholite of Igaliko as far as is known shows a rather simple, geological structure, the Ilimausak batholite contains many interesting rock types which are arranged in an unusual manner. The details of the geology and petrography of this complex have been presented in the preceding chapters, and at this place the principal features will be considered from a more theoretical point of view.

The Ilimausak complex of abyssal rocks can be divided into two parts which are very different in their geological structure: a western which is unstratified, and an eastern, stratified part. The main rock of the western part is a syenite. The eastern, stratified part consists largely of lujavrites and other peculiar rock types belonging to the family of nepheline-syenites.

*The unstratified part of the complex.* — In the unstratified complex the inter contact surfaces of the abyssal rocks are generally more or less vertical, and present the ordinary structures found in complex batholites.

This part of the Ilimausak complex occupies a considerable area in the west of the district, from Sermilik to Kakarsuak. South of Tunugdliarfik Fjord it occupies only a narrow zone, and fringes the southwestern and southeastern border of the stratified complex.

The rocks of the unstratified complex are essexite, syenite (nordmarkite and augite-syenite), and granite. These rocks are generally coarse-grained even at the very contact of one rock with another, and must all, therefore, belong to one period of igneous activity. Wherever a difference of age is demonstrable, the essexite is seen to have consolidated prior to the syenite, which in turn is prior to or almost contemporaneous with the granite.

The essexite occupies a small area around the Narsak settlement. The original form of the whole essexite body cannot be indicated, as the rock on one side borders upon the sea while on the other it is in contact with the younger syenite. The syenite apparently has stoped away a portion of the essexite, and the structural planes of this latter rock are cut off by syenite which contains fragments of essexite.

The essexite was probably intruded in a different way from the other abyssal rocks of the complex. This is indicated (1) by the presence of very wide dykes of coarse-grained essexite — which increase slightly in width towards E. N. E. — (eg. on the isle of Tugtutok (west of Narsak), and in the case of one large dyke of a similar rock at Kangerdluak (N. E. of Narsak)), and (2) by the frequent occurrence of flow structures, which are more or less vertical even within the main body of the essexite. The strike of this vertical structure was noted during the field work at one place only (namely at Panernak) where it runs from E. N. E. to W. S. W., and parallel to the ordinary direction of dykes over the entire district. These circumstances seem to indicate that the essexite of Narsak cannot be considered as an ordinary 'batholitic' rock body but may, perhaps, represent the confluence of two or more converging dykes, whose westward continuation is concealed under the sea, and whose eastern continuation has been stoped away by the syenitic magma.

In this part of the complex the syenite is the dominant rock. It has a wide distribution in the country north of Narsak where it has a reddish colour, and as it often contains a little quartz it has been called Nordmarkite. South of Tunugdliarfik Fjord the syenite most often is a gray and olivine bearing augite-syenite. The difference in chemical composition between the two varieties is not very great (compare analyses **16** and **17**) and transitional forms are observed. Geologically both syenite masses may perhaps be regarded as one unit.

*The stratified batholite.* — Upon the map this part of the complex shows a roughly ellipsoidal outline, and is about 16 kilometers long and 10 kilometers broad. It consists of a large number of coarse-grained rocks arranged as approximately horizontal sheets or strata one above the other. Each stratum exhibits a platy parting parallel to the upper and lower surfaces. The thickness of the successive strata is variable, but most of them are thinnest at the northern margin of the complex. As the topography of the region has not been surveyed in detail the thicknesses can only be given approximately.

Between the top of the batholite and sea level the following stratified series are present (the figures indicate the thicknesses):

arfvedsonite-granite, 150—400 meters
quartz-syenite, 0—20 meters
pulaskite, 10—30 meters
upper foyaite, 0—10 meters (?)
sodalite-foyaite, 2—150 meters
naujaite, 200—600 meters
lujavrites, more than 600 meters.

The lowermost series 'the lujavrites' to speak more definitely consists of irregular alternating sheets of arfvedsonite-lujavrite and ægirine-lujavrite, and in the southern part of the batholite there is also a heavy series of kakortokite sheets occurring as an intercalation among the lujavrites.

The character of the contact phenomena at the junction of the successive sheets is as follows:

1. The size of grains does not change appreciably towards the junction.

2. There is a gradual transition from sheet to sheet, but the transition zones are generally rather narrow. Away from the transition zones each sheet seems to maintain a uniform composition.

3. There are no apophyses passing from one sheet into the next.

The junction of the naujaite with the lujavrite is exceptional. In some places there may be found a slow and gradual transition, but more usually this junction is represented by a characteristic breccia zone which will be considered more fully below.

From these contact relations it is inferred that all the sheets are of approximately the same age, and that most of them have probably been in a semi-fluid or viscous state at the same time. Furthermore, the tolerably horizontal disposition of the sheets seems to indicate that gravity was the main factor which controlled the form and the distribution of the individual rock bodies.

The most simple assumption, therefore, which at once lends itself as a possible explanation of the sheeted structure, is that we are dealing with the results of differentiation in place; or speaking more precisely, that which was originally a more or less homogeneous magma, has, while yet in a semi-fluid condition, separated itself under gravity into horizontal sheets of different compositions. Upon closer examination, however, the question proves to be more complicated, but before it can be discussed more fully it will be necessary first to consider some other facts relating to the structure of the batholite.

*The concave shape of the sheets.* — In the above statement, the batholitic sheets have been spoken of as approximately horizontal. Their actual form more exactly can be characterized as that of flat saucers piled up upon each other (Fig. 29). This is seen very clearly in the natural sections, especially in those on the two sides of Tunugdliarfik Fjord (see p. 68, Fig. 11, and Pl. VI, Fig. 1).

The behaviour of the stratification at the boundaries of the batholite is variable. At some places the sheets are at right angles to the boundary planes (see p. 42, Fig. 6, and p. 61, Fig. 10), but in such cases the stratification becomes indistinct, and finally disappears on approaching the boundary. At other places, especially at the eastern boundary, the marginal parts of the sheets are bent almost vertically upward until they become almost parallel to the walls of the encasing rocks (see p. 73, Fig. 12).

Apart from this last mentioned abnormal dip the sheets show, on the whole, a low and moderate inclination towards the centre of the area occupied by the stratified batholite. Towards this point also the porphyry strata which form the roof of the batholite are inclined, and the same dip also affects the series of sandstone beds and volcanic sheets which surround the southwestern, the northwestern, and the northeastern sides of the batholite. From this we may conclude that the sheets of the batholite were originally more horizontal than at present, and that they have attained their concave form by reason of a local subsidence, which reaches its maximum beneath the central part of the batholite.

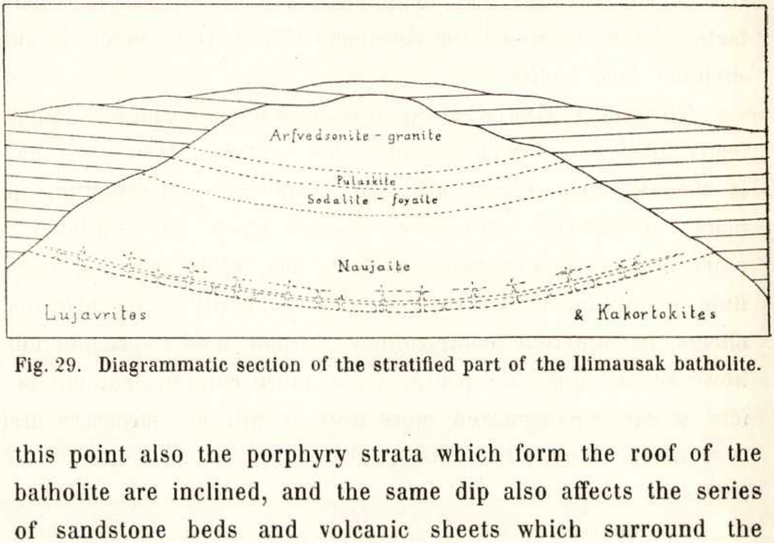

Fig. 29. Diagrammatic section of the stratified part of the Ilimausak batholite.

*The breccia zone.* — At the junction of the light-coloured naujaite with the dark lujavrite the regular transitions from sheet to sheet, described above, are replaced by a peculiar breccia zone.

The character of this breccia zone which may be more than two hundred meters thick is best seen from the photograph, (Pl. XII). The rock consists of immense blocks of naujaite in a network of lujavrite veins; a detailed description is given (p. 37). The breccia is evidently an igneous breccia; as proved by its flow structure it has originated at a time when the naujaite was solid and the lujavrite semi-fluid, but since the lujavrite shows no noticeable diminution in the size of its grains towards the contacts with the naujaite, the latter must have been hot when the breccia was formed.

It can hardly be doubted that the formation of this breccia was due to the same local subsidence which gave the concave form to the batholitic sheets, and the subsidence, thus, must have occurred after the consolidation of the naujaite and during the crystallization of the lujavrite. This view is corroborated by the fact that the schistose structure of the main mass of the lujavrite — a structure produced before the final consolidation of the rock (see p. 166) — is parallel to the general concave benching of the batholite; while the lujavrite along the eastern vertical walls of the batholite, where it has apparently been forced upward by the subsidence of the central portion, is characterized by an almost vertical schistosity.

It may be asked why the breccia zone cannot have originated from magmatic stoping. The character of the breccia indeed is in some respects about such that might be expected of a true 'stoping breccia'. But there are also considerable differences, viz.:

1. The lujavrite, as mentioned above, shows no noteworthy diminution in size of grains at its junction with the naujaite.

2. The upper surface of the lujavrite is on the whole concave, while the upper surface of a stoping magma, as a rule, must be convex.

3. The number of detached blocks of naujaite imbedded in the upper part of the lujavrite mass is very large, and nearly all lie undisturbed with their partings parallel to those of the overlying unbroken naujaite mass. In a 'stoping breccia' relatively few roof blocks would fail to sink, and the sides of the different blocks would in sinking take up very various positions.

The absence of stoping action may evidently be referred to the low specific gravity of naujaite, as compared with that of lujavrite. The specific gravity of naujaite is 2·5, and of lujavrite 2·8. At the time of formation of the breccia the lujavrite magma was of course lighter than 2·8, but lujavrite magma was probably rather viscous, and that it had already started to crystallize has been proved by the flow structure. It is not, therefore, probable that the specific gravity at the time of intrusion should have been so much lower than 2·8 that naujaite blocks could sink.

The breccia zone is, thus, assumed to have been produced by the same movements which gave rise to the concave form of the sheets, viz. the unequal subsidence of the mass. In seeking for the explanation of this local subsidence which, as we have seen, must have occurred during the latest stages of the consolidation of the batholite, two possibilities are to be considered: either, the batholitic chamber at the time of the subsidence may have communicated with more deep-seated reservoirs, or, it may have been cut off from communications of this kind. If the batholitic chamber were open, the most simple explanation is that the magma has sunk. If closed, the unknown substratum of the lujavrite may perhaps have remained fast, and the subsidence may have been caused by the diminution of volume of the lujavrite, as it crystallized and became solid. As we do not know the thickness of the lujavrite mass it must remain undecided, whether the latter hypothesis suffices to explain the subsidence or not.

*Mutual relation of the stratified and the unstratified parts* *of the batholite.* — Though north of Tunugdliarfik Fjord the stratified part of the batholite is separated from the unstratified part by a strip of volcanic rocks, it may be inferred from the inclinations of the junction surfaces exposed in the large valley north of Narsak, that the two parts of the batholite are in contact below sea level. South of Tunugdliarfik Fjord the unstratified part of the batholite is only represented by a narrow zone of augite-syenite which encircles the southwestern, southern, and southeastern boundaries of the stratified batholite (see Pl. III), which itself here consists entirely of nepheline-syenites. The augite-syenite thus forms, as it were, an outer shell around the southern third of the stratified batholite, and on both sides of Kangerdluarsuk the junctions are well exposed.

The relations between the nepheline-syenites and the bordering zone of the augite-syenite are of more than local interest, for apparently similar geological features are also met with in other localities, such as the western side of the Igaliko batholite (Pl. IV) and at Umptek in Kola[1]. At Umptek the northeastern margin of a great nepheline-syenite mass is bordered by a narrow zone of umptekite (a syenite related to the nordmarkite of Narsak), but Kangerdluarsuk is the only one of these localities where the contact relations have been studied in any detail.

A glance at the map, (Pl. III), will show that the distribution of the rocks admits of three different interpretations:

(1) The syenite may represent an endomorphic contact modification of the nepheline-syenite. This is the hypothesis indicated by Ramsay to explain the conditions at Umptek, but, as Harker remarks[2], no observations which could give any direct support to this view are cited.

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[1] W. Ramsay und V. Hackman, Das Nephelinsyenitgebiet auf der Halbinsel Kola. Fennia XI, No. 2, 1894, p. 81.

[2] Natural History of Igneous Rocks, 1909, p. 136.

(2) The syenite may be a later intrusion forced up between the nepheline-syenite and the encasing rocks. The syenite on this assumption would be a kind of dyke.

(3) The syenite may have been intruded prior to the nepheline-syenite.

In order to settle the question it is necessary to discuss the contact relations. At the outer margin, where the syenite borders upon Algonkian granite and sandstone, the contact features are of the well known kind which characterize the junction of a batholite with country rock. They are the reduced size of grains, enclosed fragments of the wall rock, numerous apophyses, and contact metamorphism of the wall rock, which have been described (pp. 51, 59, 103). Away from the margin of the batholite, at the junction of the syenite with the nepheline-syenite, the contact relations are entirely different. There, in the exposed sections, the junction generally appears as a definite line, and both rocks are coarse-grained to the very contact. There is no contact metamorphism, and no apophyses have been observed. At Iviangusat, where this junction is excellently exposed, the size of grains of the nepheline-syenite actually increases near the contact, and fragments of the syenite are enclosed within the nepheline-syenite. The latter, moreover, is cut by numerous veins of extremely coarse-grained pegmatite, and the veins are parallel to the contact plane (p. 48), and hence the nepheline-syenite must have consolidated later than the syenite, but not so much later than that the syenite had time to cool down.

Another circumstance of great interest is the peculiar behaviour of the stratification of the nepheline-syenite near the contact. The contact plane, as a rule, is almost vertical and the stratification nearly horizontal. Moreover, on approaching the contact the stratification does not change its direction, but gradually fading away becomes indistinct, until the nepheline-syenite nearest to the junction does not present any sheeted structure, but changes its composition gradually from sea level to the top of the mountains.

It will be seen, therefore, that the syenite can neither be interpreted as a contact modification of the nepheline-syenites, nor regarded as a dyke, but that it must have originated as an independent intrusion prior to the arrival of the nepheline-syenites. To some extent at least it must have been solid when the nepheline-syenitic magma was intruded, but it has had no chilling effect on that magma.

If, as here asserted, the complex has come to place mainly by magmatic stoping the syenite can only be interpreted as a remnant of an older batholite, of which a great portion has been replaced by the nepheline-syenite (Fig. 30). As the specific gravity of the nepheline-syenite is considerably lower than that of the syenite, it is probable that also the nepheline-syenitic magma was less dense than the syenitic magma, and the replacement, therefore, may perhaps have occurred at a time when the syenite was in a somewhat viscous state. On the other hand, the fragments mentioned above tell us that some portions of the syenite at least have been removed in the solid state.

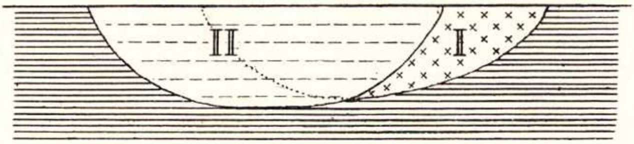

Fig. 30. Idealized section of the Ilimausak batholite, illustrating its complex nature.

I The older, unstratified part of the batholite (mainly syenite). II The newer, stratified part of the batholite (mainly nepheline-syenite) which has partially replaced the syenite.

This hypothesis for the mutual relation of the stratified and the unstratified parts of the abyssal complex gives a satisfactory explanation of their distribution, both horizontally and vertically. On the northeastern side the nepheline-syenitic magma has entirely replaced the older filling of the batholitic chamber, and as proved by the contact relations at Nunasarnak has even advanced beyond the former limits of the chamber (see p. 74); on the southeastern and southwestern sides a narrow zone of syenite, which now coats the nepheline-syenites as an outer shell, remains; and on the western and northwestern sides of the complex a large portion of the original syenite-batholite has been left. This latter portion has later on been penetrated by some independent granitic invasions (see map, Pl. III).

The hypothesis also explains the presence of a small remnant of augite-syenite in the southernmost part of the Ilimausak Mountains (at the north side of Tasek) where it rests between the arfvedsonite-granite and the roof of the batholite (mentioned p. 88).

## THE LUJAVRITIC STRUCTURE.

*Abyssal nature of lujavrites.* — The lujavrites of Ilimausak are very different in their structural characters to ordinary abyssal rocks. As a rule they are fine-grained and display a pronounced schistosity which has been assumed during the crystallization (see p. 166). It is true that coarse-grained varieties also occur, but these are quite subordinate. When, in 1892, I undertook the examination of these rocks I had not seen the occurrence in the field, and from the structure I incorrectly drew the conclusion that the lujavrites should be regarded as a peculiar kind of chilled edge to the coarse-grained nepheline-syenites[1].

For the lujavrites of Kola, which are on the whole a little more coarse-grained and a little less schistose than those of Ilimausak, a somewhat similar view was enunciated by W. Ramsay

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[1] Forhandlinger ved 14. Skandinaviske Naturforskermøde. København 1892, p. 433.

at about the same time. Ramsay regarded the lujavrites as making up 'the upper portion of a laccolite'[1]. But this view is mainly inferred from the structure of the rock[2], for at Lujavr-Urt no remnants of the cover of the 'laccolite' has escaped destruction, and there is no indication that the lujavrite has been covered directly by the country rock. On the other hand, the presence of some remnants of coarse-grained tavite in the upper portions of the mass suggests that, as is still the case with the Greenlandic lujavrite, the Kola lujavrite may originally have been overlain by similar coarse-grained abyssal rocks.

At Ilimausak the geological position of the lujavrite is clear. (1) It is the lowest visible rock of a batholite whose upper part consists of very coarse-grained naujaite, foyaite, syenite, and granite, and these rocks already occupied their present position when the lujavrite solidified. The lujavrite, thus, has consolidated in a situation more abyssal than that of the granite. (2) The total mass of the lujavrite exceeds that of all the other nepheline-syenites of this batholite put together (the volume of lujavrite at Lujavr-Urt is perhaps still greater). (3) At the junction with the wall rock the lujavrite exhibits a contact modification quite analogous to the junctions of ordinary abyssal rocks (see p. 176).

We must, therefore, conclude that the lujavrite, in spite of its fine-grained and schistose structure, is a true abyssal rock.

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[1] Fennia XI, no. 2, 1894, p. 97. The laccolitic nature of the Kola nepheline-syenites, suggested by Ramsay in this important memoir, is a matter of inference as no bottoms to the laccolites have been observed. The assumption is based mainly upon the observation of stratified rocks which have been found locally at the margin of the nepheline-syenites. These stratified rocks dip towards the Plutonic mass and are, partly, covered by it. The conditions apparently are analogous to those described in the present report as occurring at Mount Iganek (see Fig. 21, p. 252) and at several other places.

[2] "Dafür spricht in erster Linie die Structur der Lujavrite" loc. cit. p. 97.

*Interpretation of the structure.* — The fact, that when abyssal or hypabyssal rocks are considered the size of the grains is independent of depth, has been demonstrated at other localities[1]. Many instances are also known where a coarse-grained rock has crystallized nearer the surface of the earth than a less coarse-grained one[2]. The usual explanation given is that the size of grains depends upon the chemical composition of the magma. An explanation of this kind, however, is not applicable to the structure of the lujavrite of Ilimausak. Firstly, it does not explain the schistosity of the rock, and secondly, it appears to be quite insufficient to account for the small size of grains. Not only is there a vast contrast between the size of grains of the lujavrite and those of the superincumbent rocks, but the lujavrite itself contains an intercalated rock body of kakortokite which has the same chemical composition, but is much coarser grained. Moreover the fine-grained texture seems to be related to the schistosity: where the schistose structure is wanting the rock is somewhat coarser.

A key to the explanation both of the small size of grains and of the primary schistosity of the Greenlandic lujavrite may probably be found in the fact (see p. 324), that during the crystallization of the lujavrite the overlying strata have sunk; as far as that part of the rock which envelops the naujaite fragments of the breccia zone (p. 322) is considered, it is obvious that there must be a connection between the magmatic movements and the structure of the lujavrite. On the other hand, there is no perceptible difference in structure between the lujavrite of the breccia zone and the bulk of the rock, but that the parallel arrangement of the mineral components in the

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[1] W. Cross, The Laccolitic Mountain Groups of Colorado, Utah, and Arizona. U. S. Geol. Survey, 14th Annual Report, Part II, 1894, p. 230.

[2] W H. Weed and L. V. Pirsson, Geology of the Judith Mountains. U. S. Geol. Survey, 18th Annual Report, Part III, 1898, p. 574; Geology of the Little Belt Mountains, ibidem 20th Ann. Rep., Part III, 1900, p. 562.

upper portion of the mass follows surfaces which curve round the naujaite fragments, while in the main part of the rock the structure follows the general inclination of the batholitic sheets which are indicated in Fig. 29 (p. 322), though there is an even transition between the two arrangements. Observations, thus, seem to indicate that the schistose structure of the whole lujavrite mass is causally connected with the sinking down of the upper strata. But here we meet a difficulty, for it would appear that a structure produced in this way must be limited to the border zone, whereas, as a matter of fact the schistose structure affects the whole mass.

The lujavrite has crystallized after the other rocks of the batholite, and, therefore, probably at the lowest temperature. The high content of low melting point minerals, such as arfvedsonite, and the behaviour of the felspars of the rock (see p. 160), confirm the assumption that the crystallization occurred at a low temperature. On the other hand the large quantity of secondary analcime replacing almost all the light coloured minerals occurs as anhedra which are larger than the average crystals of the primary constituents of the rock. The very common pneumatolytic alteration products which are found in all rocks of the batholite, also seem to indicate that the lujavrite during its crystallization must have given off great quantities of volatile substances.

For these reasons the lujavritic magma is supposed to have been very rich in volatile substances, and to have cooled down to a relatively low temperature before it became finally consolidated.

Another peculiar circumstance relating to the crystallization of this rock may be mentioned, namely the absence of an active pressure from below. When an ordinary abyssal rock crystallizes, it must be assumed that the decrease of volume caused by the crystallization, as a rule, is compensated by an additional supply of magma from below. But since the overlying rocks subsided during its crystallization it must have been otherwise with the lujavrite. The cause of this peculiar condition may perhaps be found in the very low consolidation temperature of the lujavrite. We do not know what underlies the lujavrite at Ilimausak, but whether it be an essexite, or an augite-syenite, or any other rock, it had probably a higher consolidation temperature than lujavrite, and it may thus in spite of the greater depth have been capable of crystallizing first.

By these assumptions — (1) a low temperature of consolidation; (2) a large proportion of water etc.; and (3) a solid substratum — the peculiar structure of the lujavrite seems to be intelligible. The subsidence and the fissuring of the upper strata, and the accompanying forcing up of a portion of the lujavritic magma along the eastern and perhaps the northern borders of the batholite, would facilitate the escape of volatile substances, and would thus accelerate the cooling and crystallization, but would counteract the development of large crystals. The solid substratum would prevent the supply of additional magma, and the contraction produced by the escape of water vapours, and by the transition to the crystalline state must therefore have resulted in a subsidence of the overlying rocks which continued during the entire period of crystallization. This subsidence of the solid roof, being somewhat irregular, would produce movements within the magma basin, and the movements would continue, and gradually affect all parts of the magma, until even the deepest portions had contracted to solid rock. The movement, thus, would be, not only an additional cause favouring the development of a fine-grained structure, but might also produce a primary schistosity of the whole mass. The observed geometry of the schistosity, the dip of the parting planes etc. are in agreement with this hypothesis.

It will easily be seen that the above attempt to explain the lujavritic structure does not imply the assumption that absolutely all parts of the magma must crystallize to a schistose rock, nor that the rock must always be fine-grained, as would be the case if the size of grains depended upon the chemical composition only.

It will also be seen that the assumption of a solid and passive substratum is an important point in the interpretation of the schistose structure. At Ilimausak the presence of this kind of substratum cannot be proved by direct observations, but its presence may be inferred with great probability from the form of the upper surface of the lujavrite body which has been actually observed. On the other hand, it must be remembered that the simplest explanation of the passive substratum depends upon the assumption of an exceptionally low temperature of consolidation for the lujavritic magma, and we are, thus, referred back to the chemical composition of the magma as the ultimate cause of the peculiarities of the lujavritic structure.

It might, therefore, be expected that lujavrites also at other localities would often show structures like those of the Ilimausak lujavrite. Some other occurrences of lujavrite have already been described, but in these the analogy with the Ilimausak rock is very striking.

The most important lujavrites outside Greenland are those of Kola[1] and of the Transvaal[2], and from both localities the small size of the crystal grains and the schistosity are mentioned as usual and characteristic features of the rock. A similar structure also characterizes the lujavrite of Ruma[3].

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[1] W. Ramsay, Das Nephelinsyenitgebiet auf der Halbinsel Kola II. Fennia XV, No. 2, 1899.

[2] H. A. Brouwer, Oorsprong en Samenstelling der Transwaalsche Nepheliensyeniten. s'Gravenhage 1910, p. 107.

[3] A. Lacroix, Sur les facies de variation de certaines syénites néphéliniques des îles de Los. Comptes rendus CXLII, 1906, p. 681.

Ramsay, in 1899, discusses the problem of the lujavritic structure in some detail[1]. He points out the difficulty connected with the interpretation of this structure, and expresses the opinion that 'it must be referred to a slow cooling and a quiet crystallization of the magma'. He opposes the view held by **Brögger** and others, that the structure is an ordinary flow structure. His objections are mainly based upon the assumption that the schistosity, if produced by magmatic movements, must be connected with the intrusion of the magma, and are apparently of no effect if the movements have been produced in the manner explained above.

It appears, therefore, that the schistose structure of lujavrites in Greenland and elsewhere may be explained as a true flow structure produced under peculiar conditions.

## CHEMICAL COMPOSITION OF THE ILIMAUSAK AND IGALIKO ROCKS.

The analyses of igneous rocks from the country around Julianehaab have been given and discussed separately in the chapters dealing with the petrography of the country. For convenient reference all analyses are grouped in one table at the end of the volume, and at this place the main features characterizing the igneous complexes will be briefly considered from a chemical standpoint.

*Common characters.* — The igneous rocks of Ilimausak and Igaliko belonging to a single cycle of igneous activity (probably of late Devonian date) exhibit certain common characters which may be summarized thus: —

(1) All belong to the alkali family of rocks.

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[1] Fennia XV, No. 2, p. 11.

(2) Soda predominates strongly over potash.

(3) Magnesia is almost entirely absent. An exception is found in the magnetite-pyroxenite of Narsak (analysis **19**), but this rock only occurs within a limited area of quite insignificant dimensions.

(4) Lime is relatively low.

(5) When the basic rocks (essexites and trachydolerites) are left out of consideration alumina in relation to alkalies is low.

While these characters illustrate the general consanguinity of the Ilimausak and Igaliko rocks, a close relationship asserts itself within some of the main divisions of the complexes. As only a few analyses of the effusive and hypabyssal rocks have been made, these rocks are omitted from the following discussion.

*Igaliko batholite.* — The main rock is a nepheline-syenite (analysis **25**) which agrees with the habit of the ordinary Foya type. It is also chemically related to the Foya type, but shows a marked tendency towards the agpaïtes mentioned below. Associated with the main rock is an augite-syenite (analysis **26**), closely related to that of the Ilimausak batholite. This rock is the only type which is common to the two batholites.

*Unstratified part of the Ilimausak batholite.* — The analyses of the principal rock types are graphically represented in Fig. 31[1]. The figure shows that the compositions of the syenites (nordmarkite and augite-syenite) are generally intermediate between the compositions of the granite[2] and the essexite. This,

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[1] In the Figs. 31 and 32 the horizontal rows represent the analyses calculated at 100 per cent., omitting $H_2O$, F, and $Nb_2O_5$. $TiO_2$ and $ZrO_2$ have been added, and the sum is given as $TiO_2$ if $TiO_2$ be predominant, and as $ZrO_2$ if this be predominant. The percentage weights are given as abscissæ.

[2] In Fig. 31 the first column ought to give the composition of the arfvedsonite-granite of Narsak, described (p. 115). As, however, no chemical analysis has been made of this rock, the corresponding rock from North Siorarsuit has been taken to represent the Narsak granite, with which it agrees very closely.

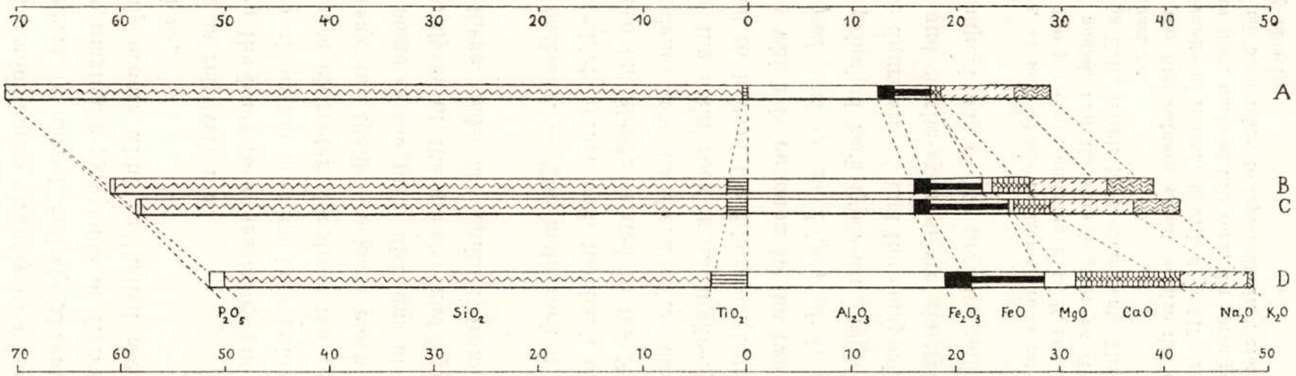

Fig. 31. Analyses of rocks of the unstratified part of the Ilimausak complex.

A arfvedsonite-granite (analysis 1, p. 114); B nordmarkite (17); C augite-syenite (16); D essexite (18). The vertical distances between the rows have been chosen proportional to the differences between the silica percentages.

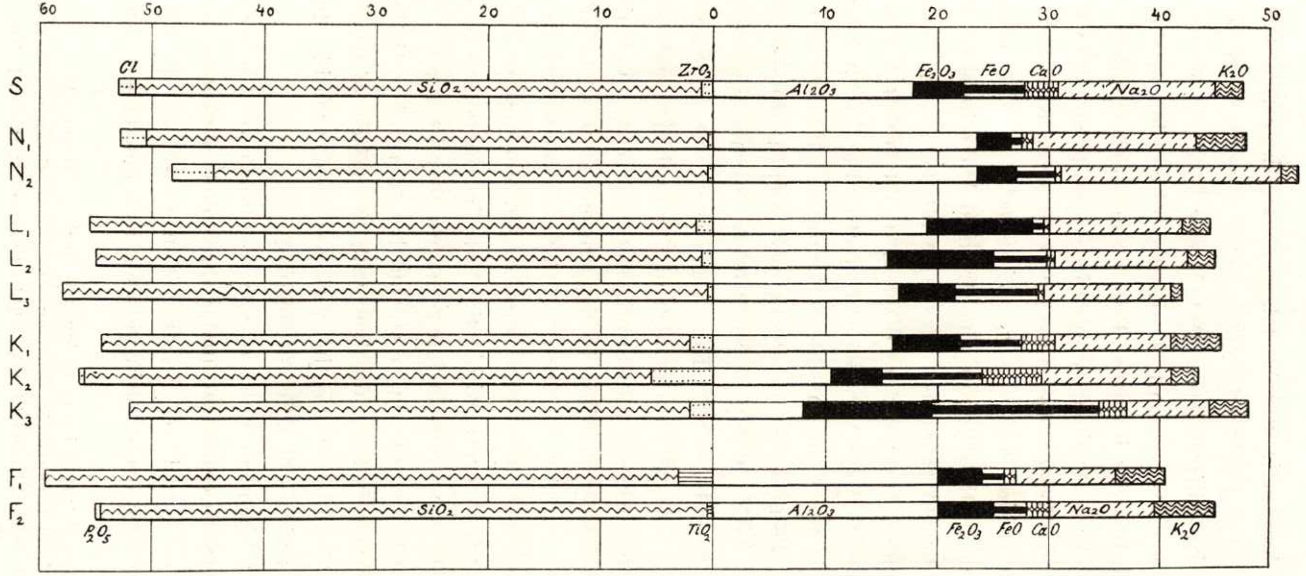

**Fig. 32. Analyses of the nepheline-syenites of Ilimausak (all columns excepting the last one) and of Igaliko ($F_2$).**

S sodalite-foyaite (analysis 5, p. 141); $N_1$ and $N_2$ naujaites (6 and 7); $L_1$, $L_2$, $L_3$ lujavrites (9, 11, 12); $K_1$, $K_2$, $K_3$ kakortokites (13, 14, 15); $F_1$ and $F_2$ foyaite (4 and 25). See also footnote 2 p. 335.

as is well known, is usually taken as an indication that the rocks have been produced from a parent magma by some kind of progressive differentiation, but it would by far exceed the scope of the present report to give any discussion of the problems which this view involves. Here we need only mention that if the rocks of the unstratified batholite have been produced by differentiation, that differentiation must have been prior to the intrusion.

*The stratified batholite of Ilimausak.* — The chemical compositions of the rocks of the stratified batholite show much more complicated relations. If the results of all the analyses are represented in a variation diagram of the ordinary kind[1], it will be found that the variations are pictured as highly irregular curves. It is not even possible to arrange all the analyses into one series, because several rocks with almost identical silica percentages differ widely in their other constituents (compare analyses **5** with **14**, **6** with **15**). A glance at the accompanying figure (Fig. 32) in which a number of the nepheline-syenites are graphically represented will show the same fact (comp. $N_1$ with $K_3$).

It is scarcely possible in the present state of knowledge to arrive at a quite satisfactory interpretation of the genetic relations between the large number of chemically differing rock types which occur within the stratified batholite, although in some details a probable interpretation may be given. Some of the variations appear to be attributable to a differentiation by fractional crystallization combined with the effects of gravity in situ, while in other cases the variations are probably due to successive arrivals of different magmas.

From a chemical point of view the rocks of the stratified batholite may be comprised under three main divisions: (1) the granite; (2) the rocks of the transition zone; and (3) the agpaïtes, the latter name[2] being chosen as a convenient term for

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[1] A. Harker, Natural History of Igneous Rocks, 1909, p. 118.

[2] Agpaïte from Greenlandic *agpa*, auk, pl. *agpat*, the name of a locality on the S. side of Tunugdliarfik, within the area of the batholite.

that peculiar subdivision of nepheline-syenites which is represented at Ilimausak, by the rocks described as sodalite-foyaite, naujaite, lujavrite, and kakortokite. In the following table the rocks are enumerated in order from the top of the batholite downwards, with indication of the main divisions:

| | |
|---|---|
| I. Granite (arfvedsonite-granite) | |
| II. Transition zone | Quartz-syenite<br>Pulaskite<br>Foyaite |
| III. Agpaïtes | Sodalite-foyaite<br>Naujaite<br>Lujavrites and kakortokites. |

I. *The arfvedsonite-granite* constituting the uppermost 150—400 meters of the stratified batholite is, chemically, related to the soda-granites of the Christiania district. The flat under surface of this rock body and the gradual transitions to the underlying rock lend some support to the view that the granite has not been separately intruded, but has originated by differentiation in place. On the other hand it is difficult to imagine any process by which the arfvedsonite-granite could originate in situ as a differentiation product of the agpaïte rocks which now underlie it.

The question can, however, be viewed in another light. It has been pointed out that the stratified abyssal rocks do not represent the original filling of the batholitic chamber. At several places large masses are left which suggest that the original filling was a syenitic magma. It is perhaps not impossible to imagine that the granite in some way may have originated from the syenitic magma. Owing to its lower specific gravity it may have accumulated at the top of the chamber, while both magmas were yet in a semi-fluid condition. For reasons given above (p. 321) a genetic relationship between the granite and the syenite is probable, and it appears to be indicated also by the presence of granite enclosures in the augite-syenite of Iviangusat (see p. 53).

II. *The transition zone* between the granite and the agpaïtes consists of three layers: quartz-syenite, pulaskite, and foyaite, the total thickness of which only amounts to 10—50 meters. Only the central one of these layers, the pulaskite, has been found constantly separating the granite from the agpaïtes, while the two other layers are wanting at some places, and are always somewhat variable in their mineralogical constitution.

The quartz-syenite has not been chemically analyzed. The pulaskite (analysis **3**) is chemically very closely related to the syenites (nordmarkite and augite-syenite) which occur in the unstratified part of the batholite. The foyaite (analysis **4**) has about the same silica percentage as the syenites, but differs in its alkalies which are a little higher, in alumina which is about 5 per cent higher, and in iron oxides and lime which are lower. The presence of this rock as a subordinate sheet within the Ilimausak batholite is remarkable, for the rock is chemically of a type which is very different from all the other rocks of this batholite, but shows a certain analogy with the foyaite of the Igaliko batholite (compare $F_1$ and $F_2$, Fig. 32) and is very like the foyaites of many localities outside Greenland.

The rocks of the transition zone cannot apparently be regarded as having been brought in by successive intrusions along the boundary plane which separates the granite from its substratum. Here, as elsewhere, the hypothesis of successive intrusions fails to explain the differences between contiguous sheets, and only accounts for contact phenomena which appear at the boundaries between the sheets. But at Ilimausak such phenomena are entirely wanting; the sheets are uniformly coarse-grained throughout; and there is everywhere a gradual transition without any trace of a contact plane between them. These facts seem to point to the conclusion that the junctions of the sheets have been viscous at the same time, and thus an origin by successive intrusions seems to be precluded.

The most probable interpretation of the rocks of the transition zone appears to be that they have been produced in situ by an interaction between the granitic and the agpaïtic magmas, and that the mingling along the junction has given rise to reaction sheets which have crystallized at a higher temperature than either magma. Another theory is that the above explanation should only be applied to the upper and lower sheets, and that the middle sheet, the pulaskite, is a remnant of the original syenite which at one time filled the reservoir. The latter view is perhaps supported by evidence from the northeast side of Nunasarnausak, where the pulaskite sheet comes next to the augite-syenite of the unstratified complex. Here no boundary has been detected between the two rocks, but further observations are needed before the question can be settled.

*The agpaïtes.* The term agpaïte (see footnote p. 338) is here introduced as the name of a subgroup of the great family of nepheline-syenites. As a subgroup it is characterized by certain peculiarities of chemical composition. The compositions for the Ilimausak agpaïtes are given in the analyses **5—15**, and the main types are represented graphically in Fig. 31 (S, N, L, and K). For comparison the figure also gives the composition of two other nepheline-syenites, one of which ($F_1$) may be taken as a representative of ordinary non-agpaïtic foyaites, while the other ($F_2$) is approximately intermediate between the ordinary foyaites and typical agpaïtes.

The chemical character which distinguishes the agpaïtes from other nepheline-syenites is the excess of alkalies in proportion to alumina. Thus, if *na, k,* and *al* are the relative amounts of Na-, K-, and Al-atoms in the rock, the apaïtes may be characterized by the equation:

$$\frac{\mathrm{na} + \mathrm{k}}{\mathrm{al}} \geqq 1{\cdot}2,$$

whereas in ordinary nepheline-syenites this ratio does not exceed 1·1[1]. The agpaïtes are thus in a position within the nepheline-syenite group which is somewhat analogous to that occupied in the family of rhyolites by the pantellerites.

Iron is generally present in large quantities, but owing to the excess of alkali it does not appear as iron ore in the rocks: it crystallizes instead as ægirine, arfvedsonite, and ainigmatite. Even in the black kakortokite ($K_3$ in Fig. 32) with 25·4 per cent. of iron oxides there are no iron ores. Alkalies are also unusually high, while magnesia is wanting, and lime in most cases is low. A very characteristic feature is the presence of zirconia and chlorine. In some extreme differentiation products of the agpaïtic magma these elements are present in considerable quantities: thus, the red kakortokite contains 5 per cent. of zirconia, and some varieties of the naujaite consist of almost pure sodalite.

A glance at the curves given in Fig. 32 will show that the agpaïtic rocks vary from melanocratic to leucocratic. In this report the *melanocratic agpaïtes* have been classified under three heads according to their structure: — (1) lujavrites, characterized by ægirine and arfvedsonite in needle shaped crystals; (2) kakortokites, which are coarse-grained with stumpy anhedra of ægirine and arfvedsonite and rather thin tabular crystals of felspar; and (3) sodalite-foyaite, a very coarse-grained rock with thick tabular crystals of felspar and a considerable quantity of allotriomorphic sodalite. The name which has been given to the last mentioned rock is not very adequate, and may be regarded as only provisional. Chemically the rock is closely related to the tavite of Ramsay, but structurally it is quite different,

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[1] The values of the ratio (na + k) : al for each of the types which have been analyzed for this report, are given at the end of the volume in the table of analyses calculated at 100 per cent. In the agpaïtes of Ilimausak the ratio varies from 1·2 to 2·1, while in ordinary nepheline-syenites the ratio is from 0·8 to 1·1.

as the tavite is characterized by a poikilitic structure more analogous to that of the naujaite.

*The leucocratic agpaïtes* are represented at Ilimausak by the naujaite, which after the lujavrite is the major constituent of the batholite. The chemical composition of the naujaite differs so much from that of the melanocratic agpaïtes, that it might seem somewhat arbitrary to class both kinds of rocks into one subgroup merely on account of the alkali excess. The chemical type represented in the naujaite of Ilimausak has, however, hitherto always been found associated with melanocratic agpaïtes (in Greenland, Kola, Transvaal, Los Islands) and it is probable, therefore, that the two types are genetically connected.

*Mean composition of agpaïtes at Ilimausak.* — Since the variations of chemical composition within individual rock bodies are only imperfectly known from a small number of analyses, the mean composition of the types cannot be accurately calculated. Still greater uncertainty necessarily affects any calculation of the mean composition of the entire agpaïtic rock body, in which the volumes of the individual rock bodies can only be roughly estimated. The compositions given in the table on the next page can only, therefore, be regarded as probable mean compositions, and in the last column ('Agp') the calculation based on an estimation of the relative original volumes of the lujavrites, naujaites, etc. is given; for the purpose of affording a probable guess as to the mean composition of the *agpaïtic magma* at Ilimausak.

Considering that the agpaïtes are chemically characterized by medium silica, extremely high sodium and iron, relatively low aluminium, and no magnesium, their composition seems to indicate a silicate mixture which had a definite melting point. Hence, if the agpaïtic magma owes its origin to any kind of differentiation processes connected with partial solidification, this magma is probably a residual magma. This view is in

*Mean composition of agpaïtes, Ilimausak.*

| | S | N | L | K | Agp. |
|---|---|---|---|---|---|
| $SiO_2$ | 50·42 | 46·93 | 55·12 | 51·81 | 51·86 |
| $TiO_2$ | ·64 | ·18 | ·36 | ·35 | ·33 |
| $ZrO_2$ | ·62 | ·33 | ·84 | 2·05 | ·79 |
| $Al_2O_3$ | 17·68 | 23·59 | 16·28 | 13·68 | 18·35 |
| $Fe_2O_3$ | 4·29 | 3·37 | 8·66 | 7·32 | 6.50 |
| FeO | 5·36 | 2·16 | 3·53 | 7·27 | 3·68 |
| MnO | ·08 | ·08 | ·29 | ·57 | ·23 |
| MgO | ·54 | trace | ·03 | ·09 | ·08 |
| CaO | 2·28 | ·69 | ·77 | 3·06 | 1·13 |
| $Na_2O$ | 14·16 | 17·40 | 11·30 | 9·75 | 13·26 |
| $K_2O$ | 2·60 | 2·96 | 2·75 | 3·92 | 2·91 |
| Cl | 1·72 | 2·98 | ·09 | ·16 | 1·13 |
| $P_2O_5$ | — | — | trace | — | — |
| | 100·39 | 100·67 | 100·02 | 100·03 | 100·25 |
| $\frac{na + k}{al}$ | 1·5 | 1·3 | 1·3 | 1·5 | 1·4 |

S composition of sodalite-foyaite calculated at 100 per cent., with $H_2O$ omitted (analysis 5).

N approximate mean composition of naujaite (mean of analyses 6 and 7).

L approximate mean composition of lujavrite (mean of analyses 8, 9, 11, and 12).

K approximate mean composition of kakortokite (sum of nine parts of white kakortokite (analysis 13), one part of red (14), and three parts of black kakortokite (15)).

Agp. probable mean composition of the agpaïtic batholite of Ilimausak, calculated as a sum of one part of sodalite-foyaite (analysis S), three parts of naujaite (N), five parts of lujavrite (L), and one part of kakortokite (K). —

$10 \text{ Agp.} = S + 3N + 5L + K.$

agreement with the circumstance that the agpaïtic type is sometimes represented among dyke rocks (certain tinguaïtes) even in petrographical provinces where no abyssal agpaïtes have been found.

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## SPECIFIC GRAVITY OF THE ABYSSAL ROCKS OF ILIMAUSAK.

While the specific gravity of an abyssal rock is a quantity of very little interest from the standpoint of the laccolitic theory of intrusion, the theory of batholitic invasion of subsidence of roof blocks demands that it be given considerable importance. Though we are not able to calculate the original specific gravity of the magma from the observed specific gravity of the rock, the latter quantity will in most cases give an approximate idea of the relative specific gravities of different magmas. The peculiar stratification of one part of the Ilimausak batholite seems to show that in this peculiar case differences of specific gravity have not been without importance in the arrangement of its rocks. For these reasons the specific gravities of the abyssal rocks of Ilimausak have been grouped together in the following table. The determinations were made at about 20° C.

As most of the rocks are conspicuously miarolitic Dr. Steenstrup suggested that it might be of interest to examine, not only the specific gravities of the rocks in a powdered condition, but also in large unbroken specimens. Thanks to his great kindness I am able to utilize the results which he obtained by weighing whole specimens, and subsequently determining their volumes with a mercury volumenometer. The specimens used for these determinations weighed from 500 to 1000 grams. The table shows that the porosity varies very greatly, and evidently it varies more in the case of such local factors as the decomposition of the rocks, than does the specific gravity of rock powder. Even slight decomposition will generally lower perceptibly the specific gravity of the powder, but by sometimes filling the pores and sometimes enlarging them in different cases it affects the porosity very differently.

The sandstone, the specific gravity of which is entered in the last line, has been taken from the great sandstone fragments which are inclosed in the augite-syenite at Iviangusat (see p. 51).

| | Specific gravity (powdered rock) | Weight pr. cm³ (whole specimens) |
|---|---|---|
| *Stratified part of the batholite:* | | |
| Arfvedsonite-granite, Ilimausak (very fresh, greenish) | 2·72 | 2·70 |
| Arfvedsonite-granite, Ilimausak (fresh, brownish) .. | 2·66 | 2·65 |
| Pulaskite, N. Siorarsuit........................ | 2·72 | 2·69 |
| Foyaite, Naujakasik.......................... | 2·67 | 2·62 |
| Sodalite-foyaite, Tupersuatsiak.................... | 2·65 | 2·59 |
| Naujaite, Kangerdluarsuk........................ | 2·53 | 2·51 |
| Ægirine-lujavrite, Nunasarnak.................. | 2·75 | 2·70 |
| Arfvedsonite-lujavrite, Nunasarnak.............. | 2·79 | 2·76 |
| Kakortokite, white, Kringlerne.................... | 2·76 | 2·72 |
| Kakortokite, black, Kringlerne.................. | 3·12 | 3·05 |
| *Unstratified complex:* | | |
| Nordmarkite, Narsak.......................... | 2·74 | 2·66 |
| Augite-syenite, Nunasarnausak.................. | 2·77 | 2·74 |
| Essexite, Narsak............................ | 2·90 | 2·87 |
| Sandstone, quartzitic, Iviangusat................ | 2·66 | 2·64 |

# DIFFERENTIATION OF THE AGPAITIC MAGMA.

It has been shown above that the nepheline-syenites which make up the bulk of the stratified Ilimausak batholite have certain common distinctive chemical characters, and it was found convenient to group them under a common name: *agpaïtes* (see p. 338). The several agpaïtes — viz. sodalite-foyaite, naujaite, lujavrites, and kakortokites — are closely related to one another, both from a chemical and from a mineralogical point of view. All of them contain practically the same minerals, but in very different proportions. From this evidence it is extremely probable that all the agpaïtic rocks of Ilimausak are genetically connected, or speaking more precisely, are differentiation products of one parent magma: the agpaïtic magma. Further, if we consider, (1) the stratiform arrangement of the rocks, (2) the absence of any structural differences between the inner part of each stratum and its border zones, and (3) the gradual transitions from sheet to sheet, it will be seen that the conditions are such as to suggest a differentiation in situ. This supposition also agrees with the circumstance that the stratified batholite of Ilimausak is the only occurrence of agpaïtic rocks in southern Greenland.

In the following paragraphs we shall try to show that the assumption of a differentiation in place is not inconsistent with the observed facts, and that in this case the differentiation may partly be explained on the old principle of mechanical separation by gravity of crystals from their magma.

As is well known observations bearing directly upon a process of this kind are extremely rare, and we may safely assume that in most batholites the viscous condition of the magma has prevented even heavy crystals from sinking[1]. This,

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[1] A. Harker, Natural History of Igneous Rocks, 1909, p. 322.

however, in our case does not constitute an objection, for the composition of the agpaïtic magma suggests that its final temperature of consolidation was extremely low, whereas several of the minerals which are characteristic of agpaïtes under magmatic conditions have exceptionally wide temperature ranges of crystallization[1]. It is, therefore, not difficult to imagine that the agpaïtic magma during the early stage of crystallization may have been more fluid than are most other magmas.

As quoted above the agpaïtic sheets from above downwards are as follows (the figures in parantheses indicate the average thickness of each rock body):

sodalite-foyaite (100 meters)
naujaite (300 meters)
lujavrites and kakortokites (more than 600 meters).

The approximate mean composition of these rocks as well as the probable composition of the undifferentiated agpaïtic magma (leaving out volatile matter) has been given in the table (p. 344).

It is obvious from this table that the composition of the uppermost layer — the sodalite-foyaite — is very near to the average composition of the agpaïtes. Considering that the sodalite-foyaite is a very coarse-grained rock, and that only one analysis has been made, it can hardly be said that any difference in chemical composition between this rock and the mean agpaïte has yet been proved. Provisionally, then, the sodalite-foyaite may be regarded as undifferentiated agpaïte which in the upper part of the magma chamber has crystallized entirely without disturbance.

The naujaite and the lujavrite differ from the mean agpaïte

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[1] This follows from the observation that sodalite, ægirine, and arfvedsonite, often constitute the latest products of crystallization in the same agpaïtic rocks where idiomorphic crystals of these minerals are enclosed in the felspars.

in opposite directions. The first problem to be considered is whether the compositions and the mutual arrangement of naujaite and lujavrite can be accounted for by the hypothesis of differentiation in place.

When this problem has been dealt with, the relation of naujaite to sodalite-foyaite will be separately considered.

Finally the origin of the kakortokite mass with its regular alternations of white, red, and black sheets will be discussed.

*Origin of naujaite and lujavrite.* — It is generally admitted that differentiation in place may be produced either by fractional crystallization[1], with one or more minerals crystallizing at the coolest border of the magma chamber, while the remaining magma by diffusion or convection currents is kept homogeneous, or by gravity, by which the first formed crystals are mechanically separated from the magma. In both cases the normal result of the process is a solid rock which contains a very large proportion of the first mineral to crystallize, and a residual magma showing corresponding impoverishment in that substance[2].

In the present case we are taught by observation that the naujaite crystallized before the lujavrite. It has also been stated that the first formed mineral of the naujaite is sodalite. The first question is, therefore, whether the composition of naujaite is such as would result if a portion of the agpaïtic magma has become strongly enriched in sodalite, and if so whether the remaining portion, impoverished in that substance, would assume the composition of lujavrite.

This question must be answered in the affirmative: a mixture of 63 per cent. of 'mean agpaïte' and 37 per cent of

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[1] G. F. Becker, Fractional Crystallization of Rocks. Amer. Journ. Sc., 4 ser., vol. IV, 1897, p 257.

[2] As Teall has pointed out complications may arise when crystals descending to lower levels are dissolved there (Geolog. Magazine, new series, decade 3, vol. II, 1885, p. 119.)

sodalite will give a rock of the same composition as naujaite (see table p. 351). It is true that the values which have been calculated according to the supposed process of differentiation differ a little from the average composition of the naujaite as calculated from the analyses. But as all the rocks contain varying quantities of alteration products, mainly zeolites, the agreement may be regarded as close enough.

It will thus be seen that the chemical as well as the mineralogical composition of naujaite is sufficiently explained by the hypothesis that this rock has originated from the agpaïtic magma by a differentiation set up by the local concentration of the first crystallized mineral (sodalite).

In the calculation given in the table (next page) the starting point is the average composition of the entire agpaïte mass which is regarded as made up of the mixture;

$$S + 3N + 5L + K$$

the letters signifying respectively sodalite-foyaite, naujaite, lujavrite, and kakortokite (comp. p. 344). It might perhaps be more correct to deduce S before calculating the mean composition, but since in this particular case S has approximately the mean composition of the agpaïte mass, and forms only one tenth of the whole, the result will be practically the same.

As the calculated composition of the 'mean agpaïte' depends mainly upon the naujaite and the lujavrite, it follows that the hypothesis set forth in the preceding paragraphs will account for the mean composition of the lujavrites (including kakortokites) just as well as it does for the naujaite.

Passing now to examine the relative position of naujaite and lujavrite from the point of view of the supposed differentiation process, we find that the evidence agrees with the supposition of differentiation in situ. The differentiation, if due to fractional crystallization, must give rise to an upper layer

| | Agpaïte (mean) see p. 344 | 0·63 agpaïte | Sodalite | 0·37 sodalite | 0·63 agpaïte + 0·37 sodalite | Naujaite (mean of analyses) | Difference |
|---|---|---|---|---|---|---|---|
| $SiO_2$ ..... | 51·86 | 32·67 | 37·14 | 13·74 | 46·41 | 46·93 | ÷ ·52 |
| $TiO_2$ ..... | ·33 | ·21 | | | ·21 | ·18 | ·03 |
| $ZrO_2$ ..... | ·79 | ·50 | | | ·50 | ·33 | ·17 |
| $Al_2O_3$ .... | 18·35 | 11.56 | 31·60 | 11·69 | 23·25 | 23·59 | ÷ ·34 |
| $Fe_2O_3$ .... | 6·50 | 4·10 | | | 4·10 | 3·37 | ·73 |
| FeO ...... | 3·68 | 2·32 | | | 2·32 | 2·16 | ·16 |
| MnO ..... | ·23 | ·15 | | | ·15 | ·08 | ·07 |
| MgO ..... | ·08 | ·05 | | | ·05 | trace | ·05 |
| CaO...... | 1·13 | ·71 | | | ·71 | ·69 | ·02 |
| $Na_2O$..... | 13·26 | 8·35 | 25·60 | 9·47 | 17·82 | 17·40 | ·42 |
| $K_2O$ ..... | 2·91 | 1·83 | | | 1·83 | 2·96 | ÷ 1·13 |
| Cl ....... | 1·13 | ·71 | 7·31 | 2·71 | 3·42 | 2·98 | ·44 |
| | 100·25 | 63·16 | 101·65 | 37·61 | 100·77 | 100·67 | |

strongly enriched in sodalite which was the first mineral to crystallize, and consequently it must have formed at the upper border of the magma chamber, where heat was being continually lost by conduction. The layer enriched in sodalite would consolidate as naujaite, and the remaining magma would be left with the composition of lujavrite. As a matter of fact the naujaite does constitute the upper layer, and is underlain by the lujavrite. In its broad features, therefore, the mode of occurrence of the rocks is in harmony with the hypothesis. Upon closer examination, however, it will be seen that fractional crystallization has probably not been the only cause of differentiation. For if it had, we should expect to find naujaite, not only as an upper layer, but also as a border zone along the walls of the lujavrite body, in all places where the marginal decrease in the size of grains indicates that the magma has been in contact with a cooler wall rock. As a matter of fact, however, the naujaite nowhere occurs as a border zone to the lujavrite; and the whole form of the naujaite mass is in favour of the view that gravity has been the dominant factor controlling the distribution of the rocks. It seems, therefore, very probable, that the low specific gravity of sodalite has played an important part in the process. Indeed, as lujavrite has a specific gravity of 2·7—2·8, compared with the 2·2—2·3 of sodalite, it will be seen that even if the lujavritic magma has been considerably lighter than the solid lujavrite, it may yet have been heavier than sodalite.

To sum up, the above discussion indicates that it is extremely probable that naujaite and lujavrite are differentiation products of the same magma and have separated in situ. The cause of the differentiation may be referred partly to fractional crystallization — sodalite crystallizing at the upper border of the magma chamber —, and partly to the floating away of sodalite crystals from the heavier residual magma under the influence of gravity. Both causes have acted in the same direction, and it is, therefore, not possible to decide which was the more important.

Conditions of this kind — fractional crystallization and gravitative separation acting with it — are unusual with most magmas, for nearly all minerals will no doubt tend to sink in any magma in which they grow. The co-operation of the two processes explains the considerable thickness (about 300 meters) of the naujaite layer.

The structural differences between naujaite and lujavrite, and the character of their mutual contact have been discussed in earlier sections (pp. 322, 328).

*Relation of sodalite-foyaite to naujaite.* — The coarse-grained sodalite-foyaite occurring as a sheet of varying thickness (2—150 meters) immediately above the naujaite, seems at first sight to present characters which are incompatible with the hypothesis advanced in the preceding paragraphs. The chemical composition of sodalite-foyaite is that of undifferentiated agpaïte, with some slight enrichment in sodalite (see table p. 344). The rock, accordingly, is heavier than the naujaite (2·65 as against 2·55). The sodalite contents is considerably lower (about 15—20 per cent. as compared with 30—60 per cent. in the naujaite) and the sodalite is largely allotriomorphic. In its lower portion the sodalite-foyaite passes into naujaite slowly and gradually — the only perceptible change being a gradual increase in the number of idiomorphic sodalite crystals — and both rocks must evidently have been solidifying in their present position at about the same time.

The difficulty in interpretation is this: — If sodalite be the first mineral of the agpaïtic magma to crystallize, as indicated by the structure of the rock (the minute crystals of ægirine etc. inclosed in the sodalite crystals are here for the moment left out), and if the magma, as explained above, differentiate either by fractional crystallization or by the movement of crystals under gravity, then the uppermost layer of the agpaïte should be naujaite and not sodalite-foyaite. Since the conditions of differentiation in this case belong to the early stages of crystallization, no assumption that sodalite-foyaite crystallized before differentiation commenced, can remove this difficulty.

A key to the explanation is probably found in the observation, made during the field work, that the sodalite-foyaite shows a certain structural and mineralogical resemblance to the horizontal pegmatite veins or benches of the naujaite.

As more fully discussed in the descriptive section, the naujaite possesses a peculiar suite of pegmatites. Besides a number of pegmatitic veins which occur like ordinary pegmatites (exceedingly large size of grains, varying width, irregular course), there are also others which both in age and structure occupy a position intermediate between the naujaite, properly so called, and the ordinary pegmatites. These intermediate types are strictly regulated in their distribution by the benching of the rock, and should perhaps be considered as the latest products of the consolidation phase rather than as the first products of the pneumatolytic phase. It is probable that the sodalite-foyaite in the manner of its formation ought to be compared with these.

Under this assumption the succession of events leading to the formation of naujaite and sodalite-foyaite is believed to have been as follows.

When the crystallization of the agpaïtic magma commenced fractional crystallization and gravitational separation caused an accumulation of sodalite crystals in the uppermost portion of the magma. If consolidation had been accomplished without reduction of volume the entire upper portion of the magma would have crystallized as naujaite, and the sodalite-foyaite would not have come into existence. But as crystallization involved contraction water and other expansible matter would tend to accumulate above the naujaite; and if we assume that volatile substances lower the temperature of consolidation and the specific gravity of the magma, it is evident that by degrees a moderate quantity of magma rich in volatile matter would accumulate above the naujaite (and later between the naujaite benches also). This uppermost magma sheet by reason of its low specific gravity would prevent sodalite crystals from rising, and perhaps by this time the temperature would have fallen so much that viscousity hindered further differentiation. Under these conditions the magma would not grow richer in sodalite, and when consolidation took place the structure would be similar to that of the pegmatite benches mentioned above. In this way both the position, the composition, and the structure of the sodalite-foyaite would be explained.

*Origin of banded kakortokites.* — The kakortokite mass of Kringlerne is the most remarkable portion of the abyssal complex of Ilimausak. The batholite on the whole is characterized by an uncommonly well marked stratification, but with the kakortokite this structure is developed to such a degree that it may almost be said to be unique (comp. Pl. IX). The geological description of this rock body is given in the third chapter (pp. 43—47); for petrography and analyses see (pp. 177—184).

The kakortokite mass considered as a whole has the composition of a lujavrite which is slightly enriched in arfvedsonite and eudialyte (see table p. 344). As it belongs to the more deeply seated portions of the agpaïtic complex this enrichment may perhaps be due to subsidence of crystals through the magma. The coarse-grained structure proves that the kakortokite has crystallized under much more undisturbed conditions than the lujavrite. As to the date of its consolidation observations seem to show that it is approximately contemporaneous with the lujavrite, but the exact age relations between these rocks have not with certainty been made out. As previously mentioned the kakortokite at some places is not only covered with lujavrite, but also underlain by this rock. It may be, however, that the kakortokite consolidated first, and that as a result of the movements connected with the subsidence of the roof of the batholite a portion of the lujavrite in a fluid condition was forced into its present position below the other rock.

From other countries several examples of stratified abyssal rocks are known. The most famous are the banded gabbros of Skye, described by A. Geikie and Teall[1], and the ultrabasic rocks of Rum, described by Harker[2]. Of these only the latter occurrence presents features which are all comparable with those

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[1] Quaterly Journal of the Geol. Soc., Vol. 50, 1894, p. 645.

[2] Geology of the small Isles of Invernessshire. Memoirs of the Geol. Surv., 1908, p. 69.

of the stratified kakortokite. There are, however, also considerable differences, and the interpretation given by Harker — that the different sheets of the ultrabasic rocks of Rum represent distinct intrusions — is not directly applicable to the case here considered.

The peculiar kind of stratification characterizing the kakortokitic complex will appear from the following list of a number of consecutive sheets:

| | | | | | | |
|---|---|---|---|---|---|---|
| black kakortokite; | thickness ca. | 2—3 | meters; | sp. gr. | ca. | 3·12 |
| white kakortokite | » | 6—9 | » | » | » | 2·76 |
| red kakortokite | » | 1—2 | » | » | » | 2.85 |
| black kakortokite | » | 2—3 | » | » | » | 3·12 |
| white kakortokite | » | 6—9 | » | » | » | 2·76 |
| red kakortokite | » | 1—2 | » | » | » | 2·85 |
| black kakortokite | » | 2—3 | » | » | » | 3·12 |

The succession as given in this table continues through a total thickness of about 400 meters, the number of individual sheets amounting to more than a hundred, while the number of repetitions of colour sets is about forty. It is worth mentioning that the red sheets in many places are badly developed or even wanting, but even in such cases the lowermost portions of the white sheets or the uppermost portions of the black ones are relatively rich in eudialyte.

In general it may be said that a considerable number of processes are known which can produce banded structures in igneous rocks. In the present case, however, since we are concerned with abyssal rocks in a locality where the co-operation of crustal stresses is precluded, the question is less complicated, and the banded structure of the kakortokite must be supposed to have originated either by successive intrusion of different kinds of magma or by differentiation in place.

The theory of successive intrusion, as has already been pointed out, has failed to account for the differences between the individual rocks of the agpaïtic complex. In that case the difficulties raised were the very close chemical and mineralogical relations between the individual sheets, the absence of contact phenomena, the gradual transitions, the horizontal distribution, and the fact that no dykes are found which are exactly like any of the individual agpaïtic sheets; and all these factors tell against the assumption that differentiation occurred before intrusion. The regular order of succession of the banded kakortokites, and the fact that each white sheet is much thicker than the immediately underlying red or black sheets, are further difficulties which must be faced by the theory of successive intrusion. If only white and black sheets took part in the building up of the complex it might be conceivable — though not probable considering what has already been said — that the black sheets had been intruded along partings between the white ones or vice-versa, but when the intercalation of red sheets below and not above each of the white ones is considered, a conception of this kind is precluded. In short, it may be said that no observations whatever have been made which would suggest the hypothesis of successive intrusion by different magmas, and the only significance of the hypothesis in the present case is that it would refer the differentiation processes to unknown depths, and to causes which are beyond any observation, whilst it gives no explanation at all to the actual present arrangement of the rocks.

The main factors which can produce differentiation in place are thought to be fractional crystallization and separation by gravity. Upon closer examination it appears improbable that fractional crystallization has played an important part in the formation of the banded kakortokites. True, fractional crystallization may be able to produce sheeted structures, and if with this we combine the assumption that the magma at the contact with the crystallizing rock became supersaturated with different compounds alternately, a recurrent deposition of three different kinds of rock sheets might perhaps be produced. With the kakortokites supersaturation is extremely improbable, for all the sheets contain the same minerals, and the ægirine and the arfvedsonite, which were generally the last to crystallize, occur also as minute crystals inclosed in all the earlier minerals. Moreover, the succession of the sheets bears no apparent relation to the order of crystallization.

The question remains to be discussed whether the hypothesis of separation by gravity can account for the peculiarities of the banded kakortokite or not. This problem may be conveniently considered under two heads. The differentiation of the kakortokite into white, red, and black sheets is readily explained by the assumption of gravitative separation, but the recurrence of the sheets is not explicable in this way.

That gravitative separation is able to account for the differentiation will appear from the following consideration. The black kakortokite sheets (sp. gr. 3·12) are characterized by the abundance of arfvedsonite (sp. gr. 3·4); the red sheets (2·85) which overlie the black ones abound in eudialyte (2·9); and the white rock (2·76) which covers the red sheets has alkali felspar as its dominant mineral (2·6). The arrangement, thus, agrees with what should be expected if it were due to gravitation. Further it must be remembered that the difference between the individual sheets depends almost exclusively upon the relative quantities of the different mineral components, and that each mineral exhibits the same habit and the same size of grains throughout each set of sheets, and generally in contiguous sets also. Finally the microscopical examination of the kakortokitic rocks has shown a much less marked order of crystallization for the mineral components than is commonly the case with abyssal rocks. It will, thus, be seen that if each set of kakortokite sheets (a white, a red, and a black) is considered separately, the observations tell decidedly in favour of the view that the differentiation is due to separation of crystals by gravity.

Accepting this as a working hypothesis the recurrence can be more precisely understood. The complex now can be regarded as made up of about forty layers which, originally, all alike have been each in its turn differentiated by a separation of its crystals under gravity so that each layer has given rise to three dissimilar sheets. Such a succession of processes may be accounted for in two different ways.

(1). Each layer (of three sheets) may represent a separate intrusion. The objections we have raised in discussing the hypothesis of successive intrusions of the different rocks ('intrusion after differentiation') disappear for the most part if intrusion preceded differentiation. The remaining objections — absence of contact phenomena and gradual transitions between the sheets — may perhaps be met by the assumption that the intrusions followed upon one another rather quickly, and that the magma was not superheated, but it will be seen that the hypothesis of successive intrusions, applied in this way, simply expresses a particular mode of manifestation of the recurrence, and does not explain the recurrence in itself.

(2). The entire kakortokite mass, in a tolerably homogeneous state, may have taken up its present position before consolidation. Outside influences may then have determined the recurrent crystallization of a certain qauntity of magma. Thus crystals would be formed which would sink towards the bottom, and these when sinking might be to some extent separated according to specific gravity, after the manner of a coarse rock powder when treated with THOULET's solution. This hypothesis of 'intermittent crystallization' does not explain the recurrence of the conditions which caused the crystallization, and in this the hypothesis is no more satisfactory than is the assumption of recurrent intrusion. It does however harmonize with the contact relations between the kakortokite and the augite-syenite, for at this contact it is observed that the stratification of the kakortokite gradually disappears, and that the rock which comes nearest the contact is completely unstratified, whilst instead of horizontal partings vertical pegmatitic segregations occur parallel to the contact plane.

Under either hypothesis the recurrence of the processes, as expressed in the forty repetitions of the same set of sheets, demands some further explanation by an outside source. In the interior of the earth any plausible cause for such regular recurrence seems very difficult if not impossible to find. At the earth's surface recurrence is generally connected with igneous activity, and it may even be said that recurrence is a fundamental character of volcanic outbursts. Recurrence is manifest in the stratified structure of every lava plateau at every age, and the volcanic rock series of Ilimausak is no exception to the rule.

It does not seem improbable that a large volcanic outburst should influence the physical conditions of the subjacent magma bodies. In the first place the pressure within the magma reservoirs must vary: an explosive outburst will cause a rapid decrease of pressure, and the quiet outflow of lava increasing the pressure at some places must lessen it at others. Secondly, as each eruption causes a considerable loss of heat the subterranean temperature will be affected. Thirdly, volcanic eruptions may cause movements or currents within the magma bodies. All these processes may be assumed to be able to modify the rate of magmatic crystallization, and if crystallization is in progress concurrently with the volcanic activity, this latter condition will probably often be realized. Thus it must be admitted as possible that volcanic outbursts under favourable conditions may leave a permanent record upon the structure of abyssal rocks, and the characteristic feature of such marks must be that they are recurrent.

For the banded kakortokite of the Ilimausak complex the simplest supposition is perhaps that the recurrent layers have originated in consequence of repeated variations in pressure. Each reduction in the pressure may have caused the dissociation of a certain quantity of volatile matter from the magma, and this process in its turn may have caused the crystallization of a certain quantity of the magma[1].

The above attempt at the interpretation of the peculiar stratified structure of the coarse-grained kakortokites may be summarized thus: —

The entire series, comprising more than one hundred individual sheets, may be divided into a smaller number of groups of layers (about 40), in which each group consists of an upper white sheet and a lower black one, and betveen them as a general rule an intercalated red sheet or a transition zone rich in eudialyte. Each group of sheets is supposed to have originated by differentiation in situ owing to a separation of crystals under gravity. The repetition of the groups indicates that the consolidation process was of recurrent or intermittent character, and it is suggested that the repetition is a kind of abyssal reflection of the intermittence which characterizes igneous surface activity.

Of course this mode of abyssal stratification is only possible where the crystallizing magma possesses an exceptionally high fluidity. It is, therefore, important to note that the stratification here considered is not the only fact which suggests a very fluid condition of the magma: a number of other peculiar features of the agpaïtic rocks of Ilimausak, which have been discussed in the preceding sections, point to the same conclusion. In ordinary viscous magmas the variations of pressure etc., caused by contemporaneous volcanic eruptions, must of course also be supposed to influence the crystallization of the

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[1] Compare F. Rinne, Durch Entgasung bewirkte Krystallisationen in Schmelzflüssen. Neues Jahrbuch für Mineralogie, 1909, II, p. 129.

magma. But with even a moderate viscousity there can be no separation of crystals by gravity, and although the crystallization may have been intermittent the consolidated rock will be uniform in structure. Viscousity to some extent will also check the transmission of rapid variation in the pressure.

## ABSORPTION OF PRE-EXISTING ROCKS BY THE MAGMA.

*Hybrid nature of the soda-granite of Iviangusat.* — The Palæozoic igneous rocks of South Greenland do not as a rule show any indications whatever which point to an assimilation of the wall rock. There are, however, some exceptions to this rule, and one of these is of special interest from a theoretical point of view.

At the foot of the Iviangusat Mountains, in Kangerdluarsuk, the augite-syenite contains large and small fragments of sandstone, and these fragments are surrounded by a zone of soda-granite the width of which may vary from about half a meter up to two meters. The detailed geological and petrographical descriptions have been given in the preceding chapters (pp. 51 and 116). The naked coast cliffs exhibit very fine sections in which the mutual relations of these rocks have been studied, and there can be no doubt that the soda-granite zones are rootless igneous rocks connected with the contact between sandstone and augite-syenite. As most of the small fragments are well rounded it must be supposed that the magma has dissolved sandstone, and there seems to be no escape from the conclusion that the soda-granite at this place is a hybrid rock[1], and has originated by the assimilation of sandstone in the augite-

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[1] A. Harker, Natural History of Igneous Rocks, 1909, p. 333.

syenite magma. Further evidence is afforded by the fact that the syenites of the Ilimausak complex, and at all other places where they come into contact with the sandstone, contain considerable quantities of quartz, while no enrichment in this mineral is ever observed at the junctions with Algonkian granite or diabase.

Under these conditions it is of interest to see whether the composition of the hybrid granite agrees with what we might expect if it were the result of an addition of sandstone material to augite-syenite. The sandstone has not been chemically analyzed, but on microscopic examination the sandstone fragments in the augite-syenite of Iviangusat have been proved to consist of rather pure quartzite, and their structure in consequence of the contact metamorphism is crystalline. At other localities felspar grains also are found in the sandstone, and with them a cementing material which is mainly silica. It has therefore been calculated, first, how much pure quartz must be added to augite-syenite in order to raise the silica percentage to the same value as in the soda-granite; and secondly, how much quartz and felspar have to be added to augite-syenite in order to produce a mixture which has the same percentages of silica and alkalies as the granite.

*Calculated and actual composition of hybrid soda-granite.*

| | A | B | C | D |
|---|---|---|---|---|
| $SiO_2$ . . . | 56·25 | 70·7 | 70·7 | 70·69 |
| $TiO_2$ . . . . | 1·82 | 1·2 | ·6 | ·67 |
| $Al_2O_3$ . . . | 15·89 | 10·6 | 13·8 | 13·67 |
| $Fe_2O_3$ . . . | 1·61 | 1·1 | ·5 | 1·29 |
| FeO . . . . . | 7·62 | 5·1 | 2·5 | 2·81 |
| MnO . . . . | ·14 | ·1 | — | ·15 |
| MgO . . . . . | ·41 | ·3 | ·1 | trace |
| CaO . . . . . | 3·73 | 2·5 | 1·2 | ·38 |
| $Na_2O$ . . . . | 7·79 | 5·2 | 5·3 | 5·28 |
| $K_2O$ . . . . . | 4·38 | 2·9 | 5·1 | 5·06 |
| $P_2O_5$ . . . . | ·36 | ·2 | ·1 | — |
| Total . . . . | 100·00 | 99·9 | 99·9 | 100·00 |

A Analysis of augite-syenite from Kangerdluarsuk calculated at 100 per cent. with omission of $H_2O$ (analysis **16**a).

B Calculated composition of a mixture of augite-syenite (A) and quartz in proportion $A : SiO_2 = 100 : 49{\cdot}5$.

C Calculated composition of a mixture of augite-syenite (A) with quartz, orthoclase, and albite, in proportion $A : SiO_2 : Or : Ab = 100 : 67{\cdot}5 : 67 : 72$.

D Analysis of soda-granite from Kangerdluarsuk calculated at 100 per cent. (analysis 2a)

The calculation shows that the qauntity of quartz, which must be dissolved in the augite-syenite if the silica percentage is to be raised to the same value as found in the granite, is not less than half the weight of the augite-syenite (more exactly 49·5 per cent., compare column B in the table). This mixture of 100 parts of syenite with 49·5 parts of quartz has, however, a composition which differs considerably from the actual composition of soda-granite.

Again, if we calculate the quantities of quartz, albite, and orthoclase which must be added to the augite-syenite in order to make the percentages of silica, soda, and potash identical with the values given by the granite, it will be found that it is necessary to add about 70 per cent. of each of these minerals. This proportion of quartz to felspar differs widely from that actually found in the sandstone. Moreover, if the result of the calculation (given in C) is compared with the composition of the soda-granite (D), it will be seen that there are considerable differences in the iron oxides and in lime. In this case the discrepancy of the iron oxides is of no great interest, for the magma might be supposed to have taken up iron oxides from the sandstone which is locally rich in hæmatite, and thus the agreement might be made up. With lime, however, the difference is more significant, as in spite of the fact that the dissolved matter in the calculation is supposed to be free from lime, the calculation gives too much of this compound. The dissolved sandstone may probably have contained small quantities of lime bearing felspars.

From what has just been said the following conclusions may be drawn: —

(1) There is geological evidence that the augite-syenite at Iviangusat has dissolved some sandstone, and has produced a hybrid rock: soda-granite.

(2) The composition of the hybrid rock *cannot* be calculated as a simple addition mixture of the component rocks. On the contrary, it must be supposed that the assimilation of the sandstone has been accompanied by processes of differentiation or diffusion[1]. When evidences for and against the assimilation theory are discussed the circumstance that assimilation may produce differentiation is not seldom overlooked; though it appears to be in harmony with the fact that assimilation will change temperature and sequence of crystallization, and specific gravity of the magma.

(3) The quantity of solid material which has been absorbed by the magma is probably not less than half the weight of the absorbing magma, but by reason of the differentiation (mentioned in (2)) it cannot be calculated until we have a more detailed knowledge of the differentiation processes which have taken place.

*The arfvedsonite-granite of Ilimausak.* — The hybrid soda-granite of Iviangusat is of special interest from another point of view. As already mentioned it agrees chemically and in all mineralogical essentials with the arfvedsonite-granite of Ilimausak (compare analyses 1 and 2, p. 114). The latter rock mass both in size and in mode of occurrence has quite the character of an ordinary abyssal rock. The arfvedsonite-granite type, moreover, though by no means a common rock, is known from several foreign localities; and is usually regarded as a normal differentiation product of magmas belonging to the

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[1] A. Harker, Natural History of Igneous Rocks, 1909, p. 358.

alkali series. The soda-granite of Iviangusat, thus, though it is of hybrid origin, produced at moderate depth through the assimilation of sandstone by an alkali-syenitic magma, is an instance of a rock possessing the composition of a normal abyssal rock.

The theoretical question thus arises, whether or not it is possible that the Ilimausak granite could have come into existence as a consequence of assimilation processes which were similar to the processes indicated by the small granite bodies which envelop the sandstone fragments at Iviangusat. **Harker** raises the general objection to any theory of absorption of sediments on a large scale 'that it demands an enormous amount of heat to raise the solid rock to the point of melting and to melt them, and no source of this heat is indicated[1]'. In the case here considered an objection of this kind can scarcely be maintained. The sediments dissolved are not those in the roof of the batholite, but fragments which are slowly sinking through the magma, and such fragments may be rather intensely heated. Further, since the soda-granite at Iviangusat not only surrounds the sandstone fragments, but also occurs as veins in the syenite (p. 53), we are taught by actual observation that the temperature of the consolidation of the hybrid rock was lower than that of the original magma. The amount of heat, contained in the syenitic magma, under these conditions must be supposed to have been sufficient to melt considerable quantities of sandstone; just as salt even at a low temperature may be dissolved in water.

In this way it seems probable that the syenitic magma has been able to dissolve considerable quantities of sandstone. The rock interpreted as an assimilation product has a lower specific gravity and a lower consolidation temperature than the syenitic magma, and it seems to be within the bounds of possibility that

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[1] Natural History of Igneous Rocks, 1909, p. 339.

portions of the hybrid magma have gradually moved upward into the upper portion of the batholite, and are thus separated both from the syenite and from the sandstone. The final result of the movement should be an upper layer of granitic magma resting on the syenitic, and taking into consideration that the greater part of the syenite, as previously mentioned, must be supposed subsequently to be replaced by the agpaïtic magma, this is in harmony with the actual mode of occurrence of the arfvedsonite-granite at Ilimausak.

It will, thus, be seen that the assimilation hypothesis is not in this particular case disproved by actual observation. On the other hand, no definite proof has been found, and the question of the origin of the Ilimausak granite is therefore left undecided. The above considerations are mainly intended to show that the assumption of assimilation, operating on rather a large scale within moderate depths of the earth's crust, may be in some cases a reasonable working hypothesis.

# CHEMICAL ANALYSES OF ROCKS.

For convenient reference the analyses of rocks made for this report are tabulated below. Of these analyses, numbers 1, 3, 5, 7, 9, 11, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 29 have been made by Dr. Chr. Winther; numbers 2, 4, 10, 15, 27, by Mr. C. Detlefsen; numbers 12 and 14 by Mr. Chr. Christensen; and numbers 6, 8, 13 by the author. The same analyses, calculated at 100 per cent. omitting water, are given under the numbers 1a—29a. For the calculated mean compositions of the agpaïtic main types the reader is referred to the table (p. 344).

*Igneous Rocks of the Ilimausak Complex, S. Greenland.*

| | 1. Arfvedsonite-granite, Ilimausak | 2. Soda-granite, Iviangusat | 3. Pulaskite, N. Siorarsuit | 4. Foyaite, Naujakasik | 5. Sodalite-foyaite, Tupersuatsiak | 6. Naujaite, Kangerdluarsuk | 7. Naujaite, Nunasarnak |
|---|---|---|---|---|---|---|---|
| $SiO_2$ ........ | 70·59 | 71·24 | 57·88 | 56·31 | 49·38 | 49·46 | 43·39 |
| $TiO_2$ ....... | ·44 | ·68 | 1·23 | 2·82 | ·63 | ·16 | ·20 |
| $ZrO_2$ ....... | — | — | — | | ·61 | ·38 | ·27 |
| $Al_2O_3$ ...... | 12·38 | 13·78 | 14·80 | 20·11 | 17·31 | 23·53 | 23·13 |
| $Fe_2O_3$ ...... | 1·61 | 1·30 | 5·86 | 3·93 | 4·20 | 3·04 | 3·62 |
| $FeO$ ........ | 3·33 | 2·83 | 3·71 | 1·45 | 5·25 | 1·02 | 3·24 |
| $MnO$ ........ | ·08 | ·15 | ·15 | ·60 | ·08 | ·17 | trace |
| $MgO$ ........ | none | trace | none | ·36 | ·53 | trace | none |
| $CaO$ ........ | ·93 | ·38 | 2·71 | ·62 | 2·23 | ·80 | ·56 |
| $Na_2O$ ....... | 6·95 | 5·32 | 9·12 | 8·76 | 13·87 | 14·71 | 19·68 |
| $K_2O$ ........ | 3·74 | 5·10 | 3·06 | 4·65 | 2·55 | 4·34 | 1·51 |
| $H_2O$ above 110° | ·21 | trace | ·90 | 1·13 | 1·30 | 1·38 | 1·36 |
| $H_2O$ at 110° .. | ·20 | — | ·23 | — | ·16 | — | ·21 |
| Cl .......... | none | none | none | ·15 | 1·68 | 2·25 | 3·63 |
| $P_2O_5$ ....... | trace | — | none | ·13 | none | none | none |
| $CO_2$ ........ | none | none | none | none | none | none | none |
| | 100.46 | 100·78 | 99·65 | 101·02 | 99·78 | 101·24 | 100·80 |
| Cl = O ..... | | | | ·03 | ·38 | ·51 | ·82 |
| | | | | 100·99 | 99·40 | 100·73 | 99·98 |
| Sp. gr. ...... | 2·66 | 2·64 | 2·77 | 2·67 | 2·65 | 2·53 | 2·55 |

| | 8. Ægirine-lujavrite, Kangerdluarsuk | 9. Ægirine-lujavrite, Tupersuatsiak | 10. Ægirine-lujavrite S. Siorarsuit | 11. Arfvedsonite-lujavrite, Lille Elv | 12. Arfvedsonite-lujavrite, Nunasarnak | 13. Kakortokite (white sheets), Kringlerne | 14. Kakortokite (red sheets), Kringlerne | 15. Kakortokite (black sheets), Kringlerne |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ....... | 53·74 | 53·44 | 50·72 | 53·01 | 56·64 | 51·62 | 49·39 | 48·90 |
| $TiO_2$ ....... | ·50 | ·30 | 2·84 | ·33 | ·30 | ·44 | ·49 | 1·96 |
| $ZrO_2$ ....... | 1·63 | 1·00 | | ·65 | none | 1·70 | 4·89 | |
| $Al_2O_3$ ...... | 14·02 | 18·64 | 15·45 | 15·33 | 16·10 | 15·63 | 10·39 | 7·85 |
| $Fe_2O_3$ ...... | 10·63 | 9·38 | 11.82 | 9·14 | 4·90 | 6·06 | 4·31 | 11·46 |
| FeO......... | 1·71 | ·86 | ·80 | 4·44 | 6·86 | 4·98 | 7·72 | 13·32 |
| MnO ....... | ·36 | ·20 | ·31 | ·13 | ·57 | ·33 | ·97 | 1·11 |
| MgO ....... | trace | none | ·13 | ·10 | none | trace | none | ·38 |
| CaO......... | 1·18 | ·79 | ·14 | ·67 | ·39 | 3·13 | 5·11 | 1·95 |
| $Na_2O$ ...... | 9·02 | 12·10 | 10·83 | 11·86 | 11·50 | 10·09 | 11·45 | 7·40 |
| $K_2O$ ....... | 4·77 | 2·43 | 2·94 | 2·60 | 1·00 | 4·19 | 2·62 | 3·23 |
| $H_2O$ above 110° | 3·40 | 1·12 | 4·66 | 1·88 | 1·54 | 2·12 | 1·24 | 1·80 |
| $H_2O$ at 110° .. | — | ·34 | — | ·20 | ·04 | — | ·22 | — |
| Cl .......... | n. d. | ·12 | n. d. | ·23 | none | ·17 | ·51 | ·03 |
| $P_2O_5$ ....... | none | none | none | trace | trace | none | none | none |
| $CO_2$ ....... | none | none | none | none | none | none | none | none |
| | 100·96 | 100·62 | 100·64 | 100·57 | 100·29[1] | 100·46 | 100·36[2] | 99·39 |
| Cl = O ..... | | ·03 | | ·05 | | ·04 | ·44[3] | ·01 |
| | | 100·59 | | 100·52 | | 100·42 | 99·92 | 99·38 |
| Sp. gr....... | 2·67 | 2·83 | 2·70 | 2·84 | 2·79 | 2·76 | 2·85 | 3·12 |

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[1] Including 0·45 $Nb_2O_5$.

[2] Including 0·30 $Nb_2O_5$ and 0·75 Fl.

[3] Including Fl = O 0·32.

*Igneous Rocks of the Ilimausak Complex, S. Greenland.*

| | 16. Augite-syenite, Nunasarnausak | 17. Nordmarkite, Narsak | 18. Essexite, Narsak | 19. Magnetite-pyroxenite, Narsak | 20. Essexite-porphyrite, Kakarsuak | 21. Trachydolerite, Nunasarnausak | 22. Trachydolerite, Tasek |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 55·79 | 58·17 | 46·10 | 31·77 | 50·98 | 45·27 | 47·79 |
| $TiO_2$ | 1·81 | 2·09 | 3·34 | 12·97 | 1·38 | 4·41 | 3·82 |
| $ZrO_2$ | none | none | none | none | none | none | none |
| $Al_2O_3$ | 15·76 | 16·07 | 18·59 | none | 22·15 | 15·03 | 16·88 |
| $Fe_2O_3$ | 1·60 | 1·30 | 2·63 | 12.97 | 1·04 | 4·04 | 4·66 |
| $FeO$ | 7·56 | 5·04 | 6·68 | 10·23 | 4·25 | 9·10 | 5·92 |
| $MnO$ | ·14 | ·07 | ·05 | trace | trace | trace | trace |
| $MgO$ | ·41 | 1·20 | 3·23 | 15·77 | ·79 | 6·59 | 1·51 |
| $CaO$ | 3·70 | 3·42 | 9·86 | 12·20 | 7·90 | 6·64 | 5·58 |
| $Na_2O$ | 7·72 | 7·41 | 6·22 | 2·69 | 6·84 | 5·07 | 7·76 |
| $K_2O$ | 4·34 | 4·65 | ·63 | ·54 | 2·71 | 1·08 | 3·26 |
| $H_2O$ above 110° | ·18 | ·41 | ·80 | ·60 | 1·22 | 1·85 | 1·17 |
| $H_2O$ at 110° | ·34 | ·19 | ·11 | ·05 | ·12 | ·14 | ·14 |
| Cl | none | none | none | none | trace | trace | none |
| $P_2O_5$ | ·36 | ·42 | 1·41 | trace | ·38 | ·16 | ·76 |
| $CO_2$ | none | none | none | none | trace | ·38 | none |
| | 99·71 | 100·44 | 99·65 | 99·79 | 99·76 | 99·76 | 99·25 |
| Sp. gr. | 2·77 | 2·74 | 2·90 | 3·56 | 2·82 | 2·99 | 2·92 |

*Igneous Rocks of the Ilimausak and the Igaliko Complexes, S Greenland.*

| | 23. Ilimausak-porphyry, Ilimausak | 24. Quartz-porphyry (comendite), N. Siorarsuit | 25. Foyaite, Korok | 26. Augite-syenite, Korok | 27. Nepheline-porphyry, Akuliarusek | 28. Nepheline-porphyry, Akuliarusek | 29. Hedrumite, Akuliarusek |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49·64 | 73·68 | 53·53 | 53·71 | 51·31 | 54·58 | 56·90 |
| $TiO_2$ | 4·25 | ·57 | ·44 | 3·40 | 1·20 | ·62 | 1·09 |
| $ZrO_2$ | none | ·24 | none | none | | none | none |
| $Al_2O_3$ | 13·74 | 11·05 | 19·69 | 15·37 | 21·54 | 20·43 | 16·34 |
| $Fe_2O_3$ | 7·10 | 3·93 | 5·09 | 3·28 | 3·68 | 2·08 | 3·61 |
| FeO | 4·97 | 1·45 | 2·83 | 5·72 | 3·37 | 3.39 | 5·72 |
| MnO | ·03 | trace | ·24 | ·14 | ·41 | trace | trace |
| MgO | 1·58 | none | none | 1·58 | 1·18 | trace | ·22 |
| CaO | 4·88 | ·48 | 1·87 | 5·20 | 1·39 | 1.56 | 2·21 |
| $Na_2O$ | 6·33 | 5·20 | 9·61 | 6·84 | 9·25 | 10·70 | 8·10 |
| $K_2O$ | 4·42 | 4·05 | 5·23 | 4·11 | 5·49 | 5·74 | 4·96 |
| $H_2O$ above 110 | ·81 | ·08 | ·34 | ·45 | ·84 | 1·02 | 1·10 |
| $H_2O$ at 110° | ·14 | .17 | ·25 | ·33 | — | ·12 | ·08 |
| Cl | none | trace | ·04 | none | ·17 | none | trace |
| $P_2O_5$ | 1·57 | none | ·31 | .52 | trace | trace | ·17 |
| $CO_2$ | none | none | ·40 | none | ·15 | none | none |
| | 99·67[1] | 100·90 | 99·87 | 100·65 | 99.98 | 100·24 | 100·50 |
| Cl = O | | | 0·01 | | 0·04 | | |
| | | | 99·86 | | 99·94 | | |
| Sp. gr. | 2·89 | 2·69 | 2·75 | 2·70 | 2·71 | 2·70 | 2·78 |

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[1] Including 0·21 BaO.

*Analyses calculated to 100 per cent., omitting $H_2O$.*

| | 1a. Arfvedsonite-granite, Ilimausak | 2a. Soda-granite, Iviangusat | 3a. Pulaskite, N. Siorarsuit | 4a. Foyaite, Naujakasik | 5a. Sodalite-foyaite Tupersuatsiak | 6a. Naujaite, Kangerdluarsuk | 7a. Naujaite, Nunasarnak |
|---|---|---|---|---|---|---|---|
| $SiO_2$ . . . . . . . | 70·55 | 70·68 | 58·75 | 56·39 | 50·42 | 49·77 | 44·09 |
| $TiO_2$ . . . . . . . | ·44 | ·68 | 1·25 | 2·82 | ·64 | ·16 | ·20 |
| $ZrO_2$ . . . . . . . | — | — | — | | ·62 | ·38 | ·27 |
| $Al_2O_3$ . . . . . . | 12·37 | 13·67 | 15·02 | 20·14 | 17·68 | 23·68 | 23·50 |
| $Fe_2O_3$ . . . . . . | 1·61 | 1·29 | 5·95 | 3·94 | 4·29 | 3·06 | 3·68 |
| FeO . . . . . . . . | 3·33 | 2·81 | 3·76 | 1·45 | 5·36 | 1·03 | 3·29 |
| MnO . . . . . . . | ·08 | ·15 | ·15 | ·60 | ·08 | ·17 | trace |
| MgO . . . . . . . | — | trace | — | ·36 | ·54 | trace | — |
| CaO . . . . . . . | ·93 | ·38 | 2·75 | ·62 | 2·28 | ·81 | ·57 |
| $Na_2O$ . . . . . . | 6·95 | 5·28 | 9·26 | 8·77 | 14·16 | 14·80 | 20·00 |
| $K_2O$ . . . . . . . | 3·74 | 5·06 | 3·11 | 4·66 | 2·60 | 4·38 | 1·53 |
| Cl . . . . . . . . . | — | — | — | ·15 | 1·72 | 2·27 | 3·69 |
| $P_2O_5$ . . . . . . | trace | — | — | ·13 | — | — | — |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·39 | 100·51 | 100·82 |
| Cl = O . . . . . | | | | | ·39 | ·51 | ·82 |
| | | | | | 100·00 | 100·00 | 100·00 |
| $\frac{na + k}{al}$ | 1·2 | 1·0 | 1·3 | 1·0 | 1·5 | 1·2 | 1·5 |

*Analyses calculated to 100 per cent., omitting $H_2O$, $Nb_2O_5$, and Fl.*

| | 8a. Ægirine-lujavrite Kangerdluarsuk | 9a. Ægirine-lujavrite Tupersuatsiak | 10a. Ægirine-lujavrite S. Siorarsuit | 11a. Arfvedsonite-lujavrite, Lille Elv | 12a. Arfvedsonite-lujavrite, Nunasarnak | 13a. Kakortokite (white sheets), Kringlerne | 14a. Kakortokite (red sheets), Kringlerne | 15a. Kakortokite (black sheets), Kringlerne |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ....... | 55·08 | 53·91 | 52·84 | 53·85 | 57·64 | 52·51 | 50·54 | 50·12 |
| $TiO_2$ ....... | ·51 | ·30 | 2·96 | ·33 | ·31 | ·45 | ·50 | 2·01 |
| $ZrO_2$ ....... | 1·67 | 1·01 | | ·66 | — | 1·73 | 5·00 | |
| $Al_2O_3$ ...... | 14·37 | 18·81 | 16·10 | 15·58 | 16·38 | 15·90 | 10·63 | 8·04 |
| $Fe_2O_3$ ...... | 10·90 | 9·46 | 12·32 | 9·29 | 4·99 | 6·17 | 4·41 | 11·74 |
| FeO ......... | 1·75 | ·87 | ·83 | 4·51 | 6.98 | 5·07 | 7·90 | 13·65 |
| MnO ....... | ·37 | ·10 | ·32 | ·13 | ·58 | ·34 | ·99 | 1·14 |
| MgO ....... | trace | — | ·13 | ·10 | — | trace | — | ·39 |
| CaO ........ | 1·21 | ·79 | ·14 | ·68 | ·40 | 3·18 | 5·23 | 2·00 |
| $Na_2O$ ...... | 9·25 | 12·21 | 11·29 | 12·05 | 11·70 | 10·26 | 11·72 | 7·58 |
| $K_2O$ ....... | 4·89 | 2·45 | 3·07 | 2·64 | 1·02 | 4·26 | 2·68 | 3·31 |
| Cl ......... | — | ·12 | — | ·23 | trace | ·17 | ·52 | ·03 |
| $P_2O_5$ ....... | — | — | — | trace | — | — | — | — |
| | 100·00 | 100·03 | 100·00 | 100·05 | 100·00 | 100·04 | 100·12 | 100·01 |
| Cl = O ..... | | ·03 | | ·05 | | ·04 | ·12 | ·01 |
| | | 100·00 | | 100·00 | | 100·00 | 100·00 | 100·00 |
| $\frac{na + k}{al}$ | 1·4 | 1·2 | 1·4 | 1·4 | 1·2 | 1·4 | 2·1 | 2·0 |

*Analyses calculated to 100 per cent., omitting $H_2O$.*

| | 16a. Augite-syenite, Nunasarnausak | 17a. Nordmarkite Narsak | 18a. Essexite, Narsak | 19a. Magnetite-pyroxenite, Narsak | 20a. Essexite-porphyrite, Kakarsuak | 21a. Trachydolerite, Nunasarnausak | 22a. Trachydolerite, tephritic, Tasek |
|---|---|---|---|---|---|---|---|
| $SiO_2$ ....... | 56·24 | 58·26 | 46·69 | 32·05 | 51·80 | 46·48 | 48·80 |
| $TiO_2$ ....... | 1·83 | 2·09 | 3·38 | 13·08 | 1·40 | 4·53 | 3·90 |
| $ZrO_2$ ....... | — | — | — | — | — | — | — |
| $Al_2O_3$ ...... | 15·89 | 16·10 | 18·83 | — | 22·51 | 15·43 | 17·22 |
| $Fe_2O_3$ ...... | 1·61 | 1·30 | 2·66 | 13·08 | 1·06 | 4·16 | 4·75 |
| FeO ........ | 7·63 | 5·05 | 6·76 | 10·32 | 4·32 | 9·34 | 6·05 |
| MnO ....... | ·14 | ·07 | ·05 | trace | trace | trace | trace |
| MgO ....... | ·41 | 1·20 | 3·27 | 15·91 | ·80 | 6·77 | 1·54 |
| CaO ........ | 3·73 | 3·43 | 9·99 | 12·31 | 8·02 | 6·82 | 5·70 |
| $Na_2O$ ...... | 7·79 | 7·42 | 6·30 | 2·71 | 6·95 | 5·20 | 7·93 |
| $K_2O$ ....... | 4·37 | 4·66 | ·64 | ·54 | 2·75 | 1·11 | 3·34 |
| Cl ......... | — | — | — | — | trace | trace | |
| $P_2O_5$ ....... | .36 | ·42 | 1·43 | trace | ·39 | ·16 | ·77 |
| | 100·00 | 100·0 0 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |
| $\frac{na + k}{al}$ | 1·1 | 1·1 | ·6 | — | ·6 | ·9 | 1·0 |

*Analyses calculated to 100 per cent., omitting $H_2O$ and $CO_2$.*

| | 23a. Ilimausak-porphyry, Ilimausak | 24a. Quartz-porphyry (comendite), N. Siorarsuit | 25a. Foyaite, Korok | 26a. Augite-syenite Korok | 27a. Nepheline-porphyry, Akuliarusek | 28a. Nepheline-porphyry, Akuliarusek | 29a. Hedrumite, Akuliarusek |
|---|---|---|---|---|---|---|---|
| $SiO_2$ ....... | 50·29 | 73·20 | 54·14 | 53·78 | 51·85 | 55·08 | 57·29 |
| $TiO_2$ ....... | 4·30 | ·57 | ·45 | 3·40 | 1·21 | ·63 | 1·10 |
| $ZrO_2$ ....... | — | ·24 | — | — | — | — | — |
| $Al_2O_3$ ...... | 13·92 | 10·98 | 19·91 | 15·39 | 21·77 | 20·62 | 16·45 |
| $Fe_2O_3$ ...... | 7·19 | 3·90 | 5·15 | 3·28 | 3·72 | 2·10 | 3·63 |
| FeO ........ | 5·04 | 1·44 | 2·86 | 5·73 | 3·41 | 3·42 | 5·76 |
| MnO ....... | ·03 | trace | ·24 | ·14 | ·41 | trace | trace |
| MgO ....... | 1·60 | — | — | 1·58 | 1·19 | trace | ·22 |
| CaO........ | 5·16[1] | ·48 | 1·89 | 5·21 | 1·41 | 1·57 | 2·23 |
| $Na_2O$ ...... | 6·41 | 5·17 | 9·72 | 6·85 | 9·35 | 10·79 | 8·16 |
| $K_2O$ ....... | 4·47 | 4·02 | 5·29 | 4·12 | 5·55 | 5·79 | 4·99 |
| Cl ......... | — | trace | ·04 | — | ·17 | — | trace |
| $P_2O_5$ ....... | 1·59 | — | ·31 | ·52 | trace | trace | ·17 |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·04 | 100·00 | 100·00 |
| $\frac{na + k}{al}$ | 1·1 | 1·2 | 1·1 | 1·0 | 1·0 | 1·2 | 1·1 |

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[1] Including 0·21 BaO.

# Beretning

om

# den geologiske Ekspedition til Julianehaab Distrikt

## i Sommeren 1900.

Af

**N. V. Ussing.**

1912

Denne Afhandling forelaa ved Professor N. V. Ussings Død i Juli 1911 som trykfærdigt Manuskript og er udgivet i uforandret Stand.

O. B. Bøggild.

# INDLEDNING.

Ingen Del af Grønland har i mineralogisk Henseende naaet saa stor en Berømmelse som Fjeldstrækningerne Nord for Julianehaab. Her, ikke langt fra de Egne, hvor Erik Røde og hans Ledsagere grundlagde Landets Bebyggelse, har først Giesecke (1806) og efter ham talrige Rejsende gjort forbavsende Fund af sjældne Mineraler. Har end intet af disse vist sig af teknisk Betydning, maatte dog allerede den Omstændighed, at man intet andet Sted i Grønland og kun yderst faa Steder i den øvrige Verden finder saa mange sjældne Mineraler samlede paa en lille Strækning, vække videnskabelig Interesse. Hertil kom, at man fra de samme Egne, men tilsyneladende uden Forbindelse med de sjældne Mineraler, havde lært at kende en begrænset Forekomst af rød Sandsten, som blev noget nøjere undersøgt af Pingel (1828), og som maatte tildrage sig en særlig Opmærksomhed som den eneste i hele Syd-Grønland opbevarede Levning af Aflejringer fra det uhyre Tidsrum mellem Urfjældets Dannelse og Nutiden. Da Staten paa J. F. Johnstrup's Initiativ paabegyndte de sammenhængende videnskabelige Undersøgelsesarbejder i Grønland (1876), var det saaledes naturligt, at den første Ekspedition, som udsendtes, gjaldt Julianehaab og blandt sine Opgaver havde Undersøgelsen af den røde Sandsten og af Mineralfindestederne ved *Kangerdluarsuk*[1].

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[1] Dette i Grønland paa saa mange Fjorde anvendte Navn er i den ældre mineralogiske Litteratur Fællesbetegnelsen for de sjældne Mineralers Findesteder Nord for Julianehaab.

Julianehaab-Ekspeditionen i 1876, som ledededes af daværende Museumsassistent K. J. V. Steenstrup, medens de øvrige Deltagere var daværende Premierlieutenant i Flaaden G. Holm og cand. polyt. A. Kornerup, maatte ifølge Sagens Natur være en Rekognosceringsrejse, ved hvilken dels de da foreliggende Kort kunde forbedres, dels Egnens almindelige geologiske Bygning oplyses i Hovedtrækkene, dels endelig de Steder udpeges, hvor i Fremtiden mere indgaaende mineralogiske, geologiske og arkæologiske Undersøgelser maatte foretages. Ikke desto mindre lykkedes det Ekspeditionen bl. a. i geologisk Henseende at naa betydningsfulde og paa mange Punkter ret detaljerede Resultater og et stort Udbytte af indsamlede Mineraler og Bjærgarter; hertil bidrog, at Ekspeditionens Leder allerede i 1874 havde aflagt et kort Besøg i de samme Egne, ligesom han ogsaa i Efteraaret 1877 blev i Stand til at gøre enkelte supplerende Iagttagelser.

Som et Hovedresultat af disse Undersøgelser erholdt man et geologisk Kort over Julianehaab Egnen[1], som klarlagde det væsentlige i Egnens Bygning, og som har været til uvurderlig Nytte for de senere Ekspeditioner.

En udførlig mineralogisk Bearbejdelse af Samlingerne fra Julianehaab Egnen paabegyndtes efter Dr. Steenstrup's Hjemkomst af J. Lorenzen, medens førstnævnte i en Aarrække helligede sine Kræfter til Undersøgelser i Nord-Grønland. En Række Resultater af sine Arbejder offentliggjorde Lorenzen i «Meddelelser om Grønland»; hans tidlige Død (1884) og dertil Christiansborg Slots Brand i samme Aar, hvorved den overvejende Del af de i Julianehaab Egnen indsamlede Bjærgartprøver tilintetgjordes, hæmmede en Tid lang Arbejdernes Fortsættelse.

Imidlertid havde en rivende Udvikling bragt Petrografien og særlig Læren om de eruptive Bjærgarter frem i Forgrunden mellem Geologiens Arbejdsfelter. H. Rosenbusch havde (1877) udsondret *Nefelinsyenit* (Elæolitsyenit) som en selvstændig Hoved-

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[1] Medd. om Grønland II (1881), Tav. I.

gruppe af Bjærgarter, sidestillet med Granit og Syenit; han havde paapeget, at Bjærgarten fra Kangerdluarsuk, hvori de sjældne Mineraler var Bestanddele, tilhørte den førstnævnte Gruppe, og det blev gennem hans, W. C. Brøgger's og andres Arbejder lagt for Dagen, at de paa forholdsvis smaa, men over hele Jorden spredte Pletter optrædende Nefelinsyeniter havde Krav paa den allerstørste Interesse og gav ny og uventede Indblik i de Udviklingsprocesser, der er foregaaet i Jordskorpens dybere Partier.

Der var saaledes stærk Opfordring til at fortsætte og udvide Undersøgelserne i Julianehaab Egnen. Imidlertid ønskede Dr. Steenstrup at overdrage de udførligere Undersøgelser til en anden, og han opfordrede mig til under forskellige Studieophold i Udlandet at forberede mig til et saadant Arbejde. Selv sørgede han for at erstatte de tilintetgjorte Samlinger med omfangsrige ny, medens han i Somrene 1888 og 1899 i anden Anledning opholdt sig i Julianehaab Egnen.

Efter at jeg havde gennemgaaet det rige Steenstrup'ske Materiale af Prøver fra Julianehaab Egnens Bjærgarter og afsluttet Bearbejdelsen af nogle Dele deraf[1], blev det af «Kommissionen for Ledelsen af de geologiske og geografiske Undersøgelser i Grønland» overdraget mig i Sommeren 1900 at fortsætte de geologiske Arbejder paa Stedet.

I den af Kommissionen udfærdige Instrux af 2. April 1900 fastsattes som Ekspeditionens Hovedformaal «en Undersøgelse af de Eruptivbjærgarter i Egnen omkring Tunugdliarfik-Fjord, som er brudt frem efter den derværende røde Sandstens Dannelse». Saa vidt Tiden kunde tillade det, skulde endvidere de nefelinførende Bjærgarter ved Ivigtut undersøges, og paa Overrejsen skulde anstilles Iagttagelser angaaende Havvandets Farve og Planktonmængde efter Steenstrup's Metode[2].

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[1] Meddelelser om Grønland XIV.

[2] Medd. om Grønl. XXIV, 1901, p. 251 og XXVI, 1904, p. 143.

Ved velvillig Imødekommen fra den kgl. Grønlandske Handel og fra Kryolit Mine- og Handelsselskabet blev Rejsen ordnet saaledes, at den foregik med Kryolitselskabets Skib til Ivigtut, medens Turen derfra til Julianehaab og Rejserne i de indre Fjorde skete i en lille, Kolonibestyrelsen i Julianehaab tilhørende Træbaad med grønlandske Roere, et Befordringsmiddel som i dette Tilfælde var i høj Grad at foretrække fremfor de sædvanlig anvendte grønlandske Skindbaade; disses Hovedfordel, at kunne tages i Land omtrent hvorsomhelst, vilde nemlig være uden Betydning i de berejste Egne, hvor Grønlænderne forud kendte tilstrækkelig mange Landingssteder, hvor Træbaaden uden Vanskelighed kunde skærmes mod Søgangen.

Forinden jeg i det følgende gaar over til en nærmere Redegørelse for Ekspeditionens Forløb, maa det være mig tilladt paa dette Sted at rette en ærbødig og hjærtelig Tak til de Institutioner og Personer, ved hvis Imødekommen og Understøttelse den geologiske Ekspedition blev sat i Stand til med forholdsvis smaa Midler og paa kort Tid at udrette sit Arbejde; nemlig til Kommissionen for Ledelsen af de geologiske og geografiske Undersøgelser i Grønland, til Direktionen for den kgl. Grønlandske Handel og til Direktionen for Kryolit Mine- og Handelsselskabet, og dernæst til Embedsmænd og Funktionærer i Grønland — fremfor alle Kolonibestyrer Brummerstedt i Julianehaab og til Driftsbestyrer Edwards og Kontrollør Hastrup i Ivigtut — som ikke alene viste min Ledsager og mig den mest udstrakte Gæstfrihed, men tillige ved at forberede og ordne alt, hvad der angik Baadrejserne, og ved at bistaa os med Raad og Anvisninger i høj Grad lettede Rejsen for os.

En særlig Tak skylder jeg Dr. Steenstrup, som ikke alene har ført mig ind paa dette Arbejdsfelt, men som ved sin kyndige Vejledning under talrige Samtaler har gjort det muligt for mig orud at lægge en udførlig Plan for Rejsen og forud at være orienteret i en stor Del af de videnskabelige Opgaver, som paa hvert enkelt Sted skulde søges løste.

Endelig maa det her fremhæves, at Museumsassistent, Docent O. B. Bøggild, som paa Rejsen var min Assistent, har en meget væsentlig Andel i de gjorte Iagttagelser; vi foretog fra de enkelte Opholdssteder et stort Antal af Fodturene hver for sig og i forskellige Retninger og sammenstillede bagefter Iagttagelserne, en Arbejdsdeling, der bl. a. var en Betingelse for at faa det geologiske Kort over Julianehaab Egnen færdigt i den til Raadighed staaende Tid.

# Oprejse. — Ivigtut.

Ekspeditionen, bestaaende af N. V. Ussing og O. B. Bøggild afgik fra Kjøbenhavn den 10. Maj 1900 med Kryolitselskabets Skrueskonnert «Fox II», Kaptajn Frederiksen. Den 25. Maj om Aftenen fik vi Kap Farvel i Sigte. Som sædvanlig laa der en Del Storis langs Grønlands Kyst, dog ikke mere end at Skibet i klart Vejr, om Formiddagen den 27. kunde nærme sig Arsuk indtil omtrent 40 km Afstand; men derfra indefter laa tæt sammenpakket Is. Vinden gik samme Dag om i Nordvest, og Isbæltet tiltog nu efterhaanden i Bredde, medens Skibet, der holdtes tæt op ad Iskanten, langsomt drev udefter. Den 29. Maj om Morgenen var vi drevet saa langt, at Isbæltets Bredde maatte antages at være omtrent 100 km, og da Vinden tillige var løjet af, sattes Maskinen i Gang, og vi dampede ind i Isen i diset Vejr. Der viste sig at være god Plads mellem Flagerne, kun en enkelt Gang maatte en smal Isbarriere gennembrydes. Det var en forunderlig og uforglemmelig Sejlads mellem de vidtstrakte hvide Flager med deres dybtblaa Skygger og deres Befolkning af Klapmydser og Søfugle. Efter fem Timers Sejlads klarede det noget, og Fodstykket af Umanak — den maleriske Klippeø, som betegner Indsejlingen til Ivigtut — blev synligt under de lavthængende Sneskyer. Yderligere syv Timers Sejlads gennem Storisen, forbi Arsuks uanselige Grønlænderhytter og gennem Fjorden, bragte os til Ivigtut. Her modtoges vi med overordentlig Gæstfrihed af Driftsbestyreren, Hr. E. F. Edwards, og fik Bopæl i det s. k. Amerikanerhus.

Ved Ankomsten til Ivigtut modtog jeg Brev fra Kolonibestyrer Brummerstedt i Julianehaab, at han havde ordnet vor Sommerrejse saaledes, at vi erholdt den samme Træbaad («Otto») og delvis den samme, med de indre Fjordkyster og med Mineralfindestederne fortrolige, grønlandske Besætning, som i 1897 havde ført Dr. Flink og i 1899 Dr. Steenstrup om i Julianehaab Egnen. Næste Dag (30. Maj) tilbagesendtes derfor Kajakposten til Julianehaab med Underretning om vor Ankomst, og allerede den 7. Juni ankom den ene af de Grønlændere, Kolonibestyrer Brummerstedt havde skaffet os, nemlig «Grønlands Mineralog», Kajakmanden Paulus og meddelte, at «Otto» med Besætning var sejlet fra Julianehaab til Kipisako (omtr. 30 km Sydøst for Ivigtut), hvor den afventede vor Ankomst, saaledes at alt nu var klart til Rejsen.

Vejret, som i de første Dage efter Ankomsten til Grønland havde været godt, var imidlertid bleven regnfuldt og stormende, saa at Søgangen i den ydre Del af Fjorden forhindrede Afrejsen lige til den 14. Juni.

Det nødtvungne 15 Dages Ophold i Ivigtut faldt os ikke langt. Paa tre Godtvejrsdage undersøgtes forskellige Steder i den indre Del af Arsuk-Fjord: Grønne-Dal, Ekaluit og Isbræen; paa Regnvejrsdagene foretoges, saavidt Vejret tillod det, Undersøgelser og Indsamlinger i Kryolitbruddet og dets nærmeste Omgivelser. Ved Grønne-Dal og Ekaluit konstateredes Tilstedeværelsen af en anselig Nefelinsyenitmasse[1].

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[1] A. E. Törnebohm (Geol. Fören. i Stockholm Förh. VI, 1883, p. 693) har paa Grundlag af Prøver indsamlede af N. O. Holst beskrevet en nefelinfattig Augitsyenit sammestedsfra, der kun kan være en lokalt og i ringe Udstrækning optrædende Facies af Nefelinsyeniten.

# Fra Ivigtut til Julianehaab.

Den 14. Juni forlod vi i Graavejr det venlige Ivigtut med dets travle Virksomhed. Ved Driftsbestyrerens Velvillie tilbagelagdes de første 30 km med Kryolitbruddets lille Dampbaad, og vi naaede ved Middagstid Kipisako, hvor vore Grønlændere ventede med Baaden «Otto». For dem havde de 8 Dages Ventetid i Kulde og Regn paa dette ugæstmilde Sted, hvor Vinden staar lige ind fra Davis-Stræde, været alt andet end behagelig; i Julianehaab var der medgivet dem 20 Dages Proviant, men Kulden havde forøget Kaffeforbruget, og da Lyngen var saa vaad, at den ikke kunde brænde, saa at de maatte koge ved Spæk, var baade den sidstnævnte Nødvendighedsartikel og Kaffen sluppet op syv Dage før vor Ankomst. Dette var den eneste Gang under hele Sommerrejsen, hvor det gode Humør syntes at have forladt vore Grønlændere. Der behøvedes dog ikke mere end Kaffe og

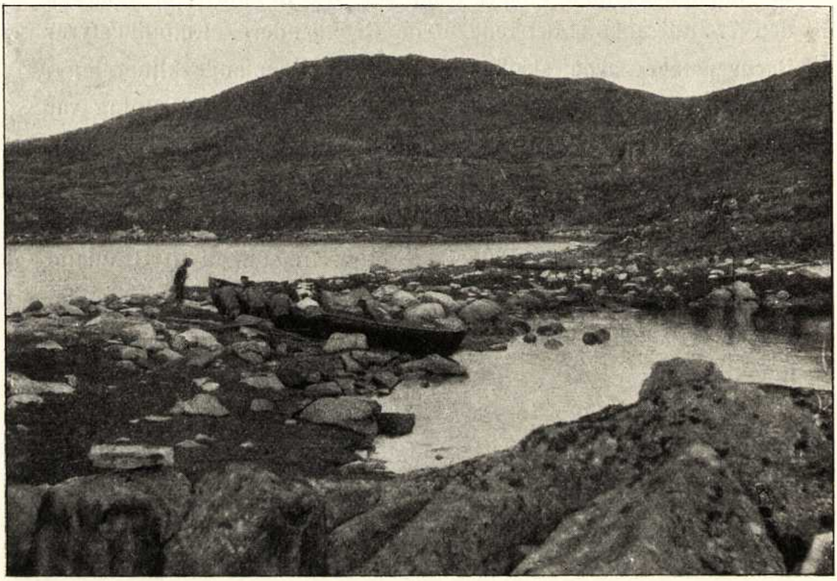

Fig. 1. Overbærestedet (Itivdliatsiak) paa Vejen fra Ivigtut til Kagsimiut (1900).

den Afveksling, som Arbejdet gav, til atter at bringe Humøret op hos Grønlænderne; med stor Snildhed forstod de at faa anbragt vor ret voluminøse Bagage i den lille Baad, og vi kunde endnu samme Dag passere det grunde Løb ved Kipisako og endda ro et Stykke videre.

Vejret var raakoldt, og der laa tyk Is paa vor Vandspand den næste Morgen. Kl. $9^1/_2$ naaede vi det bekendte Overbærested (Itivdliatsiak, Fig. 1) og derfra gik det i gunstigt Vejr videre ad Kagsimiut til. Da vi havde passeret Torsukatak, blev Farvandet stærkere og stærkere isopfyldt, idet Isen først nylig var brudt op fra de indre Fjorde. Kajakmændene maatte Gang paa Gang op paa de nærmeste Højder for at spejde efter brugbare Passager, og kun ad talløse Omveje og under idelige Kollisioner med Isen kunde Baaden komme frem. Farvandet vilde have været ufremkommeligt, om vi havde haft Skindbaad, og vore Julianehaab Grønlændere var flere Gange ved at opgive Ævret; vi havde imidlertid det Held at være i Følge med Missionær Balle, hvis Baad med en rask Besætning af Arsuk Grønlændere altid var foran, vante som disse var til saadan Sejlads i Træbaad gennem Isen. Ud paa Aftenen kom vi ud i mere aabent Farvand mellem store Isfjælde og utallige Smaaøer. I den blikstille, kolde Sommernat, under Grønlændernes stemningsfulde Nynnen og med fri Udsigt til Indlandsisens Majestæt i Nord kom vi rask fremad, men det blev dog langt over Midnat, før vi naaede Udstedet Kagsimiut.

I Kagsimiut, hvor Udstedsbestyrer Hans Jensen modtog os med stor Elskværdighed, blev vi en Dag over, for at Besætningen kunde udhvile sig efter den 19 Timers Rotur. I straalende Solskinsvejr præsenterede denne livlige Grønlænderby sig overordentlig tiltalende; Kajakker og Konebaade kom og gik, Sælhunde bragtes i Land og blev flænsede, og der var en ivrig Beskuen af de nyankomne. Takket være vort Følgeskab med Missionær Balle fik vi her Lejlighed til at overvære en sjælden Fest, idet alle Børn, som var fødte, siden Byen sidste Gang besøgtes af en Præst, og derfor var døbte af den indfødte Kateket, nu blev fremstillede i Kirken for at faa Daaben bekræftet af Missionæren. Alle kom i Stadstøjet og en sydlandsk Livlighed bredte sig til den talrige Befolkning, som med Kvindernes og Børnenes smukke brogede Dragter bød et malerisk Skue, da den efter Kirkehøjtidens Slutning spredte sig over Byen. Den mandlige Befolkning gav sin Stemning Luft ved at skyde med løst Krudt med Geværerne, og denne barnlige Fornøjelse fortsattes en halv Timestid. Derpaa kom Kaffedrikningen, som vedvarede Resten af Dagen, idet Kaffen tilberedtes i alle Huse, og alle besøgte hverandre. Min Ledsager og jeg mente at have gjort vor Skyldighed med ét Kaffebesøg, men vi slap ikke saa let, thi Grænlænderne kræver, at hans Næste i fuldt Maal skal dele hans Glæde; én for én kom alle Husmødrene med deres Kaffekedel og fyldte vore Kopper. Om Aftenen viste tre unge Grønlændere deres Kajakfærdighed i den af Isfjælde opfyldte

Fig. 2. Kirken i Kagsimiut; i Forgrunden Grønlænderhuse, liggende paa nøgne Rundklipper af Julianehaab-Granit (1900).

Havn ved utallige Gange at vende rundt, ro over hinanden o. s. v. En Dans i det fri til langt ud paa Natten dannede Afslutningen paa den festlige Dag.

Den følgende Dag var Søndag. Efter at der var holdt Gudstjeneste, forlod vi ved Middagstid Kagsimiut sammen med Missionær Balle og slog om Aftenen Telt ved Ipsens Havn paa Kerrortusok. Mandag den 18. Juni naaedes *Julianehaab*. Her modtoges vi med største Imødekommen af Kolonibestyrer Brummerstedt, og vi forblev ved Kolonien i nogle Dage, idet vi under hans kyndige Vejledning fuldstændiggjorde Udrustningen og traf de sidste Forberedelser til vort Hovedarbejde.

## Kakortok- og Igaliko-Fjordene.

Den 21. Juni roede vi fra Julianehaab ind ad *Kakortok-Fjord* og slog Telt ved Udløbet af Kugssuak, der fra Kidtlavat (Redekammen) søger mod Syd. Skønt Afstanden fra Julianehaab næppe er 20 km, fandt vi os her pludselig Ansigt til Ansigt med den ejendommelige Natur i Syd-Grønlands indre Fjorde: i Stedet for det raakolde og taagede Vejrlig paa de nøgne Klipper ved Davis-Stræde og de ydre Fjorde, hvor vi indtil da færdedes, mødte os nu et prangende, solbeskinnet Blomsterflor og saftig grønne Græs- og Kratstrækninger; straks ved Landstigningen overfaldtes vi af Myg og Fluer i tætte Sværme, og Termometret viste 14° C i Skyggen.

Kugssuak-Elv, hvis Udløb kun ligger et Par Kilometer Nordvest for den berømte Kakortok Kirkeruin, afvander Dalen mellem de to høje Fjælde: Østre-Iviangusat og Kirkefjæld. Bjærgarten ved Fjorden er gammel Granit (Julianehaab Granit), der ogsaa udgør de nævnte Fjælde; men allerede i den nærmest nordligere Fjord, Kangerdluarsak har man Nefelinsyenit og andre yngre Eruptiver, saaledes at Sydgrænsen for disses Omraade maatte søges mellem de to Fjorde. Nærmere at kortlægge og undersøge denne Grænse var Øjemedet for vort Ophold ved Kugssuak.

Ved Stranden og i den vestre Skraaning af Kugssuak-Dal fandtes løse Blokke af Nefelinsyenit og Augitsyenit i saa store Mængder, at man maatte formode, at disse Bjærgarter var faststaaende indenfor det Omraade, som Elven afvander; i Virkeligheden drejer det sig dog overvejende om Blokke, der er komne over Vandskellet ved Istransport, hvad der viste sig, da vi den næste Dag fra Teltpladsen gik nordpaa for at opsøge Grænsen. Vi fandt Graniten faststaaende helt op til Vandskellet mellem Kakortok-Fjord og Kangerdluarsuk; straks efter at man har passeret Pashøjden (520 m o. H. if. Barometermaaling), begynder Augitsyenit, som et Stykke længere nedad mod Kangerdluarsuk afløses af Nefelinsyenit. Omtrent ved dette Pas naar Nefelinsyenit-Omraadet sit sydligste Punkt, og Grænsen forløber iøvrigt saaledes, at den er lettest tilgængelig fra Kangerdluarsuk-Siden. Der var derfor ingen Grund til at forlænge Opholdet ved Kugssuak; vi roede den næste Dag ind gennem Igaliko-Fjord og slog om Aftenen Telt paa den røde Sandstens Græssletter ved Igaliko.

I *Igaliko* forblev vi fra 23. til 30. Juni. Dette for sine talrige Nordboruiner berømte Sted fortjener ikke mindre Paaagtning i geologisk Henseende. Grundfjældet, den røde Sandsten og de yngre Eruptiver træder her frem med et saa karakteristisk Ydre i Former, Farver og Forvitringsfænomener, at de overalt kan kendes paa lang Afstand; de vældige Spring, som skiller Grundfjældet fra de øvrige Dannelser, ses allerede ved første Øjekast med større Tydelighed end paa nogen skematisk Tegning; smaa og store Eruptivgange gennemkrydser hele Terrænet, og de kornede Eruptivmassers Grænseforhold, deres Udløbere og Kontaktvirkninger ligger klart i Dagen. Naturen taler her med større Tydelighed end nogen Lærebog, man kan ikke undgaa at tænke paa, at en Mængde af de geologiske Resultater, som først er naaede efter megen Tvivl og gennem Menneskealderes møjsommelige Arbejde i de europæiske Bjærgegne, hvor Fjældet ligger skjult under Plantetæppet og Forvitringsgruset, her kunde være vundne uden mindste Besvær.

Fra Igaliko undersøgtes Landet omkring den indre Del af Igaliko-Fjord, mod Syd indtil Nuluk paa Fjordens Vestside og Tavdlorutit paa Østsiden og mod Nord indtil Minerallokaliteten Narsarsuk. Igaliko er berygtet for sine hyppige og stærke Føhnstorme, og vi undgik heller ikke denne Ulempe: omtrent samtidig med vor Ankomst blæste det op fra Øst, og Vindstyrken steg i Løbet af nogle Dage til en endog i Igaliko sjælden Højde, saa at det blev umuligt at færdes oprejst i det fri, og begge Teltene blæste itu; kun paa to af de syv Dage, Opholdet varede, var Vinden svag. De almindelige geologiske Forhold i Igalikos nærmeste Omegn er omtalt af tidligere Ekspeditioner; vore Undersøgelser kom derfor væsentlig til at dreje sig om Egnen

Fig. 3. Igaliko. Græssletter i den røde Sandstens Omraade (1900).

Øst for Fjorden, dels Bjærget Iganek, dels Egnen Sydøst for dette, hvor det viste sig, at de yngre Eruptiver strakte sig langt ud over de af Dr. Steenstrup besøgte Egne. For at undersøge deres Udbredelse i den sidstnævnte Retning besteges den Fjældryg, som ender ned mod Fjorden med Tavdlorutit-Fjæld, indtil en Højde af 1020 m, ligesom Undersøgelserne ogsaa førtes 6—7 km ind i Dalen Nord for Fjældryggen. Fra nysnævnte Højde aabner der sig en pragtfuld Udsigt mod NØ. til Fjældpartierne Øst om Igdlerfigsalik: mægtige spidstakkede Alpefjælde af stærkt smuldrende, nefelinsyenitiske Bjærgarter, et Landskab som staar i iøjnefaldende Modsætning til de is-afrundede Klippeformer, der ellers er næsten eneherskende.

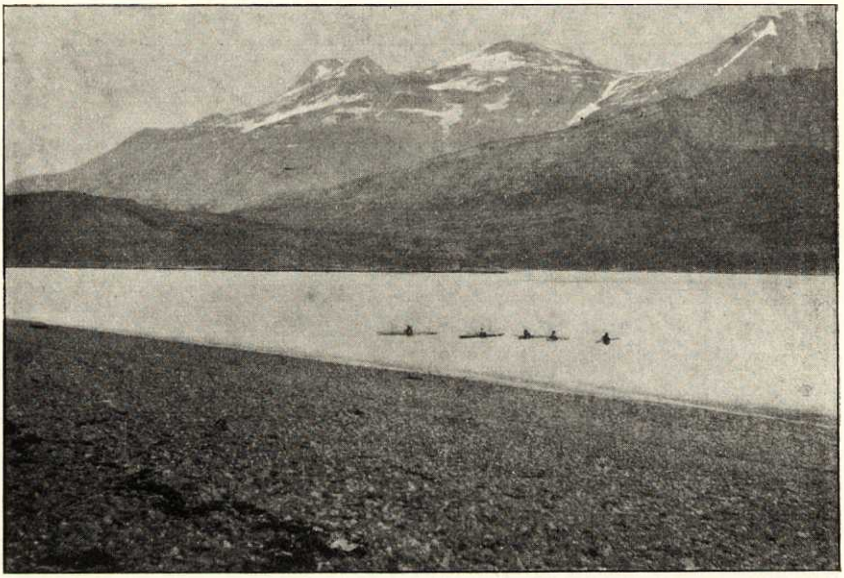

**Fig. 4. Udsigt fra Igaliko mod Nordøst. Over Fjorden ses tilhøjre det nordlige Affald af Iganek, i Baggrunden Igdlerfigsalik (Kistefjæld, 1750 m). Fot. 1900.**

Den 1. Juli forlod vi Igaliko og roede ud ad Fjorden. Kortere Ophold gjordes ved *Akuliarusek*, Gieseckitens Findested, hvor Grundfjældet gennemsættes af interessante, til de yngre Eruptiver hørende Gange, endvidere ved *Kagsiarsuk*, hvor der hverken faststaaende eller mellem de løse Blokke fandtes noget Spor af yngre Eruptiver[1], samt ved *Kanortok*, lidt Syd for Sigsardlugtok paa Igaliko-Fjords Vestside. I de iøjnefaldende sorte Fjælde, hvorefter dette Sted har Navn, ansaa jeg det for muligt, at der kunde foreligge et til de yngre Eruptiver hørende Essexitmassiv, men Undersøgelserne viste, at det drejer om Gabbromasser, der tilhører Grundfjældet.

Den 2. Juli kom vi tilbage til Julianehaab, hvor vi forblev to Dage for at faa Teltene reparerede og Provianten ordnet til den følgende Tur. Det var Hensigten herfra at ro direkte til Bunden af Kangerdluarsuk, men Regn og Modvind nødvendiggjorde et midlertidigt Ophold ved Indløbet til denne Fjord, og først den 8. Juli kunde vi slaa Teltene op i Bunden af Kangerdluarsuk paa det samme Sted, tæt under Nunasarnausaks mægtige Fjældmur, hvor de tidligere Ekspeditioner under Steenstrup og Flink havde boet.

## Kangerdluarsuk.

*Kangerdluarsuks* indre Ende er en smal og dyb Grydedal; enkelte Steder findes en smal Strandbred, bag hvilken de stærkt smuldrende Klipper hæver sig i stejle Skraaninger, andre Steder rejser Fjældvæggen sig næsten lodret lige fra Vandet, eller Fjorden hegnes af vældige «Rovser» af nedstyrtede Blokke, uden foranliggende Strandbred. Kun paa Nordsiden, under Nunasarnausak-Fjæld (Fig. 5) er smaa Stykker af Skrænterne græs-

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[1] Rejsen til Kagsiarsuk var foranlediget ved en Notits i Meddelelser om Grønland XVI, 1896, p. 123, som fremhæver Sandsynligheden af, at der kunde findes yngre Eruptiver i Egnen Sydøst for Kagsiarsuk, og at disse mulig kunde være sammenhængende med dem ved Igaliko. En saadan Sammenhæng synes altsaa at være udelukket, men det vil være forbeholdt fremtidige Undersøgelser at faa oplyst, om der findes Nefelinsyenit i det store, omtrent ukendte Omraade Sydøst for Kagsiarsuk.

klædte, og Uren delvis likénbevokset, iøvrigt ses kun nøgen Sten. Stiger man op over de stejle Fjordsider, naar man i 3—500 m Højde noget fladere Terræn, dannet ved Klippemassernes Hensmuldren; her findes vidtstrakte svagt skraanende Grussletter, hvis Materiale i Snesmeltningstiden er i langsomt flydende Bevægelse nedover, saa at næsten ingen Plante kan finde Fæste; man kan færdes her i Timevis uden at møde saa meget som en Kvadratmeter Græs- eller Mostæppe. Bag disse øde Vidder hæver sig mod Syd og Øst mægtige spidstoppede Fjælde, blandt hvilke det 1260 m høje, mærkelig formede Kidtlavat behersker hele Landskabet. Faa af de grønlandske Fjorde gør i landskabelig Henseende saa skummelt og øde et Indtryk.

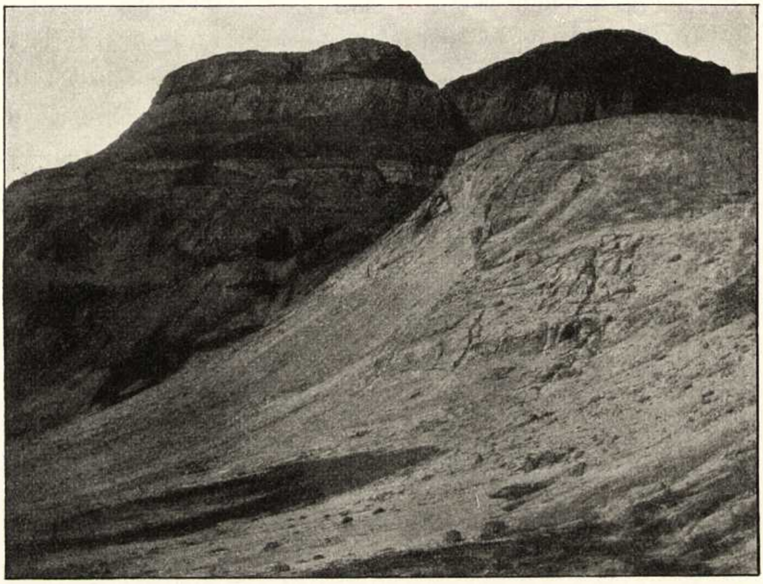

Fig. 5. Nunasarnausak i Kangerdluarsuk. Fotograferet af Dr. K. J. V. Steenstrup.

Helt anderledes i geologisk Henseende. Man mindes uvilkaarligt om Monzonis berømte Klippe-Amfiteater i Tyrol; men det geologiske Indtryk af Kangerdluarsuk er langt mægtigere og indholdsrigere. Sædvanlig søger man til Bjærgtoppene for at faa Overblik over geologiske Bygningsforhold; her, midt mellem de fra Dybet fremtrængte Eruptivmasser, faar man nede fra Stranden i Bunden af Fjorden et sikkert enestaaende Indblik i, hvad der er foregaaet i Jordskorpens Dybder.

Paa det Sted hvor vi staar, maa vi tænke os, at der til at begynde med — længe før Fjordens Dannelse — var en ensformig Grundfjælds-Jordskorpe, der naaede højere op end de nuværende højeste Fjælde, og over hvilken den røde Sandsten og mægtige Lavadækker bredte sig som et flere Tusind Meter tykt Tæppe. Nede fra Dybet nærmede sig den ildflydende, damprige Eruptivmasse («Magmaet»); Temperaturen steg, og Jordskorpen løsnedes mere og mere i sine Sammenføjninger; det ene mægtige Stykke efter det andet af Grundfjældsjordskorpen sank langsomt ned i det ildflydende Magma, som derved trængte højere og højere i Vejret. Efterhaanden blev Grundfjælds-Jordskorpens hele Tykkelse gennembrudt paa denne Maade, og Stykke efter Stykke af de omliggende Sandstensmasser maatte nu synke og give Plads for Magmaet. Højere og højere kom dette op, men samtidig begyndte det at afgive sine Dampmasser, som fandt Vej gennem den overliggende Jordskorpes Sprækker, og dette Forhold i Forbindelse med den tiltagende Afkøling fra oven kan have sat en Grænse for den videre Fremtrængen, saa at det ikke er umuligt, at Eruptivmassen til sidst størknede, endnu inden Jordskorpen var helt gennembrudt. Først i langt senere Tider har Erosionen taget største Delen af det Dække bort, som laa over den størknede Eruptivmasse, saaledes at nu selve denne træder i Dagen i anselig Udstrækning (se Kortet Tav. III). Den yngste af de større geologiske Forandringer i Egnen er Fjorddannelsen, som væsentlig maa tilskrives den udgravende Virksomhed af Istidens Gletschere; det er fremfor alt disse dybt nedskaarne Fjorde, som gør det muligt at studere Jordskorpebygningen. Tunugdliarfik-Fjord gennemskærer Eruptivmassen omtrent paa Midten, hvor den er bredest, Kangerdluarsuk naar vestfra kun et Stykke ind i den.

Den, som staar i Kangerdluarsuk-Fjords Bund, omgiven næsten til alle Sider af stejle Nefelinsyenit-Vægge, befinder sig saaledes dybt nede i Eruptivmassen. Mod Sydvest, Sydøst og Nordøst begrænses den Egn, man kan overse, af høje Fjælde: Iviangusat, Kirkefjæld og det før nævnte Kidtlavat, som i Farve og Overfladebeskaffenhed straks forraader sig som væsensforskellige fra Forgrundens Nefelinsyenitmasser; det er i Virkeligheden Grundfjældet, som her med næsten lodrette, mod Beskueren vendte Vægge rager adskillige hundrede Meter op over Nefelinsyeniten, og disse Grundfjældsvægge er intet andet end Sidevæggene i den fordums Magmabeholder (sml. Tav. V). Nefelinsyeniten og de øvrige yngre Eruptiver er yderst let hensmuldrende i Sammenligning med Grundfjældets Graniter, og derfor hæver nu de sidste sig til langt større Højder. Ogsaa mod Vest og Nordvest ser man fra Kangerdluarsuks Bund den gamle Magmabeholders Grænser, men Billedet er her væsentlig forskelligt fra det forrige: den mægtige, 750 m høje Fjældklods Nunasarnausak, som her træder tæt ud til Fjorden er et Stykke af den øverste lagdelte Jordskorpe (Sandsten med intrusive Diabaslag), som oprindelig hvilede paa Grundfjældet, men nu er sunket dybt ned i de yngre Eruptivmasser, der tydeligt ses at strække sig ind under den (Tav. V). Isolerede mindre Sandstenspartier — dog hver for sig saa store som smaa Fjælde — ses paa Fjordens Sydside under det vestre Iviangusat-Fjæld; de er under deres Nedsynken i de oprindelig flydende Eruptivmasser ligesom standsede paa Halvvejen, saa at de blev omgivne af størknet Syenit, ved hvis Smuldring de nu er begyndt at stikke frem i Dagen.

Men det er ikke alene den gamle Magmabeholders Vægge og Form og Nedsynkningsprocesserne, ved hvilke den dannedes, som træder frem for Beskueren ved Kangerdluarsuks Strand. Ogsaa indenfor selve Eruptivmassen falder de forskellige Udviklingsformer og deres Anordning stærkt i Øjnene, takket være Bjærgarternes raske Hensmuldren, som ikke alene umuliggør

Bevoksning, men i mange Tilfælde forhindrer Skorpedannelse. De allerfleste af Bjærgarterne fremtræder derfor allerede paa Afstand med samme Farve som paa friske Brudflader. Nærmest Teltpladsen har man den hvide storkornede «Naujaït», en Nefelinsyenit-Varietet, som udgør den hele Eruptivmasses mest karakteristiske og kvantitativt mest fremtrædende Bjærgart; længere borte ser man i østlig Retning de sorte og sortgrønne Lujavriter i uregelmæssige, faa hundrede Meter høje Fjælde, og op over disse rager et 660 m højt Ægirinlujavrit-Fjæld, som, skønt det ligger 4 km borte, skinner med denne Bjærgarts ejendommelige, stærkt grønne Farve[1]). Mod Syd hæver sig paa den modsatte Fjordside et Fjæld af afvekslende «Lag» af hvid og sort Nefelinsyenit («Kakortokit»); set fra neden fremtræder «Lagene» nogenlunde vandrette, men set fra højereliggende Standpunkter danner de sorte Lag, ejendommelige uregelmæssige Figurer, der har skaffet denne Fjældmasse Navnet «Kringlerne». Derover igen ses Augitsyeniten, som trods sin smuldrende Beskaffenhed er beklædt med rustbrune Skorper. Med et eneste Blik fra vort Standpunkt i Bunden af Kangerdluarsuk-Fjord ser vi saaledes en velafgrænset Eruptivmasse, der er størknet som en hel Række af forskelligartede Bjærgarter.

Opholdet i Kangerdluarsuk strakte sig over en Uge, hvor Vejret i det hele var gunstigt; Undersøgelserne udstraktes mod Nord til Vandskellet mod Tunugdliarfik, mod Vest til Niakornarsuk[2]), mod Syd og Øst til Grænserne for de yngre Eruptiver; de vanskelig tilgængelige Grænser under Kidtlavat-Fjæld naaede vi dog ikke at faa undersøgt.

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[1]) Dette Fjæld, som for den geologiske Beskrivelses Skyld behøver et Navn, er her — efter Laxeelven, der flyder rundt om det — betegnet som «Laxefjæld».

[2]) I Medd. om Grønl. II, 1881, p. 35, omtales Forekomsten af Sodalitsyenit (Naujait) paa Halvøen Niakornarsuk i Kangerdluarsuk; vi fandt imidlertid, at det her kun drejer sig om en stor istransporteret Blok af nævnte Bjærgart, der ved Smuldring har drysset saa meget Grus omkring sig, at den i høj Grad ligner en lille fast Klippe, der stikker frem af sit Grus.

# Tunugdliarfik og Korok.

I Midten af Juli forlagdes Undersøgelserne til den nærmest nordligere Fjord, Tunugdliarfik, den gamle Eriksfjord. I Stedet for den mørke og dødsstille Kangerdluarsuk havde vi fra nu af foran Teltene en bred og solbeskinnet Vandflade, hvis talrige Isfjælde bragte Afveksling og jævnlig Larm; Kajakker og Konebaade kom ikke sjælden forbi, og adskillige af dem aflagde Besøg i vor lille Lejr. Vor første Teltplads ved Tunugdliarfik var *Søndre Siorarsuit.* Der er paa dette Sted ingen Havn for Baaden, men denne kan trækkes paa Land, idet der er sandet Strandbred paa en lille, i Fjorden fremspringende Deltakegle, dannet af en Vildbæk fra Nunasarnausak. Fjordvinden indfandt sig her regelmæssig hver Eftermiddag, medbringende en gennemtrængende Kulde, der kunde være generende nok, naar man varm efter Dagens Fjældtur kom ned til Teltene. Ogsaa Myggene syntes paavirkede af den kolde Vind; i det mindste har jeg intetsteds i Grønland fundet dem saa ivrige efter at trænge ind i Teltet som her.

Paa Søndre-Siorarsuits Sandstrand var der bekvem Lejlighed til at iagttage Gletscherisens Beskaffenhed i de talrige ved Kalvningen dannede Smaastykker, som ved Ebbe blev liggende paa Sandet. Alle Stykkerne bestod her af ren Is (uden Morænemateriale), kun de færreste var imidlertid saa optøede af Solvarmen, at Strukturen kunde ses, og denne viste sig da altid at være overmaade storkornet, ja i adskillige af Stykkerne var Gletscherkornene knytnævestore. Isstykkernes Overflade var som sædvanlig bedækket med store, fladt skaalformede Fordybninger. Man har undertiden villet sætte disse i Forbindelse med den kornede Struktur[1]; det fortjener derfor at fremhæves, at den direkte Iagttagelse viste, at de to Fænomener er uafhængige af hinanden, idet selv de største af Kornene er langt mindre

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[1] Meddelelser om Grønland XVI, 1896, p. 164—165.

end de skaalformere Fordybninger, der iøvrigt udviskes mere og mere, jo stærkere Solskinnet bringer Kornstrukturen til at træde frem. De skaalformede Fordybninger er øjensynlig et Smeltningsfænomen, fremkaldt ved det bevægede Vands Angreb paa Isen, medens denne endnu er saa gennemfrossen, at Kornstrukturen slet ikke er i Stand til at influere paa Smeltningen.

Søndre-Siorarsuit ligger omtrent paa Grænsen mellem de yngre Eruptiver og Sandstenen, som nærmest disse ved Kontaktmetamorfose er omdannet til hvide grovkornede Kvartsaggregater. Efterhaanden som man fjerner sig fra Grænsen, antager Sandstenen mere og mere sin normale Struktur, kun den hvide Farve viser, at man endnu er indenfor det af Eruptiverne paavirkede Omraade; først naar man er kommet henved 3 km fra Grænsen træffer man Sandsten, der har bibeholdt sin oprindelige røde Farve. En anden interessant Omdannelse iagttoges tæt Øst for Teltpladsen indenfor de yngre Eruptivers Omraade, idet disse her over et større Areal viste sig forandrede næsten til Ukendelighed ved Dannelse af talrige sekundære Mineraler: Epidot, Albit, Jærnglans, Lievrit m. m., delvis i smukke Smaakrystaller. Efter sin lokale Optræden og hele Beskaffenhed maa denne Omdannelse formodes i sin Tid at være frembragt af hede Kilder, og vi fik denne Forklaring bekræftet ved senere paa Fjordens Nordside at træffe en lignende, øjensynlig til en Spalte bunden Omdannelse. Undersøgelsen af disse Forhold i Forbindelse med Kortlægning af Grænserne og den nøjere Udforskning af Nunasarnausak-Fjæld, som bekvemmest bestiges fra denne Side, medtog fire Dage, saaledes at vi den 20. Juli kunde flytte Teltene til Tupersuatsiak.

*Tupersuatsiak* (Fig. 6) ligger ved Sydkysten af Tunugdliarfik og omtrent midt i det hele Nefelinsyenit-Omraade, saaledes at man herfra — mod Syd til Lands, mod Nord efter først at ro over Fjorden — paa én Dags Ture kan besøge største Delen af Omraadet. Dertil kom, at Stedet bød en fortrinlig lille Baadehavn, og en udmærket Teltplads med Læ for Fjordvinden og med forholdsvis faa Myg, og vi besluttede da at udføre saa stor en Del som muligt af Undersøgelserne med Benyttelse af dette Udgangspunkt. Opholdet kom derved til at strække sig over et Tidsrum af tre Uger, i hvilken Tid Vejret næsten uafbrudt var gunstigt.

Umiddelbart ved Tupersuatsiak findes et lille Stykke smal Strandbred, men baade Øst og Vest derfor gaar Klipperne lodret ned i Havet. Indenfor Teltpladsen hæver Fjældet sig stejlt ca. 100 m, højere oppe træffer man svagere Skraaninger og vidtstrakte Flader af Smuldringsgrus, som paa fugtige Aarstider flyder langsomt nedover; Vegetationen mangler næsten helt. Bjærgarten er den lyse, storkornede Naujait, og Stedet er fortrinlig egnet til at følge de strukturelle Variationer i denne interessante Bjærgart. I Teltpladsens nærmeste Omegn indeholder den en Mængde, oftest vandrette Pegmatitgange, ved hvis Smuldring sjældne og ofte vel krystalliserede Mineraler kommer til at ligge løst paa Overfladen; især af det sjældne Mineral Ainigmatit var det her muligt at indsamle et stort Materiale.

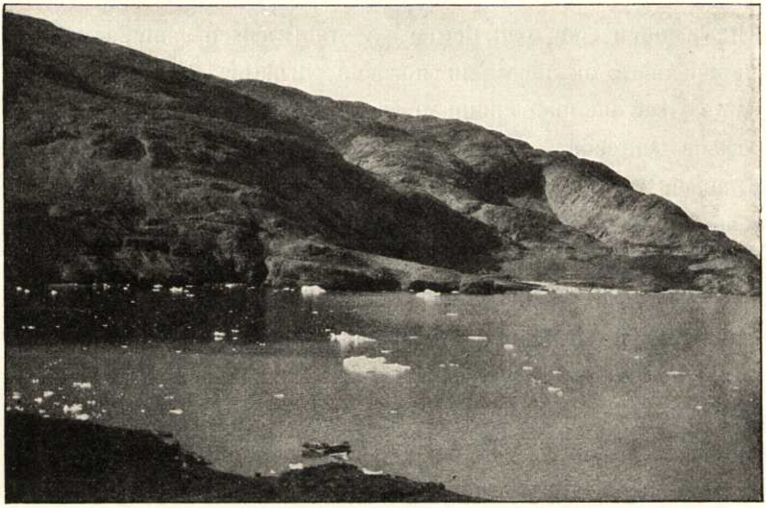

Fig. 6. Tupersuatsiak set østfra. Fotograferet af Dr. K. J. V. Steenstrup.

Ror man langs Kysten et Par Kilometer mod Vest, naar man ved Naujakasik et bekvemt Landingssted; dette er berømt ved de talrige smukke brune Eudialytkrystaller, som tidligere Ekspeditioner har indsamlet dér. Mod Øst træffer man efter 4 km Roning det imponerende Agpat, der med en regelmæssig, 75° stejl (altsaa tilsyneladende næsten lodret) nøgen Fjældflade rejser sig over 300 m lige op fra Vandet, og hvis truende Udseende ligesom understreges af Bjærgartens sælsomme grønne Farve; Fjældet bestaar helt af Lujavrit. I Kløften umiddelbart Øst herfor har man Eruptivfeltets Østgrænse; de yngre Eruptiver støder her sammen med en omtrent lodret, Nord—Syd-gaaende Væg af Sandsten og derunder liggende Granit.

Mod Nord og Nordvest, tværs over Fjorden, ser man fra Tupersuatsiak over til *Ilimausaks* mægtige Fjældmasse, der ifølge tidligere Maalinger hæver sig 1410 m over Havet. Ilimausak udgøres foroven af et Plateau af vandret udbredte Porfyr- og Diabasmasser, men Plateauet er dybt indskaaret af amfiteatralske Dale med flad og højtliggende Dalbuud og næsten lodrette Sider — Botner — og frembyder derfor overordentlig maleriske Former (Tav. X). De mod os vendende Botner, som ligger paa Solsiden, er omtrent snebare; deres Dannelse tilhører Istiden, da mægtige Snemasser fyldte dem. De to største af dem løber sammen bagtil, saa at en Del af det Fjældparti, der oprindelig skilte dem, nu staar isoleret som en mægtig, afstumpet Pyramide. Paa Kortet og de geologiske Profiler er dette ca. 1250 m høje Bjærg kaldt for «Hatten». Fra Botnerne kommer to Vildbække ned, en paa hver Side af «Hatten»; de har skaaret sig dybe Kløfter i de letsmuldrende Bjærgarter. Bækkene forener sig ved Foden af Fjældet; her har de givet Anledning til Dannelsen af en flad Gruskegle af imponerende Udstrækning, det s. k. *Nordre Siorarsuit*, som rager langt ud i Tunugdliarfik. Gruskeglens Toppunkt ligger ca. 200 m o. H. — Umiddelbart ved Fjorden og tæt Øst for den store Gruskegle ligger det lille isolerede Bjærg *Nunarsuatsiak* (160 m), nær hvis Top der findes en uregelmæssig Pegmatitmasse med kæmpemæssige (henimod meterlange) Feldspat- og Arfvedsonitkrystaller, der jævnlig er omtalte i Litteraturen[1]. I Strandklipperne foran Nunarsuatsiak samlede vi et betydeligt Materiale af et gult Mineral, Erikit[2], det eneste ny Mineral, som iagttoges paa denne Ekspedition.

*Ilimausak-Partiets* geologiske Bygning, saaledes som den fremtræder i de nøgne Fjældvægge mod Tunugdliarfik-Fjord, er overordentlig interessant (Tav. VI). De højeste Fjældtoppe bestaar som ovenfor nævnt af vandrette Bænke af Porfyr- og Diabas, men disse danner kun et forholdsvis tyndt og delvis sønderskaaret Dække over de yngre Eruptivers vældige Masser. Her er m. a. O. endnu bevaret en Del af den gamle Jordskorpe, som laa over Eruptiverne, da de størknede; disses Natur af «Dybbjærgarter» træder saaledes tydelig frem for den umiddelbare Betragtning. At Eruptiverne virkelig er yngre end de overliggende Porfyrer o. s. v., bevises af de talrige Udløbere (Apofyser), som hine sender ind i Porfyrerne, og ved den stærke Kontaktmetamorfose, som de sidste har lidt. Er saaledes Kangerdluarsuk enestaaende ved den Udstrækning og Tydelighed, hvormed dér den fordums Magmabeholders Vægge træder frem, giver Nordsiden af Tunugdliarfik os et for Forstaaelsen nødvendigt Supplement ved at vise Taget, som laa over Magmabeholderen.

Selve Eruptivmassen er her, ligesom Syd for Tunugdliarfik, iøjnefaldende «bænket», d. e. delt ved nogenlunde vandrette Sprækker, og Bænkene forandrer Beskaffenhed, efterhaanden som man følger dem nedefter. Allerøverst, umiddelbart under «Taget», er Eruptivmassen kiselrig, af granitisk Beskaffenhed (Arfvedsonitgranit) og overvejende rødfarvet. Under denne Granitmasse, hvis Tykkelse er flere hundrede Meter, kommer efter nogle Overgangslag de lyse Nefelinsyeniter hvis Hovedmasse, Naujaiten,

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[1] Saaledes af K. J. V. Steenstrup i Ussing, Alkalifeldspaterne (Meddelelser om Grønland XIV, p. 22; Stedet er her betegnet som «Serrarsuit») og af G. Flink (sammesteds p. 246).

[2] Meddelelser om Grønland XXVI, 1903, p. 93.

i Midten af Omraadet naar helt ned til Havfladen, medens dens Underflade skaalformet løfter sig ud mod Omraadets Periferi. Under Naujaiten ligger de mørke (sorte og grønne), jærnrige Lujavriter, som paa Grund af den skaalformede Lejring hæver sig højt op i Fjældene langs Omraadets Periferi. Overgangen mellem de to sidstnævnte Bjærgarter, er dog ikke pludselig: der er mellem begge en ejendommelig Blandingszone af adskillige hundrede Meters Tykkelse, hvor den hvide grovkornede Naujait er sønderstykket i kantede eller linseformede Fragmenter, som er helt omflydte ,af den mørke finkornede Lujavrit (Tav. X).

De her skitserede Hovedtræk i Eruptivmassens Bygning tænker jeg mig forklarede paa følgende Maade. I den oprindelig homogene, smeltede Masse skete ved begyndende Udkrystallisation og væsentlig efter Vægtfylde en Sortering (Differentiation), hvorved de tre nævnte Hovedlag (Granit, Naujait, Lujavrit) dannedes og adskiltes med omtrent vandrette Grænseflader. Senere, da allerede de to øverste Lag var nogenlunde størknede, skete en Nedsynken af det øverste og midterste Parti; herved opstod den nuværende skaalformede Lejring, og samtidig pressedes den dybtliggende og endnu halvtflydende Lujavritmasse op langs Randene og op i alle Sprækkerne i den ovenoverliggende Naujait, hvorved den ovennævnte Blandingszone opstod. Den her antydede Forklaring angaar kun de ovennævnte Hovedbjærgarter; fra en nærmere Omtale af de mere underordnede, til dette Eruptivomraade knyttede Bjærgarter maa der paa dette Sted ses bort; det anførte vil være tilstrækkeligt til at give en Forestilling om det enestaaende Indblik i Dybets Eruptivmasser og deres indbyrdes Forhold, som Kangerdluarsuk- og Tunugdliarfik-Fjordenes Fjælde giver.

For at fuldende Undersøgelserne og Kortlægningen af Ilimausak Omraadet behøvede vi endnu Kendskab til de Vest for Ilimausak liggende Egne ved Narsak og Sermilik; paa Grund af Beliggenheden var det imidlertid hensigtsmæssigst at opsætte dette Arbejde til sidst, og da vi den 5. August forlod Tupersuatsiak, sattes derfor Kursen til det indre af Tunugdliarfik-Fjord, hvor det ved Igaliko begyndte Arbejde skulde fortsættes mod Nord og Nordøst.

Samme Dags Eftermiddag slog vi Lejr paa Tunugdliarfik-Fjords Sydøstkyst, umiddelbart Nord for det berømte Mineralfindested *Narsarsuk*, ved det mægtige Igdlerfigsaliks vestlige Fod. Tunugdliarfik-Fjord gaar herfra med en brat Ombøjning videre indefter i nordlig Retning, medens en smallere Sidearm, Korok-Fjord, strækker sig mod Nordøst i Fortsættelse af den ydre Tunugdliarfik. Korok er ca. 12 km lang, i dens Bund udmunder en jævnlig kalvende Udløber fra Indlandsisen, og i Fjorden er der derfor altid talrige Isbjærge. Baade Korok og de tilgrænsende Dele af Tunugdliarfik er for største Delen uden Strandbred, idet Fjældet gaar lodret ned i Vandet, men just ved Korok-Fjords Munding ligger der støttet op til den stejle Fjældvæg et Stykke gammel og delvis kratbevokset Moræne, hvor Baaden kunde hales paa Land, og Teltene slaas op.

Denne lille helt af Moræne dannede Halvø bestaar af flere parallele Rygge med foranliggende smaa Lagunsøer og veludviklede sandede Strandvolde og strækker sig henved en Kilometer langs Fjældsiden. Moræneryggene peger ud i Fjorden mod Vest, og den undersøiske Fortsættelse af Morænen er let at spore ved de tætliggende Isfjælde, som staar paa Grund her: Morænen strækker sig i en stor Bue mod Nord og Øst og støder atter til Land omtrent ved Spidsen af Halvøen Nord for Korok; ogsaa her ved den nordlige Ende rager Morænegrusmasserne op over Havet og danner en lignende, til Fjældsiden støttet Morænehalvø som paa Sydsiden (se Kortet, Tav. IV). Det drejer sig her om en gammel, af Koroks Isstrøm afsat Endemoræne. I Morænehalvøen paa Sydsiden naar de enkelte Rygge omkring 30 m Højde; den indre Struktur er synlig i flere naturlige Indsnit og er typisk Morænestruktur: Udseendet svarer ganske til det hos almindeligt dansk, stenrigt Moræneler, kun er Lermængden saa ringe, at Materialet maa betegnes som

Morænegrus. Farven er graa, og Stenene, der forekommer i alle Størrelser, er overvejende isskurede og temmelig kantede, rullede Sten findes kun som Undtagelser. Af særlig Interesse er, at Moræneryggenes ydre Former øjensynlig er fuldkomment upaavirkede af Fjordens Bølger og Strøm helt ned til de mægtige Nutids-Strandvolde; thi heraf kan vi med Sikkerhed slutte, at Landet ikke har hævet sig i det Tidsrum, som er forløbet, siden Korok-Isstrømmen trak sig tilbage fra Moræenen. Sikre Iagttagelser over Tidsforholdet mellem Landets Hævning og Indlandsisens Tilbagevigen er iøvrigt yderst sparsomme[1].

Fra Teltpladsen naar man efter et Par hundrede Meters Opstigning ad den bratte Fjældvæg et Plateau, der er dannet af rask smuldrende graat Syenitgrus. Hist og her stikker malerisk formede Rester af den faste Klippe op gennem Gruset; vi befinder os paa *Narsarsuk*. Det berømte Mineralfindested er paa Kortet (Tav. IV) mærket med et ×; det ligger omtrent 270 m o. H. De sjældne Mineraler hører hjemme i Pegmatitmasser, som optræder uregelmæssig fordelt i Syenitbjærgarten og er underkastede Vejrsmuldringen i endnu højere Grad end denne. Man er derfor henvist til at søge Mineralerne i det løstliggende Grus, og det Udbytte, som nu kan erholdes uden større Gravninger, er yderst ringe, da hele Omraadet, hvor de sjældne Mineraler optræder, er ganske lille og allerede er grundigt gennemsøgt[2]. Vi turde derfor ikke anvende mere end en Dag til Mineralsøgning paa dette Sted og maatte iøvrigt koncentrere Opmærksomheden paa de geologiske Forhold.

Syenitbjærgarten ved Narsarsuk viste sig at være en umiddelbar Fortsættelse mod Nord af den paa Østsiden af Iganek-

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[1] Sml. den udførlige Omtale af Spørgsmaalet hos A. Jessen i Meddelelser om Grønland XVI, 1896, p 154.

[2] Med Hensyn til Mineralforekomsten Narsarsuk henvises i øvrigt til den udførlige Beskrivelse af G. Flink i Meddelelser om Grønland XIV, 1898 (P. 226 og Tav. IX) og XXIV, 1901 (p. 10 og Tav. IX); ved en Fejl er paa disse Steder den til Augitsyeniten mod Vest grænsende Bjærgart angivet som Granit i Stedet for Sandsten.

bjærget faststaaende Syenit, som vi havde undersøgt under vort Ophold i Igaliko. Den danner kun en forholdsvis smal Bræmme langs Vestsiden af det vældige *Igdlerfigsalik*-Massiv, der saa vidt hidtil vides, helt igennem bestaar af Nefelinsyenit, ligesom Tilfældet ogsaa er med de Nord og Øst for Korok liggende Egne. Som det ses af Kortet (Tav. IV), er det endnu ukendt, hvor langt denne østlige Nefelinsyenitmasse strækker sig ind i det indre af Landet; af hvad der allerede er kendt, fremgaar dog sikkert, at den er langt større end Nefelinsyenitmassen ved Kangerdluarsuk og Ilimausak, ja den synes at være en af de største Masser af denne Art, som findes i Verden.

En særlig Interesse frembyder Forskellighederne mellem de to saa nær ved hinanden liggende sydgrønlandske Nefelinsyenitomraader. Medens Eruptivmassen ved Kangerdluarsuk—Ilimausak som ovenfor skildret udmærker sig ved at være rigt differentieret, idet den frembyder en Mængde og yderst interessante Variationer i Bjærgartbeskaffenheden — for største Delen vidt forskellige fra, hvad man kender andensteds i Verden — er den kolossale Eruptivmasse i Igdlerfigsalik-Omraadet af forholdsvis ensformig Beskaffenhed, saa vidt den hidtil er undersøgt, og de her iagttagne Bjærgartvarieteter ligner i ikke ringe Grad dem, man kender fra andre Nefelinsyenit-Omraader i Amerika og Europa.

En anden Forskellighed, som mulig hænger sammen med den forrige, angaar Eruptivmassens Forhold til Omgivelserne. Ved Ilimausak er som ovenfor nævnt en Del af Taget over Eruptivmassen bevaret, og i Fjældvæggen ned mod Fjorden paa Sydsiden af Ilimausak ser man tydelig, hvorledes Eruptivmassen bliver bredere og bredere nedefter, saa langt den kan følges; hvad der rager op over Havfladen, er saaledes kun den øverste Del af en i Dybet stivnet Eruptivmasse, hvis største Part rimeligvis ligger under Havets Niveau. I Igdlerfigsalik-Massivet er Forholdet et ganske andet. Her er intetsteds fundet Spor af de Masser, der i sin Tid dannede Taget over den underjordiske

Magmabeholder, denne er her bleven hævet saa højt, at Erosionen har borttaget alt det, der laa over den og sandsynligvis ogsaa alt det øverste af selve Eruptivmassen; ja Erosionen er trængt saa dybt ned, at der endog er blottet Klippemasser, som synes at tilhøre den gamle Magmabeholders Underlag. Undersøger man nemlig Syenitens Vestgrænse, viser det sig, at paa hele Strækningen fra Morænen ved Narsarsuk i Nord til Iganek i Syd, (i alt ca. 7 km), falder de tilgrænsende Sandstenslag mere eller mindre stejlt ind under Syeniten, og endnu ejendommeligere er Forholdene længere mod Vest. Her fortsætter Narsarsuk-Plateauet sig i det næsten helt horizontale, 250—300 m o. H. liggende Iliortafik-Plateau, der bestaar af vandrette Sandstenlag med underliggende Grundfjælds-Granit, og her iagttager man, at de øverste Sandstenslag i langt højere Grad end de nederste har undergaaet saadanne Forandringer i Beskaffenhed, som frembringes ved store Eruptivmassers Nærhed (Kontaktmetamorfose); i de allerunderste Lag har Sandstenen bevaret den røde Sandstens oprindelige Beskaffenhed. Dette gør det meget sandsynligt, at de yngre Eruptiver, før Erosionen var skredet saa vidt frem som nu, dækkede en stor Del af Iliortafik-Plateauet, og at dette saaledes maa siges at tilhøre Eruptivmassens Underlag. Igdlerfigsalik Partiet viser sig herigennem at give et storslaaet Indblik i helt andre Omraader af Eruptivmassernes Geologi end Ilimausak- og Kangerdluarsuk-Egnen.

Fra Teltpladsen ved Narsarsuk foretog vi den 9. August en Rotur ind i *Koroks* berømte Isfjord, som paa Grund af sine Ismasser regnes for utilgængelig for grønlandske Skindbaade. Dog har GIESECKE saavel i 1806 som i 1809 besøgt Fjorden i en saadan, og han er til Dato den eneste, som — rigtignok ufrivilligt — har overnattet derinde (1). Fjorden har senere (i Træbaad) været besøgt saa vel af FLINK (1897) (2) som af STEENSTRUP.

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(1) Gieseckes mineralogiske Rejse i Grønland ved F. JOHNSTRUP. København 1878, p. 35 og 173.

(2) Meddelelser om Grønland XIV, 1898, p. 253.

Om Bjærgarterne var dog omtrent intet bekendt, og da vi desuden i Modsætning til, hvad Tilfældet var ved de to sidstnævnte Besøg i Fjorden, havde helt klart Vejr, blev Turen rig paa Udbytte baade i geologisk og i landskabelig Henseende. Faa Timers Roning med indadgaaende Strøm førte os langs Igdlerfigsalik Fjældvægge til Pynten Nord for dette Bjærg. Allerede denne ydre Del af Korok gør ved Fjældenes mægtige Højde og Stejlhed et mere storslaaet Indtryk end nogen anden Fjord, vi besøgte i Grønland. Ved den nævnte Pynt aabner sig en Bugt mod Øst, medens Isfjorden selv bøjer om i nordlig Retning. Fra Bugten strækker sig mod Øst den af Giesecke besøgte Dal, som paa Kortet er betegnet med hans Navn; denne Dal gennemstrømmes af en slamrig Elv fra Indlandsisen, og dens nedre Del er derfor helt udfyldt af Sand og Ler, aflejret i pragtfulde Terrasser. Den ovenfor fremhævede fuldstændige Mangel paa

Fig. 7. Ca. 1600 m højt Fjæld Nordøst for Igdlerfigsalik, set fra Vest. De smaa Isfjælde i Forgrunden svømmer i den østlige Bugt af Korok. (1900).

hævede Terrasser ved Narsarsuk lærer os, at disse Terrasser i den indre Korok ikke kan skyldes nogen Hævning af Landet; de maa øjensynlig være afsatte, medens Bræen nordfra strakte sig ud gennem hele Korok-Fjord og saaledes kunde omdanne den ydre Del af Giesecke's-Dal til en Indsø med opstemmet Vandspejl. Opefter mod Øst deler Giesecke's Dal sig i en nordøstlig og en sydøstlig Arm; mellem begge ligger en malerisk Fjældpyramide af kolossale Dimensioner (Fig. 7). Det er dog først, naar man er naaet ind til Nordsiden af Giesecke's-Dal, at denne Egns storslaaede Alpenatur helt udfolder sig. Man kan da se ind i den nævnte sydøstlige Arm af Dalen, hvis Bund hæver sig rask opefter, hegnet af mægtige, spidstoppede Fjælde med bratte Styrtninger og mellemliggende Hængegletschere, og end mere gribende ved sin storslaaede Skønhed er Nordsiden af Igdlerfigsalik-Massen, mellem hvis maleriske Toppe fire Gletschere hænger ned. Længst inde i Giesecke's-Dals Sydøstgren kunde jeg genkende en spids Fjældpyramide, som jeg tidligere havde iagttaget i nordvestlig Retning fra Tavdlorutit ved Igaliko-Fjord. Der synes at være Sammenhæng Øst om Igdlerfigsalik-Massen mellem Sydøstgrenen af Giesecke's-Dal og den Dal, som fra Igaliko-Fjord strækker sig ind mellem Iganek og Tavdlorutit.

Overalt i den indre Korok møder Øjet en malerisk Fjældskulptur, som viser hen til intensiv Erosion i Nutiden, — en paafaldende Modsætning til de afrundede, fra Istiden overleverede Former, der behersker den overvejende Del af det grønlandske Kystbælte. Vi finder lignende Alpelandskaber længere mod Øst, f. Eks. i den berømte Tasermiut Fjord. Utvivlsomt er det væsentlig Fjældenes betydelige Højde, som betinger denne stærke Nutidserosion og de bratte Affald, i det de store Højder giver Anledning ikke alene til intensiv Vejrsmuldring, men ogsaa til Dannelsen af anselige lokale Gletschere, som udmejsler skarpe Fjældkamme, og som i Forening med Indlandsisens Udløbere graver de dybe Trugdale. Mangelen paa beskyttende Vegetation og de yngre Eruptivers Tilbøjelighed til at smuldre er medvirkende, men vistnok ganske underordnede Faktorer. Hvad særlig Smuldringstilbøjeligheden angaar, fortjener det at fremhæves, at den ikke er fast knyttet til de yngre Eruptiver: netop i Korok-Egnen finder man ingenlunde sjældent Fjældvægge, som er saa yderst lidt smuldrende, at man efter Erfaringerne fra Kangerdluarsuk-Egnen skulde anse dem for Grundfjælds-Granit, medens de i Virkeligheden bestaar af yngre Syenit og Nefelinsyenit; og omvendt finder man ogsaa (f. Eks. i Tavdlorutit ved Igaliko-Fjord) Grundfjælds-Granit, der er saa stærkt smuldrende, at man efter Udseendet i Frastand vilde tro, man havde at gøre med yngre Eruptiver. De ældste geologiske Kort over Egnen er aabenbart paavirkede af dette Forhold.

Omtrent 12 km Nord for Koroks Munding ligger *Kiagtut* paa Tunugdliarfik-Fjords Østside. Til dette for sin «Skov» (Fig. 8) bekendte Sted havde vi allerede i Slutningen af Juli gjort en Udflugt. Ved Kiagtut udmunder en anselig Elv fra Indlandsisen, og der har dannet sig en stor Grusslette, afbrudt af flere smukke Endemorænevolde og mellemliggende Gryder og Søer. Disse Endemoræner indeholder i Modsætning til den ved Narsarsuk overvejende rullede Sten. Omtrent gennem denne Slette gaar Nordgrænsen for Igdlerfigsalik-Omraadets Nefelinsyenitmassiv: Fjældet paa Nordsiden af Sletten viste sig at bestaa af Grundfjælds-Gnejs, og Syd for Sletten har Steenstrup allerede 1876 fundet Nefelinsyenit.

Under vort Ophold ved Narsarsuk var Vejret i det hele ugunstigt, dels med Kulde og Regn, — der faldt endog lidt Sne ved Havoverfladen den 8. August, — dels med Tilløb til Føhn; kun den Dag, der benyttedes til Turen i Korok, dannede en Undtagelse. Dagen efter, den 10. August, bragte ganske vist ogsaa Solskin, saa at vi haabede at kunne fortsætte Undersøgelserne Nord for Korok, men Grønlænderne nægtede paa det bestemteste at ro ind ad nogen af Fjordene. De pegede ind mod Korok, og unægtelig var det ikke indbydende, hvad man her saa: ud fra Giesecke's-Dal kom med uregelmæssige Mellemrum enorme Støvskyer, som førtes over mod den stejle nordvestlige Fjordside med saadan Fart, at de dér hævede sig adskillige hundrede Meter op i Vejret. Det var Føhnen, som for Alvor havde taget fat derinde, skønt der ved Teltpladsen endnu raadede Vestenvind (Fjordvind). Da Føhnen antagelig snart vilde naa ud til vor Teltplads, brød vi op og roede et lille Stykke ud ad Fjorden.

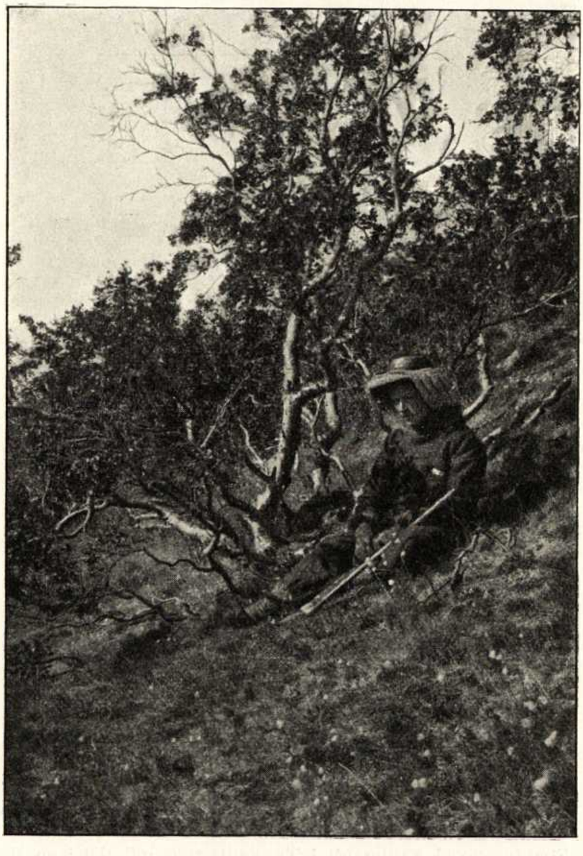

Fig. 8. Birketræ ved Kiagtut i Tunugdliarfik (1900).

Vi slog Telt ved *Musartut* paa Nordsiden af Tunugdliarfik, et af de fleste tidligere Ekspeditioner besøgt Sted, hvor vi kunde gøre Indsamlinger af et af Steenstrup fundet sjældent Mineral, Willemit, medens vi ventede paa, at den næste Dag skulde bringe bedre Vejr. Den smukke blaa Willemit findes i Strand-

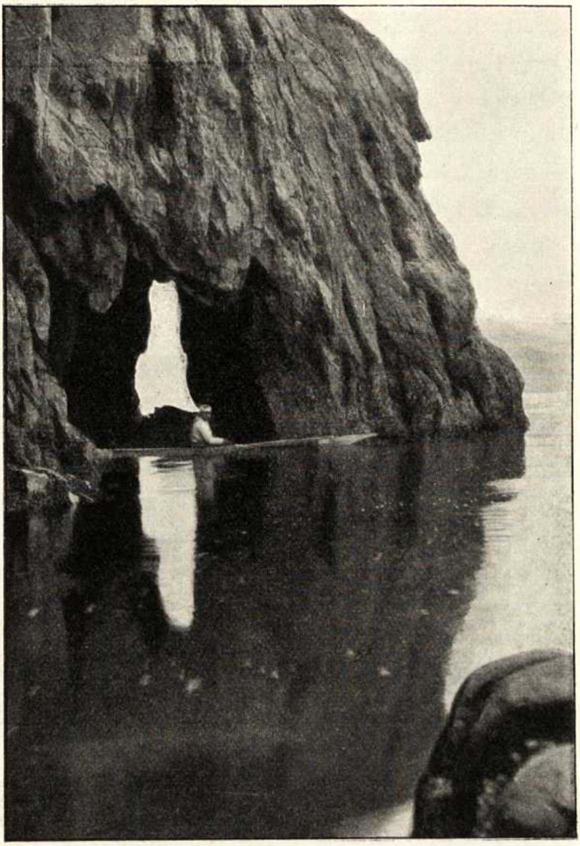

Fig. 9. Fjældport ved Naujarsuit i Tunugdliarfik, udhulet i en Porfyrgang i den røde Sandsten. (1900).

klipperne og er ikke kendt fra noget andet Sted i Grønland; den viste sig at være meget sparsomt til Stede, men Besøget gav dog noget Udbytte, idet det lykkedes at konstatere Tilstedeværelsen af smaa (indtil 25 cm brede) Sandstengange, d. e. Sprækker, som er fyldte med nedgledet og senere hærdet Sand

(Willemiten sidder i disse). Bjærgarten paa Stedet er den røde Sandsten i omtrent vandrette Lag, og Sandstengangene er lodrette med samme Retning som de talrige Porfyrgange, der næsten overalt gennemsætter Fjældet, d. e. Nordøst—Sydvest. Sandstengangenes Tilstedeværelse antyder saaledes, at Sandstenen endnu kun delvis var hærdnet, dengang de vulkanske Udbrud begyndte.

Umiddelbart ved Musartut er Landet lavt og bevokset med tæt og højt Krat; men lidt Vest for Teltpladsen hæver den røde Sandsten sig i et prægtigt, ved sine iøjnefaldende Porfyrgange udmærket Fjæld, kendt fra Kornerup's Tegning[1]). Ud mod Fjorden vender dette Fjæld imponerende lodrette Vægge, som kaldes Naujarsuit, idet de er Yngleplads for utallige Tejster og Maager. Porfyrgangene forvitrer lidt raskere end Sandstenen, og da de gaar omtrent parallelt med Kysten, giver de Anledning til Dannelsen af mægtige Kløfter og af Fjældporte nede ved Vandet (Fig. 9).

Den næste Dag bragte ikke det ventede bedre Vejr, og da vi kun havde en halv Snes Dage til Disposition, besluttede jeg at anvende disse paa Egnen ved Narsak, hvor vi allerede gentagne Gange havde aflagt Besøg for Provianteringens Skyld og havde set, at der var et yderst interessant geologisk Arbejdsfelt, der kunde undersøges uden Brug af Baaden, saa at man var nogenlunde uafhængig af Vejret. Med Føhnen tæt i Hælene naaede vi Narsak den 11. August om Eftermiddagen.

## Narsak og Sermilik-Fjord.

Ved det venlig beliggende Udsted *Narsak* opholdt vi os til den 17. August. Teltene sattes op paa en frodig Græsslette, og da Stedet ligger overmaade lunt, havde vi trods forholdsvis

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[1]) Meddelelser om Grønland II, 1881, Tav. 3.

uroligt Vejr ingen andre Ulemper end den, at Køerne indfandt sig regelmæssig hver Morgen, saa snart det lysnede, for at gnubbe sig op ad Teltene, der daarlig kunde staa for den Behandling. Omegnen er overordentlig kompliceret i geologisk Henseende og frembyder en saadan Mængde Forhold af Interesse, at den sikkert vil lønne Maaneders Arbejde; nogle af de geologiske Hovedtræk lykkedes det dog formentlig at faa udredet med Sikkerhed. Paa dette Sted skal kun fremdrages, at Egnens Hovedbjærgarter er yngre Eruptiver, men af væsentlig forskellig Beskaffenhed fra de tidligere omtalte; her findes Essexit, Syenit (Nordmarkit) og Granit, som er brudt frem til noget forskellige Tider og synes at vise en bestemt Eruptionsrækkefølge i den nævnte Orden, saaledes at Graniten er yngst; man faar her Indblik i Kapitler af Eruptivbjærgarternes Historie, som danner et vigtigt Supplement til dem, der kan studeres i de tidligere omtalte Omraader. Som endnu yngre end Graniten, ja som en af de allersidste Ytringer af den fordums Eruptivvirksomhed i Syd-Grønland maa man vistnok betragte en anselig Intrusivmasse af rød Kvartsporfyr, som man træffer i en malerisk Fjældkløft, et Par Kilometer Nord for Narsak.

Nordøst for Narsak træffer man i omkring 600 m Højde et vidtstrakt Plateau, opbygget af vandret udbredte Porfyr- og Porfyritmasser, og delvis dækket af Morænegrus. Ad dette Plateau, som viser sig at være en nedsunket Flage af den gamle Jordskorpe over Eruptivmasserne, naar man efter nogle Kilometers Vandring Indsøen Tasek, hvor Ilimausak-Partiets tidligere omtalte Nefelinsyeniter begynder. Størst Interesse i geografisk Henseende frembyder imidlertid den Nordvest for Plateauet liggende Dal, der gaar paa langs gennem den ydre Del af Narsak-Halvø. Denne Dal viser sig ved sin typiske U-Form med stejle Sider og flad Bund som en udpræget Gletscherdal; men nu er kun dens øverste Ende optaget af en lille Gletscher (Tav. XIII) hvis Elv strømmer ned over Dalbundens Lujavritbænke i en Række af smukke Vandfald. At det er længe siden Gletscheren udfyldte Dalen, fremgaar af de dybe Kløfter i Dalbunden, som Erosionen ved Vandfaldene har frembragt. Interessant er ogsaa den anselige Sidemoræne, som ses paa Afbildningen, og som viser, at Gletscheren i den allersidste Tid har trukket sig tilbage.

Fra Narsak foretoges den 17.—20. August en Udflugt i *Sermilik*-Fjord. Paa dennes bratte Sydside findes ingen brugelig Teltplads, og vi maatte derfor slaa Lejr ved *Igdlomiut* paa Nordsiden og derfor lade Baaden ro os frem og tilbage til Sydsiden. Sermilik-Fjord danner nemlig, som vi véd fra Dr. Steenstrup's Rejser, Nordgrænsen for de yngre Bjergarter i denne Egn, dens Nordside bestaar af Grundfjæld.

Udsigten fra Teltpladsen ved Ilimausak tværs over den isfyldte Fjord gjør et mægtigt Indtryk. Uden Forstrand rejser Fjældmassen sig stejlt op fra Vandet som en regelmæssig Mur, der paa en lang Strækning er over 1000 m høj; foroven bærer den et Plateau, dækket af evig Sne og Is, som dog ikke kan ses nede fra Vandet. Men over Plateauet ser man hæve sig som en isoleret Kegle den af Steenstrup i 1875 bestegne Top (1370 m), som jeg paa Kortet har betegnet med hans Navn, og lidt til venstre for den skimtes over Plateauranden det øverste, mod Nordvest lodrette Affald af Ilimausaks Top (1410 m). Selve Fjældmuren er iøjnefaldende og omtrent vandret lagdelt; de nederste to Trediedele af Lagene har den røde Farve, som udmærker den sydgrønlandske Sandsten, medens Bænkene foroven er sorte Eruptiver[1]). Den nøjere geologiske Undersøgelse gav det kærkomne Resultat, at Sermilik-Fjords Sydkyst i et eneste sammenhængende Profil blotter *den røde Sandsten* i sin fulde Tykkelse og dertil saa meget af de øvrige Dannelser, at man her har ligesom et Generalprofil for hele Julianehaab-Egnen

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[1]) Af den østlige Del af denne Klippevæg har A Jessen meddelt et Fotografi i Meddelelser om Grønland XVI, Tav. XL. Paa dette i Forsommeren 1894 tagne Billede ligger der Sne paa alle de fremspringende Afsatser, hvorved Lagdelingen bliver særdeles iøjnefaldende. Ved mit Besøg i August 1900 var Fjældvæggen helt snebar, og de smaa Gletschere traadte derfor tydelig frem.

(Tav. VI). Sandstenlagene skraaner svagt mod Sydsydvest, saa at man nede ved Fjordene træffer ældre og ældre Lag, efterhaanden som man ror indad; til sidst, i Bunden af den lille Sidefjord Kangerdluak, finder man den underliggende Grundfjælds-Granit. Den samlede Tykkelse af Sandstenformationen, regnet fra den gamle Overflade af Grundfjælds-Graniten op til de øverste Sandstenbænke under Diabaserne i Ilimausaks Højder, viser sig at være ikke mindre end 1100 m! Sandaflejringens oprindelige Tykkelse har dog været mindre end den nuværende; thi Formationen er efter sin Aflejring og Hærdning blevet i nogen Grad fortykket ved de talrige Diabasbænke, der under den paafølgende vulkanske Virksomhed blev pressede ind mellem Lagene. Disse Diabasbænke tegner sig som sorte Baand i den røde Sandstenvæg, de er talrigst i den øvre Del af Sandstenen, og man kan følge deres regelmæssige Forløb over lange Strækninger; dette Forhold i Forbindelse med Kontinuiteten i de Eruptivbænke, som dækker Sandstenen, viser, at Profilet ikke er gennemsat af større Spring, som vilde gøre den ovennævnte Tykkelseberegning illusorisk.

Over den røde Sandsten ser man de mørke Eruptivmasser, der danner Ilimausaks øverste Plateau og de op over dette ragende Toppe. Ogsaa denne Eruptivformation, som vi her for Kortheds Skyld vil kalde *Porfyrformationen*, viser sig i Sermilik-Profilet iøjnefaldende lagdelt og regelmæssig afsat ovenpaa Sandstenen. Man har her for sig vulkanske Masser, der har bredt sig vandret ud over Sandstenaflejringen kort efter dennes Dannelse. Porfyrformationens Bjærgarter (Diabaser, Porfyriter og Porfyrer) svarer i Hovedtrækkene til dem, der produceres af Nutidens Vulkaner; de synes delvis at være virkelige Lavastrømme fra hin fjerne Tid, delvis er de Intrusivlag, pressede ind mellem og under Lavastrømmene. Da de har ligget øverst, har de i endnu langt højere Grad end Sandstenen været udsatte for Nedbrydning, og hvad der nu er tilbage af dem, er udentvivl kun en forholdsvis ubetydelig Rest; at de oprindelig har bredt sig i vid Udstrækning over Egnen, derpaa tyder de talløse Eruptivgange, som gennemsætter ikke alene Sandstenen, men ogsaa Grundfjældet udenfor Sandstenens nuværende Grænser.

Ilimausak-Partiet og dets Affald mod Tunugdliarfik er det eneste Sted i Grønland, hvor denne Porfyrformation findes bevaret. Grunden hertil falder let i Øjnene fra vort Standpunkt i Sermilik: følger vi Sandstenlagene i den Retning, de ses at skraane, finder vi Porfyrformationen bevaret i større og større Tykkelse. Hvad der er tilbage af denne Formation, indtager i det hele og store det dybest *sænkede* Parti af den gamle Jordskorpe og ligger altsaa paa det Sted, hvor Nedbrydningen mindst kunde gøre sig gældende. I Detaillerne viser Udbredelsen betydelige Uregelmæssigheder, saaledes som det ses af Kortet, og saaledes som det nødvendig maa blive paa Grund af den Uregelmæssighed, hvormed Erosionen skrider frem.

Porfyrformationen danner foroven et udpræget Plateau, hvad der er en letforstaaelig Følge af den lagdelte Bygning. Lige saa let forstaaelig i Hovedtrækkene er Plateauets Trappetrins-Skraaninger og dets talrige Indskæringer, som skyldes Erosionen. Derimod kan man ikke af det ydre forklare sig de stærkt iøjnefaldende Porfyrtoppe, som vi ser hæve sig over Plateauet og danne Ilimausaks, ja hele Egnens højeste Fjælde. Men undersøges disse nærmere, finder man, at deres Diabas- og Porfyrbænke er gennemvævede af Granit- og Syenitgange (delvis Udløbere fra de nedenunder liggende Masser), som har hærdet og omdannet (kontaktmetamorfoseret) dem i betydelig Grad og derved lokalt frembragt Partier, der er særlig modstandsdygtige mod Erosionen. Da saaledes de højeste Porfyrtoppe kun er Erosionsrester, kan Porfyrformationens oprindelige Tykkelse ikke konstateres, men kun Tykkelsen af den til vore Dage bevarede Del. Denne kan dog i Modsætning til Sandstentykkelsen ikke uden videre maales i Fjældvæggen paa Sermilik Sydside; thi Bænkene skraaner ikke alene i Fjordretningen, men ogsaa i Retning mod Tunugdliarfik, og de højeste Toppe ligger et godt

Stykke derhenad. Tages dette i Betragtning, finder man for den bevarede Del af Porfyrformationen en Tykkelse af henved 1000 m. Heraf følger, at de lagdelte Sandsten- og Porfyrformationer, som i sin Tid dækkede store Dele af Syd-Grønland, tilsammen maa have haft en oprindelig Tykkelse af betydelig over 2 km. Ser vi nu hen til, hvor faa og smaa Rester, der i vore Dage er tilbage af disse mægtige Formationer, faar vi et Indtryk af det uhyre Arbejde, Erosionen har udrettet siden Porfyrernes Dannelse, og det bliver forstaaeligt, at naar vi nu i Væggene af de dybt nedskaarne Fjorde undersøger Nefelinsyeniternes og de øvrige kornede Eruptivmassers Forhold, faar vi Indblik i Resultaterne af geologiske Processer, hvis virkelige Skueplads laa kilometerdybt under Jordoverfladen; ligeledes vil det forstaas, at disse kornede Eruptivmasser med Rette karakteriseres som «Dybbjærgarter».

Ogsaa disse sidste er repræsenterede i det Profil vi har for os paa Sermilik-Fjords Sydside. Omtrent lige over for Teltpladsen paa Igdlomiut ser man alle Sandstenlagene og de nederste af Porfyrbænkene brat afskaarne af en stor Syenitmasse, som vedvarer vestefter, saa langt Profilet rækker. Nedadtil strækker Syenitmassen sig til ubekendte Dybder, men foroven ser man en stor Del af de over Sandstenen liggende Porfyrbænke fortsætte sig mod Nord og Syd som et fladt Tag over Syeniten. At denne Syenitmasse er yngre end baade Sandstenen og Porfyrformationen, som saaledes dannede den Jordskorpe, i Ly under hvilken Syeniten størknede som Dybbjærgart, lod sig sikkert konstatere ved Undersøgelsen af Grænseforholdene.

Under Opholdet i Sermilik-Fjord besøgtes ogsaa Nordsiden af Kangerdluak, hvor Jessen kortelig nævner, at han har iagttaget yngre «Syenit»[1]. Det viste sig, at det her drejer sig om en mægtig Gang af en stærkt smuldrende yngre Dybbjærgart (Essexit). Gangen, hvis Retning stemmer overens med den

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[1] **Meddelelser om Grønland XVI, 1896, p. 123.**

almindelige Fjordretning, saas fra Baaden at fortsætte sig mindst en Kilometer ind over Land; dens Bredde er flere hundrede Meter, men Grænserne saas intetsteds blottede. I denne Sammenhæng kan det anføres, at vi iagttog en ganske lignende, dog noget friskere Essexitmasse ved Sigsardlugtok paa den store Ø Tugtutok (Vest for Narsak), der væsentlig bestaar af Grundfjæld; saa vidt det kunde skønnes fra Baaden, strakte Essexiten sig som en eller flere Gange mindst 5 km langt gennem nævnte Ø, følgende Fjordenes Hovedretning.

I Sermilik-Fjord og paa Ilimausak er der rig Lejlighed til at gøre Studier over *Gletscherfænomenerne*; under vort korte Ophold med andet Hovedformaal kunde der dog kun blive Tale om en Indsamlen af tilfældige Iagttagelser. I Fjordens Bund udmunder de af Moltke og Jessen i 1894 undersøgte Udløbere fra Indlandsisen[1]), som er saa produktive, at de dannede Isbjærge ofte gør Sejladsen i Fjorden ret besværlig, og det er allerede fremhævet i den nævnte Ekspeditions Beretning, at mange af Isbjærgene i Sermilik transporterer anselige Mængder Morænemateriale. Her hidsættes (Tav. XIX) et Par Fotografier af saadanne Isbjærge; det ene, som udmærker sig ved sin maleriske Form med en høj af Vinden udvidet Port, indeholder kun en mindre Mængde Morænemateriale, medens det andet præsenterer sig som en mægtig, svømmende Morænevold.

Særlig Interesse frembyder de *lokale Gletschere paa Ilimausak*, og da de ikke tidligere har været omtalte, skal her anføres de faa Iagttagelser, vi fik Lejlighed til at gøre over dem. Hele det øverste Plateau paa Ilimausak er Firn-dækket. Højden af dette Fjældplateau synes at kunne anslaas til omtrent 1150 m (Firnen naar betydeligt højere); da man nu paa det Fjæld, der ligger Sydvest for Ilimausak (mellem denne og Søen Tasek), har en meget anselig Flade i ca. 1100 m Højde, en Flade der den 19. Aug. fra Toppen af Steenstrup's-Fjæld saas at være saa godt

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[1]) Meddelelser om Grønland XVI, 1896, p. 93, 163.

som snebar, vil man næppe kunne ansætte Snegrænsen i disse Egne lavere end til 1100 à 1150 m o. H.; paa Skraaninger, hvor Sollyset falder svagere, eller hvor der endog delvis er Skygge, kan Sneen naturligvis holde sig Sommeren over i langt ringere Højde.

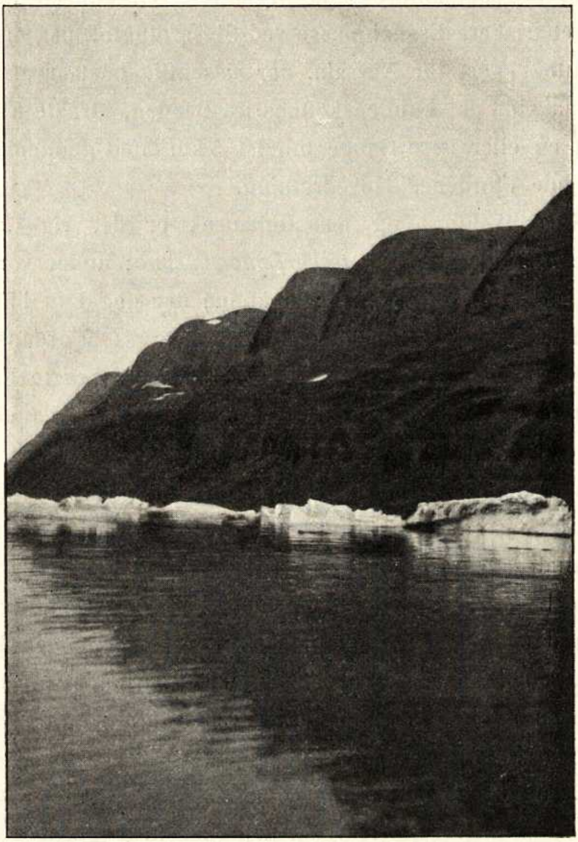

Fig. 10. Ilimausak-Plateauets Affald mod Sermilik-Fjord, set vestfra. Billedet viser omtrent vandrette Bænke, foroven af Diabas og Porfyr, forneden af rød Sandsten. Mellem de bastionagtige Fremspring ligger de tre Botner med Gletschere. (Fot. 17. August 1900).

Ilimausak-Firnen giver Næring til mindst 5 Gletschere. Den største af disse, den tidligere omtalte Narsak-Gletscher (Tav. XIII,

Fig. 1) gaar i vestsydvestlig Retning og skønnedes at være betydelig over en Kilometer i Længde. De øvrige blev ikke iagttagne paa nærmere Hold; én af dem gaar mod Sydøst og har Afløb gennem den Elv, der ved Tunuarmiut munder ud i Tunugdliarfik-Fjord, medens de tre øvrige gaar mod Nordvest ad Sermilik-Fjord til. Disse tre Gletschere naar saa langt nedefter som til 4—500 m o. H. Den vestligste af dem gaar tæt norden om Steenstrup's-Fjæld stejlt nedad som en sammenhængende Gletschertunge; de to andre er derimod ved næsten lodrette, flere hundrede Meter høje Bratninger skilte fra Firnplateauet og er saaledes «regenererede» Gletschere. Den østligste ernæres kun af Laviner fra Plateauranden. Den mellemste faar desuden Næring fra en lille Hængegletscher, som hænger et Par hundrede Meter ned fra Plateauranden; Hængegletscheren kalver i Luften, og den nedstyrtende Is falder først ned paa en Fjældafsats, hvor noget Is bliver liggende, og derfra styrter Gletscherlavinerne videre ned paa Hovedgletscheren i den lille Dalbund. Udseendet af denne mellemste Gletcher vil sandsynligvis paavirkes stærkt selv af smaa Forandringer i Gletscherstanden.

Alle Gletscherne paa Ilimausak har udskaaret sig regelmæssige Botner med halvkredsformede, for største Delen næsten lodrette Sidevægge og jævn, udadskraanende Bund. Foruden disse, endnu under Dannelse værende Botner findes der flere paa Sydsiden, som nu er gletschertomme (Side 403). Plateauet er saaledes fra alle Sider dybt indskaaret af Botner, af hvilke de fleste stadig udvides og rykker deres lodrette Indervægge længere og længere ind; geologisk talt kan den Tid næppe ligge fjernt, da Plateauet bliver helt gennemskaaret og forvandlet til et Alpelandskab med isolerede Fjældkamme og Tinder[1]).

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[1]) Plateauet syntes (set fra Steenstrup's-Fjæld) noget smallere, og Botnerne dybere indskaarne og stærkere fremtrædende, end det er vist paa det geologiske Kort (Tav. III), hvor disse ikke opmaalte topografiske Detailler kun er løst skitserede.

Udsigten fra Steenstrup's-Fjæld over dette gletscherindskaarne Ilimausak-Plateau gør et overvældende Indtryk ved sin vildt sønderrevne Karakter. Netop fordi en Del af de oprindelige Overfladeformer er bevaret i Plateauet, træder her de glaciale Erosionsfænomener Tilskueren i Møde med en Tydelighed, som er enestaaende i Syd-Grønland. Man har her ligesom Nøglen til Forstaaelsen af de vilde Alpelandskaber, der genfindes i Korok og i en stor Del af Landet Sydøst for Julianehaab, og som staar i en saa paafaldende Modsætning til de mere jævne og afrundede Bjærgformer, der behersker største Delen af det grønlandske Kystland. Det jævnede Bjærglandskab skyldes Indlandsisens Erosion i tidligere Tider, da den strakte sig længere ud; Alpelandskaberne skyldes lokale Nedisninger og er endnu under Dannelse i saadanne Egne, hvor Fjældstrækninger udenfor Indlandsisens nuværende Omraade rager op over Snelinien.

De yngre Dannelsers Nordgrænse i Sermilik-Fjord beror øjensynlig paa Tilstedeværelsen af et Spring i Jordskorpen, et Spring, langs hvilket Landet paa Sydsiden er sunket flere Tusind Meter i Forhold til det paa Nordsiden. Springet følger Fjordens Retning. Ved et tilsvarende Spring afgrænses den røde Sandstens Omraade mod Syd i Igaliko Egnen. Dannelsen af disse store Spring maa i det mindste for en Del føres tilbage til en Tid, da den eruptive Virksomhed endnu ikke havde forladt Egnen; thi den nærmere Undersøgelse viser, at nogle af Springene er ældre end eller samtidige med Dybbjærgarternes Fremtrængen; endvidere er Springenes Retning — omtrent Nordøst —Sydvest — den samme som Retningen af de talløse store Gange af Porfyrer og Diabaser, der gennemsætter næsten hele Egnen, og som ved Igaliko og Musartut er særlig smukt blottede.

Den samme nordøst—sydvestlige Hovedretning karakteriserer ogsaa det vigtigste Fjordsystem i hele Egnen. Derved opstaar naturlig det Spørgsmaal, om Fjorddannelsen mulig i nogen Grad er voldt ved Sænkninger langs Spring, og den her betragtede Egn er med sine store Variationer i Bjærgartbeskaffenheden særlig egnet til at belyse dette Spørgsmaal. Vi ser da ved nærmere Betragtning af det geologiske Kort, at der udover den nævnte Overensstemmelse i Hovedretning ikke er noget væsentligt Afhængighedsforhold mellem Fjordene og Springene: langs gennem Sermilik gaar et stort Spring; Kangerdluarsuk er paaviselig uden Spring i Længderetningen, og det samme er i det mindste overvejende sandsynligt for Igaliko-Fjords Vedkommende; Tunugdliarfik endelig har i sin midterste Del en kortere Strækning, hvor Sydkysten repræsenterer et Spring, men dette følger kun Fjorden paa en ca. 10 km lang Strækning og fortsætter sig til begge Sider ind over Land uden engang at følge noget udpræget Dalstrøg, medens Fjorden bortset fra den nævnte Strækning forløber ganske uafhængigt af Jordskorpeforskydninger. Tilbage bliver da kun Overensstemmelsen i Retning, og denne lader sig naturligt forklare saaledes, at Jordskorpen allerede paa den Tid, da de yngre Eruptiver dannedes, slog talrige Revner i omtrent nordøst—sydvestlig Retning; nogle af Revnerne fyldtes af Eruptivmasser og blev til Gange, nogle blev Sædet for Forskydninger, og alle kom de til at indvirke paa Erosionsfænomenerne, som lettest skrider frem langs Revner og Bjærgartgrænser.

Fjordene kan saaledes i deres første Anlæg mulig gaa meget langt tilbage i Tiden, og da Grønland har været hævet over Havet og haft mildt Klima under lange Tidsrum efter de her omtalte Bjærgarters Dannelse, kan Dalene efterhaanden være bleven udviklede til anselige Floddale, indtil Indlandsisen overtog Erosionsarbejdet og omformede Dalene til Fjorde. Som bekendt har Forholdet mellem Floderosionens og Iserosionens Betydning for Fjorddannelsen været et længe omstridt Spørgsmaal, og Diskussionen herom kan næppe regnes for afsluttet[1]; det synes mig, at man for de her behandlede Fjordes Vedkommende maa tilskrive Iserosionen den langt overvejende Rolle i de nuværende Fjorddales Tilvejebringelse. For dette taler især, at Fjordene

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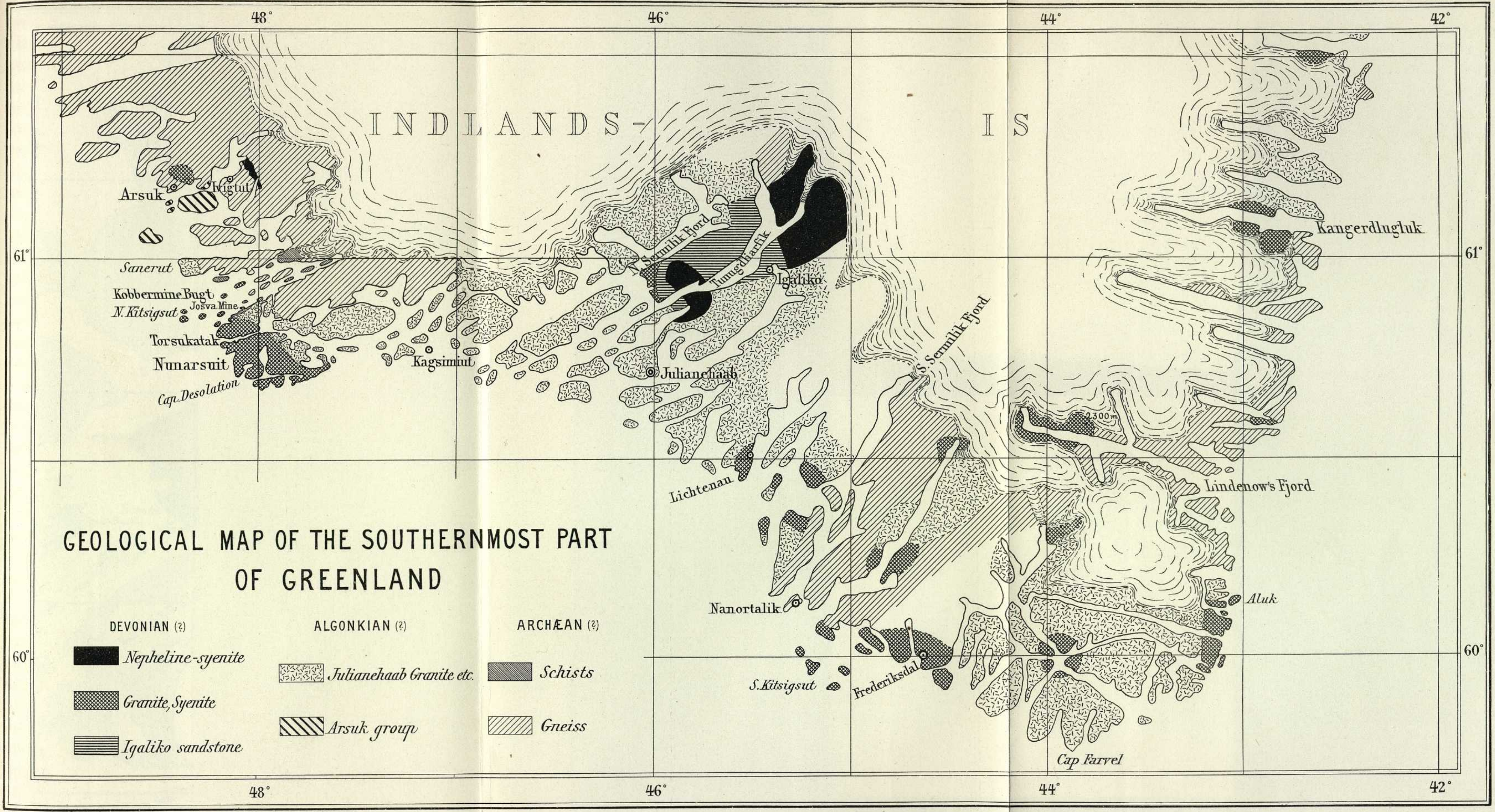
[1] Se bl. a. den betydningsfulde Behandling af dette Spørgsmaal af F. NANSEN (Norwegian North Polar Expedition, Vol. IV, 1904).

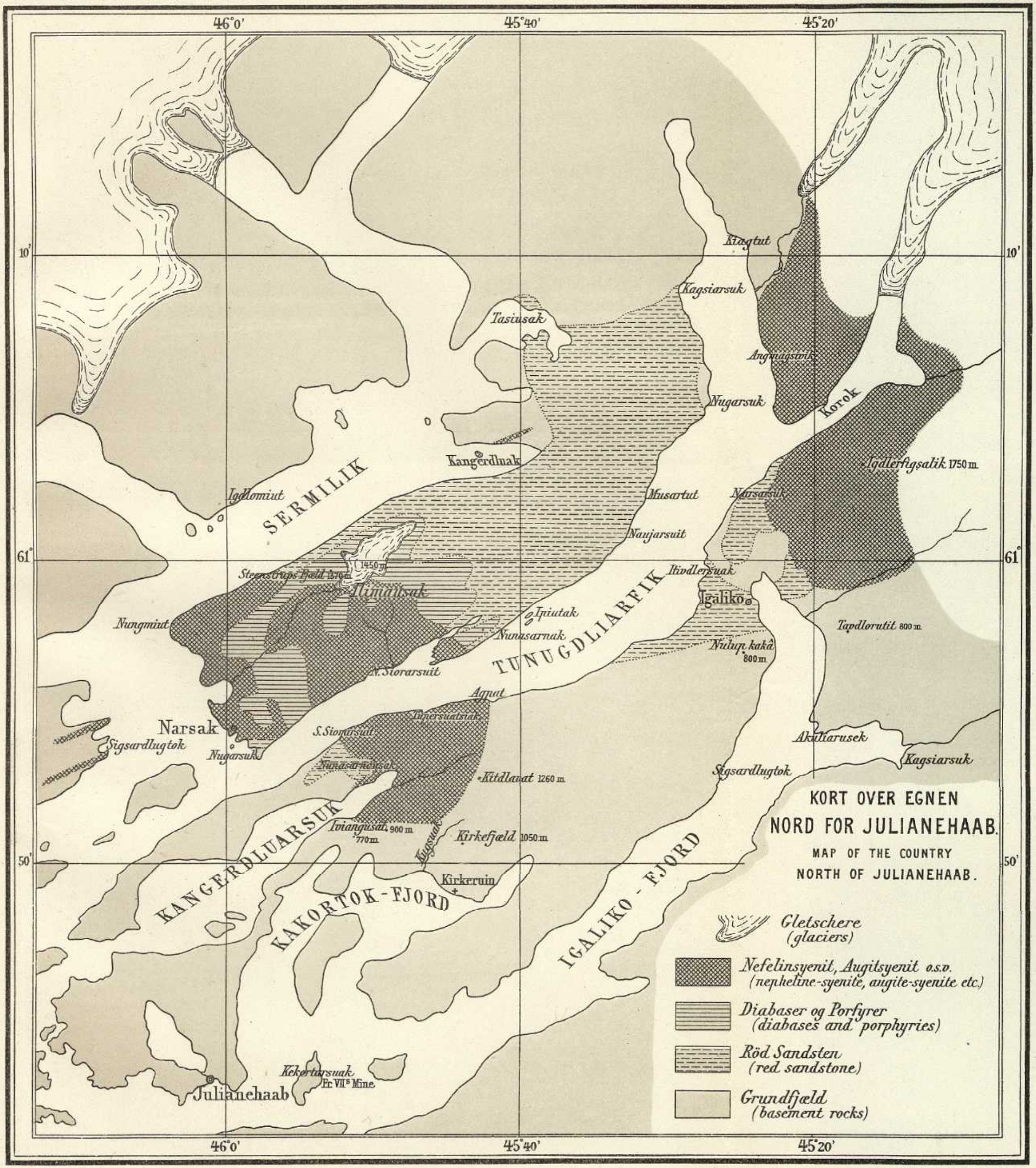
er saa talrige og tætliggende netop i den ydre Del af Egnen, medens Floddale maatte antages udefter at samle sig i færre og bredere Lavninger; endvidere synes en udpræget Fjord som Kangerdluarsuk, der udspringer paa en smal Halvø mellem to længere Fjorde, vanskelig at kunne tænkes udgravet af Vandet, der maatte finde naturligere Afløb gennem de store Nabolavninger.

Den 21. August tiltraadtes Tilbagerejsen fra Narsak. Regnvejr opholdt os tre Dage i Kagsimiut, saa at vi først den 28. om Aftenen naaede Ivigtut. I de følgende otte Dage, som for største Delen var regnfulde, gjordes forskellige supplerende Undersøgelser ved Kryolitbruddet samt en Tur til Bunden af Ika-Fjord, hvor vi formodede og ogsaa fandt Fortsættelsen af Grønne-Dals Nefelinsyenitmasse.

Den 6. September forlod Ekspeditionen Ivigtut om Bord paa «Fox II», der paa 19 Dage førte os til Kjøbenhavn.



GEOLOGICAL MAP OF THE SOUTHERNMOST PART OF GREENLAND



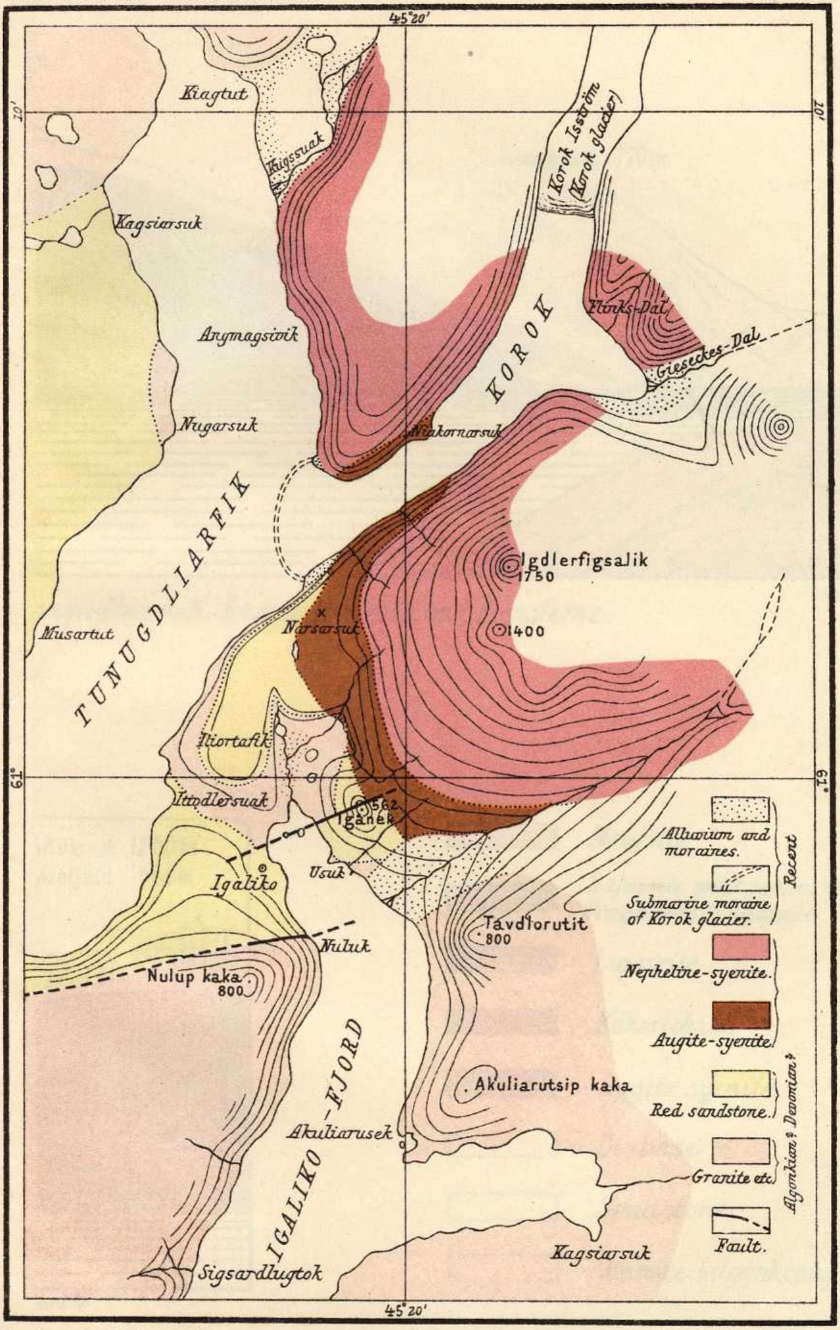
KORT OVER EGNEN
NORD FOR JULIANEHAAB.
MAP OF THE COUNTRY
NORTH OF JULIANEHAAB.

GEOLOGISK SKITSE AF ILIMAUSAK OMRAADET. — GEOLOGICAL SKETCH MAP OF THE ILIMAUSAK REGION.

N. V. USSING 1900 and 1908.

0 5 10 kilometers

*Contour interval 100 meters.*



Geologisk Skizze af Igaliko Omraadet. — Geological Sketch Map of the Igaliko Region.

N. V. USSING & O. BÖGGILD 1900.

0 5 10 Km.

Contour interval 100 meters.

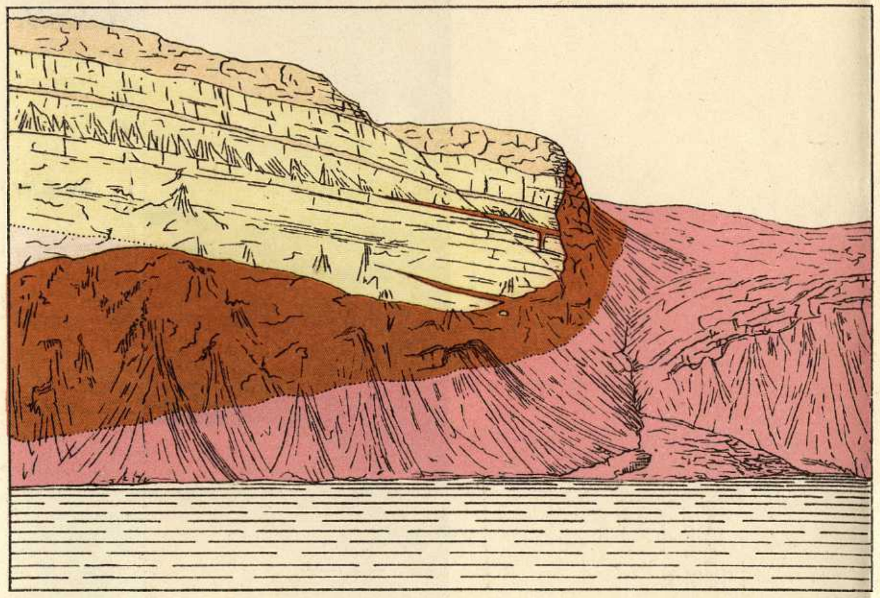


Fig. 1. North-side of Kangerdluarsuk. — Nunasarnausak (750 m) from S.E.

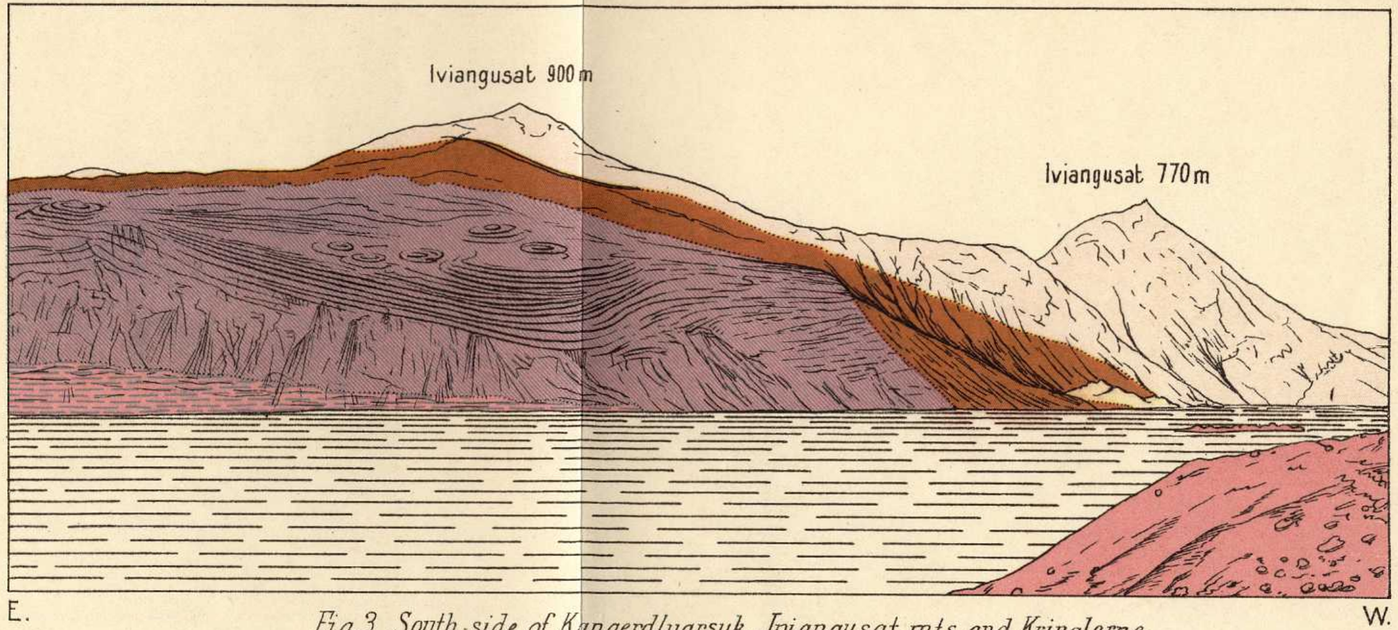


Fig. 3. South-side of Kangerdluarsuk. - Iviangusat mts. and Kringlerne.

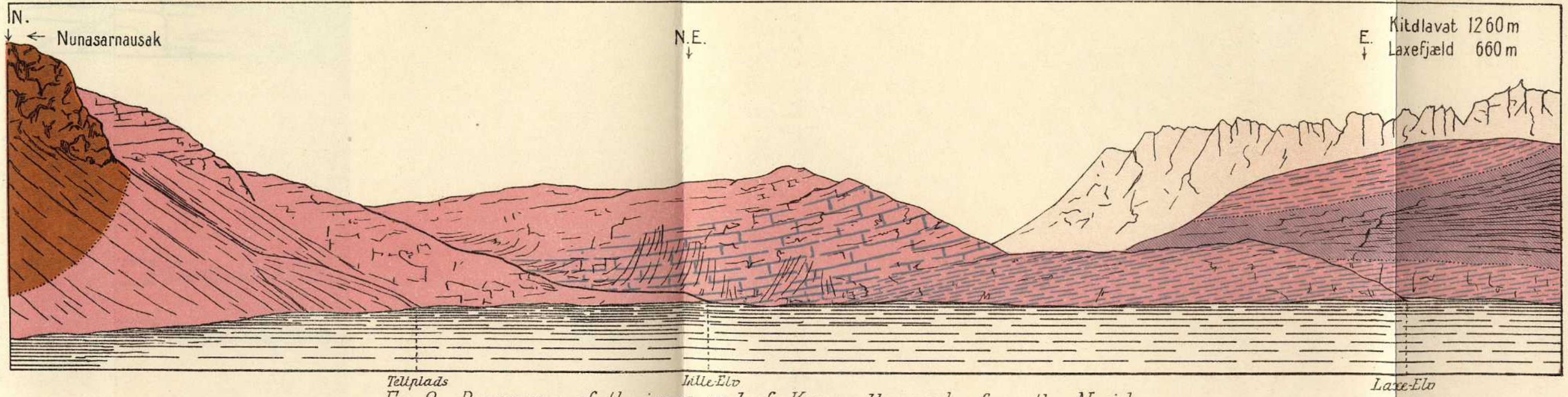


Fig. 2. Panorama of the inner end of Kangerdluarsuk, from the N-side.

▨ Naujaite

▨ Lujavrite with lenses and fragments of naujaite

▨ Lujavrite

▨ Kakortokite

▨ Augite-syenite

▨ Diabase

▨ Sandstone

▨ Granite (algonkian)

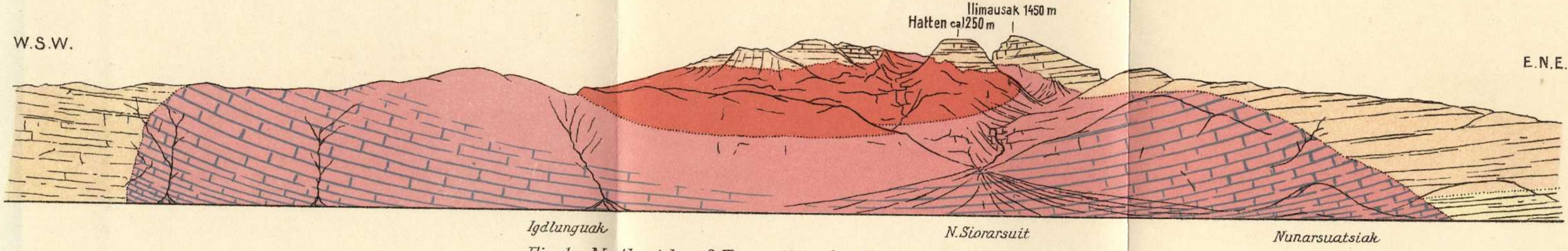


*Fig. 1. North-side of Tunugdliarfik-Fjord. (Scale about 1:40000)*

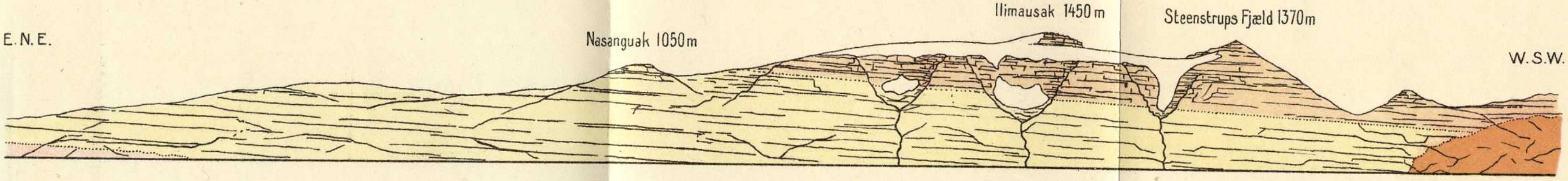


*Fig 2. South-side of Sermilik-Fjord. (Scale about 1:55 000)*

🟥 *Arfvedsonite-granite*

🟪 *Naujaite and sodalite-foyaite.*

▨ *Lujavrite with lenses and fragments of naujaite.*

🟧 *Nordmarkite.*

🟫 *Diabase and porphyry (sheets)*

🟨 *Red sandstone.*

⬜ *Granite (algonkian).*

Fig. 1. Kitdlavat Mountain (1460 m), seen from the West. The mountain is Algonkian granite. The plain in the foreground is rapidly decaying augite-syenite.

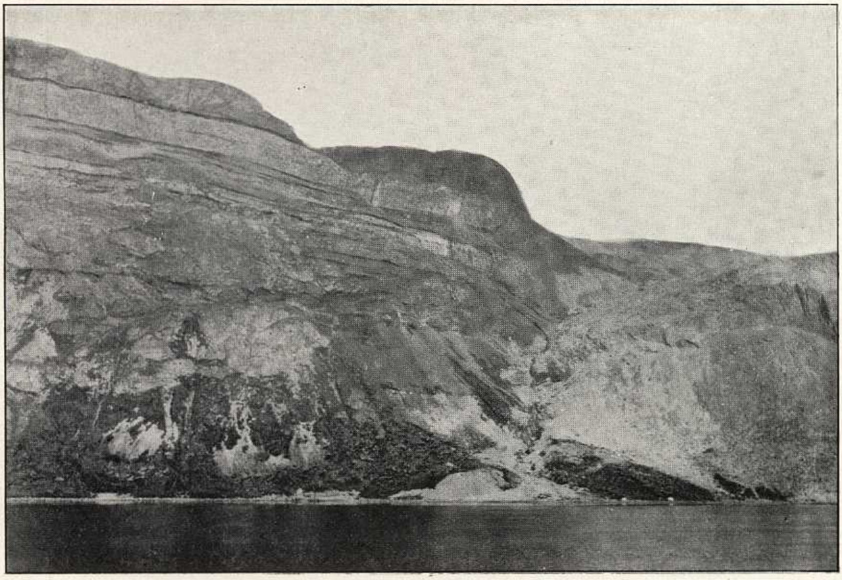


Fig. 2. Nunasarnausak Mountain (750 m), seen from Kangerdluarsuk. Sandstone with diabase sills on left, naujaite on right.

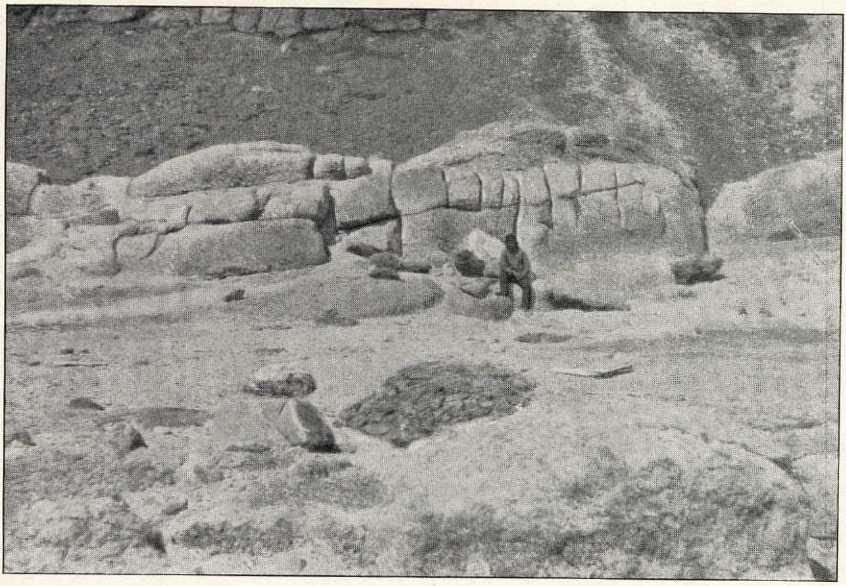


Fig. 1. Cliffs of naujaite. Kekertausak. Showing horizontal partings.

Fig. 2. Cliffs of naujaite. Kangerdluarsuk. Large screes downwards passing into stone rivers.

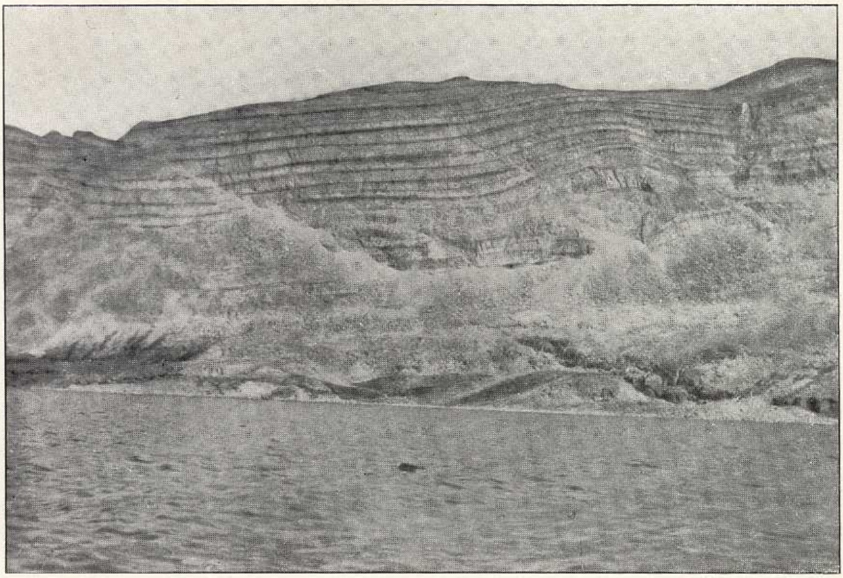


Fig. 1. Banded kakortokite. Kringlerne, Kangerdluarsuk.
The height of the escarpment is about 350 meters.

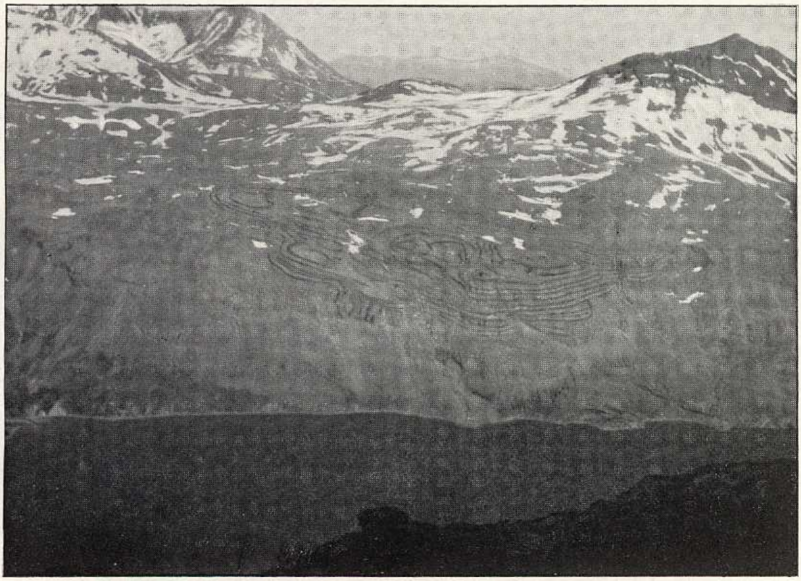


Fig. 2. Mountain plateau of Kringlerne, seen from the summit of Nunasarnausak. Note the banded structure of the kakortokite exposed below the snow covered areas. Phot. by G. Laub.

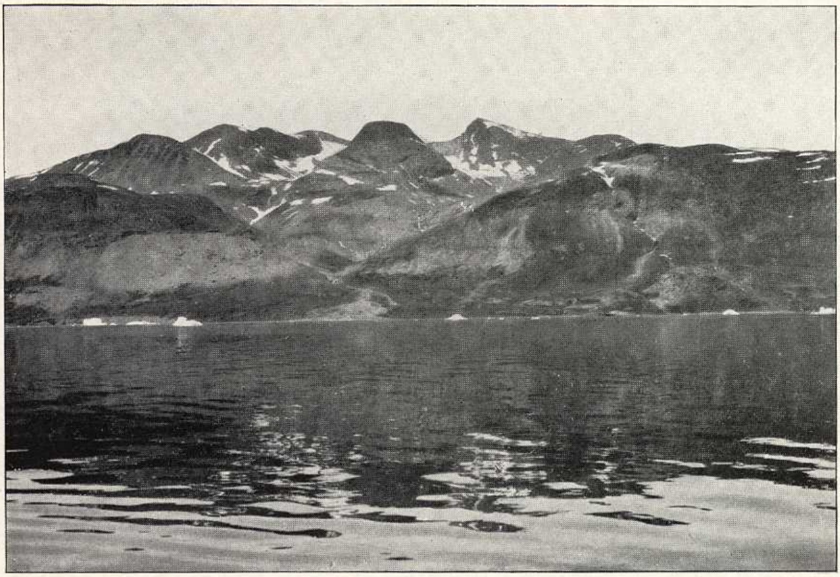


Fig. 1. North coast of Tunugdliarfik, Ilimausak Mountain (1450 m) in the rear. Showing remnants of the roof resting on the abyssal rocks (comp. Pl. VI, Fig. 1).

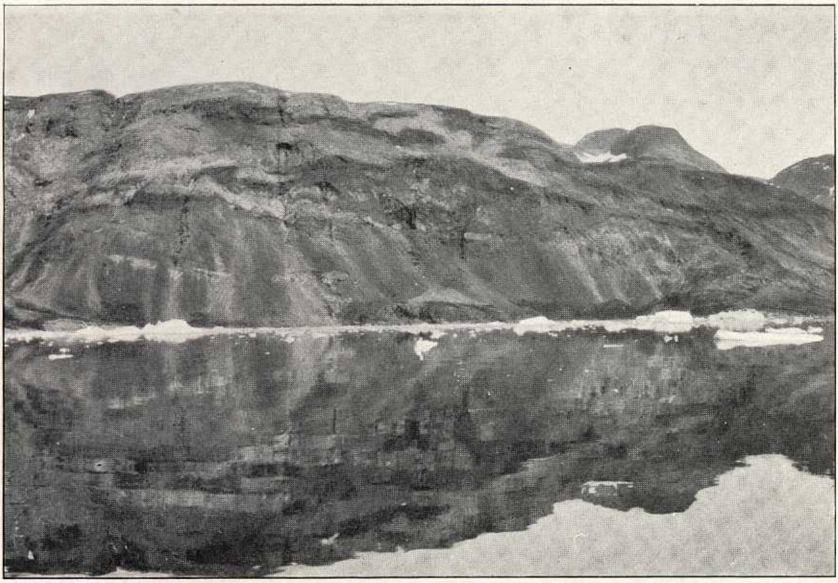


Fig. 2. North coast of Tunugdliarfik: Tugtup Agtakôrfia. Showing naujaite fragmants in dark-coloured lujavrite. Height about 750 meters.

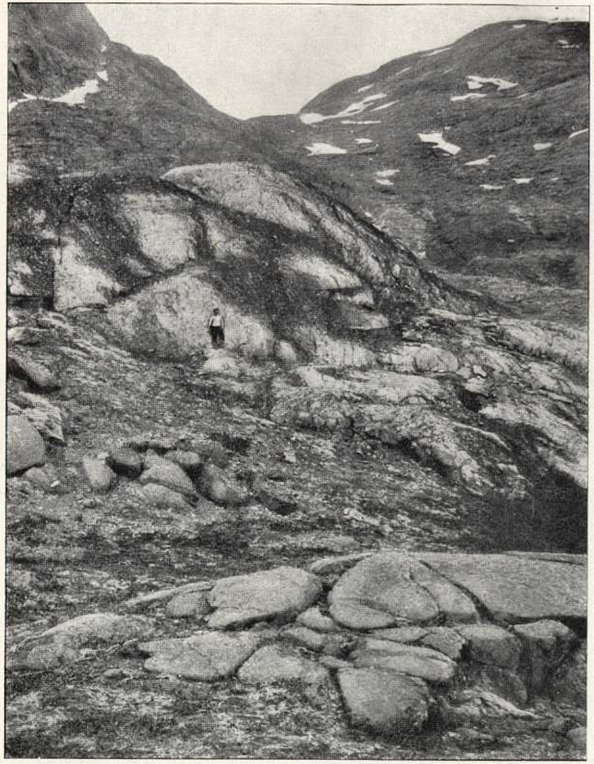


Fig. 1. Sandstone fragments in syenite. Iviangusat. The white sandstone cliff in the middle is entirely surrounded by augite-syenite.

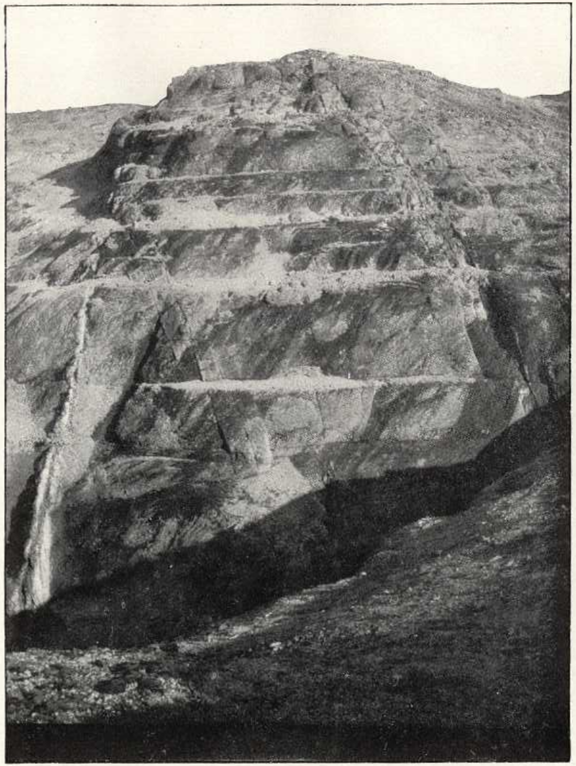
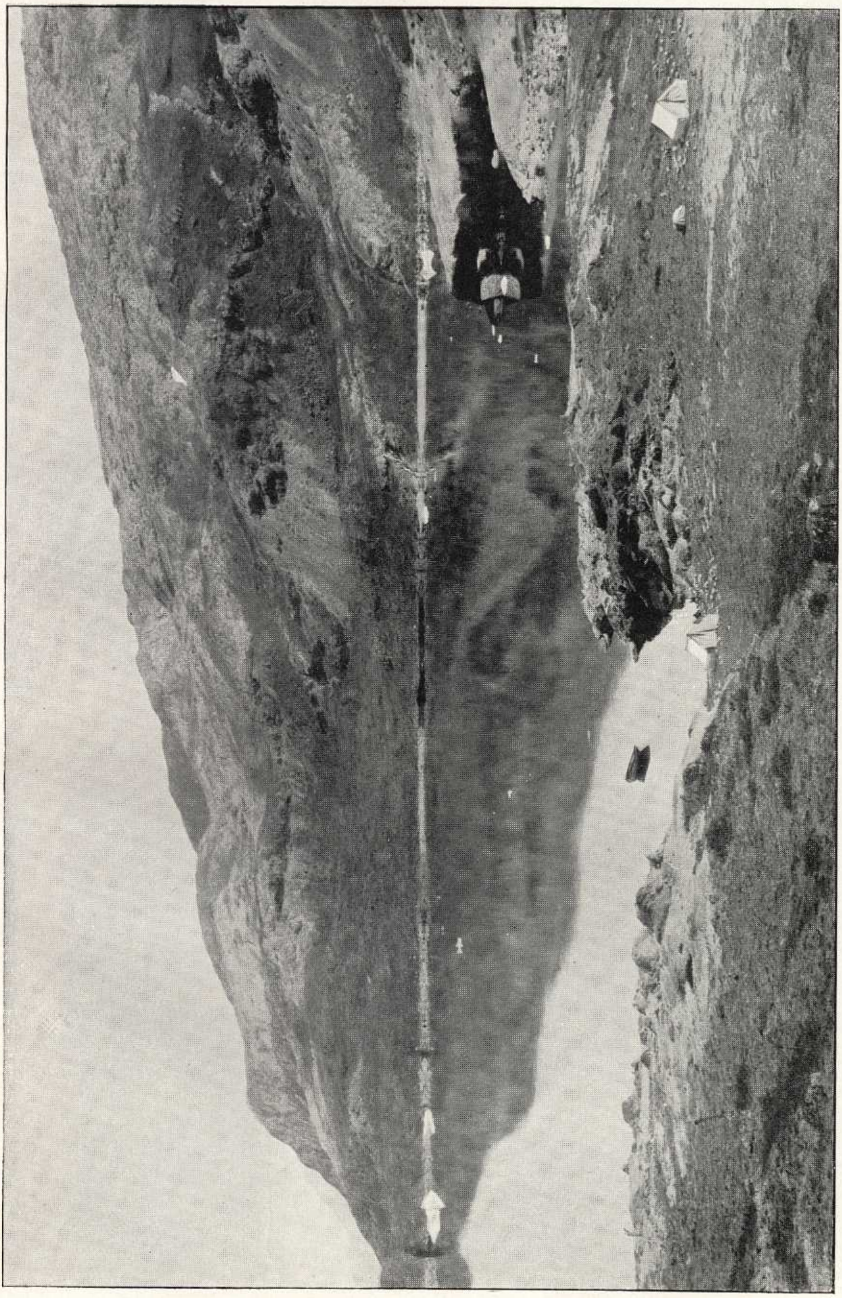


Fig. 2. Cliffs of naujaite, near Tupersuatsiak. Showing horizontal pegmatite veins. Phot. by K. J. V. Steenstrup.



Tupersuatsiak, Tunugdliarfik. Showing naujaite with veins of lujavrite.

Fig. 1. Narsak Glacier, from the West. Phot. Aug. 13., 1900.

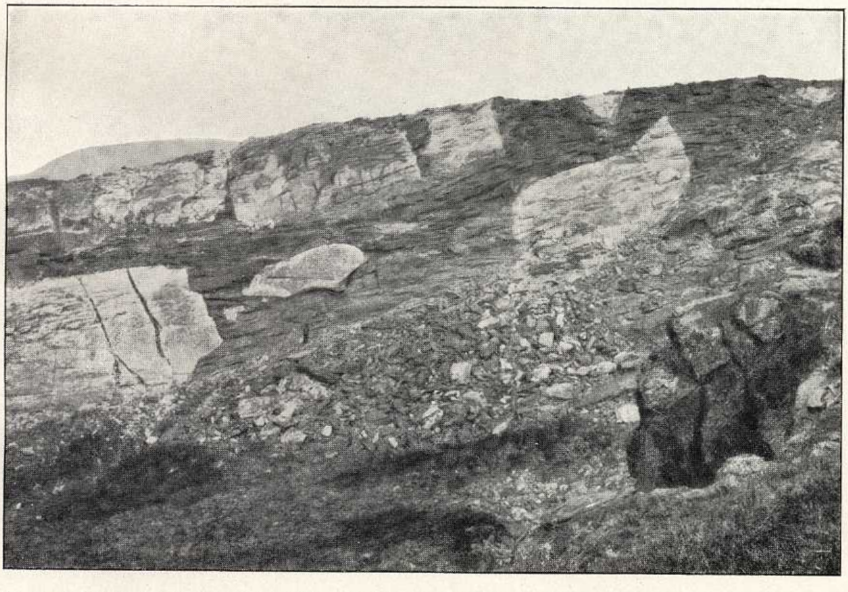
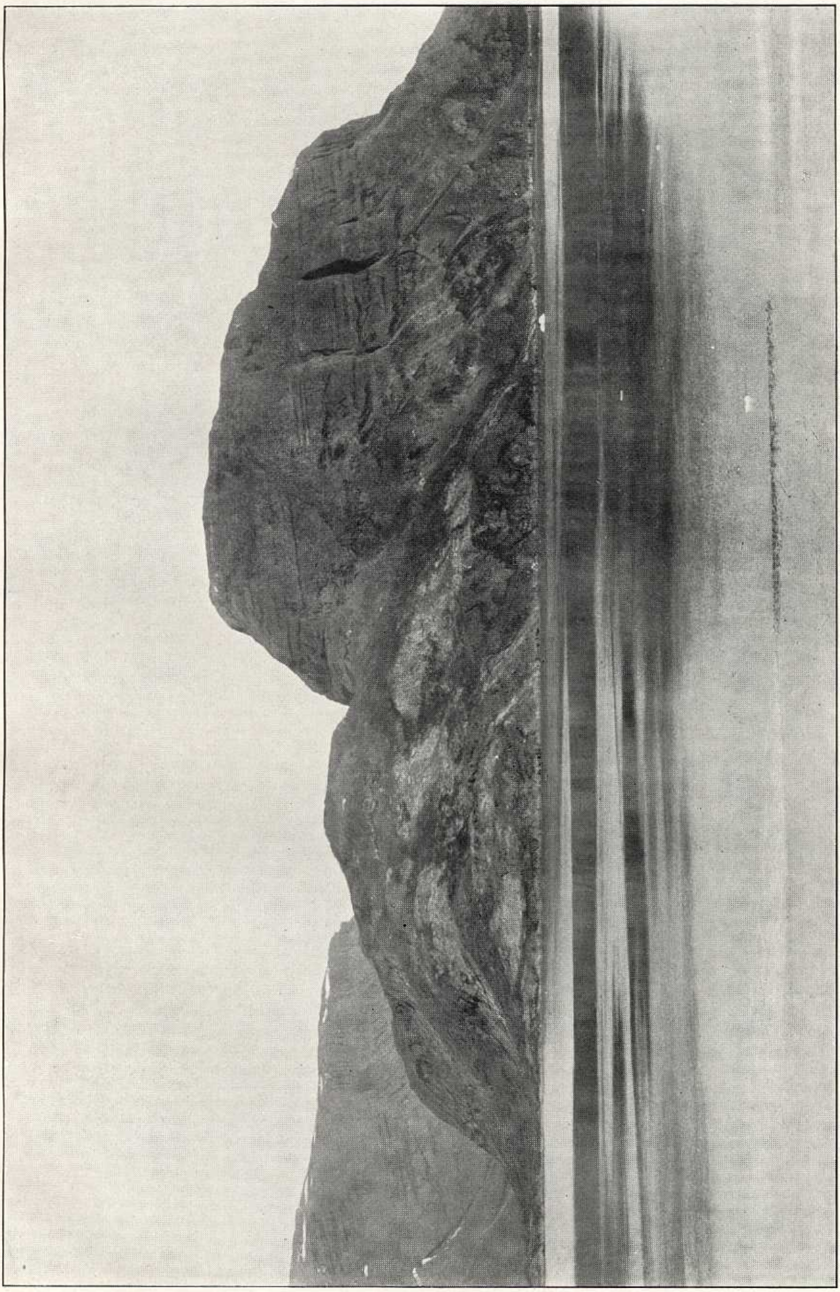


Fig. 2. Naujaite fragments in lujavrite. Near Tupersuatsiak. A person stands as a scale of measurement below the rounded naujaite block.



Nunasarnak Mountain (620 m), seen from Tupersuatsiak. The low mountain in the middle is lujavrite with naujaite lenses. To the right sandstone and diabase.

Environs of Nunarsuatsiak, seen from Tupersuatsiak. Showing junction of the naujaite (on left) with the volcanic series.

The mountain group of Igdlerfigsalik, seen from Tupersuatsiak. Distance about 35 kilometers.

Narsarsuk Plateau and Igdlerfigsalik Mountain (1750 m). The outcrops in the foreground are augite-syenite. Korok Fjord on left. Phot. by K. J. V. Steenstrup.

Surface of naujaite cliff. Showing poikilitic structure. Scale about 1:10.

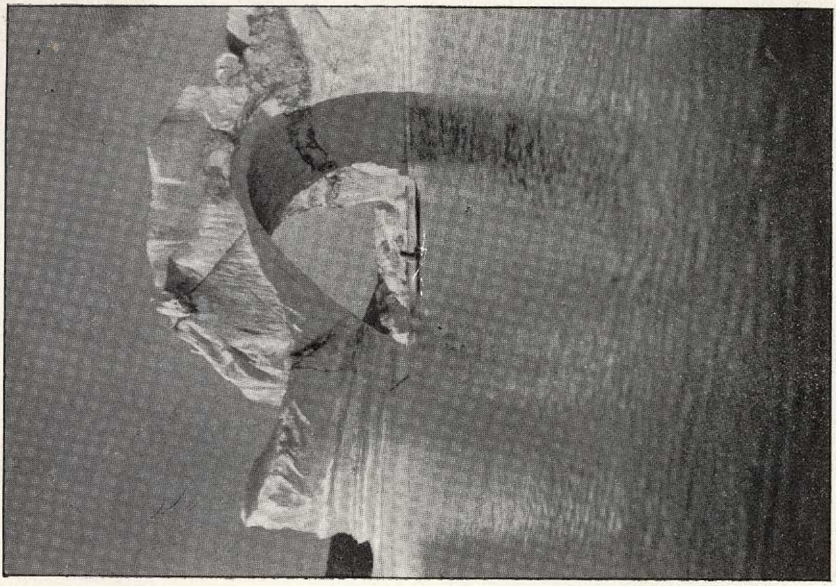


Fig. 2. Isbjærg udenfor Narsak.
21. Aug. 1900.

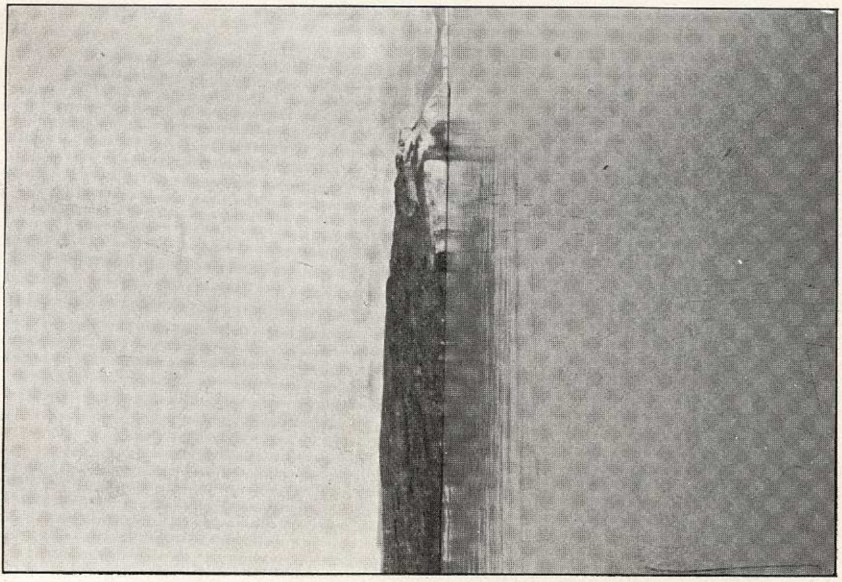


Fig. 1. Morænedækket Isbjærg.
Sermilik Fjord. 17. Aug. 1900.