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UNDER LEDELSE AF LAUGE KOCH

GEOLOGICAL INVESTIGATIONS IN
SOUTHERN GREENLAND

PART I.

ON THE STRUCTURAL DIVISIONS OF
SOUTHERN GREENLAND

BY

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WITH 70 FIGURES IN THE TEXT AND 7 PLATES

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I. PREVIOUS INVESTIGATIONS AND INTRODUCTION

The geological investigation of West Greenland was initiated in the years 1806—13 by GIESECKE's thorough-going explorations (GIESECKE 1910). He visited the southern parts of the country twice, viz. in 1806 and 1809. His journeys must be regarded as one of the outstanding scientific exploits of the last century, especially if it is taken into account that they were carried out by a single man under very difficult circumstances. On travelling with his diary in one's hand, one is again and again astounded at his great powers of observation and his ability to describe his observations by means of the very primitive terminology then at his disposal. Even at the present day his book is the only written source of information of some areas which have not later been visited by any geologist.

His main object was a mineralogical and petrographical investigation. He was the first, and the only investigator, who ever tried to gain a broad areal view of the crystalline regions of West Greenland. Thus he drew attention to a number of special mineral deposits which have subsequently attracted more and more interest.

If we are to outline in broad features the development of our knowledge of the geology of South Greenland, two main lines can be traced: one is mostly a mineralogic-petrographical line, while the other concerns the structure of the country and its evolution. Both branches of knowledge to some extent developed independently of each other. Later they converged again, only to be finally separated for good, mineralogy in an ever-increasing degree losing contact with the structural aspect.

The mineralogical branch is characterised by names such as STEENSTRUP, KORNERUP, LORENZEN, FLINCK, USSING, and O. B. BØGGILD. Part of the development of mineralogical research is reflected in the names here enumerated. To begin with the investigators were much interested in the relation of the minerals to the locality in which they were found; subsequently a tendency to describe the crystals became more pronounced; and with the advance of chemistry the chemical com-

position was more closely studied (LORENZEN, 1881, 1893). Then mineralogy developed from a more descriptive into a genetic science. Thus TÖRNEBOHM and VRBA have supplied valuable petrographical descriptions. In Greenland STEENSTRUP had already attempted to apply broader points of view; but it was left for USSING to explain the history of the alkaline rocks on the basis of broadly planned mineralogical and petrographical investigations; he coupled the chemical development with the structure of the country, and for a limited area drew a general picture of an impressive character. His works have become classical, and are much quoted, especially in the petrographical literature.

The useful minerals found in southern Greenland and several attempts at mining them have given rise to economic-geological investigations (BALL, 1923). Later mineralogy pursued its own course, isolating itself more and more, and confining itself to describing mineral substances without supplying any contributions to the study of the conditions under which the minerals have developed in their natural surroundings.

The geological part of the investigation was carried out in connection with the physiographic survey of the country, in part on mapping expeditions. Much information of a geological nature is due to GRAAH, RINK, JENSEN, GARDE, BLOCH, MOLTKE, HOLM, and other explorers. Further contributions were supplied by the geologists who accompanied the mapping expeditions, as for instance KNUTSEN, EBERLIN, A. JESSEN, ØDUM, and BØGVAD. Special mention should be made of such journeys as had for their main object geological investigations, e. g. those of LAUBE, PINGEL, and STEENSTRUP. The latter was no doubt the highest authority on the geology of southern Greenland.

EBERLIN shows a distinct tendency to explain the structure of the country genetically, connecting it with the eruption of the igneous masses. On the other hand, he also suggests the influence of the material on the action of erosion. In 1896 A. JESSEN supplied a good summary of his own results and those of earlier explorers, which he also embodied in a map. With the ever-increasing attention given to glacial problems in Europe, and especially in Denmark, these phenomena, too, were more closely studied. The last contributions to the first-hand accounts was supplied by ØDUM (1927) and BØGVAD (1937); the former is a topographic-geological study of an interesting branch-valley of the Igaliko Fjord, which was made in connection with archæological investigations, thus following the tradition of STEENSTRUP.

In the second-hand accounts USSING's description of the alkaline rocks takes a very important place; it is quoted in the greater number of mineralogical and petrographical hand-books and text-books whose authors are mostly concerned with the petro-chemical aspect. It should

be mentioned here that in 1932 BACKLUND made a very interesting attempt at a new interpretation of USSING's observations which set forth fresh views on the *mise-en-place* of the masses.

The investigations of the alkaline massifs attracting the general attention, the geology of the crystalline basement of Southern Greenland was bound to fall into the background. As had previously been the case in other countries with a pre-Cambrian bed-rock, it comprised a large material, secured through the industrious work of geologists and collectors of minerals. But the compilation of the material had merely the character of a catalogue. It was in Finland, under the direction of J. J. SEDERHOLM, that the confusing multitude of disconnected descriptions first took the form of a general picture, arranging themselves into a system of actions and reactions. Through the introduction of the principle of actuality these ancient formations were rendered accessible to human intelligence. Even though this new organic view could not include in the general picture the material outside Fennoscandia, we look with admiration towards this first classical account from all the areas where the eye is still wearied by a number of disconnected facts.

This work indicated the lines of investigation and the objects of research in other pre-Cambrian areas, too. I mention it here, because I have tried to apply the principles which my beloved teacher and fatherly friend, J. J. SEDERHOLM, used at his time to reveal the great leading lines in the chaos of granites, gneisses, and other crystalline rocks which once constituted the bed-rock of Fennoscandia. I wish, therefore, to dedicate this work to his memory as a token of gratitude for all that he has taught me, which I could not but think of every day during my work in the field. I hope it will not be a conclusion, but a beginning.

That the geology of the pre-Cambrian basement of South Greenland is still at a disorganised state, and that an attempt at a tectonic investigation is justified, will no doubt be admitted by the majority of the geologists who have attempted to study its genesis. The state is best seen from the catalogue-like account which BØGGILD gives in his survey of the geology of Greenland (1917). Even as late as 1928 the same author characterised the investigations in the following words (BØGGILD 1928, p. 233): "It may be said of the Archean formations in Greenland generally that not in a single place have they been made subject to more exact investigations; as a rule, it has merely been noted what kinds of rocks were to be found in a certain place, whereas no attempt has been made to unravel the details of their manner of formation and genesis." However, without any new geological investigations having been published

in the meantime BØGGILD seems to have changed his mind, claiming in 1935, assisted by ten other persons (BØGGILD etc. 1935), that the earlier investigations have supplied the full explanation of the structure of the ancient shield. Hence we are anxiously looking forward to the publication of the new results which BØGGILD has gained through the study of the earlier literature. But although a summary may be expected from his hand, it may not be too assuming to publish here a survey which is based on personal observations in the field.

The only tectonic hypothesis I have been able to find in the literature which attempts to connect organically the Julianehaab district with the main tectonic lines of Greenland is that of LAUGE KOCH (1935), according to which the Caledonian folding zone in East Greenland should extend along the east coast, through the Julianehaab district, and onward to Newfoundland. Through this hypothetic connection South Greenland would become of unusual structural interest. The investigations made last summer have shown that many other problems, too, remain to be solved in South Greenland. It is therefore to be hoped that a more detailed investigation will be rendered possible.

The first reconnaissance of last summer has given a number of results which justifies a preliminary survey. It must, however, be borne in mind that the greater number of important localities could only be visited once on a journey covering the area from Arpagfik north of Arsuk to Frederiksdal. The investigations lasted from June 16 to September 10, 1936. Thus these results are merely preliminary.

I wish here to express my deep gratitude to Dr. LAUGE KOCH for having rendered this journey possible, for having helped me in many ways, and for having followed my investigations with the greatest interest. I further wish to thank the Administration of Greenland, more especially Director DAUGAARD-JENSEN and Mr. GALSTER, civil engineer, from whom I received much kind help. The Danish officials in Greenland, notably Mr. VEDEL, manager of the colony, and Dr. LAURENT-CHRISTENSEN at Julianehaab, Mr. HEDEMANN, manager of the colony of Nanortalik, Mr. JENSEN, manager at Arsuk, gave me the help and advice I needed. I have not forgotten the kindness and hospitality extended to me by Danes and Greenlanders wherever I went. I remember with pleasure the reception I found at Ivigtut, and take the opportunity to thank Mr. CORP, chief engineer, and his staff, as also Mr. FISCHER. For the successful course of the journey I am indebted to my assistant Mr. S. V. SØLVER, civil engineer. He and the motorman ADAM SØRENSEN from Nanortalik were my good companions during the whole journey; without their energetic assistance we should not have gone so far. Finally I wish to tender my cordial thanks to all those who have furthered these journeys and investigations ashore and at sea.

In the present brief survey I shall not treat all the localities visited, but only try to give a general view. I shall not enter into petrographic descriptions, but confine myself to such things as seem necessary for an understanding of the development. A fuller description with petrographic examinations accompanied by analyses I hope to be able to give in a more detailed work.

A first contribution to the sediment-petrography of the area and conditions connected therewith on the basis of the material collected in 1936 has been made by Dr. R. D. CROMMELIN (1937). I am much indebted to Dr. CROMMELIN for being allowed to see his manuscript.

II. CLASSIFICATION

GIESECKE laid the first foundation for the later chronological scheme. His fundamental classification into older and younger granites was adopted by the later authors and partially further developed, especially by EBERLIN, STEENSTRUP, and JESSEN. USSING chiefly confined himself to the field of the alkaline rocks, though he supplies an introductory scheme (1912, p. 9), which has passed into the literature:

Quaternary	Moraines and alluvium.
Devonian(?)	{ Plutonic rocks (granite, nepheline-syenite, etc.) and volcanic sheets.
	{ Red sandstone.
Algonkian(?)	{ Plutonic rocks (granite, diorite, etc.) Arsuk group.
Archaean	Gneisses and crystalline schists.

In a sketch-map (1912, Pl. 1) he compiles the works of previous authors, which works form the basis of further investigations.

USSING's classification attempts to include the rocks of southern Greenland in a more general system, which means a long distance correlation. Of his stratigraphical terms, however, Archaean and Algonkian are somewhat doubtful concepts. In this connection Archaean merely means "highly metamorphic crystalline rocks"; whereas Algonkian means "not highly metamorphosed rocks belonging to the pre-Cambrian". Thus it is no chronological classification but a petrographic classification according to the degree of metamorphism, which was previously very common for the crystalline parts of ancient mountain chains. However, this method of division was abandoned both in the Hercynian and the Caledonian mountain ranges. In pre-Cambrian geology, too, this principle of classification has been abandoned, under the influence of J. J. SEDERHOLM, to be replaced by

a classification on the basis of chronological formations. This classification subsequently led to a subdivision of the pre-Cambrian rocks according to orogeneses or orogenic cycles. The latter form the large time-units which correspond fairly well in function to the Caledonian, Hercynian, and Alpine cycles. But in contrast to the latter, which are usually determined by the known stratigraphical methods, the work in the pre-Cambrian cycles is somewhat more intricate.

Hence for some length of time, mainly in Finland, a number of methods have been adopted which may be developed further, and some of which will be mentioned below. They might be divided into heuristic, critical, and interpretative methods, according to the object of the geologist at work. However, since I hope within a not too distant future to treat the problem from this aspect, I prefer here to start from the relation between the conception of the orogenic cycle and the observations.

An orogenic zone is a section of the earth's crust which forms a unit of development, that is to say, an area which forms a unit of motion for a certain period. Before and after, certain pieces form parts of other units. The period during which they belong to the same unit of motion is termed the period of an orogenic cycle. This is, accordingly, a natural group of movements of different character through which a mountain range is built up. These movements leave marks of different kinds. It is these marks only which are now accessible to observation, usually only part of them being preserved. Our object is to reconstruct the movements from the traces left. These may be either a) of a structural or b) of a material kind.

All traces found over a certain area need not be contemporaneous and need not belong to the same unit. Traces of older units may be embedded in the younger ones. I shall here merely call attention to the Hercynian massifs of the Alps and similar ancient massifs within the Hercynian zones. It is important, therefore, to be able to distinguish the non-contemporaneous movements from each other and unite certain groups into a unit. The methods of this chronological differentiation are manifold; most of them will only lead to results when they are combined. On the basis of the nature of the traces the methods for the determination of units may be divided into several groups.

The structural determination of a unit is made by geometric-tectonic methods, by the demonstration of a uniform structural plan controlling the whole, as done for instance for the Carelides in East Finland. It is assumed that a uniform plan of structure must belong to one and the same structural period. It will be obvious that either the structural unit or the chronologic unit or other auxiliary data must be determined, if we are to unite areas situated far from each other

into one orogenic zone. We cannot combine such areas into a unit which are situated very far from each other and of which we only know that they are folded, without knowing the character of the folding or its age. This would seem obvious; still, it should be emphasized here, because the opposite opinion has recently been set forth from other quarters precisely in connection with questions relating to the geology of Greenland (BØGGILD, etc., 1935).

The material determination of a unit is made on the basis of the nature of the material; it may be a) sedimentary, b) eruptive, or c) metamorphic.

The sedimentary formations of an orogenic cycle are often full of minor unconformities, but are bounded by two major disconformities. Thus they are formed in the interval between two major breaks in the development, with which the minor unconformities can be correlated. Starting from the well-known development of the Alps, some special sediment-facies which have a distinct function in the genesis of the structure, such as flysch and molasse, have been employed for certain unit determinations. Recently BACKLUND has illustrated this view in several interesting works (1936, 1937).

The unit of the eruptive formations, again, may be determined by structural, stratigraphic, and petro-chemical methods. We may consider the unit of their related geometric forms, which is determined by tectonic methods. Usually they are more or less unconformable in relation to the wall-rocks, and may often be traced to an unconformity; this may be a major unconformity, or a minor unconformity which can be placed in a certain connection with a major unconformity. On these conditions J. J. SEDERHOLM founded his divisions according to granite generations and the method of the basic dykes.

The petro-chemical unit-determination assumes that rocks belonging to a certain chemical system belong to the same period. This view was recently pointed out by VON ECKERMANN (1937). However, like considerations on the basis of facies determinations, this method is not quite safe without the support of other methods, since the same facies and the same petro-chemical types may recur in different periods.

The metamorphic phenomena may comprise a whole series of different transformations. It is not always easy to unite the different metamorphic influences in one unit and separate them from other similar, older or younger, groups. A first approximation to a determination of age is given in the age of the original rock and the time when the metamorphic product first became a subject to erosion. A more detailed division is obtained by studying a) the product of the metamorphism, b) its nature, c) its development, d) its educt. For the time being we disregard what has also been termed "the causes of metamorphism".

The first point (a) is chiefly based on a mineralogic-petrographical investigation; in this different principles of division can be applied, as for instance GRUBENMANN-NIGGLI's depth zones, ESKOLA's mineral facies, etc. The unit-determination here takes place on the basis of certain petrographic associations.

The character of the metamorphism may be a mechanical transformation or a recrystallisation, or both may be combined in many different ways. It may take place with or without the exchange of material with the wall rock. An alternation of the different kinds of metamorphism, especially the relation between kinetic transformation and crystallisation, often permits a division of the whole development into episodes. This is especially important in areas in which time-marks are usually so sparse as in the metamorphic districts.

Finally, the original state of the rock must be determined. This alone allows of a reconstruction of the development of the mountain range. It also allows of a distinction between rocks belonging to the cycle itself and older rocks; for both are transformed, and phenomena may become quite similar to each other through metamorphic convergence. Hence it is of importance to elaborate methods by which it will be possible, even in highly metamorphic terrains, to distinguish between the different original rocks.

A classification based on the metamorphic products must therefore necessarily be very different from a presentment based on the original material of the metamorphism. A petrographic classification will lay the main stress on the former. During a certain period the view was held, for instance in Finland, that all mapping should comprise the mineral facies groups only, that is to say, it should be a classification based on the products. This should then be a classification purposely based on the degree of metamorphism. The division into Archaean and Algonkian in the south of Greenland must then be designated an unconscious division based on degrees of metamorphism. It takes the degree as its basis, but purports to be a division based on the age.

A classification based on orogenic cycles is founded both on the unit of the original material and on the unit of the conditions of metamorphism.

In the above some of the principles of classification applied in modern pre-Cambrian research have been briefly and incompletely explained. To most geologists studying these problems these lines will hardly be new. Moreover BACKLUND has set forth similar views in a paper just out (1937). That, nevertheless, it is necessary to go into details on this subject, is due to the fact that a group of persons have attempted to introduce a number of contrary principles into the geology of Greenland (BOGGILD, etc., 1935). The same persons have likewise

postulated the invariability of the classifications once adopted by earlier authors within the geology of Greenland.

Against this view it must be claimed that one day we shall have to attempt to adopt for the pre-Cambrian basement of Greenland, also, the working methods which have given good results in Fennoscandia. I hope I have now sufficiently justified my boldness in setting forth here a somewhat new classification, without running the risk of further infertile polemics.

Finally, against the contrary principles mentioned above I wish to add that geology is not the totality of available rocks and the events that have given rise to them, but it is merely our knowledge of them; and this knowledge changes, the total knowledge as well as the parts of it under the care of each of us.

Applying the principles set forth above, we may divide the rocks of southern Greenland into

- a) an old basement, and
- b) younger formations.

These two divisions are separated by a long period of erosion, and thus belong to very different periods. It will be shown below that the courses of events are not parallel, but that each of these periods forms a certain natural unit of very different character.

The basement consists of the remains of an ancient mountain chain. The old folds are comparatively well exposed in the region of Tasermiut Fjord, or the Ketils-Fjord of the ancient Icelanders. I therefore propose the name "the Ketilides" for this old mountain range. Thus the whole period during which the Ketilides developed constitutes a section of the development of South Greenland. As long as this period cannot be definitely paralleled with a better known time scale, for instance with Fennoscandia, I think it best to call it the Ketilidian period. It seems to me to be more convenient to work out a provisional chronological system which can be used for the pre-Cambrian of Greenland, than to prevent later progress by a premature long-distance correlation, fixed through its name. For such a division is not of a purely local nature; its area of applicability has a certain size. On considering the difficulties that have been, and still are, connected with the correlation of the formations in Sweden and Finland, one cannot seriously uphold designations such as "Archaean" and "Algonkian".

In the fjord districts of Julianehaab the so-called Igaliko sandstone rests on a surface which intersects unconformably the internal structure of the ancient basement. It is interstratified with, and overlain by, large volcanic masses. The upper part of it was called the por-

phyry-formation by earlier authors. The Igaliko sandstone, the porphyry-formation, and a number of other formations, which will be described at greater length below, belong to the same cycle. After the old name of Igaliko, the bishopric Gardar of the old Icelandic authors, this cycle may be called the Gardar Formation. It has a far wider distribution than the Igaliko sandstone, extending over the whole of southern Greenland.

Thus the development may be divided into two periods, each with its great monument left to us, viz.

- a) the Ketilides,
- b) the Gardar Formation.

III. THE KETILIDES

Of the edifice of the Ketilides in southern Greenland only remnants remain, so it is no easy matter to reconstruct the mountain range. In the first place a large part has been removed by erosion even before the deposition of the Gardar Formation. Secondly, only a belt is left, which is bounded on one side by the sea, on the other by the inland ice. Thirdly, so far only the area between the Arsuk district and Frederiksdal is known fairly well (but not in detail); thus it is merely a limited section of it that is accessible and can be treated here. Whether it happens to be a characteristic section, is not yet known.

The original formations are so highly transformed over vast areas as to be almost unrecognisable.

This must be borne in mind in judging the present account. It is therefore not possible, either, to give a definite opinion on certain relations; many solutions are still ambiguous. In the interpretation of the observations it is of importance, in this more than in many other cases, to keep many possibilities open, and to work on the principle of the multiple working hypothesis.

The basement may be divided according to the area of occurrence of the different rocks. In this way about the same districts would be obtained as were stated by A. JESSEN (1896), viz. from south to north:

- 1) the southern granite area, comprising mainly the archipelago at Cape Farewell, characterised by gneisses and granites rich in garnets, to the north passing into
- 2) the gneiss area of Tasermiut and S. Sermilik Fjord, probably extending right across to the east coast, and characterised by the occurrence of more or less strongly metamorphosed sedimentary and volcanic rocks;

- 3) the area of the so-called Julianehaab granite, which extends from S. Sermilik to Kobbermine Bay; it is characterised by the Julianehaab granite;
- 4) the area from Kobbermine Bay to Arsuk, characterised by several zones of the so-called Arsuk Formation, in which basic volcanic rocks are especially conspicuous;
- 5) the area north of Arsuk, which contains both Julianehaab granites and the accompanying migmatites.

However, such a mainly geographic survey does not tell us very much about the structural conditions. Moreover, all the rocks mentioned pass into each other, and each of them is found in all the other districts also.

If we regard the mountain range as a unit of development, we may divide the rocks on the basis of their relation to this unit. Such a division is in itself an interpretation, and accordingly no longer purely descriptive. However, such a procedure seems best suited for this preliminary account. And in addition it may show, both through its positive and its negative aspects, which lines should be followed in future investigations.

Hence I shall first describe the building materials of the mountain range and their genesis, and subsequently the metamorphoses of the material. Finally an attempt will be made to give a brief summary of the development and position of the Ketilides. We distinguish primarily between

- a) the old material of the mountain range, i. e. fragments of older ranges which have been included again in the new belt of kinetic transformation;
- b) the younger material, i. e. the material which has been deposited on the old foundation during the first part of the orogenic cycle; it may consist both of sediments and of volcanic rocks.

The old material is highly metamorphosed, so it will be mentioned below after the account of the fresh material and its structure.

1. The younger material of the Ketilides.

Within the area investigated nothing of the younger material of the mountain range was found to be entirely unmetamorphosed. However, there exist two areas in which it is easier to reconstruct the pre-metamorphic state, i. e. where the supracrustal rocks have been metamorphosed to a less extent. One of these areas is situated between Kobbermine Bay and Arsuk, the other in the district round S. Sermilik and Tasermiut Fjord. From these districts the series can be traced to

areas in which they are more highly metamorphosed. The whole series of fresh material may be divided into two groups:

- a) the Sermilik group,
- b) the Arsuk group.

a. The Sermilik group.

This group occurs in its more easily recognisable form round the fjords S. Sermilik and Tasermiut and southward from these fjords. It comprises the islands Angmalortok, Amitsok, and the archipelago at Nanortalik, and from this place the coastal region as far as the edge of the Frederiksdal massif. It is typical in the mountain sides which rise steeply from the strandflat of Iglokasik (pl. 2, fig. 1). According to EBERLIN (1889) granitic gneisses occur at the east coast of Greenland, too, at Lindenow Fjord and northward to Kangerdluk; hence the Sermilik series may be assumed to extend across southern Greenland.

As far as it has hitherto been possible to observe the rocks, they were to a great extent metamorphic. They are mostly gneisses, tending partly towards micaschist, partly towards quartzites. Various types of amphibolites often occur.

The gneisses may contain biotite, garnets, graphite, cordierite, andalusite, staurolite, disthene, and sillimannite. So far several of these minerals have but rarely been met with. In several places highly graphitic strata are found which usually contain a number of pyrites also. On weathering the latter lend to the rock a deep rusty-red colour, visible from a long distance. These beds may thus be used as guide-horizons during the more detailed unravelment of the structure of the folds. The graphite was worked at the south point of the island Amitsok.

The whole complex is in great part made up of pelitic and psammitic sediments, which often alternate in very thin beds. In Fennoscandia this manifold alternation has been termed varves; recently BACKLUND has proposed the more neutral term "cyklothem" (1937).

Provisionally the group may be divided into a lower Nanortalik division, which is comparatively rich in quartz and highly metamorphic, containing minerals which are characteristic of highly metamorphosed sediments (fig. 1). Above these there follows a darker, more slaty division with pyrites and graphitic shales, which, again, are overlain by a more light-coloured division. The whole series terminates in thick beds of dark amphibolites, which must be referred to the upper group, the so-called Arsuk group. Future investigations must show whether this provisional division can be followed up further.

In the southern area no limestone beds have hitherto been found in this immense series. Calciferous beds are, however, found in several places at Angmalortok and Sermersok, which shows that probably beds

richer in lime once occurred here, but that they have now been almost completely converted into silicates. They are at any rate present in such small quantities that they cannot be said to be characteristic of the series. Either conditions have not permitted a precipitation of lime on a large scale, or it has constantly been overshadowed by the supply of pelitic and psammitic material. The whole facies conveys the impression

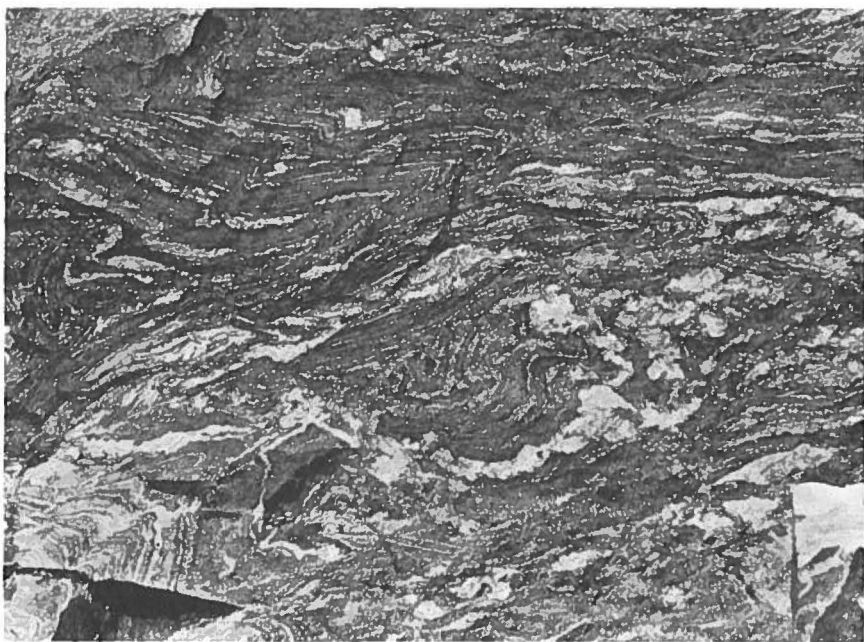


Fig. 1. Folded gneisses of the Nanortalik division near the harbour of Nanortalik¹⁾.

of having been deposited in a geosyncline over a comparatively short period.

In the northern area the huge greenstone beds of the Arsuk group are underlain in several places by a series mainly composed of sediments in part but slightly metamorphosed. They are well developed between Weber's Harbour and Taylor's Harbour, on the mainland behind Arsuk Island. From this point they extend to the northeastern part of Arsuk Island and on both sides of the sound Ikerasak and farther west along the north coast of Arsuk Island. They are well exposed in the northeastern part of Arsuk Storø (fig. 2).

In the vicinity of Taylor's Harbour (pl. 3) the following section is found, in ascending order: strongly kinetically transformed migmatitic gneisses; thick beds of white quartzites, mostly not much transformed

¹⁾ All the photographs and sketches from nature, with the exception of fig. 14, have been executed by the author.

internally but with zones of breccia; gneissic schists, much crumbled and folded, with a dolomite horizon, which is *boudinée* and partially converted into actinolite; the latter are overlain by dark schists with pyrites, graphite pigment, and layers of quartzitic slabs. At the transition

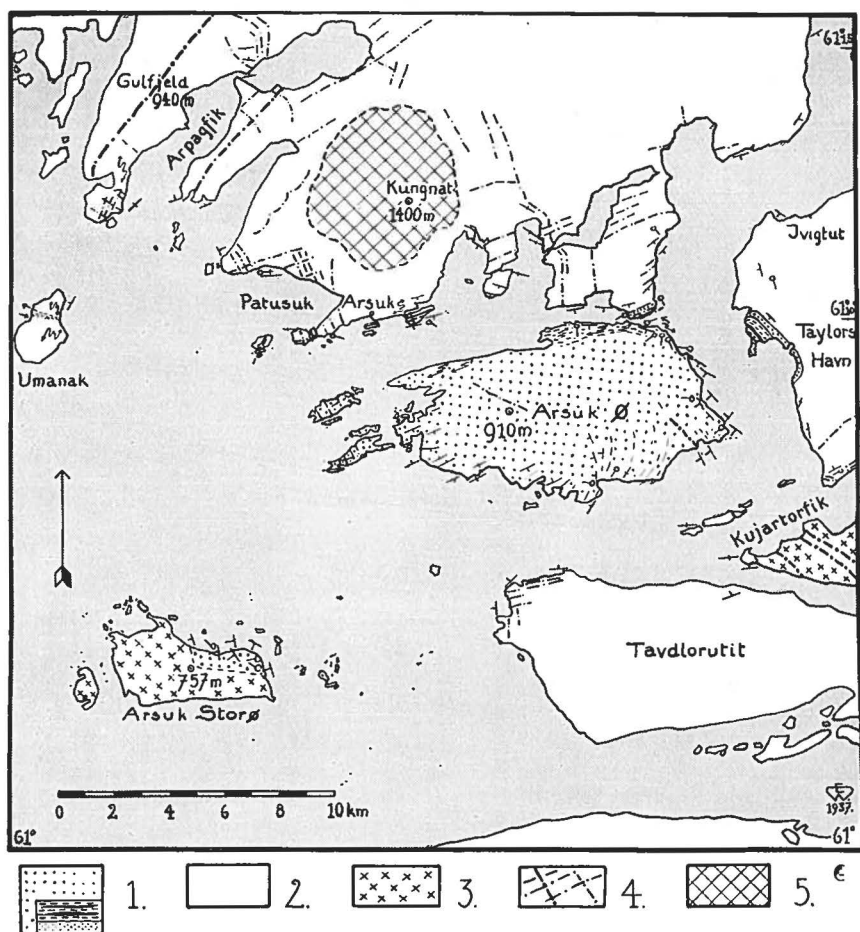


Fig. 2. Sketch map of the Arsuks area. 1) Ketilidian groups (partly undivided); at the base, the Sermilik group with quartzites, schists, dolomitic and limestone beds; above, the Arsuks group, chiefly volcanic beds; 2) Migmatites; 3) Granite of the younger Julianehaab generation; 4) Systems of basic dykes of the Gardar Formation (only schematical); 5) Kungnat granite.

from the much transformed schists to the less metamorphic ones small grains of chloritoids and biotite are to be found in different beds. The dark schists, again, contain a carbonate horizon. All pliable horizons are much transformed, and the measurable thickness cannot, therefore, give a correct picture. It is a little over 1000 m from the lower boundary of



Fig. 3. Folded dolomitic limestone on the northern shore of Arsuk Island; pitch to the south below the Arsuk group.

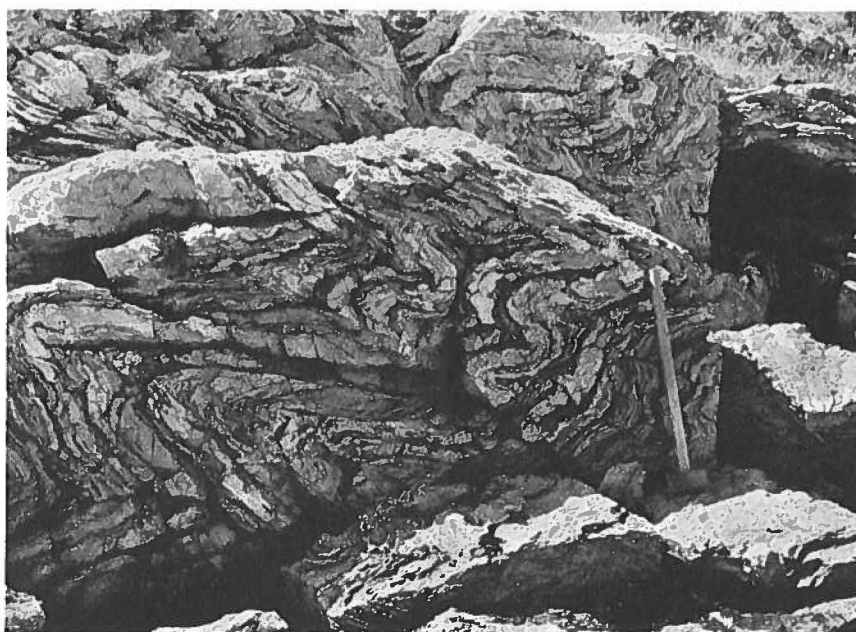


Fig. 4. Folded and migmatized limestone on the northern shore of the sound of Ikerasak; the axes strike ENE—WSW.

the quartzites, but varies somewhat. The carbonatic rocks occupy some few metres, at the most; they are *boudinées* and folded and not of constant thickness.

Almost the same series is found again at the sound Ikerasak, at the northeastern corner of Arsuk Island; at the sound itself the metamorphism has spread higher up, the rocks adjoining the lower carbonatic rocks being more transformed (figs. 3, 4). However, here, too, the car-



Fig. 5. Layers of quartzitic slabs, slightly folded. North coast of Arsuk Storø.

bonates are present in small quantities as compared with the thickness of the series. They are only remarkable, because carbonatic rocks are absent over wide stretches of southern Greenland. The greater part of these sediments have probably originally been dolomitic. At the transformation they became in part richer in lime, the calcium carbonate recrystallising in more abundant quantities than the mixed calcium-magnesium-carbonate. It is a kind of metamorphic differentiation, well known from the Triassic dolomites of the Penninian Alps.

The schists rich in pyrites and graphite are of principal importance. They are much crumpled and folded. North of the sound the quartzites are already entirely surrounded by gneissified material. These lower, mostly white, quartzites should not be confused with the quartzites which occur higher up in the series, chiefly in the Arsuk series, and which are of a light-blue colour and a different character. Certain

mylonitic rocks, originating from the migmatites and occurring in the same zone, might also be mistaken for quartzites. Thus conditions are not quite simple, and we must await a detailed investigation before a fuller account can be given.

On Arsuk Storø the rocks are on the whole less transformed, so that it is possible to recognise several types which it is otherwise difficult to study on account of the intensive metamorphism. Layers of quartzitic

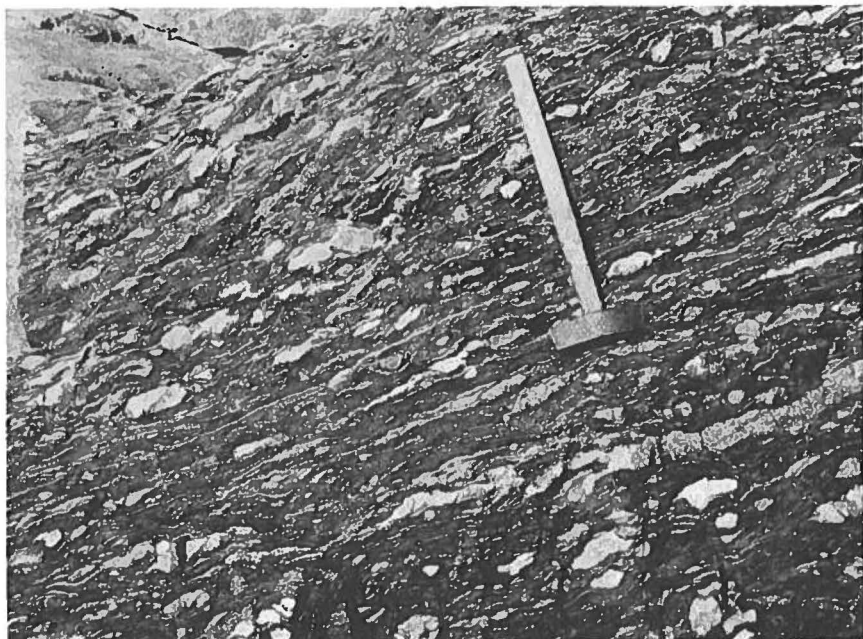


Fig. 6. The same as fig. 5, but rolled out and gneissified. Small island south of the southwestern cape of Sanerut.

slabs and quartz schists may, for instance, be observed there in their more original form (fig. 5). Usually they are much transformed, and if so resemble rolled-out conglomerates (fig. 6). In addition more kinetically transformed rocks occur, too. Very interesting, also, are the fine-grained pelitic sediments with traces of slidings, foldings, and crumplings, no doubt originating from the sedimentation period. They are unconformably overlain by finely stratified sediments. Such phenomena are often observable in the varved clay and other finely bedded sediments.

Pyritic schists and quartzites further occur in the western part of the island Midtluvfik (west of Arsuk Island); they are much folded, but not highly metamorphic. It is uncertain, however, whether they do not belong to the Arsuk group.

In the form of highly metamorphic gneisses the rocks of the Ser-

milik group are found in the north coast of Patusuk, continuing in a zone towards the east. At Ekaluit blocks of garnet gneiss which must be derived from this group were found within the Quaternary deposits.

The same series appears again at the south side of the island Sanerut. Here both schists (fig. 6), carbonates, and quartzitic rocks are found, but they are much more metamorphosed. The zone extends from the mouth of Kipisako Sound in the east to the southwestern point of Sanerut; it is easily accessible at Borgs Havn.

On the south side of Kobberrmine Bay between Karmak kaka and Josva Mine we find remnants of the same series. However, in both places they are much more metamorphic and in part more transformed, too, than in the Arsuk area. Some few rocks are also recognisable in a more highly metamorphic state and can therefore be traced farther on. Thus remnants of quartzites are found in the archipelago south of Nyeboe Canal and as inclusions in the younger granite round Helene Harbour on the north side of the island Nunarsuit. From this place the formation was not investigated in detail, but at many landing places remnants of this formation were constantly met with, thus at Aurora Harbour, in the Sarkamiut archipelago, in the Kagsimiut skerries, on the island Apokatak, and farther towards the interior of Brede Fjord. To the south, however, the traces of the Sermilik group are more difficult to discover, it being mostly entirely granitised. The traces grow more visible again in the Sardlok skerries, in Akugdlek Fjord, and in Lichtenau Fjord.

The special nature of the gneisses at Sardlok was already pointed out by A. JESSEN, who regarded them as a separate type (1896). However, part of them originate from the rocks of the Arsuk group. In the sand samples from Akugdlek Fjord R. D. CROMMELIN (1937) found garnets, which indicates that the gneisses are derived from the rocks of the Sermilik series. As pointed out by CROMMELIN, the sands have not come from very distant parts.

Already in the interior of Unartok Fjord the pyritic and graphitic schists are easily recognisable in the rock walls in which their complicated folds can be followed up.

In the southern area the part of the Sermilik series which is easily recognisable as such is very thick. It is much folded and crumpled, and the measureable thickness therefore in no way gives the actual thickness of the series before it was folded. So far no sections have been found where this minor crumpling is lacking. But when values ranging from two to three thousand metres are obtained, it must be assumed that the series is of a geosynclinal magnitude. For it is not the whole series; the deeper parts of it are more granitised, so that at present the boundary towards the substratum is not known.

It might be asked whether this boundary was not to be found at the lower surface of the huge beds of white quartzites in the Arsuk area, between Taylor's Harbour and Weber's Harbour; for it is a distinctly unconformable boundary. But the observations tend to show that this unconformity has resulted from an unconformable movement of the migmatites underlying the quartzites. In spite of all search, no basal conglomerate has been found so far; but it is quite possible that the quartzites rested almost without any transition on an older substratum, as for instance the quartzites of the Igaliko sandstone in the naze south of Narsak. As regards the substratum of the Sermilik series, this aspect of the question has not yet been solved. Some further considerations on another aspect of this substratum will be given below.

b. The Arsuk group.

The Arsuk group has long existed as a name, but its importance has never been fully discussed. On studying the earlier literature, one receives the impression that the Arsuk group is mainly distinguished from the surrounding gneisses and granite areas by its low degree of metamorphism. In the older literature the lower sedimentary part is included in the Arsuk group if not highly metamorphic. On the other hand, large occurrences of the Arsuk group were referred to the "Archean". Thus here, too, the classification was made on the basis of the degree of metamorphism and not from stratigraphic points of view. Hence it seems justifiable to say that as regards the Arsuk group, too, the old division cannot be maintained; it is moreover designated by BØGGILD (1935) and his adherents as a meaningless term, though neither he nor his collaborators have attempted to go more fully into the question; possibly further information and publication of their new results on the pre-Cambrian basement of Greenland may be expected.

If the old designation is to be retained, it may presumably be given a new, more stratigraphic content. I therefore propose to name the upper, almost purely volcanic series the Arsuk group. It has its largest continuous distribution on Arsuk Island and the surrounding smaller islands. There it is least metamorphic, and the original facies is therefore most easily studied there.

It would take us too far to enter here into a description of the many different formations; it will be done in the petrographic section. I shall merely mention some characteristic types which may supply some information of the genetic conditions of the group. For a large part of the greenstones have been transformed, and exhibit but few original features. On the other hand, both on Arsuk Island and on the islets west of it as far as Arsuk Storø a large number of fairly well preserved structures are found.

Among these structures pillow-lavas are widely distributed (fig. 7). The size of the pillows may vary from a decimeter to the size of a large bag. Often they exhibit zonal structures, the edges being mostly darker. In some of them the centre has burst, in others the crust is full of fissures. Some have been full of vesicles, whereas others are massive. Between the flows, agglomerates are found, partially with large fragments. On



Fig. 7. Pillow-lava, Arsuk group, Arsuk Storø.

Arsuk Island we may observe in places how the flows moved upon the substratum.

The cavities between the pillows are often filled with carbonate and quartz. They are frequently accompanied by epidote and chlorite. In the cracked pillows they may be found in the centres, too. The quartz often forms fully developed small crystals; further the epidote may occur in crystals with many faces. On transformation and further metamorphosis these small accumulations of carbonate form patches with a number of characteristic mineral associations; if we follow the development through all its stages, it is possible to recognise the nature of the original material even when highly metamorphosed.

Tuffs of different degrees of fineness occur, too. Several of the greenstones may be termed sills, and all transitions to microgabbro are found in them. In addition to less basic rocks there occur rocks which must be designated ultrabasic. They form in part talc and actinolite

rocks, in a more metamorphic form hornblendites. Many of these rocks further form sills in the underlying Sermilik group. It is, therefore, not always easy to give the definite boundary, especially in certain parts of Arsuk Island, where sills are of very frequent occurrence.

On Arsuk Storø the finely bedded sediments of the north coast are overlain by formations which must be interpreted as fanglomerates. They



Fig. 8. Greenstones with aplitic veinlets and migmatitisation; southern shore of Kobberrmine Bay, northeast of Josva Mine.

are overlain by tuffs, on top of which pillow lava extends. Small beds of fine-grained light-blue quartzites are often found between the beds of pillow lava, also on Arsuk Island. In places even cross-bedding may be observed in the quartzites and hence we are sure they are not directly volcanic deposition products. Future investigations must show whether they were transported there by water, or have been carried there by the wind from remote regions. In addition highly pyritic brown schists occur, reminiscent of similar formations in the Bymark formation of the Trondhjem region (CARSTENS 1920). Much reminds us of this formation. On the other hand there are many features similar to those of the large greenstone formation of the Sveco-Fennides as known from Pelling (SEDERHOLM 1923) and from the eastern skerries of Helsingfors (KRANCK 1931, WEGMANN 1931). Notably our knowledge of the latter formation greatly facilitates the understanding of the different modes of occurrence of the Arsuk formation, and renders it possible to follow it up through

its various metamorphic facies. Both north and south of the Arsuk area there are a number of deposits in which the rocks of the Arsuk formation are distinctly recognisable.

North of the Arsuk area traces are found on Kajartalik, on Arsuk's Umanak, and in several places in the northern wall of Arpagfik Fjord. The latter consist of the metamorphosed products of pillow-lava.

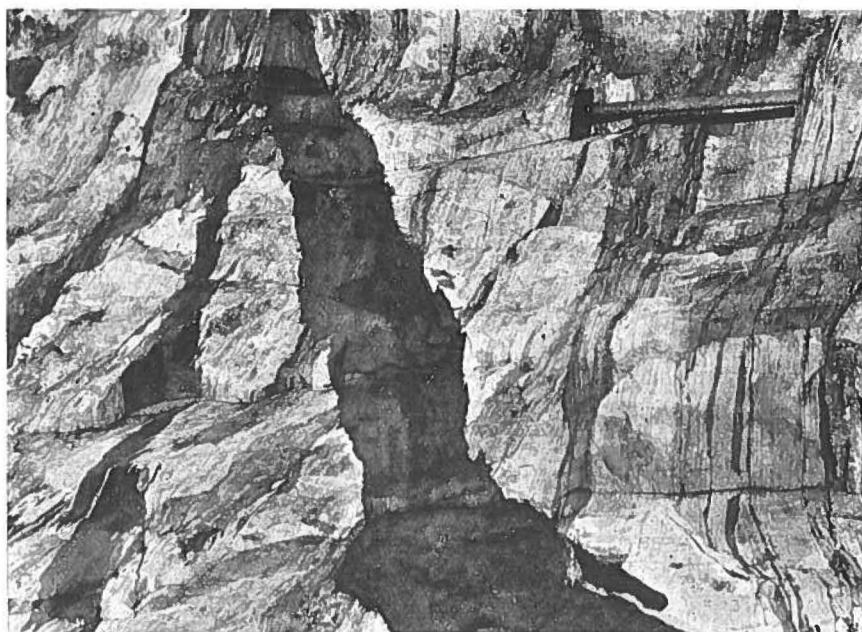


Fig. 9. Basic dykes belonging to several generations, folded and partly migmatitised. Northeast of Josva Mine.

To the south the formation can be traced in a more metamorphic state at the northernmost point of Tavdlorudit, as also in other parts of this island. It is most easily recognisable again on the south side of the island Sanerut, in a zone extending from the mouth of Kipisako Sound to the southwestern point of the island, and comprising also several of the islands situated off this coast. Here remnants of a pillow structure as well as of other volcanic formations are found. The rocks are more metamorphic. Besides dark green amphiboles epidote is still characteristic.

A well defined zone of the rocks of the Arsuk formation, traversed by white granites, extends along the coast on the south side of Kobbermine Bay. Here, too, the rocks are highly metamorphosed (fig. 8, 9). The ores of the Josva Mine, derived as solutions from the younger granites, have partially become fixed through the transformed pillow-lavas, which

still contained carbonates to some extent. In this coast different generations (fig. 9) of pre-granitic basic dykes can be ascertained, which have given rise to the immense volcanic series of the Arsuk formation. The differences in the rocks of the dykes seem often to become more distinct through the metamorphism, since dykes with comparatively small differences behave differently on recrystallisation. Especially noticeable are

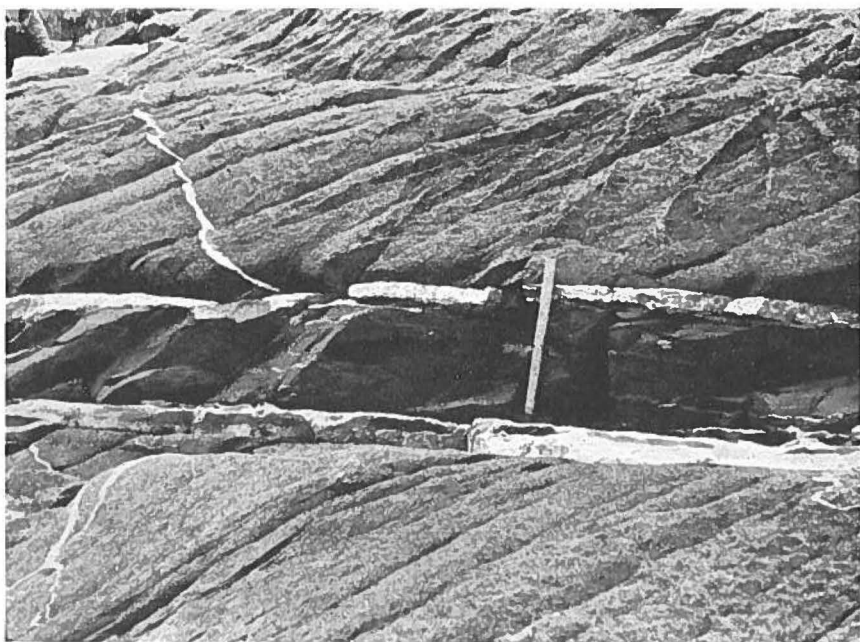


Fig. 10. Basic dyke in ultrabasic rock with apitic margins; Katitit Island, archipelago of Holl nder Island.

the porphyrites in which large dark amphiboles begin to grow, so that they show a resemblance to uralite-porphyrites.

At Sanerut the series turns the lower part towards the north, at the Josva Mine towards the south.

Farther south remnants of the well-known rocks are constantly met with in the gneiss and granite territory. Often remnants of the dykes are found, in many places even in several generations (cf. fig. 9). This is very distinctly seen in the surroundings of Aurora Harbour. In the skerries of Kagsimiut smaller or greater occurrences of the Arsuk formation are often found, mostly highly metamorphic. I shall not here enter upon a description of the many occurrences observed. It is more than probable that so far only a rather small part of them are known. It is almost impossible to investigate merely a fairly large piece of shore within the area of the Julianehaab granite without encountering remnants

of the Arsuk rocks. The most basic rocks will, of course, withstand digestion longest. Especially in places in which the dykes are embedded in rocks more easily granitised such a paradoxical case will arise as has been described by SEDERHOLM from many places in Finland (SEDERHOLM 1926), that the dykes are older than the surrounding rocks. That this is actually the case, may be seen from the fact that the dykes are often *boudinées* and the granite has penetrated into them.

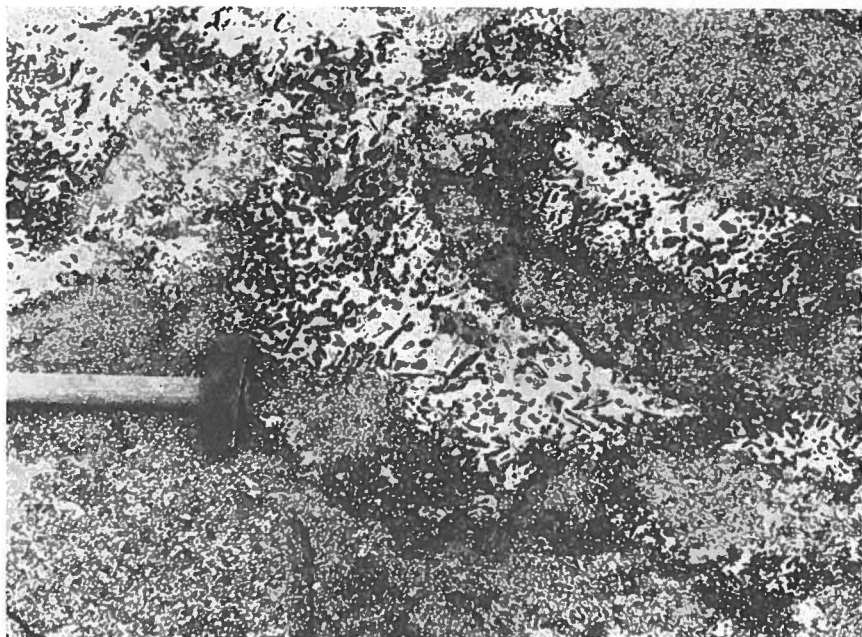


Fig. 11. Mixed rock, originated through granitic digestion of ultrabasic rocks; Katitit Island, archipelago of Holländer Island.

A large basic area is formed by the west coast of Hollænder Island and parts of the islands situated west of it, Kekertarsugsuk and Katitit. Here highly metamorphosed rocks are found, whose metamorphism will be described in another place. The ultrabasic mass is penetrated by basic sills and dykes, probably lamprophyres, which are accompanied by a margin of aplite (fig. 10), from which veinlets issue into the dyke. The above-mentioned dykes are not preserved outside the inclusions and thus owe their preservation to the protection of the ultrabasic mass. Naturally all types of mixed rocks occur (fig. 11), surrounding the inclusions and partly intruding in the form of dykes.

However, most of the basic rocks occurring within the area of the Julianehaab granite are not coherent like this one; they are more or less brecciated, but these zones of breccia can be traced like strati-

graphic horizons over wide stretches. One horizon may be only some few metres thick, others about ten metres thick, and often they are variable. These horizons permit an investigation of part of the pre-granitic structure. In some areas these zones are on the whole more flatly undulating, in others they are steep. So far it has been impossible to map a continuous picture of them. The occurrence at Hollænder Island continues across the southern parts of Kingigtok and Kilagtok towards the north side of the Julianehaab peninsula and onwards to the north. Over this long stretch it appears in the form of a breccia zone with large and small basic fragments embedded in a white, aplitic granite, which has a darker colour outside the brecciated zone.

Another zone extends across the islands in the Julianehaab Fjord. It is particularly interesting on the island containing the Frederik VII's Mine. It reappears again in the northeastern peninsula of the island Akkia, whence it extends across the island, to form flat-lying masses intersected by pegmatitic sills in the southwestern part.

In the Sardlok archipelago the remnants become more distinct again; several basic masses, in part with relictic structures, are found here. The next zone, again, contains more ultrabasic masses; it is traceable from the island Ujaragtarfik Tunugdlek across the peninsula north of Sydprøven towards Lichtenau and probably across the fjord and onwards near Sletten. This belt, too, is highly metamorphic. At Lichtenau it is penetrated by some few huge pegmatitic dykes, which dip 10—15 degrees towards the northeast, and set their characteristic stamp on the surrounding area, appearing as white stripes in the black mountains. Such flat-lying pegmatite dykes seem to occur in all large ultrabasic areas. As on Hollænder Island, the basic rocks are polymetamorphic and often show formation of enstatite, which on weathering lends to the surface a botryoidal appearance.

Still farther south the Sermilik series is overlain by thick beds of dark-coloured amphibolites, which are very distinctly visible in the northern part of Sermersok. The basic rocks recorded by A. JESSEN from the settlement Issua must probably be referred to these rocks.

Only the larger occurrences have been mentioned in the above; the hundreds of small occurrences which are found in series in the area of Julianehaab, have not been mentioned. They have not yet been specially studied and so fixed in the map that they can be interpreted. The reconnaissance character of the journey forbade a more detailed study of this interesting problem, so we had to be content with some characteristic examples.

That these rocks are widely distributed will further appear from CROMMELIN's sand analyses (1937). In many of the samples he found hornblende originating partly directly from these amphibolites, partly

from mixed products of the Julianehaab granite and hypersthene, whose importance he discusses. Neither of these minerals belongs to the normal Julianehaab granite, but to the more or less transformed remnants of the Arsuk formation.

It is not certain, however, that all these rocks originate from the surface formations of the Arsuk group. Some of them may very well be sills and dykes and deeper portions of the volcanic formations of the Arsuk group. The occurrences must therefore be interpreted with some caution, and more detailed investigations are required before a structural picture can be drawn which in its details, too, can be based on observations of the whole area.

Thus the following result is arrived at: Remnants of the Arsuk group and on a smaller scale of the Sermilik group are found throughout the area. Both are to a great extent in a highly metamorphic state, which is largely connected with the *mise-en-place* of the Julianehaab granite. By this we do not mean to say that the Julianehaab granite is the cause of these changes. If we were to express it briefly, though in a way that might perhaps be misunderstood, we would rather say that the Julianehaab granite is the result of these transformations. It is therefore necessary to consider the relation of the Julianehaab granite to the Ketilidian groups, or at any rate the structural aspects of this relation, the other aspects being reserved for the petrographic treatment.

2. The relation of the Julianehaab granite to the Ketilidian formations.

Already GIESECKE and subsequent investigators regarded the Julianehaab granite as younger than both the Arsuk and the Sermilik groups. USSING (1912) summarises the earlier investigations as follows (p. 13): "The latter" (i. e. the Arsuk formation) "is separated by a strip of gneiss from the nearest granites of 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." These allegations have passed into the second-hand accounts (BOGGILD 1917 and others). The recent observations permit us to give more precise details.

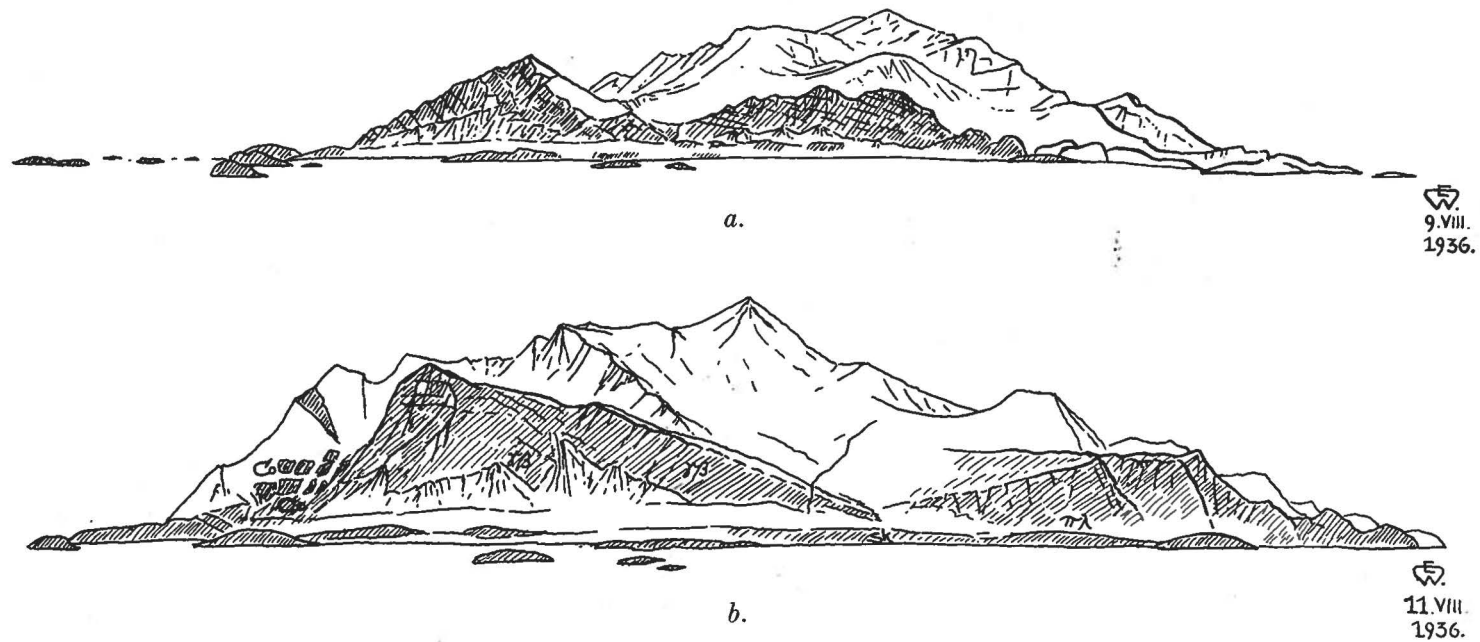


Fig. 12. Sketches of Arsuk Storø, a) from the western part of Arsuk Island, b) from Tavdlorutit; shaded = Arsuk and Sermilik groups; white = granite; Co = most interesting contact between the Julianehaab granite and the Ketilidian formations; $\gamma\beta$ = gabbro; sk = schists; $\pi\lambda$ = pillow-lavas.

The contacts with the Ketilidian formations are mainly of two kinds:

- a) intrusive contacts, where the Julianehaab granite has intruded unconformably as a more or less molten mass;
- b) transitions from the metamorphic formations to the granite, where the pre-existing rock has been converted into granitic rocks.

a. Intrusive contacts.

These contacts are in the first place found on Arsuk Storø (Fig. 2, 12). This island is stated by earlier authors to be built up entirely by the Arsuk formation, as seen on USSING's sketch map and BOGGILD's subsequent reproductions. However, actually but a small part of the island is built up of the Arsuk and Sermilik groups. If we include the islands lying close around Arsuk Storø, these formations occupy less than one-fifth of the area. The remainder, or more than four-fifths of the area, is occupied by the Julianehaab granite. The latter is intrusive, and in part forms hornfels contacts some hundred metres wide. The width is different in different rocks. Thus there are no more or less gneissic intermediate links between the granite and the Arsuk formation, but the granite comes into direct contact with the Ketilidian formations. The effects of the contact are mostly thermal, and only in the close neighbourhood of the granite can a transformation with the addition of chemical substances be ascertained. Both granite and pegmatite dykes penetrate the formations. At intervals of some hundred metres some of the least altered occurrences of the Ketilidian formations may be found. It is the type of contact which previously, in agreement with ROSEN-BUSCH, was regarded as the typical granite contact. However, this is the only place within the area investigated in which this type occurs. It is therefore of great importance. It establishes the age relation between the Ketilidian groups even for geologists who do not accept the migmatitisation phenomena. It further shows that the Julianehaab granite was able to move as an igneous mass, penetrating the overlying formations.

b. Impregnation contacts.

All other contacts are of a different character, viz. that characteristic of the deeper parts of the folding zones. Here, too, intrusive contacts may be met with, of material which have been active even later, coming from a greater distance. But the rocks are here always in a transitional stage to certain granitic rocks, often in cloudy dissolving forms. In a chemical respect the rocks are mostly mixed products and composed on the one hand of the pre-existing rock, on the other of chemical substances which have impregnated and partially digested the former. All transitions are found, in which now one now the other predominates.

The transition may be gradual, or more abrupt, as in the ultrabasic rocks, but traces of digestion will always be found on both sides. These mixed rocks have been called migmatites (SEDERHOLM 1923—24). Such rocks have previously been described from Greenland, especially from the Caledonides (KOCH 1929a, BACKLUND 1930, WEGMANN 1935). I shall not undertake here a description of the Ketilidian migmatites, but only

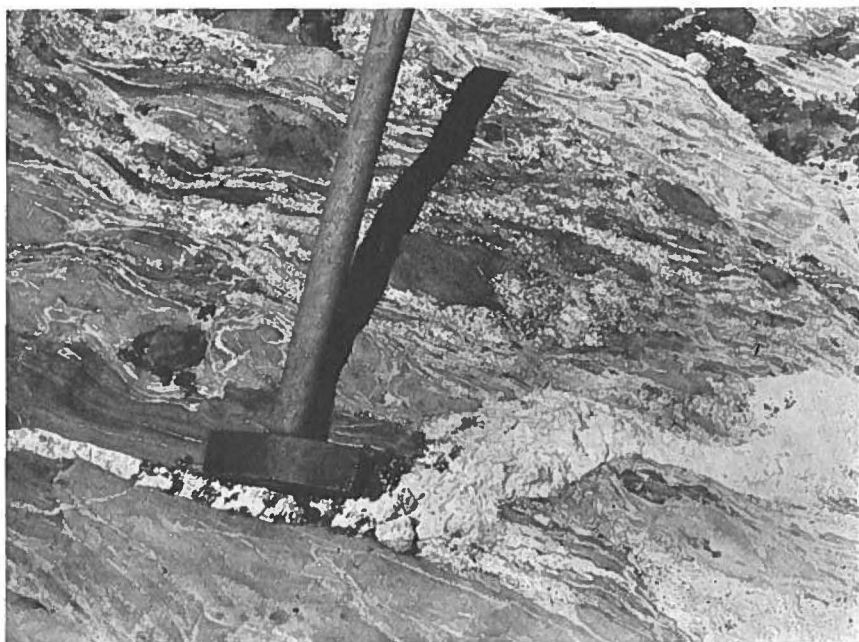


Fig. 13. Migmatite; small island southwest of Sanerut.

mention some phenomena which are of importance for the interpretation of the tectonics.

The division of the contacts into impregnation contacts and intrusive contacts only indicates the extremes; all transitions are to be found. On travelling from Arsuk Storø towards the southeast, one encounters at Sanerut a granite which exhibits both kinds of contacts. In a small island situated immediately southwest of Sanerut all transitions from schists to granite can be seen (fig. 13). In the schists feldspars crystallize, gathering into constantly larger clouds, in which the rock is already an actual granite. Through these clouds it is often possible to distinguish the contours of certain beds. Furthermore, remnants of siliceous schists may be seen as vague undulating shadows. Thus it is a typical impregnation contact; the schists pass into the granite, often without any perceptible line of demarcation (fig. 13). A little farther east there is again a small island, where the schistose zone is perfectly granitised. South of it occurs

the zone with the transformed layers of quartzitic slabs and pillow-lavas; here they are often almost unrecognisable and frequently have the appearance of banded gneiss (figs. 6, 14). In most cases they have a decidedly linear structure. On measuring the direction of the linear structure in various places, the zone will be found to be divided into some few large blocks of a length of 10—30 metres. In each of these

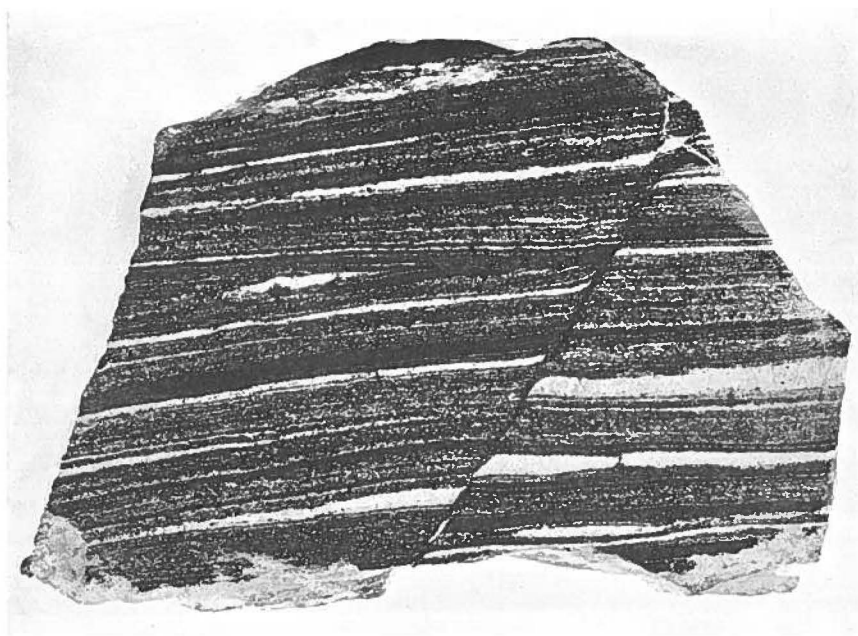


Fig. 14. Banded gneiss, mostly quartz, feldspar, hornblende, and epidote. Borgs Havn, south of Sanerut.

blocks the direction of the linear structures is constant, but varying in strike and pitch from one block to the other. Granitic dykes, frequently of irregular shape, often occur between them. In the edges of many of the blocks the rocks and the granite are somewhat mixed. Thus there seems to exist a kind of eruptive breccia in which the inclusions are very big. On either side of this fairly breccia-like zone the migmatitic material is more fluid. This shows that the migmatitisation is selective. It does not affect all the rocks in the same way; where one is impregnated, the other will be resistant for some time to come; where one begins to flow, the other will break up into larger or smaller pieces. In other places than here in the southwestern part of Sanerut these banded gneisses, too, are granitised. The great difference between the conditions at Arsuk Storø and in this place is that the same rocks which were there hornfelses, do not here show any trace of hornfels, but pass into granite by

impregnation. Similar conditions prevail on the south side of Kobberrmine Bay (figs. 8, 9).

On Arsuk Storø the rock has not been in contact with the granite in its active state for as long a period as in the other places; here the granite has intruded, heating the surrounding rocks, and has soon cooled again together with the latter. The farther one moves away from Arsuk Storø both towards the south, north, and east, the longer will the granite be found to have remained in contact with the other rocks at a high temperature, and in this way an assimilation can take place. The greater

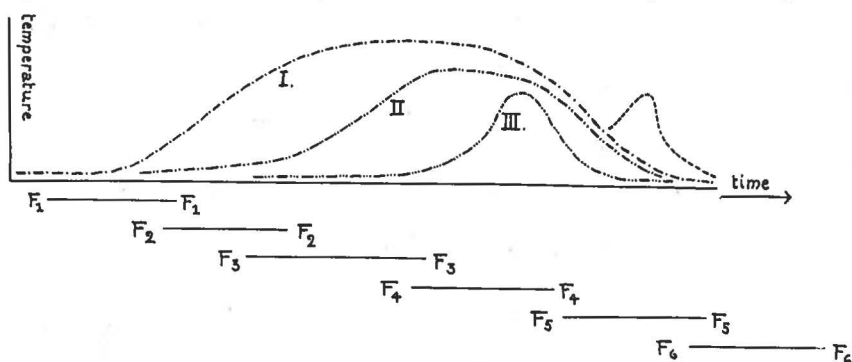


Fig. 15. Showing the course of the temperature in various districts, the abscisse indicating the time, the ordinate the temperature. The first curve shows the conditions in a highly migmatitic area, the second those of a less migmatitic area, and the third an area with a single intrusion, as for instance Arsuk Storø; the last curve illustrates the course of the temperature in an area with late intrusions, with offshoots from the depth after the cooling of the migmatites, some late granites and some pegmatites and aplites. — F_1 — F_6 indicate consecutive stages of movement in the mountain chain; F_1 will be found to be pre-granitic in all areas. F_2 indicates for I beginning migmatitisation, for II and III pre-granitic movements. F_3 means for I and II migmatitic, for III pre-granitic movements. F_4 indicates a granitic movement for III, in I and II probably difficult to distinguish from the preceding ones. F_5 shows the transition from the migmatitic movements to the mylonitic ones; these movements can be studied in the *mise-en-place* of eruptives by the so-called granite-tectonic methods; they are contemporaneous with the late granites and pegmatites. F_6 is entirely mylonitic. The same movement may leave different traces in different areas.

number of the granites seem to be mixed rocks when reaching the levels here under consideration.

In Arsuk Storø and in the vicinity of Kobberrmine Bay both the granites and the migmatites are cut through by broad pegmatite dykes which must belong to a younger phase. They are offshoots from greater depths from the time when the cooling-front descended. On Arsuk Storø the heating and cooling have taken place rapidly, on Sanerut and in other places both processes are slower; farther into the massif the development at the high temperatures has lasted even longer (cf. fig. 15).

The relation between the movements and the *mise-en-place* of the granites is here comparatively easy to determine. A large part of the folding and the kinetic transformation has taken place before the granitisation, and on Arsuk Storø before the granite intrusion. Evidence of late- and post-granitic movements are found round the Arsuk Island and at Kobbermine Bay in the form of mylonitic rocks originating from granitic rocks. Throughout the area there are numerous traces of the movements during the migmatite-stage proper. They are most distinct a little farther into the migmatite areas, as for instance north of the Arsuk Fjord, in the Ivigtut peninsula, and south of it. In these areas the migmatitisation has often reached complete granitisation. In a zone extending along the Ivigtut Fjord and along the north coast of the Arsuk Fjord across Patusuk to Arsuk Umanak, the migmatites are arranged in flow folds. At Umanak, especially, the fold-cascades are distinctly visible. They descend southward below the greenstones of the Arsuk group. The movement at this stage, however, was completed before the last aplitic and pegmatitic solutions intruded. Even then the rock was so brittle that joints were formed, and in these the solutions intruded. They are largely transversal and are associated with similar movements in the area of Arsuk Island.

In Ika Fjord, too, many of the migmatites have moved after the crystallisation of the felspar, so that augen-gneisses have formed. We may assume, then, that the movement continued during the cooling, to pass gradually into mylonitic transformations. On Tavdlorutit the migmatites have often moved at a late stage. In several places within this zone, notably on Kujartorfik, the migmatites are penetrated by a lighter-coloured Julianehaab granite a little coarser than that of Arsuk Storø. There is no doubt that this granite has also penetrated through the unmetamorphic part of the Arsuk formation, which was situated on a higher level, fairly high above the present topography. It proves that these intrusive granites belong to a late stage, when the cooling-front reached far beyond the outermost positions of the migmatite front. They are offshoots from deeper regions.

The migmatite front reaches very different stratigraphical altitudes in the different parts of the Arsuk area; consequently it cannot be used as a stratigraphic indicator. Moreover it cuts through the tectonic elements without any great regularity. It is quite possible that its starting positions have been more regular, but the possibilities of advance differ greatly in such an inhomogeneous body as the Ketilidian folded range. Hence in the analyses it is often very difficult to detect a direct connection between the movement systems of different ages.

Thus the relation of the Ketilidian formations to the granite within the northern area may be summarised as follows:

- a) kinetic transformations and folding prior to the granitisation;
- b) granitisation with movements in a highly mobile state; the axes strike largely ENE—WSW, but vary somewhat in detail; these movements continue in
- c) the late movements, which gradually assume a mylonitic character, and the intrusion of late granites.

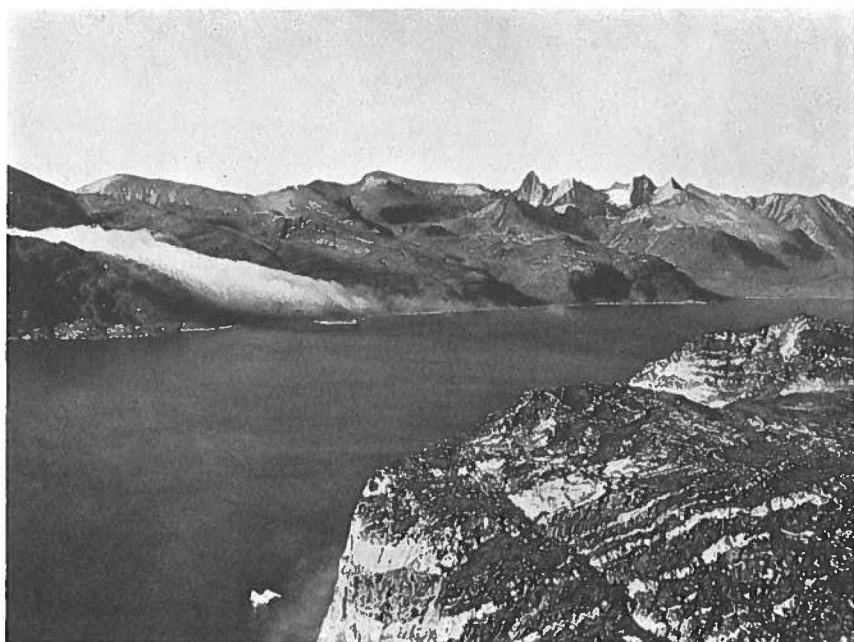


Fig. 16. Pegmatites in the Sermilik formation. Sisarigsok Mountain near Nanortalik. Looking north towards Sermersok Island.

Similar conditions prevail farther south, far into the area of the Julianehaab granite.

In the southern region conditions are somewhat different. In a few places only the granite is in direct contact with the Sermilik group; mostly a transitional zone intervenes. In places where the granite is seen to be in contact with the schists, it seems to have intruded after the migmatitisation. Such places are found in the Sardlok archipelago on the north side of Sermilik Fjord, on Sermersok, and at the entrance to Tasermiut Fjord.

The actual granitisation front is here surrounded by a huge pegmatitisation zone. It is a large anastomosing system of huge, often flat-lying lenses and undulating sills (figs. 16, 17). Only a few straight dykes are found. No doubt a large part of these pegmatites have not intruded, but impregnated the schists, the large feldspars being crystallized in

the schists, while the latter gradually disappear (fig. 18). Similar occurrences are known from other mountain chains (cf. WEGMANN 1931, pl. 13, fig. 26). The ways of migration for the supply of material in this zone cannot have been the more or less steep joints, but planes of movement associated with the schistosity. They must accordingly have developed at a time when the movements, or at any rate the tensions, still made these ways practicable. This is also evidenced by the detail



Fig. 17. Pegmatites in the Sermilik series. Central east coast of Sermersok Island.

investigations. Often the residual schists are bent round the big feldspars, which may assume the shape of an eye. Subsequently the ways were barred; and the last offshoots followed the more vertical joints. However, though the pegmatites have been lodged a little later than the actual granitisation, they are most conspicuous in the scenery (figs. 16, 17).

Some characteristic features of the granitisation in this southern district may be illustrated by an example from the island Angmalortok. The metamorphosed series consists of schists with more or less quartzitic beds. The latter were found to contain concretions which were somewhat more calcareous than the surroundings. Basic dykes also occur. The whole series is much folded. In many places only fragments of the rocks, orientated in a certain direction, are recognisable as such. Similarly *boudins*, fragments of greenstone, concretions from the pre-existing rock,

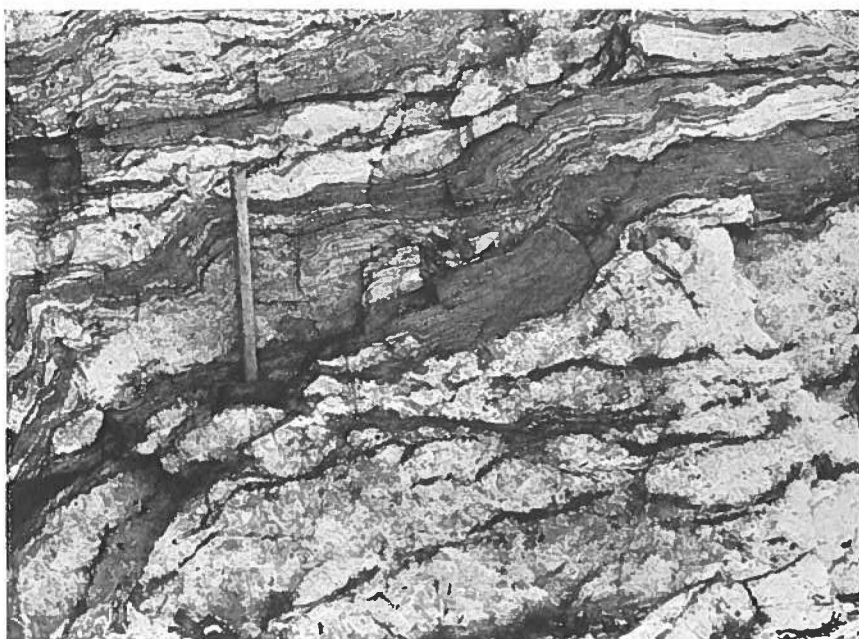


Fig. 18. Pegmatitised graphitic schists near the graphite mine of Amitsoq.

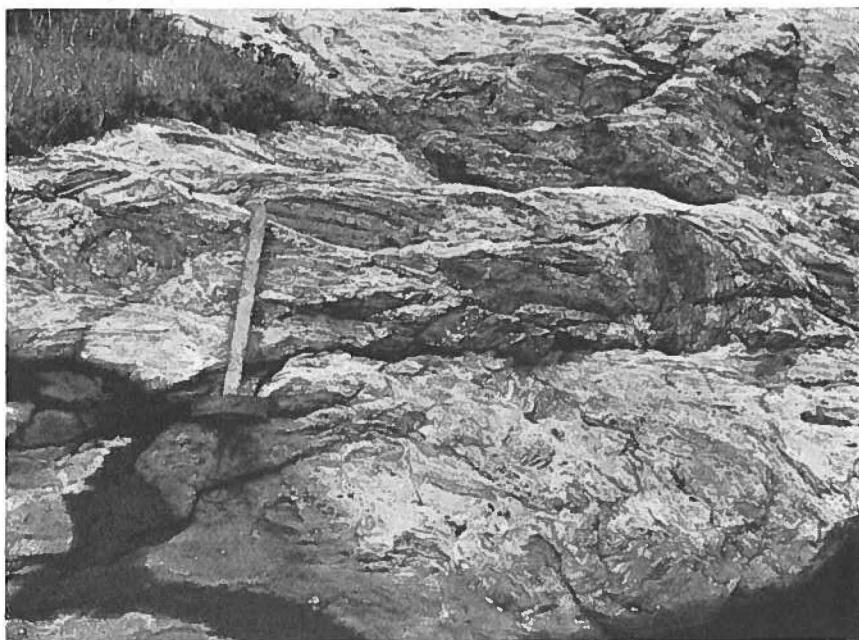


Fig. 19. Folded schists of the Sermilik group; the more rolled-out portions form a light-grey fine-grained mass in which fragments of the original rocks are embedded.
Angmalortok Island.

etc., are embedded in a light-grey fine-grained mass (figs. 19 and 20). The whole rock often resembles a kind of breccia; but on following the transitions, we find that the ground-mass is that part of the rock that has been highly kinetically transformed. In the less advanced stages the folds within this mass are traceable. The fragments less intensely squeezed out are preserved, and seem to be floating in the mass (figs. 19, 20). The latter grows more and more homogeneous; the rolled struc-

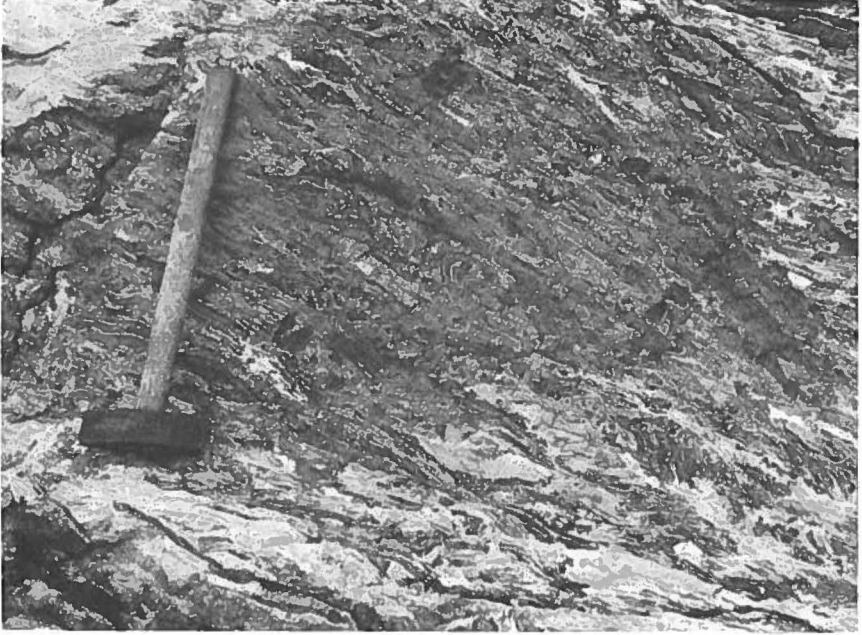


Fig. 20. Folded schists of the Sermilik group; only some limbs of the folds are preserved. Angmalortok Island.

ture disappears, and the whole is recrystallised to a fine-grained mass of quartz, biotites, and feldspars. Into this mass the feldspar components immigrated and crystallised. The "fragments" still preserve their shape and texture. When the whole ground-mass has become granitised, the fragments appear to be floating in a granitic mass, and the whole becomes what SEDERHOLM has designated as agmatites, i. e. migmatites containing fragments. Thus the whole rock corresponds entirely to the external picture of what has been termed "an intrusive breccia"; but it has a different genesis from that generally associated with that notion.

Thus for these rocks, too, the phenotype is not equivalent to the genotype. It would seem convenient, therefore, to give the term agmatite a merely descriptive meaning, that is to say, to let it denote merely a fragmental rock with a more or less granitic cement, saying

nothing about its genesis. In so doing, we may reserve the genetically influenced conception "intrusive breccia" for such cases in which the intrusion mechanics can be ascertained.

During the transformation described above two kinds of garnets will develop; spots of a sandy garnet will form in the grey mass, with many inclusions without crystalline boundaries; in the light-coloured veins there occur darker garnets with crystalline boundaries with few



Fig. 21. Granite with moved inclusions. Left margin of the Sermilik Glacier.

inclusions; the latter subsequently pass into pegmatite. In the actual area of the Julianehaab granite traces of an earlier formation of garnets are but seldom found.

The granites which arise from these agmatites have at first a streaky and inhomogeneous appearance. The felspar crystals are of different size, but are more or less idiomorphic. However, when the whole rock begins to be crowded, so that the individual crystals press against each other, the granites become somewhat more homogeneous. They have a special, easily recognisable appearance, and are previously known from the bed-rock of Finland and from the Caledonides (Norway, East Greenland).

In many cases the whole mass has been overtaken at this stage by the cooling process and thus fixed. In other cases the high temperature of the mass continues; when movements take place in the higher zones, the underlying masses have to adapt themselves to the conditions and

the flow. The fragments will then, according to their nature, be stretched longitudinally, they turn into stripes and may disappear. Other rocks, notably basic and ultra-basic ones, are more resistant, and the surrounding mass will flow round them; this is especially distinct when the mass contains stripes, which emphasize its movements. This stage, too, has been preserved in many cases when fixed by cooling; it is found in the northern district from the Kagsimiut archipelago to Sermitsialik (fig. 21). The granites which have crystallised from these moving transformed masses show a more regular crystalline texture than that derived directly from the impregnation-migmatites.

The migrating migmatites may encounter rocks along their route which are not in the same degree mobile. This difference is reflected in the mode of movement and in the traces they leave. When a mobile mass moves along a more solid rock wall, it is termed an intrusive contact, or an eruptive contact. Thus the granites and similar rocks cannot be classed according to their genesis alone, but their relation to the surrounding rocks must also be taken into account; they may be a) autochthonous, i. e. formed almost in the place in which they are found now, or b) allochthonous, i. e. emigrants; the latter are often merely more advanced stages of the former. Their chemical composition keeps within the same limits, but they differ partially by their crystalline texture. However, their condition may best be ascertained through studies in the field.

Before further treatment of the kinetic types, we shall briefly consider a line of development which starts from the stage when the feldspars have not yet immigrated. This series arrives at members different from those of the granitisation series. According to the original material the schists become more biotitic or amphibolitic. In the intermediate mass, between the moved fragments, the chemical composition has become of a mixed, intermediate type. If not granitised, the mass obtains the composition of a diorite. Large hornblendes will often form, which intersect the rock in all directions, so that it obtains a massive appearance. According to the degree of metamorphism and the content of epidote it has the character of a more or less fresh diorite. These rocks are often somewhat variable. On encountering such a rock without being prepared for it, one is inclined to consider it as an intrusive rock on account of the many fragments which are embedded in it. It is therefore necessary to investigate the occurrences in all its accessible aspects.

Thus the dioritic rocks within this area, too, are convergence-phenomena, and may arise in different ways; 1) they may be remnants of original diorites, 2) they may be mixed rocks of granite and basic rocks, as they are met with in each of the above-mentioned larger basic zones within the area treated, and 3) they may be metamorphic products

arising in the way described above, or in similar ways. With which of these alternatives we are concerned, cannot, usually, be decided from an examination of the samples alone. All three kinds of development are recorded in the literature from other mountain chains (DRESCHER-KADEN 1936, HEGEMANN 1937).

The dioritic massifs are, as a rule, not very large. They may show different boundaries towards the granite, but usually a transition is found.

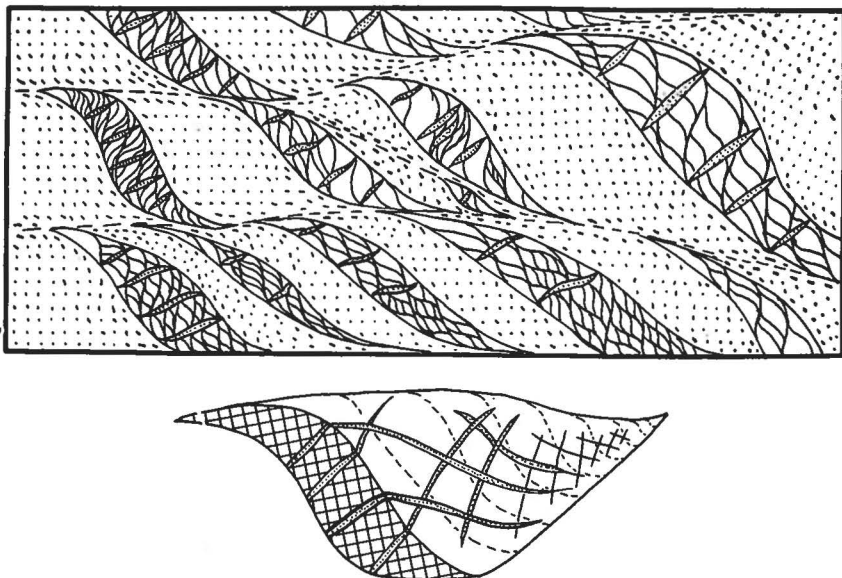


Fig. 22. Lens-gneisses. The size of the lenses ranges from 1—20 m. They consist usually of fairly basic gneisses, and are built up of smaller lenses of a size of one to several decimetres. Often the transverse fissures are filled with aplitic or pegmatitic material. Above: schematic transverse section. Below: the stereometric shape of the lenses.

In some of them the granite is intrusive; in others the hornblende is increasingly biotitised, the rock is subjected to kinetical influences, it absorbs granitic material, and becomes a light-coloured gneiss-granite.

Let us trace the subsequent fate of the agmatites where they have had the possibility of a further development at high temperatures. Each time we must move to a zone farther towards the interior; if commencing in the south, we must continue towards the north. These zones are arranged as successive but not parallel zones; some are more regularly distributed, others more irregularly. The fragments then flow more and more into stripes; some fragments do not at once obtain the same mobility as the surroundings, but only gradually, beginning from the margin, zone by zone. Each zone is acted upon, the hornblendes being biotitised, and

the feldspars enclosed, and the zone is stripped off. In this way the fragments become lens-shaped.

The lens-shape is often due to other movements, too, and if so, it corresponds to a certain internal structure, not only to the external influence, as in the above-mentioned case. These lenses, again, are built up internally of lenses, and these often of other, smaller ones. In the northern area these lens-gneisses occur at Apokatak and along Brede Fjord. In the southern area they are found in several places in the Sardlok archipelago, in Lichtenau Fjord, and in Unartok Fjord. They are especially distinct in Cape Kerrojut south of Sardlok, where their development can be traced in the high, bare rocks.

It is not only the relation of the inclusions to the surrounding rock which distinguishes this type from the banded gneisses and from the first-named lens-gneisses. In the two latter the whole mass flows in a definite direction, to which the inclusions and the stripes are adapted. They show a flow-symmetry. In the lens-gneisses of the other types this is different, as shown by the figure (fig. 22). Thus this movement does not take place in the highly migmatitic stage, but during its slow cooling. In some places there are indications that the migmatite front has alternately advanced and receded, at any rate it has remained for some time in the neighbourhood. On Kerrojut these lens-gneisses are cut across by dark dykes, which will be termed here lamprophyres; their genetic conditions will be discussed later. In the complexes that continue to move these dykes, too, are subject to movements, and are the first to be *boudinées*; subsequently these *boudins* will develop into lenses (WEGMANN 1932) and become orientated in the direction of the other lenses. Without a thorough investigation of the individual parts of the dykes it is impossible to demonstrate the nature of these parts in the advanced stage. But the tracing of them allows a subdivision of the genesis into episodes.

On Kerrojut and in the Sardlok archipelago the dark dykes are followed by two pegmatite generations. In the first-mentioned place the pegmatites constitute a somewhat irregularly ramified network, which can be readily observed on the south side of the cape. They are intermediate between the formation of the ramifying pegmatite sills of the Sermilik zone and the distribution of the late pegmatites. The latter show a flat-laying orientation through the whole rock mass. At the time of the formation of the pegmatites the granitisation front had already receded a long way.

Proceeding to the next zone, we find the further transformation of the lens-gneisses. Here the migmatite front must be assumed to have advanced somewhat again. On the formation of the lenses, part of the feldspars turn into augen and some are crushed (fig. 23). In a quieter stage

certain of these individuals grow further and re-form. They prefer certain privileged directions, mostly following the disappearing stripes. In this way a kind of porphyritic granite with large felspar phenocrysts will arise (fig. 22). In many surfaces these felspars show a somewhat irregular appearance, but if one approaches them from the right side, the "shades"



Fig. 23. Agmatitic granite developed into banded gneiss; after the first intensive movement transverse fissures were filled with pegmatitic material and subsequently subjected to slight movements; a similar development to that of the interior of the lens-gneisses. Interior of Unartok Fjord.

of the old structure are often recognisable. If the shades disappear, it is difficult to detect any regularity in the arrangement. It will be difficult to arrive at the right explanation by statistic treatment. To an observer who is unacquainted with the previous history of the rock, the arrangement of the felspars will look quite casual, or promiscuous; the latter especially if it is taken for granted that the phenocrysts are intratellurian and have intruded with the granitic magma. This case may

perhaps show once more that the phenotype "porphyritic granite" may have different origins, and does not correspond to one single genotype.

If these experiences are to find a further application, the following facts should be pointed out: in the case of the lens-gneisses the same



Fig. 24. Sardlok gneiss, Sarkardlit Island, Sardlok.

rock mass contains many different rock types, ranging from aplitic to fairly basic types, and many different mineral textures. It will be difficult to explain these rocks as due to crystallisation- or liquation-differentiation. If we move towards the higher metamorphic zones, the whole development seems, on the contrary, to tend towards a homogenisation. But it can only take place when the rock remains for a sufficiently long time at the high temperature. At certain temperatures the homogenisation will only be able to extend over a certain distance within a certain time. It may therefore to a great extent facilitate the homogenisation if the rock is affected beforehand, as was the case with the

lens-gneisses. In these gneisses, as also in the banded gneisses, the distance need not be very long to affect the whole rock. Thus it would seem that these gneisses, too, passed rather quickly into porphyritic granites. These, of course, cannot be explained either as endogenous contact products at the wall of the batholith, if these concepts are not interpreted in a



Fig. 25. Julianehaab granite, impregnating pre-existing rocks built up of acid and basic portions; the transformation has taken place without any great movements. North coast of Unartok Fjord, north of Unartok Island.

sophistic way. According to the observations recorded they should be regarded as metamorphic products which have passed through a long development.

By this I do not mean to assert that all porphyritic granites have originated in this way. They are convergence phenomena, and may have very different origins. It is not only a type in which several ascending lines meet; but several lines of development also continue from it. Thus it is a kind of cross-road. For it is no stable and final type

if not fixed through cooling. If it has a possibility of further development, the phenocrysts disappear again. Among the kinetic continuation types the augen-gneisses are best known. Another line of development of porphyritic granites has been described by KRANCK (1933); this, too, is to be found between Sardlok and Julianehaab.

A slightly different type is the rock recorded by A. JESSEN (1896) from Sardlok. It looks as if the more or less idiomorphic feldspars in this rock have been sprinkled on (fig. 24). Behind this veil of feldspars the folds of the original rock can be distinguished. In certain cases the folds move onward; in this way the feldspars immediately come to bear a certain relation to the configuration of the folds and begin to emphasize it. If this movement does not take place, the whole rock mass resembles many variations of the Hangö granite, photographs of which have previously been published (WEGMANN 1935, fig. 2). The Sardlok rocks in a way correspond to those described from Angmalortok, but without the preceding movements (cf. pp. 38—40). The product here is more even-grained, but is somewhat varying, and mottled in colour (fig. 25).

In this rock, too, pegmatites appear in two generations; they are preceded by an aplitic generation, which is still partially in motion in the lens-gneisses. The first pegmatites cut across the linear structures of the original rock, thus corresponding to a widening approximately in a NE—SW direction. They often form very large lenses or fishes, some 10—20 m long, which are orientated *en echelon*. Of the younger ones, some flat-lying dykes are known, which often show kinetic influences.

Thus from S. Sermilik to the islands off Sardlok and Julianehaab there occur numerous traces of movements of different kinds. They may be divided into groups; 1) one is traceable throughout the whole area, and is pre-granitic; it is the actual Ketilidian folding. It is very distinct in the northern area also. These movements may be assumed to be fairly contemporaneous; no exact proofs are available, but nothing speaks against it. At any rate both took place prior to the granitisation.

2) The migmatitic movements; they can be subdivided into a number of episodes, some of which have been described above. Their traces are distributed over certain zones. A whole series of developments can be followed between S. Sermilik and the actual Julianehaab granite at Kangerdluarsorujuk, in a zone which corresponds in the main to the Lichtenau-Unartok Fjords and the islands off S. Sermilik. That the traces occur in a certain zone, means that they are preserved in that zone and were fixed by the cooling. It is very probable that movements took place farther into the area of the Julianehaab granite at the same time, but they were not fixed in the same way, since they took part in the further development, which possibly again concealed the previous

marks. Thus it would be better to say that the cooling-front by its advance towards the north and towards the depth fixed constantly more developed types (cf. fig. 15). Increasingly developed types passed into the dead parts of the earth's crust. But precisely at this boundary between the dead and the living matter which made its way through the mass, special conditions of movement set their final stamp on the zones soon to die. If the phenomena are to be systematised, a distinction must be made between the endogenous development and the movements in the advanced boundary zone.

In the northern district these movements are found northwest of Sermitsialik, but in a slightly different variation. At Sermitsialik proper the fluid fragmentary rocks are well exposed in the polished coast cliffs (fig. 21). At Isortok farther to the southwest, the following sequence is observable:

- a) quartzitic and basic gneisses, with flow-structures, mottled and nebulitic;
- b) basic dykes cutting through the former; but themselves ruptured;
- c) coarse granite, passing into a more fine-grained granite with biotite spots after hornblende; this granite is of the Hangö type;
- d) basic dykes, penetrating both granite and gneiss;
- e) aplitic and pegmatitic dykes, traversing all previous ones;
- f) intense jointing with mylonitic products, slickensides and crush-breccias.

Several movements from the Arsuk area have been described in the preceding pages. In that area also it is easy to distinguish between (1) and (2) (cf. pag. 48, 37). In many places the granitic movements are not so typical as in the southern area, apart from the belt immediately north of Arsuk Fjord. In many other places there are many intrusive granites, so that the migmatitic zones show a less organic development. Much greater and more irregular variations in the advance of the cooling-front must be assumed to have occurred here. The structure and character will consequently be different, and not suited for a methodical description.

3) The pegmatitic movements; their correlation is as yet difficult. In most places there are several generations of pegmatites. They often pass into late aplitic granites. All penetrate the granite and the outer zones to a greater or smaller extent. They are very characteristic between the Julianehaab Fjord and the Sardlok archipelago. It is not probable that they are synchronous throughout the area; but there are evidences that, like the cooling front, they are metachronous in the individual zones (cf. fig. 15), that for instance the pegmatites of the Sermilik area correspond to the granitic stage in the Julianehaab area, and that the

pegmatites in the latter area have appeared much later than those occurring farther south. On this account the picture is difficult to interpret, but increases in profuseness of organic development.

4) the late mylonitic movements; will be treated below.

Even though the individual episodes of the development cannot be synchronised with certainty throughout the area, the groups are fairly synchronous. Of course there are several other possibilities, and we must for the time being leave them open; for instance the movements along the southern edge of the granite can be parallelised in two ways: the late-granitic movements in the Unartok zone may be correlated with the pegmatitic movements in the Sermilik zone, and the eugranitic movements in the Julianehaab zone; it is this working hypothesis which seems to supply the best explanation of the conditions (fig. 15). But we might also suppose the synchronism of the aplitic and pegmatitic phases throughout; one might reject the migrating metamorphic and kinetic zones and replace them by static ones, as is mostly done in descriptions of granitic districts; in this way a different picture would be arrived at, disagreeing on essential points with that given above. Whether the one or the other interpretation is chosen, does not depend on the observations, but on fundamental views. Fixism has long dominated the geology of the ancient crystalline platforms, not least from petrographic quarters. The rocks were considered as more or less final products which had reached a state of equilibrium. Of recent years mobilism has again gained ground. As in my previous works, here, too, I have attempted to interpret the observations on the mobilistic principles.

Both interpretations, the fixistic and the mobilistic, have this in common that they regard the whole transformation as belonging to one great process unit which extends not only over the whole area investigated, but also beyond. For the granitisation, at any rate, we may speak about the Ketilidian unit. But the granitisation is everywhere preceded by a folding. Very probably it belongs to the same folding zone. If one area belongs to a different folding zone, that is to say, if one area is younger than the other, the granitisation in the one area would have transformed an old dead folding zone. In such zones the granites and the other igneous rocks are usually of a different character from that observed in the Julianehaab granite. Thus it cannot be precisely a unit. It is probable, therefore, that the whole area belonged to the same folding. Below I shall briefly state some points which indicate that the folds belong to the same system.

3. Some remarks on the tectonics of the Ketilides.

It will be seen from the tectonic sketch (fig. 2) that the greenstones of the Arsuk Island are situated in a kind of syncline whose axis rises towards the east. From Ikerasak to Taylor's Harbour the quartzites form part of a cup-shaped depression (pl. 3), which becomes less distinct farther south; the quartzites themselves cannot be traced farther, as they descend below the water.

The content of the syncline shows no quite simple structure. The individual larger greenstone horizons, especially where interbedded in the schists, have slid across one another, so that the whole mass becomes a somewhat complicated system of folds and overthrusts (fig. 26). It is all the more complicated because the thrusts have not only taken place across the axis of the syncline, but also in some degree lengthwise. At Taylor's Harbour the upper schists have become folded and sheared in two directions whose axes form an oblique angle with each other. Such schists in which, according to the terminology of SANDER (1930), a B and B' direction is found, are very frequent in the region of Arsuk Island, notably in the schists. The axes of the folds within the upper limestone (fig. 3) horizon mostly descend towards the south-southeast in below the greenstones. In the lower horizon the axes of the folds run, with small varying pitches, along the sound Ikerasak (cf. fig. 4).

Looking from the outer part of the Arsuk Peninsula or from Kajartalik, a large fold can be seen in the western part of Arsuk Island, if the illumination is favourable (fig. 27). The fold is traceable across the island towards the south coast (fig. 28). It strikes NW-NNW/SE-SSE across the island, that is to say, across the longitudinal axis of the greenstones, which corresponds almost to the direction of the fjords. This fold is older than that which is associated with the synclinal structure of the Arsuk Island. A more detailed investigation gives the following result: What can be designated as the synclinal structure, is not the internal structure of the complex, but indicates its boundary towards the metamorphic areas. Thus it has come into existence during the granitisation. These boundaries intersect the lines of the internal structure, which are thus partially included in the new structural plan.

Thus in broad features also there is not only one structural plane, but two, which intersect one another. One can be correlated with the migmatitisation. This gives us a clue to the understanding of the very different metamorphic facies of mineralogical and kinetic nature in the Arsuk district; in many places they are closely interwoven, so that in the first instance an analysis is very difficult. Such intersecting structural planes may also be met with in other migmatitised orogenic zones, being known from the Caledonides of East

Greenland (WEGMANN 1935) and from the migmatitic part of the Norwegian mountain range.

At Kobberrmine Bay the previous folding direction is somewhat concealed. The zone extends in the direction of the migmatitic folding. In the minor structures, however, traces of others may be found: the beds form "ogives" or accordion folds; enveloping planes of these trend obliquely to the general strike; this in connection with the distribution of the pitches seems to indicate similar conditions to those found at Arsuk Island; but the latter traces of movement predominate.

The inhomogeneity planes that can be measured (or "s" according to SANDER's terminology (1930)) mean something highly different in the different places; they have different functions and are of different ages. Hence they cannot quite simply be combined on a map so as to represent the structure. They may be classed in several groups:

- 1) the sedimentary "s", or, for the volcanic rocks: flows and sills;
- 2) the "s" of kinetic origin at the first folding; may occur in one or several generations;
- 3) the "s" of the migmatite movements, which appears during the migmatitic development; here, too, there are often several generations;
- 4) the post-migmatitic, mostly mylonitic "s".

In tracing one of the latter "s"s, one usually comes upon inclusions or remnants of the preceding ones. On migmatitisation under quiet conditions the older "s" as such will be absorbed in the migmatite (cf. fig. 24).

In the actual migmatitic area traces of the earlier directions may be found in many places in the subsequent directions. But many additional observations are required to allow of a more detailed interpretation. The whole granitic area may be divided into a number of anticlinal zones, with somewhat different



Fig. 26. Sketch of the east coast of Weber's Havn. More resistant greenstones and gabbros between schists and schistose greenstones.

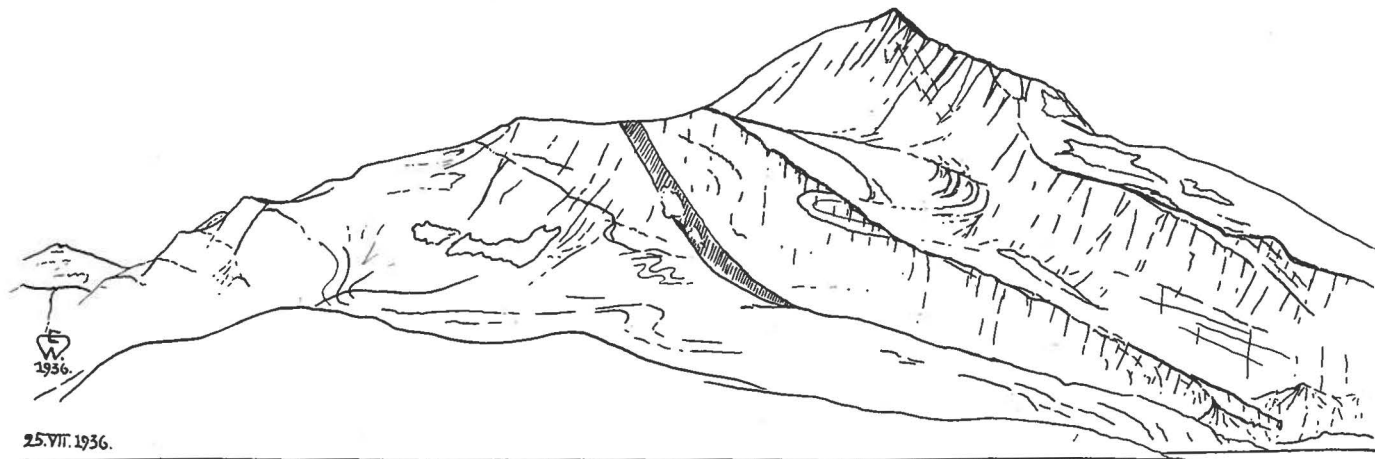


Fig. 27. Northwest coast of Arsuk Island, seen from the outermost point of the Arsuk peninsula.

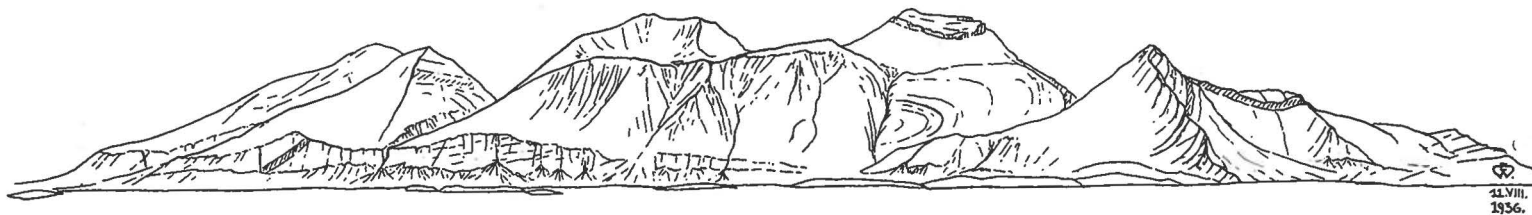


Fig. 28. The south coast of Arsuk Island, seen from the northernmost coast of Tavdlorutit; showing the foldings in the eastern part of the island.

itches; at the outer coast and in the skerries they seem to be largely towards the southwest. In the synclinal zones late-granitic offshoots are more frequent.

The basic and ultra-basic zone, Hollænder Island to Kingigtok, connects by the "Sorte Skær" (black skerries) off Julianehaab with the basic rocks on the outer Akia, which extend across this island and over Frederik VII Mine to Kakortok Fjord. From Akia they extend in a curve across the Sardlok area to Ujaragtarfik and the Lichtenau zone. Thus the basic rocks appear to form a bridge across each of the secondary granite massifs.

In the southern area conditions are a little more intricate; still more traces are preserved here; more information may be derived from them, but they are rather difficult to interpret.

The panorama of Natsinguak and Nugluartukasik may give an idea of the character of the folds (pl. 2, fig. 1).

Southward from Unartok Fjord, throughout the area of which I was able to gain a general view, the whole series has been crumpled into folds, which strike almost in the direction of the fjords. The axes of the folds are of a different pitch, so that the whole conveys a first impression of a somewhat irregular structure. But the planes ("s"s) which form these folds are in large part not sedimentary, but subsequent kinetic planes, mostly not even of primary but of a subsequent generation (cf. pag. 38 and figs. 19, 20); that is to say, the first kinetic planes have been folded again, often several times. This phenomenon is discussed in greater detail on pag. 40. It is widely distributed in the southern area. Such a structural type is known from many different orogenic zones. It is especially found in places where folded masses are getting dammed up against a resisting massif and jammed in the attempt to overcome the hindrance (WEGMANN 1931). Thus the large structures are the result of a whole series of different processes. At present the structure cannot yet be clearly dissected. A thorough survey of the whole area is therefore necessary. This still remains to be done. It appears from the examples studied last summer that here, too, different directions of kinetic transformation occur, which must belong to different phases. The pegmatites (figs. 16, 17) mark the last movements.

By means of the graphitic and other more easily recognisable beds it might be possible to determine a little more precisely the forms and direction of the older structure. As a main result the traces of movement in the southern area also may be divided into at least two groups; the one which strikes mainly in the direction NE—SW, is the youngest. As in the Kobbermine Bay, the smaller folds often strike in the migmatitic direction, whereas their planes of envelopment trend across or obliquely to that direction.

Hence, if not indisputable, yet it is natural to assume that the folds within the Arsuk area, in the southern area, and in the intermediate Julianehaab district are synchronous; the individual episodes need not, therefore, be synchronous. A further application of the working hypothesis of the Ketilidian unit would therefore seem justifiable, because

- a) their sedimentary and volcanic series are fairly uniform;
- b) the same seems to apply to their kinetic history;
- c) their metamorphic history no doubt forms a unit.

4. Some remarks on the development of the Ketilides.

In the long account given above mention has hardly been made of the basement of the Ketilidian series. For many problems, however, it is an important point; it is therefore necessary to discuss it in a few words, even though as yet only very little positive can be said. It may, however, be useful for the continued work to sum up our present knowledge and suppositions.

That such a basement has existed, may be taken for granted. But where is it to be found in the present edifice? It has been indicated above that a number of occurrences are found which must be interpreted as belonging to an older basement. But so far it has been impossible to establish a certain connection between these occurrences. However, there are indications suggestive of the occurrence of the basement.

The Sermilik series of the south is, as it were, jammed against some blocks which must have been situated north of it, almost in the present area of the Julianehaab granite. If we add the observations on the pre-granitic basic dykes in this granite, we shall arrive at the following hypothesis:

The old basement consisted of granites and gneisses; it was broken up into large blocks, in the joints of which the older metabasites, the feeding channels of the Arsuk group, intruded. The whole mass was subsequently packed together, so that parts of the Ketilidian series were much squeezed, while others were folded up. The granitic basement was first activated and accordingly became palingenetic. It formed flow folds with the Ketilidian series, and at the same time there started from it a molecular migration (WEGMANN 1931) which transformed the younger series.

In a paper recently published (v. ECKERMANN 1936) the migmatitisation and the palingenesis are contrasted. However, these two notions are not contrasts but belong to different categories. A rock, for instance a granite, which becomes palingenetic, by that process acquires properties similar to those which it possessed prior to its solidification. This is often expressed by saying that it becomes a "magma". Since once, at the time of its solidification, it lost its volatile constituents, such a heated granite or gneiss becomes a "dry" magma and gives rise to the

formation of granulitic series, as known from other areas, from Greenland for instance from Liverpool Land (KRANCK 1935, BACKLUND 1936). These series often indicate that an ancient rock ground without receiving any great addition of elements was heated and thus turned into a granulitic magma. But such a granite or gneiss may also receive additions in the form of volatile constituents, and thus become complete again. When it receives this addition, the product will be a mixture of the pre-existing rock and the elements added.

The activated rock with or without addition may move like a thick-flowing mass, penetrating into fissures and cracks, that is to say, it is endowed with the mechanical properties of the state which is termed magmatic. On the other hand it also possesses its physico-chemical properties to a smaller or greater extent, that is to say, it may give off materials which immigrate into the wall rocks, may settle there and form mixed rocks, or migmatites. Palingenesis accordingly means that a dead rock becomes alive again; to this living state belongs not only its mechanical, but also its chemico-active state. Its turning active again is not identical with the formation of mixed rocks, that is to say, migmatitisation. If it is pointed out that many migmatites become active and behave palingenetically, the answer is that many migmatite types are found, too, which are not palingenetic (WEGMANN 1935).

Thus the two notions belong to different logical categories although they move in similar fields: one denotes a rejuvenation which restores to the rock the mechanical and physico-chemical properties of a magma; the other denotes the process through which mixed rocks, i. e. migmatites, arise. Unfortunately their confusion has resulted in several misunderstandings, which have perhaps been cleared up here without entering further into them. The views set forth here seem to be in good agreement with those of DRESCHER-KADEN (1935), who in a highly suggestive work arrived at similar results in quite a different way.

If certain parts of the Julianehaab granite are regarded as palingenetic, certain working hypotheses and principles of classification are obtained for future investigation, whose usefulness must be tried in future areal research. It will also be of importance for the further division of the pre-Cambrian of Greenland; for so far the boundaries of the Ketilides are not known. To the northwest similar formations seem to occur at Fiskernæsset and in the vicinity of Godthaab. It is very difficult to form an estimate on the basis of the literature. In Disko Bay and the surrounding districts an ancient mountain chain, the Agpatides, is known, which was investigated by KRUEGER (1930) and DRESCHER-KADEN (1935). Its relation to the Ketilides is at present impossible to define.

The Ketilides no doubt continue towards the northeast a long distance up the east coast (KNUTSEN and EBERLIN 1889). Whether they extend all the way to the Angmagssalik district and thus to the basalt area, it is as yet impossible to say. The descriptions given by WAGER (1934) indicate a certain probability. The series, which he designates as "Hypersthene-granite gneisses of Charnokite affinities", has corresponding parallels in South Greenland. But on the other hand similar series are found in several places in Greenland and the surrounding regions; according to the literature they occur in North Greenland; another characteristic series from Ellesmere Land has been brought home by P. SCHEI. Thus it can only be regarded as a sign that similar conditions have prevailed in these different regions. The grey gneisses and the plagioclase amphibolites which are further mentioned by WAGER, as also the metamorphosed and injected sediments, afford no clues for a comparison. The question must therefore still be regarded as an open one. The problem cannot be solved through petrographic comparisons alone; the method that would most probably lead to a solution would be a structural survey along the coast.

The question as to the chronological parallelisation of the Ketilides with the cycles in other pre-Cambrian areas will be briefly treated below.

The majority of the rocks which now constitute the topographic surface of the country, during a great part of the genesis of the Ketilides lay deeply buried in the earth's crust, partially in its lower storey (WEGMANN 1936). Gradually the cooling-front subsided in the body of the mountain chain, probably simultaneously with the cutting of the topographic surface. In this way large and important parts disappeared. Where all the material, then removed, is found now, which geosyncline received it, and where it has again been moulded into a new mountain chain, is not yet known, because the boundaries of the Ketilides are so far unknown.

The post-Ketilidian surface is still preserved in certain parts, viz. in places where it was later covered by younger sediments. Between this and the most recent granitic manifestations of the Ketilides there are a number of traces mainly consisting of a network of joints. On the whole the joints show fairly uniform directions with comparatively small variations. These directions are emphasized by fjords, valleys, and sounds. Notably in the lower parts of the country they are exceedingly distinct. They contribute to form the slightly broken surface which reminds one of the Norwegian and in part of the South Finnish skerries. The parts rich in joints were cleared out, the result being narrow street-like valleys running between steep mountain walls which often resemble huge buildings inclining slightly to one side. KORNERUP (1881) already called

attention to the joint systems in the surroundings of Holstensborg. Subsequently the problem was discussed in greater detail by KRUEGER (1930). The connection between the joints and the formation of furrows by freezing has been pointed out by POLKANOFF and by BUBNOFF on the basis of detailed studies in the Kola Peninsula and on Bornholm. I shall not, therefore, enter further into this aspect of the question.

Joints are the results of some of the movements to which the platform has been subjected after leaving the plastosphere. Upon more local studies the distribution proves to be very variable. The system as a whole seems to continue that of the youngest pegmatites. Accordingly a great part of the jointing is very old. Often a group of joints forms a unit of a length



Fig. 29. Diagram showing the joint-groups in the skerries off Julianehaab.

of 50—200 m, which is bounded by close-set, almost perpendicular joints. In one case this steep zone forms the centre of a fan, the joints on either side growing increasingly flatter; in other cases the fan will form on one side only; in transitional cases it is unsymmetrical (fig. 29). The steep and the flat joints may still contain pegmatites; if so, the latter are often mylonitised on one side. This is frequently the case in the skerries off Julianehaab. The bending flat joints may again form flatter zones with close-set joints, which thus divide the whole mass into floors, apparently independent to some extent in their internal arrangement. If we try to connect the movements reflected in the joint systems, a widening of the surface will mostly be arrived at. Thus they are comparable to the antithetic movements of CLOOS (1936). Owing to the character of my journey some typical areas only could be studied from this point of view.

The closeness of the joints varies greatly, both locally and over large areas. On Apokatak the distance in the gneisses is 0.5—2 m, while in the granites it is 10—30 cm.

North of Sarkak the following arrangement was traced over a long distance: for more than ten metres there were but few joints; then followed a narrow zone with many joints at intervals of from 5 to 20 cm, which was succeeded again by a zone with greater distances between the joints. This is the case in both orthogonal directions. Where two zones with close-set joints meet, deep holes filled with gravel will often arise. Similar cases are to be found throughout the area, but as a rule one or the other system prevails, so that the street-like furrows in one or the other direction are predominant; this is easily observable both in the



Fig. 30. Zone of crush-breccia; Kakortok Fjord. In the opposite mountain some dark dykes are seen.

coast lines and in the scenery. Everywhere the closeness of the joints seems to show a certain periodicity of varying size.

The investigated areas seem to show a widening; hence it is not too risky to assume that the basement as a whole has widened. It might be imagined that the mountain chain, which was built up during the preceding period, was split up, sliding on the still fluid substratum. The latter filled the outermost accessible cavities and crystallised there as pegmatite. In many cases this was crushed again and unakitised. In the larger zones of movement mylonites still formed at a certain depth.

When the pre-Gardar surface reached its present level, breccias were formed in the large crush-zones (fig. 30). In these the fragments are often fairly well rounded and are embedded in crushed gravel, which, when not later cemented, easily crumbles. These formations also indicate widenings.

IV. THE GARDAR FORMATION

A series of more recent events will be comprised under this name (cf. p. 13). They form a natural group, a cycle with both supercrustal and abyssal members. This cycle is not represented here as an orogenic cycle, but is possibly a repercussion of part of such a cycle which in other places has caused the formation of a mountain chain. The continental basement was not entirely transformed; it is, if we may put it thus, a kind of unfinished attempt to form a geosyncline. This character makes the formation especially interesting, all the more so because it is comparable with an orogenesis within the same area.

The sedimentary and volcanic formations representing this period have so far been found in several areas:

The first area is situated on either side of Tunugdliarfik Fjord; it extends northward to N. Sermilik, southwards to Igaliko Fjord. Another area may occur in the feeding area of the eastern glacier of N. Sermilik; v. MOLTKE (1896, pp. 104—105) states that he has found sandstones, diabase, and porphyry resembling those of the Tunugdliarfik area. A third area may occur in the feeding ground of the Sermitsialik Glacier. The glacier, especially its right part, contains a number of sandstones, silt stones, and porphyries, which may be derived from an area of the Gardar Formation. CROMMELIN (1937) too ascertained it from the sand samples collected there. A fourth area probably occurs below the glacier of Kobbermine Bay.

The three latter areas are concealed by the ice, but their existence can be inferred from the erratics. But neither their exact positions nor their sizes are known. Hence they will not be further dealt with here, but I shall confine myself to the Tunugdliarfik area. This area has been described by several earlier authors (GIESECKE, PINGEL, STEENSTRUP, JOHNSTRUP, USSING, etc.). For a more detailed description I refer the reader to the works of these authors, and shall confine myself to a discussion of some points which seem to me to be important or new, and which may illustrate the organic unity of the formation. The fresh observations were made last summer.

1. The area of Tunugdliarfik.

a. The sub-Gardar peneplain.

The sub-Gardar peneplain cuts deep into the body of the Ketilides; it mostly traverses Julianehaab granites, partly the light-coloured varieties, partly the varieties richer in hornblende. Northeast of Kagsiarsuk more well defined migmatites occur.

The peneplain now forms a deep basin. To the southwest it begins in the cape of Nugarsuk near Narsak (pl. 4), dipping inland below the quartzites and the volcanic formation. Between Tunugdliarfik and Kangerdluarsuk Fjord the plain begins at an altitude of nearly 200 m, and dips down below the mountain Nunasarnausak, where it is cut off by a fault. It must be assumed, however, that it has extended below the present area of the alkaline rocks. Near Igaliko it is divided into sections by a number of faults, some of which are shown on USSING's map (1912, pl. IV). The peneplain appears again at Nugarsuk south of Kagsiarsuk and north of this place. However, conditions here are somewhat complicated. Still another outcrop is found in Kiagtut Valley opposite Kagsiarsuk. To the north the peneplain seems to rise by several steps across the mountain tops. On the whole the basin seems to be bounded by faults. A large fault probably extends below the sound at Narsak. Its continuation extends right across to Kakortok Fjord (fig. 30), where it forms a zone of breccia several metres broad. Near Igaliko, too, there is a number of faults; the greatest throw is probably found at the foot of Kidtlavat. A fault zone likewise extends along and below Tunugdliarfik Fjord from Ipiutak to a point off Narsak. In this the old surface is divided into a number of blocks of different height. Thus the whole ancient surface is strongly intersected and does not any longer form a large coherent area. The greatest differences in level brought about by the faults must amount to 3 km, as also pointed out by USSING (1912, p. 290). Thus very strong differential movements are met with in this rather limited area. It is to be assumed that outside this area, also, a division into a mosaic of blocks existed, at any rate partially, even though the altitudinal differences were smaller. Even if a basin has existed from the beginning, it has now been strongly increased.

To begin with the sub-Gardar peneplain was not entirely level. It shows minor altitudinal differences which indicate a slightly broken ground, in which the old joints seem to have played a role. In some places the granite has disintegrated to a depth of several metres, in other places, often situated nearby, it is not so deeply affected. Nor is the surface covered in the same degree by arkose; it merely fills small hollows. In contrast to the sands conveyed there it has not been transported very far; it is the granite which has become so disintegrated as

to crumble. These arkoses are mostly of a deep red colour, and at the present day they are often very hard. They should not be confused with the easily crumbling granites which occur near to them both at Narsak and at Nugarsuk (opposite Korok Fjord), and which are due to the influence of the essexite rocks.

The large hiatus occurring between the structural surface of the Ketilides and the sub-Gardar peneplain is due to a removal of the lacking material. For a long space of time there was consequently no accumulation of material; this only takes place when the relief-energy is much reduced and the whole surface so flat that a depression may play a role as a basin. It means a change in the history of the area when it does no longer export material, but begins to store its disintegration products in internal basins. The formation of such internal basins must be assumed to correspond to a further widening of the supra-structure (cf. p. 59), by which some portions will subside. The accumulation basin no doubt extended beyond the present boundaries, and was of a somewhat irregular nature.

b. The Igaliko sandstone.

The Igaliko sandstone is largely of red and yellow colours. The metamorphic parts of it consist of hard, white, very brittle quartzite. The red tints may vary from pink and cinnabar over "*Lie-de-vin*" to purple and violet. All sizes of grain, from the coarsest sandstones to fine siltstones, are to be found. Near the arkoses there occur some red jasper-like beds; it is the finest weathered material, probably dust, which has accumulated here.

The grains of the sands are mostly rounded. In many places they exhibit a frosted surface, which is assumed to be due to wind-blowing. The grains mostly consist of quartz; further particulars as to the mineral composition will be given in a petrographical account. The lowermost beds are made up of highly felspathic arkoses; they are mostly of a strong red colour, but the colour may assume quite bluish tints. The grains are not rounded, as they have been transported very little or not at all; often they are merely disintegrated granites in situ. The grains are not sorted either. They may be embedded in a very fine red matrix, and may contain lumps of quartz and feldspar with sharp or rounded edges. These arkoses occur wherever the substratum is visible but in varying thickness. The material of the bottom-layers has not been removed, but has remained in the place; the overlying material was transported there. The arkoses and the superjacent white and purple quartzites are mostly very hard. This first series is without volcanism. The mode of accumulation seems for the most part to be wind-blowing.

Near Musartut Bay the series is covered by volcanic formations, probably the same as occur at Kagsiarsuk and Kiagtut. The latter occurrence is not shown on Ussing's map (1912, pl. IV), but is indicated as nepheline-syenite. It is of importance for the explanation of the area. Between the succeeding volcanic formations a series with deep red and yellow colours intervenes. At Musartut (fig. 31) the rocks have been worked for ornamental and building stones. At that place the sandstone



Fig. 31. Cross-bedded red and yellow sandstones near Musartut (Igaliko sandstones).

is much spotted with red and yellow. These spots are not primary, but are grouped according to the circulation possibilities in the rock, i. e. according to seams and joints. The sedimentation shows a highly varying grain-size. Red chert-like intermediate beds may be found, too. A distinct cross-bedding, but of a somewhat varying character, is observable throughout the whole series; thus in the Musartut series it is different from that of the lower series. Very likely the Musartut series was deposited in water-filled basins which would dry up temporarily; the sun-cracks point towards that possibility. Of other sedimentary structures, ripple-marks are known throughout the whole area.

The Musartut series is overlain by another series of volcanic rocks (fig. 32). It is succeeded by a series with many conglomeratic beds dispersed in swarms in the sandstone. Here the balls usually attain a size of a few centimetres. Volcanic phenomena may be observed, too.

The series terminates at Naujarsuit by a conglomeratic bed of a thickness of about 20 m. In this bed (fig. 33) the balls are in part very large, mostly well-rounded. Balls of a diameter of 10—20 cm are of frequent occurrence, but blocks of 50 cm or more may be found. Some of them are rounded along the edges only. The matrix consists of sand, coarse gravel, and small balls, the greater number of which consist of quartzite, some of arkose. A block with rounded edges only was made up

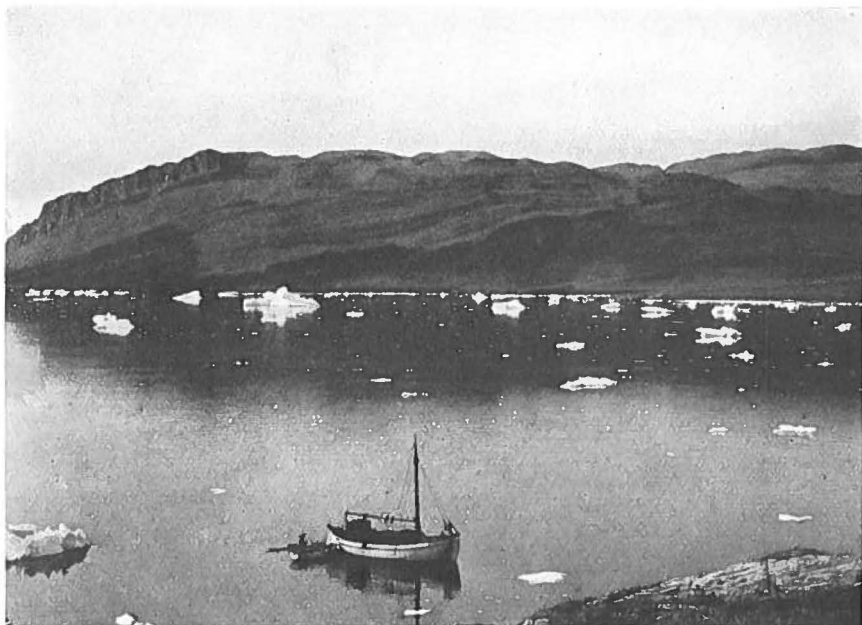


Fig. 32. Sandstones with volcanic beds, sills, and dykes, at Musartut.

of a kind of breccia containing arkose and clay-galls. This shows that the material has been redeposited several times before being embedded in this conglomerate. Some few porphyritic blocks occur. As far as can be judged, the greater part of the material is derived from the lowermost series. It is therefore natural to assume an ever increasing activity of the faults, so that erosion could set to work. In the raised part the lowermost beds were removed by erosion. The character of the deposition indicates rather a shore-deposit than a delta-deposit. The difference in material from the immediately subjacent beds indicates that the balls have been transported there from a place in which the deeper-lying beds were denuded.

The conglomerates are overlain by a huge series of light-coloured quartzites with several red beds and intermediate lava flows. The uppermost beds underlie the porphyry zone in the mountain Nunasarnak.

From this place the boundary is traceable in a high precipice towards N. Sermilik.

The whole formation may be divided provisionally into four sections:

- 4) The Ipiutak section with many lava flows;
- 3) the Naujarsuit section with conglomeratic beds terminating with a large bed of conglomerate (Fig 33);



Fig. 33. Conglomerate at the base of the mountain Naujarsuit.

- 2) the Musartut section with highly mottled sandstones and products of the explosive volcanism;
- 1) the Nugarsuk section with arkoses and the lower quartzites.

The question as to how great a part of these sections is represented in the southwestern part of the area is at present somewhat difficult to decide. Very probably the lowermost section, at any rate, is represented at Narsak and below Nunasarnausak. At Narsak it is overlain by explosion breccias, and would consequently correspond to the Musartut section. But events may here have taken a different trend. At any rate the sandstone series is not by far so thick here as in the northeastern area. Possibly the black shales below the Nunasarnausak correspond to similar black shales at Musartut. Below Nunasarnausak the sandstone is nearly 300 m thick, at Narsak nearly 100 m, while the whole series

in the northeastern area is estimated by STEENSTRUP (USSING 1912, p. 104) at 1200 m, from which should be deducted about 300 m for the intrusive sills. It has turned out that a number of the intercalated volcanic rocks are not sills, but belong to the series itself; we are therefore not in error if we estimate the thickness to more than 1000 m.

The filling of the different parts of the basin has varied somewhat. This may be due partially to the irregular shape of the basin, but probably also in some degree to the ununiform movements in the different marginal areas. There are in the main four very strongly red-coloured subdivisions; one lies right at the base, the other in the Musartut division, a third forms the beginning of the huge white series in the Naujarsuit Mountain, and the last, smaller, but very intensely coloured subdivision is situated immediately below the porphyry series. We might assume that these series, too, corresponded to a regeneration of the erosion by which the more strongly disintegrated material was transported into the basin. This material may originate from the bed-rock, but probably in part also from the volcanic material which was abundantly dispersed over the landscape. This view also has reference to movements in the basin and its surroundings. Probably the material of the upper sections was for a great part supplied by the denudation of the peripheral parts of the basin.

c. The volcanic formations.

USSING seemed to be much in doubt as to whether the sandstones were interbedded by other forms of rock than sills, and therefore expresses himself with great caution (1912, p. 18). The recent observations supplement those of USSING and STEENSTRUP in this field in a happy way.

No doubt many sills of different nature occur both in the sandstone formation and in the actual overlying porphyry formation; but in many cases the supercrustal volcanic origin is very distinct.

The first great manifestation is no doubt the violent explosions at Kagsiarsuk, at the Kiagtut Valley and at Musartut (Fig. 34). Whether all of them are synchronous, cannot be ascertained at present; but according to their position they belong to the same episode. In all three localities we find immense beds of explosion products, in part fine ashy tuffs (fig. 35). Between these occur beds of lapilli, which vary from the size of a pin to the size of a pea. They are very distinct on the weathered surfaces south of Kiagtut Valley, where they resemble layers of caviar. The complex at Kiagtut is some 20—40 metres thick, and has perhaps been even thicker. It dips slightly towards the east and extends nearly halfway between Kiagtut and the small valley Angmagsivik. It is intersected by many vertical dykes. At the margin towards the nepheline-

syenite there seems to have been a fault. This fault is intruded by red foyaitic rocks, which contrast strongly with the syenites.

The material of the finer explosion products is mostly lava. If the elements are larger, the material is mixed, and gneiss, granite, quartzites, and different dyke rocks, partly bubbly, partly massive, constitute the elements of these breccias. The largest blocks are 1 by 2 m; they have a dark marginal zone about 10—20 cm thick. Blocks consisting of brec-



Fig. 34. Explosion breccia near Kagsiarsuk.

cia occur, too. At Musartut the edge of an explosion tube is still to be seen. Another one is found north of Kagsiarsuk. Both north and south of this place the pre-Cambrian basement is completely crushed. It falls into small pieces, between which thin rusty films are found, many of them containing quartz, fluorspar, and other minerals. The rocks are further strongly chemically affected along the crevices, so that their composition has been changed. The red porphyries and the dark porphyrites penetrate the whole mass, but are not crushed in the same manner. The splintering must accordingly be older. The zone extends from Kagsiarsuk across the fjord into the mountain north of Kiagtut Valley. It has also some connection with the boundary fault. But the movements that have left the most visible marks are older than the majority of the volcanic dykes. At Musartut it would seem that the ejected masses have slid or flowed along to some extent, forming mud-

streams, as described from volcanic catastrophes of the present day. Very possibly these explosion tubes are the same phenomena as have previously been described under the name of sandstone dykes.

These explosions seem to be of a certain chronological importance, too; over a large area they provide a certain indication of time. Thus



Fig. 35. Volcanic tuffs and lappilli south of Kiagtut Valley.

in some of the black schists volcanic material (ashes) is found, which is associated with one or the other of these explosions. There seem to be two lines of occurrences: one at Musartut, Nugarsuk, and south of Kiagtut Valley, the other at Kagsiarsuk and north of Kiagtut Valley. Others may be found on the coast of N. Sermilik. A large number of younger dykes extend in the same direction and in the same zone, being especially remarkable at Musartut and Kagsiarsuk. STEENSTRUP and KORNERUP's (1881, pl. III) description contains a lithography of this scenery. The dykes, broad or narrow, traverse the landscape as long, dark walls, setting a certain Icelandic stamp on the surroundings of Kag-

siarsuk. All these dykes strike almost in the direction NE—SW; some few dykes only cut across this direction. At Kagsiarsuk the dykes strike across the fjord, lending a striped appearance to the mountain north of Kiagtut.

At Narsak also the quartzites are overlain by explosion breccias (pl. 4). Most of them are partially embedded in the essexite and accordingly somewhat metamorphosed. A group of occurrences is situated

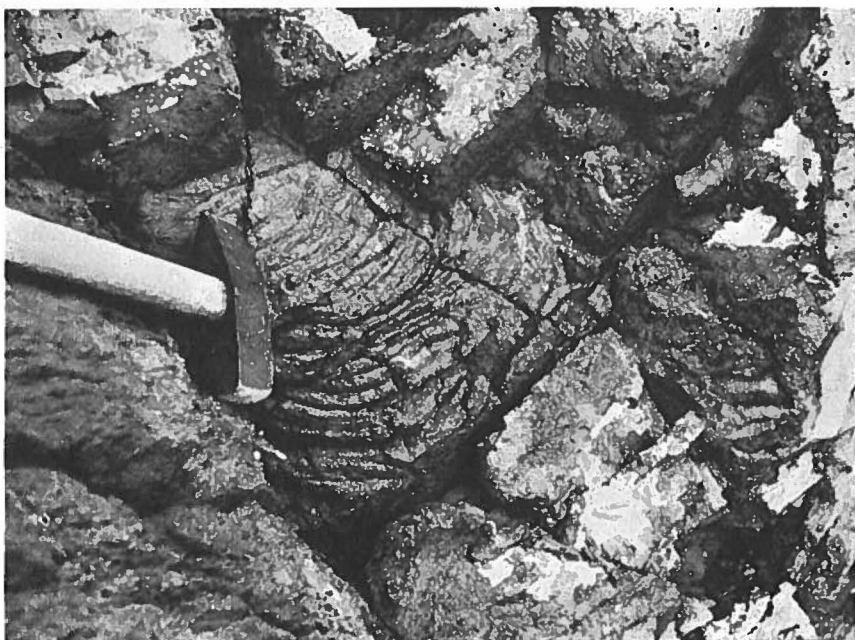


Fig. 36. Flow marks in lava flow between Ipiutak Islands and Naujarsuit.

near the sheep-farming station, another west of the settlement. Whether they correspond stratigraphically to the occurrences in the interior of Tunugdliarfik, cannot be decided at present.

On top of the series including the products of the explosive volcanic activity at Musartut the series with the abundant conglomerates begin. The rejuvenation of the relief seems to have been associated with this explosive phase. In the Naujarsuit division, and even more in the Ipiutak division, a series of beds are found which have, no doubt, been products of external volcanism. Many of these beds show not only a "slaggy structure", but also various phenomena which can be easily recognised in the modern lava flows. In many of them traces of the direction of the flow are found in the form of roll- and cord-shaped surfaces (fig. 36). In others traces of big bubbles may be seen which burst in the form of small hornito-like formations. In most beds the greater part of the

surface is full of small bubbles which lend to it a slaggy appearance. Some of the bubbles are older, some younger than the flow; some are transformed through the rolling folds, others are not. Larger volcanic flows are built up by alternately more or less bubbly beds, so that above a more bubbly horizon an almost massive lava begins. These beds attain thicknesses of 10—40 cm, and form the upper part of the flows. In several cases the lower part of such a bed is glassy and schistose, and it can be observed how the bubbles do pass downwards into small long streaks and subsequently into schistose beds. Here similar sliding phenomena are found to those described by PHILIPP (1936) from Italian lava flows of the present day. In the cases observed it is the bubbles which pass into sliding surfaces; possibly the opposite phenomenon occurs, too, namely that the bubbles grow along the sliding surfaces. The individual flow beds seem to imbricate on one another, indicating the local directions of flow. The hotter lava which slides across a bubbly stream exerts a certain influence on the substratum. A kind of crystal-turf of finely tiled to needle-like feldspars makes its way down into the underlying slaggy mass. The sizes of the phenocrysts in the bubbly and in the massive lavas differ greatly. Lava-streams overlying each other unconformably may be found, too. In some cases a great deal of material has been removed before the next stream arrived.

A further proof of the extrusive character is that many fissures and depressions, partly between the flow forms, are filled with horizontally bedded fine sand or dust. The surface of a sill will not retain such fine structures. To avoid misunderstandings I shall point out again that unmistakable sills occur, too. As proofs of these may serve that they include fragments of the roof. In a more detailed survey it will be necessary to decide to which category each individual bed of igneous rocks belongs. During my rather flying survey I was content to ascertain the character of a number of beds without investigating these one by one.

The sandstone formation is overlain by an immense body made up entirely of igneous rocks. Both streams, tuffs, explosion products, sills, and dykes occur, sills and streams forming the main part. The other forms will be important guide-horizons in a more detailed study and mapping; but for the solution of another problem, too, they are of great importance (cf. p. 76).

I have not entered here into a petrographic description, as the working up of the large material collected will take some time. Much information was supplied by USSING. A new account must be given a much broader basis and requires, therefore, collection and working up of a much larger material. Both the smaller and the more transformed types show an immense wealth of different types.

The course of volcanism shows a uniform development, and forms a volcanic cycle (RITTMANN 1936). It begins with explosions, after which the basin subsided somewhat. It continues with gassy lavas, and terminates with less gassy products. Several of the latter will remain below the surface as dykes and sills.

The presence of the many volcanic dykes means a considerable widening of the surface in the direction NW—SE. That is to say, that a number of points of the present Tunugdliarfik and certain points of N. Sermilik were removed from each other during that period. Over a short stretch at Musartut this widening comprises nearly one half of the area. North of Kiagtut and at Kagsiarsuk it amounts to almost one-third. In some areas the dykes occur close to each other, in other areas they are less close. Hence it is difficult even now to give figures for the widening of the whole area; but the movement of the whole mass may be estimated at one kilometre. This movement is accordingly a continuation of the tendency that set in after the formation of the Ketilides, and which found its expression in the breccia zones, which, as is well known, are partly older than the volcanic dykes. The breccias are cut across by sanidine porphyrites; some doleritic dykes contain inclusions of tectonic breccias.

The same tendency to move is traceable later, too. At Nuna-sarnak, above Ipiutak, the sandstone as well as the porphyry formations are dissected by a number of smaller faults; they dip some 70—80° towards the fjord, and strike along its direction; the individual blocks between them dip gently in the opposite direction. They are typical antithetic movements (CLOOS 1936). During all this part of the Gardar period the Tunugdliarfik area was subjected to widening. Thus there has been no folding in the sense that this piece of the earth's crust has been squeezed together.

d. The abyssal rocks.

It is especially this group of rocks which was closely studied and described by USSING (1912). It will suffice, therefore, to refer to his classical mineralogic-petrographical investigation and to his maps. I shall therefore confine myself to giving here some few structural remarks, some observations, and their interpretation.

USSING distinguished between two series: one extending from the essexite over nordmarkite to arfvedsonite-granite; the other comprising the nepheline-syenites and their whole suite. Both series are of a very different tectonic character.

The essexite series.

Essexite is found in the surroundings of Narsak (pl. 4) and at Sigsardlugtok on the island Tugtugtok WSW of Narsak. In the latter

place it is present in two broad dykes. In the northern locality large accumulations of labrador felspar occur, indicating a tendency to form anorthositic lumps (fig. 37). At Narsak also the rock varies. Possibly it should more correctly be termed essexite-gabbro. According to its mode of intrusion and its distribution it seems to have intruded along a broad NE—SW directed fissure, and to have subsequently spread out into flat sills or laccoliths in the basement granite and in the quartzite

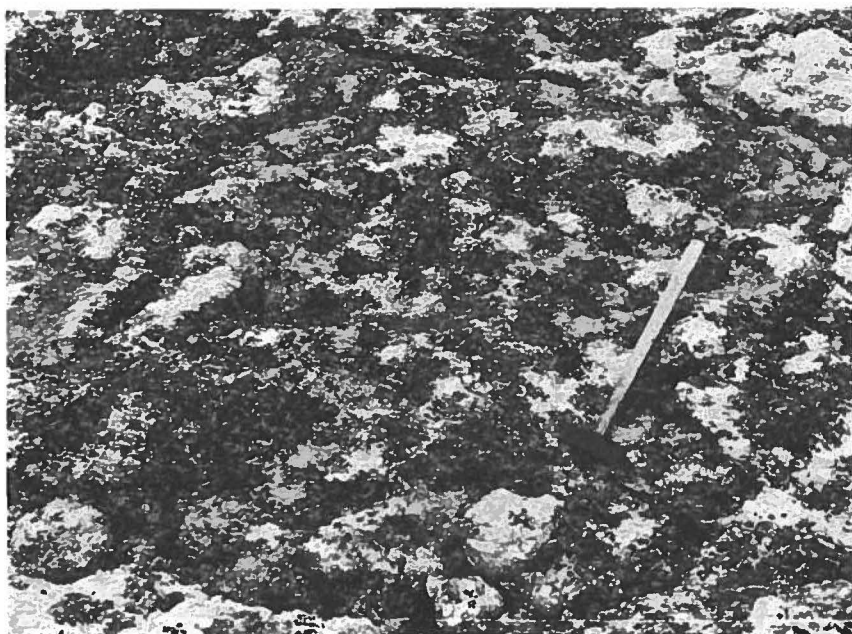


Fig. 37. Anorthositic lumps in the essexite gabbro near Sigsardlugtok west of Narsak.

and the porphyry formation. The essexite shows traces of a number of different movements. Round the harbour of Narsak the large felspars often seem to indicate a horizontal orientation. However, it has not been ascertained whether these felspar tables have been orientated according to the last flow. Large irregular masses of very coarse essexites are embedded in more fine-grained rocks, but none of them can be proved to be fragments. The coarse-grained rocks often seem to grow into the less coarse ones; in this way they come to resemble certain pegmatitic masses which impregnate the granites. On the other hand, lumps rich in labradorite are embedded in the darker varieties. In the boundary zone towards the basement the large felspars have often been ruptured. After solidification of the mass the movements have continued, especially along steep NE—SW striking surfaces. In some of them the striation seems to show that the northern part advanced towards the southwest; often

the essexite has become mylonitised. Further movements procured room to the succeeding rocks.

In a similar way succeed the nordmarkite and the arfvedsonite-granite. On Ussing's map (1912, pl. IV) the distribution near Panernak is somewhat sketchy. Actually the three rocks interlock with a number of varieties in the form of stripes; these stripes correspond to steep dykes running NE—SW or to small massifs. In the youngest aplites,



Fig. 38. *Boudinage* of naujaite in lujaurite. The cape at Nunarsarnak.

also, movements are still registered in the form of mylonitic zones. On the northwest side of Kusinga Valley the distribution is very similar; the steep walls here give a good insight into the structure. Here, too, the nordmarkite and the arfvedsonite-granite are very inhomogeneous. The veins are steep, striking NE—SW. All fine-grained portions and more acid dykes run in the same direction. Part of the nordmarkite crumbles easily, and in a crumbled state has a very similar appearance to that of the Finnish Rapakiwi. The small particles into which the rock divides seem to be arranged in a sort of horizontal layers. Thus they form a more or less right angle with the direction of the flow. If we follow up these layers through a large profile (NE—SW), they will show a kind of zig-zag, the steep sides of which dip towards the northeast, the more level sides towards the southwest. This seems to correspond to certain joints which indicate a tilting towards the south-

west. The more or less horizontal layers probably indirectly have some connection with the *mise-en-place*. Farther towards N. Sermilik also the nordmarkite is no homogeneous mass, but divided into compartments by steep zones. The nordmarkite and the granite are often filled withmiarolitic cavities and small druses which facilitate disintegration. When the rock is subjected to pressure these cavities will guide the cracking; the whole rock will be full of minor cracks, so that it will easily be reduced to gravel.

Between Narsak and N. Sermilik these abyssal rocks are penetrated by a series of younger dykes of different varieties (fig. 63). Some of them have been described by USSING. However the greater part of the dykes piercing the quartzite are cut off below by the essexite, which helps to separate the dykes. By far the greater part is older than the essexite. The younger dykes are mostly narrow, and strike nearly in the same direction as the former.

Thus during this whole period of intrusion a system of fissures formed, into which time after time the essexite and its accessories intruded, and which re-formed in the consolidated rocks. These fissures strike in the direction NE—SW. On a level with the present topography the essexite has intruded along the horizontal joints, the result being large sills or laccoliths. At Narsak, at any rate, there are no batholiths. Since it is the intrusive forms in particular which are of importance for the succeeding discussion, I have given special attention to them, for the time being disregarding the particularly interesting phenomena of digestion and contamination, which will be dealt with in another paper.

The Ilimausak massif.

The Ilimausak massif, called also the Ilimausak "batholith", is divided into two parts by the Tunugdliarfik Fjord. The southern part of it is further accessible from Kangerdluarsuk Fjord. On the southern side it bounds on the basement, in the mountain Nunasarnausak on the Igaliko sandstone and diabase, and at Agpat on a small area of quartzite. The actual Ilimausak massif is for the greater part surrounded by the porphyry formation. At Tunuarmit, too, it is in contact with the quartzites. As pointed out by USSING, it forms a cup-shaped edifice, whose deepest point lies somewhere in the fjord between Iglunguak and Tupertsuatsiak.

This massif is probably one of the massifs best described petrographically, at any rate considering the "exotic" character of the country. USSING set forth a detailed theory of its *mise-en-place* (USSING 1912, pp. 283—367). It will be difficult to give a better description of the minerals, and a better account of the observations made by USSING. But a number of fresh observations have been added, and in a petrographic

respect it is possible to gain a deeper insight by means of the methods which especially aim at petro-fabrics (SANDER 1930). If it is attempted here to give a different interpretation from that given by USSING, it may be justified by the fact that from 1912 to the present day our experiences of the genesis and the *mise-en-place* of igneous masses have been increased and partially altered, that accordingly it must be justified to attempt to interpret conditions from more recent points of view. In a paper abounding in ideas BACKLUND has already attempted to give a new and broadly planned interpretation of USSING's description (BACKLUND 1932). He seems to have fully utilised the observations recorded by USSING, so that it would be difficult to add anything without fresh observations. When I approached the classical localities with respectful interest it was not my intention to seek any new explanation. I tried to find structural and kinetic characteristics which might speak in favour of one or the other of the available interpretations. During this work I made a number of observations which could not very well fit in with any of the previous hypotheses, but which pointed in another direction. I tried to arrange them into a new working hypothesis, but must admit that it has not yet been tested as the other two in the laboratory. The contradictory observations accumulated at a time when the whole area could not be investigated after the new viewpoints. I shall therefore explain here quite briefly the most important points, trusting that I shall be enabled later on to discuss the subject at greater length. When nevertheless I shall explain here the new working hypothesis, although the work has not yet been completed, it is in order to submit it to the kind estimate of those colleagues who are studying similar problems, and who, animated through these lines, may have an opportunity of observing similar conditions in their working fields, so that some problems concerning the alkaline rocks may be discussed on a new basis.

In a concluding chapter (pp. 362—367) USSING discusses the assimilation of pre-existing rocks by the magma, and comes to the following result (p. 367). "It will, thus, be seen that the assimilation hypothesis is not in this particular case disproved by the 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 a rather large scale within moderate depths of the earth's crust, may be in some cases a reasonable working hypothesis." Since this was written, the questions about assimilation have obtained increased interest, so it is understandable that precisely this aspect of the problem must attract increased attention. The best contacts for these studies are afforded by the surroundings of Tunuarmitut, which are described by USSING (pp. 72—77).

The lujaaurite is greatly varying in that locality. Not only green lujaaurites containing ægirine and black lujaaurites containing arfvedsonite are found here, but the texture of the rock is very variable, too, so that it is possible to follow up certain beds even if their mineral content and colour vary somewhat. It is rather fine-grained and split readily into thin plates. This fissility is also reflected in the texture. It proves to be traces of movements, the greater part of which, however, must be pre-crystalline. The texture somewhat recalls the many stressed and re-crystallised amphibolites, if we disregard the different composition of the minerals. That it is a texture due to movements appears most distinctly round the so-called naujaite "lenses". Actually they are not lenses, but "*boudins*" which are embedded in the lujaaurite (fig. 38). The naujaite fragments are portions of layers which by unconformable extension slide from one another. The more ductile lujaaurite bends in between the pieces sliding from each other. On a careful study the suture between the overlying and the underlying lujaaurite will, as a rule, be detected. The whole structure shows all the characteristics of the classical *boudinage* (WEGMANN 1932). The separation of the naujaite into fragments has accordingly not taken place at the magmatic stage, but at a stage at which the lujaaurite behaved like a crystalline schist. Accordingly it is not the lujaaurite that has brecciated the naujaite, but this "brecciating" has taken place later. It is a kinetic phenomenon of a different character from that of an intrusive breccia. It is connected with the widening of the more horizontal structural planes; it is also reflected in the bending down and the partial folding of the Ilmausak massif. In most rocks the movement is to a great extent pre-crystalline. The present texture of the lujaaurite is therefore doubtless a metamorphic texture as compared with the previous state: it has undergone movement and recrystallisation. On its projecting corners only the naujaite shows visible traces of movements. This contrasts somewhat with USSING's assumption (p. 157) that the naujaite and the lujaaurite form together an intrusive breccia, the lujaaurite having intruded into the naujaite.

Supposing a connection of the naujaite *boudins*, we shall have a system of dykes and sills spreading in the lujaaurite. The dykes extend in the direction NE—SW. This alone might be an argument for assuming that the naujaite has penetrated into the lujaaurite rather than the opposite. But what, then, has the lujaaurite been before? It is a very important question, because it is the main rock of the massif. USSING states as follows (p. 157). "Roughly estimated, the volume of that part of the lujaaurite-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." Recent tectonic studies can only confirm USSING's statement.

It may be emphasized that the facies varies from bed to bed. It is peculiar, however, that in the lujaurite also the characteristic differences are found which are shown by the individual beds in the surrounding porphyry formation. They are, if we may put it so, translated into

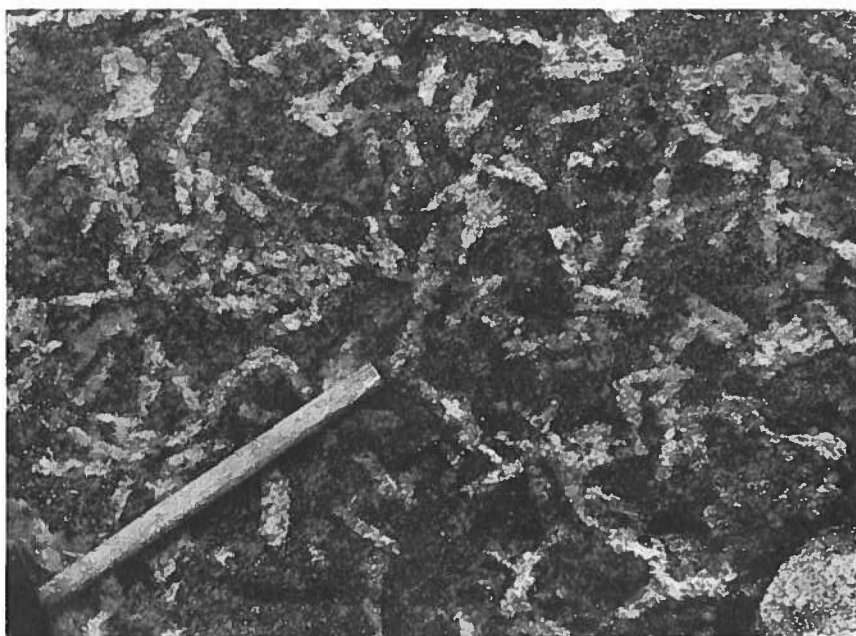


Fig. 39. Naujaite near Nunarsuatsiak.

"lujauritish"; if one has learned the "translation" at the contact, the whole does not any longer seem quite incomprehensible. If moreover the structure of the volcanic breccias are found in the massif, viz. at Nunarsuatsiak (fig. 40), it is very difficult to avoid reflecting as to the primary nature of lujaurite. All observations tend to show that the lujaurite is a metamorphic correlate to the porphyry formation.

If we try now to pursue the course supplied through this working hypothesis, we come to the question: what, then, is naujaite? The mineral composition and the chemical analyses give no information in the first instance. If, however, we consider the intrusion forms, and compare them with the other intrusion forms in the porphyry formation, there is but little doubt that they should be correlated with the essexite-gabbroes. On attempting to control this thought, one is struck by the

many structural similarities. The naujaite, too, must in this case be designated a metamorphic rock. Its mineralogical texture points in the same direction. The chemical transformations which lead to naujaite and lujaurite are fairly parallel, and are no hindrance for this hypothesis; however, this aspect will be discussed later together with the mineralogic-petrographical questions. Through this working hypothesis the whole problem becomes a question of metamorphism and no longer of crystallisation from a molten mass. All the complicated intergrowths and the strongly poicilitic minerals will be more easily understandable (fig. 39). If we accept this hypothesis, four-fifths of the massif (the lujaurite and the naujaite) will find their explanation. The pulaskite, the foyaite, and the arfvedsonite-granite which form the roof, are explained in a similar way. USSING already pointed out the relationship of the pulaskite and the foyaite with the nordmarkite. The relationship is not only mineralogical, but also structural. If it is assumed that a similar sequence of intrusions to that of Narsak is found in the Ilimausak massif, it will be understood that the uppermost rocks are granites. The transformation, which is complete in the lower part of the Ilimausak complex, did not reach beyond the lower portions of the nordmarkites and the granites, part of which form the pulaskite and the foyaite.

The arfvedsonite-granite is a convergence type. It arises on the one hand as a contamination product of the magmas of the essexite series with the old basement and the sandstones. On the other hand it arises through the wall-action of the Ilimausak massif and the quartzites at Tunuarmit. The latter retain some of the structure of the sedimentary rock. USSING, too, was aware of these transformations. They are accordingly autochthonous. Their contemporary transformation with the rocks of the porphyry group to lujaurite is distinct. There can be no question here of gravitational differentiation. The arfvedsonite granites at Narsak and below the Ilimausak peak are no doubt for the greater part allochthonous masses; they have moved in a molten state up through the fissures. The genesis, therefore, is somewhat different, but the mineral composition similar.

The augite-syenites are limited to the large faults on either side of Kangerdluarsuk and below Kidtlavat. Through this hypothesis their function will be more easily understood. The most difficult feature to explain, both as regards the older and the new theories, is the bedding of the kakortite. It is explained by USSING as a rhythmic gravitative precipitation of crystals which sank to the bottom of the batholith existing at that time. His explanation is a very plausible supposition, so obvious that it seems to anybody who has not seen the conditions in nature to be the only right and the only possible explanation. However,

a number of observations have been made which dampen the enthusiasm about this simple hypothesis, and which induce to greater scepticism; one understands why USSING expresses himself cautiously in several places, more cautiously than many of those who have reproduced his theory. I must confess, however, that my observations do not yet suffice to form a sufficiently reliable basis of another explanation, and I shall not, therefore, go further into this point.



Fig. 40. Transformed volcanic breccia in the Iujaurite near Nunarsuatsiak.

Thus three hypotheses have been set forth as explanation of the origin of the alkaline rocks of the Ilimausak massif. Two of these are expressed in the designation itself "batholith". By the adoption of this term the course of thought to be followed has become fixed. The two hypotheses which at this cross-road have made their option for the batholith are those which assume the existence of an agpaite differentiating magma. One (USSING) assumes a gravitative differentiation through crystallisation; the other (BACKLUND 1932) is based on two principles, which the author expresses as follows (p. 18): "the principles (a) of convective heat circulation, (b) of the agpaite type of differentiation (FERSMANN)". The new working hypothesis may be defined as follows: The Gardar Formation was intruded by a series of abyssal rocks and syntectonic rocks embracing the series essexite-arfvedsonite-granite. A very large part of this edifice, the intrusive rocks as well

as the wall rocks, were subsequently transformed through imbibition of solutions, thus turning into alkaline rocks. This conversion and addition increased the volume of the rocks, bending the deeper parts downwards; a rearrangement had to take place in the available space. It is this bending down and partial folding which characterises the wall of Tunugdliarfik, and which resulted in the *boudinage* of the naujaite. Most of these rocks are accordingly fairly autochtone, i. e., their one component rests still in a similar position to that which it occupied before the transformation. The other component was added. Such mixed rocks which consist of a fixed and an added component are called migmatites (SEDERHOLM 1923—34). This hypothesis might therefore be called the migmatitic hypothesis.

In the Ilimausak massif the relations are comparatively easy to demonstrate because the older structures are preserved. But in places where the converted masses have continued to move, it may be difficult to ascertain. Where these mixed rocks can emigrate through fissures, or where they are squeezed out, there is but little hope of gathering observations in support of this hypothesis. Hence it is obvious that the more speculative hypotheses operating with differentiation in the depths will be far more easy to apply there, especially since a smaller number of observations in the field are required, it being necessary only to force the chemico-mineralogical status into the pattern of the differentiation theory. This account may perhaps, even though it should not convince, induce to some caution in putting the series of alkaline rocks into ready-made patterns.

The solutions added may be assumed to be the last remnants of the essexite series. If so, it becomes in part an autopneumatolysis. In these pneumetolytic solutions, besides Cl, CO₂, P₂ O₅ and rare earths, fluorine and zirconium are especially characteristic; fluorine is especially so, because it is found so frequently throughout southern Greenland, and seems to play a certain part in other rocks, too. In the Tunugdliarfik area the F-bearing minerals are well known, especially from the localities Kangerdluarsuk and Narsarsuk near Igaliko. In addition they occur in many other places, mostly in the form of fluorspar; it occurs for instance at Musartut and abundantly in the fissures at Kagsiarsuk and north of the Kiagtut valley. It forms dark ink-blue coatings in the cracked zones. The baryte, which occurs in abundance at Kagsiarsuk, but which is recorded from Musartut and Igaliko also (BOGGILD 1905, p. 179), seems to belong to the volcanic phase. It is recorded by USSING (1912, p. 221) from the Ilimausak porphyries. Fluorspar further occurs in fault breccias right across to Julianehaab Fjord (fig. 30). The rocks in these zones are often strongly transformed, assuming red, deep red, and finally purple tints. It is by the aid of these tints one soon learns

to recognise the zones even from a distance, and afterwards it is easy to find some crystals. A somewhat greater occurrence is found within the area near Panernak (USSING p. 100). It rests on fissures which carry a great amount of quartz also, and which run in the direction NE—SW. The distribution of the fluorite over the area of Tunugdliarfik is so dense that it must be assumed that the processes which set free the fluorine required, must have been going on below the whole area.

The so-called Igaliko-"batholith" is of a somewhat different composition (USSING 1912, pp. 226—281), at any rate the portions known so far. With the exception of some augite-syenites, nepheline-syenites alone have hitherto been described from these areas. Only a small part of the contacts are known. The southwestern side of the batholith was studied by USSING; part of the western side by ØDUM (ØDUM 1930). Last summer a further portion of the contact was discovered south of the Kiagtut Valley; here the syenite bounds on the quartzite and part of the lower volcanic formation. At Igaliko it bounds on the sandstone and the basement rocks; in the Eastern Valley of Igaliko Fjord (ØDUM) on granite and the gneiss terrain. USSING points out that the known part alone represents the largest area of nepheline-syenite known in Greenland. It is not yet known how far it extends towards the inland ice. Very probably it also extends northward east of the innermost part of Tunugdliarfik; for erratics of nepheline-syenite are very often found in the river-beds there.

The massif between Korok and Kiagtut is penetrated by a large number of dark dykes, which can be detected even from a long distance. Hence it is astounding that USSING states (p. 237): "In the nepheline-syenite only a few dykes have been observed". Of these he mentions "two or three" in the large valley east of Usuk (near Igaliko Fjord) and two dykes in the mountain west of Flink's Dale in Korok. It was impossible for me to trace the whole network of dykes that could be observed in this massif. Many of them may be fairly young; but many are no doubt older and transformed. It is a case like that of the pre-granitic dykes which are preserved in the granitised areas (SEDERHOLM). It may now be asked, by what rocks were these dykes surrounded before the nepheline-syenite became their wall-rock? Here, too, the existence of a pre-nepheline-syenitic rock may be assumed; and we arrive at the hypothesis that the present nepheline-syenite with its dykes is the product of a metamorphism. But what rock existed before that time? South and north of Angmagsivik nebulitic structures may be observed which may be interpreted as relicts of an earlier rock. In this case it must be the rocks of the ancient basement; but more thorough investigations are required before this question can be settled. The contact at Igaliko must be a contact of movement similar to that found

on either side of Kangerdluarsuk and below Kidtlavat; the presence of augite-syenite is indicative of this. The contacts in which the nepheline-syenite is directly adjacent to the basement rocks, as figured by ØDUM between Østfjord Valley and Jespersen Valley, must accordingly be very illustrating; unfortunately not very much is stated about these important phenomena. Between Nugarsuk and Kagsiarsuk, at the northernmost part where the basement granites crop out on the coast-cliffs of the fjord, they are very strongly affected by the contact; however, the actual contact or the transition to the nepheline-syenite is absent. Apart from the observations of USSING and the rather few observations of the present author nothing is known about the internal structure of the massif.

A combination of intrusive movements and transformations is exhibited by the nepheline-syenites which extend from Ekaluit and Grønne Dal near Ivigtut across to Ika Fjord. They occur partly as a broad dyke, but also form sill-like or laccolithic offshoots into the basement, for instance across Ekaluit Valley. Both cooling contacts, where the wall rock was comparatively cold and where no reactions could take place, and places where the products testify to a chemical activity, are found.

If we try to obtain a general view on the basis of the new hypothesis about a metamorphic origin of the strongly alkaline rocks, we shall find a certain parallelism in the development of the first part of the Gardar Formation and the essexite series. The volcanism is initiated by the explosive manifestations. Accordingly there has been an accumulation of volatile components which have at last made their way through the roof, which at that time was not, probably, so weak as later on, since it was able to withstand the strong pressure of the steam for a longer period so that large quantities could accumulate. Subsequently lava intruded into the fissures which then opened; at first they were very rich in gases, but in the course of time the gas component seemed to decrease. If it is assumed that large new quantities of volatile constituents accumulated after the crystallisation of the essexite series — this time, however, not below a cold and resistant roof, but a roof which was much heated in its lower parts and much dissected in its upper parts — these components, instead of causing explosions, might have caused chemical reactions with the heated rocks of the roof and have thereby initiated the series of transformations which resulted in the formation of lujaurites and naujaites. A further indication of this is the high gas content of the younger dykes, e. g. in the Kusinga Valley (fig. 64). Thus after the solidification of the nordmarkite, gassy lava masses were found below Narsak. If it is assumed that these volatile components were

of the lamprophyries were distinguishable from the later dark dykes, since they have been partially included in the Ketilidian movement or contain pegmatitic veins.

The dykes exhibit all degrees of thickness, varying from veins a few millimetres thick up to some 30—40 metres, in some cases forming even small massifs. In some zones they may occur at close intervals, e. g. at Arpagfik, Ika Fjord, Nyeboe Canal and Torsukatak, Brede Fjord and across to Skovfjord, at Kakortok Fjord, extending through the mountains near the church-ruin and into Kidtlavat, South of Kangerdluarsorujuk, and in Unartok Fjord. Some of these swarms can be traced over large distances, others are less extensive. Most of them are composed of dykes varying from some few decimetres to some metres; broader dykes are rarely met with in these zones. The smaller ones, of which a general view can often be gained in the field, are often long lenses arranged "*en echelon*". As regards some larger dykes, too, this arrangement can be ascertained; probably it is widely distributed. In some cases horizontal or vertical displacements of both sides can be ascertained, in other cases both sides seem to show the same relations as prior to the intrusion of the dykes.

The *en echelon* arrangement allows one in many cases to ascertain the tendency of the movement. It is mostly antithetic. The lenses may vary from a length of some few decimetres and a width of half a centimetre (Kangerdluarsorujuk) to a width of some metres and a length of 30—40 m (SE Arsuk Island). Another very characteristic feature is the dykes jumping across from one jointing plane to another; developing the form "*en bayonet*". On closer examination it proves that several bayonet jumps and "*en echelon*"-forms occurring near each other do not show the same direction. They are accordingly links in a larger system in which not all movements show the same trend. This, again, agrees with the observations that may be made in the fault and breccia zones.

The dykes are to a great extent orientated along the direction of the fjords, but many run across this direction. The main trend varies in the different parts of the country. The orientation further varies with the different generations which compose the group. By far the greater number run in directions varying about SW—NE, in part even E—W. In many places flat sills occur with all transitions to dykes; some are wavy, originating from a steeper portion of the dyke. A more detailed mapping may inform us of the widening of the land during this period, and of the kinetics of the formation of the basin (cf. p. 61 a. s).

The dykes mostly have glassy margins; small dykes are most frequently quite glassy. Fluidal structures and series of bubbles often occur. The rocks are much chilled, the difference in temperature between

the magna and the wall rocks having been very great. This difference has decreased in some cases in the later generation. In some cases the wall-rocks along the larger dykes, especially at the intruding corner in the bayonet-jumps, have melted.

The dykes are younger than most of the fault breccias, since in many cases they intersect the latter, and in even more cases the dykes contain fault breccias and gravel. In some dykes this gravel is well preserved, but all transitions can be traced till it is completely assimilated; some are corroded and gradually digested; others are melted and subsequently re-absorbed. In some cases very peculiar rock types will result. It is, indeed, surprising to find an olivine-bearing diabase containing big orthoclase and Karlsbader twins; only later, when fragments of granite were found also, the origin was understood. The monomineral inclusions are not quite rare; a number of older granites are divisible into more or less monomineralic fragments, which are taken in by the magma of the dyke and subsequently absorbed. The feldspars may be round. Thus the dykes are not only different from their origin, but they have received different additions. Even dykes of the width of several metres may digest small fragments in the interior.

Some of these dykes seem to end blindly; but many have no doubt penetrated to the surface of that time, when consequently volcanoes have existed. Thus the volcano formation has extended over very vast areas of southern Greenland if not throughout the whole region.

An example showing that the lava of these dykes has moved upwards is found on the island Midtluvfik west of Arsuk Island. The dyke (fig. 42) piercés the greenstones of the Arsuk formation. However, it is filled with large fragments of granite and gneiss. The gneiss here lies at least some hundred metres, probably more than one thousand metres, below the surface. The blocks were consequently carried away with the upward moving lava stream. When the lower parts have moved so far upwards, the upper part of the lava column must have almost the same distance higher up. When the movement in these narrow dykes, less than a metre thick, was so strong, it has no doubt been more intensive in the larger dykes, where the friction is smaller. On the same island other dark dykes with granite fragments and granite gravel are found, too. It might also be assumed that the blocks with their gravitational upward tendency had risen in the dykes; but if so, the friction would have been even greater than when they ascended with the lava, and it is therefore less probable. In such case traces of the ascent would be found in the arrangement of the smaller fragments in the wake of the larger ones; but no such arrangement was found.

The dykes mostly show a crosswise jointing. In dykes which can be observed from one side-wall there are usually two orthogonal systems which have either the same or different distances. They are probably the result of the cooling contraction. In these joints mineral transformations and the late crystallisations may be found. In other cases (Siorak



Fig. 42. Younger dark dyke of the first generation with many gneiss and granite inclusions; the dyke cuts through the greenstones of the Arsuk formation. Midt-luvfik Island.

inside Kagsimiut) a kind of quartz porphyry is found on these ladder veins which proves to be the result of the melted granitic wall-rock. On the whole the side-walls are not very much affected, but most strongly at the intruding corners, round which the fluidal structures also are most distinctly observable, since they assume more complicated forms than in vertical dykes with parallel side-walls.

Some dykes were opened several times. They contain fragments showing a flow-structure which forms an angle with that of the sur-

rounding lavas. Some crush zones are younger than these dykes, for instance that which cuts across Arsuk Umanak.

In all the places investigated the brown diabases are younger than the dykes of this group.

b. The group of the brown dykes.

Petrographically these diabase-dykes form a more homogeneous group. In the field they are easily recognisable from a distance owing

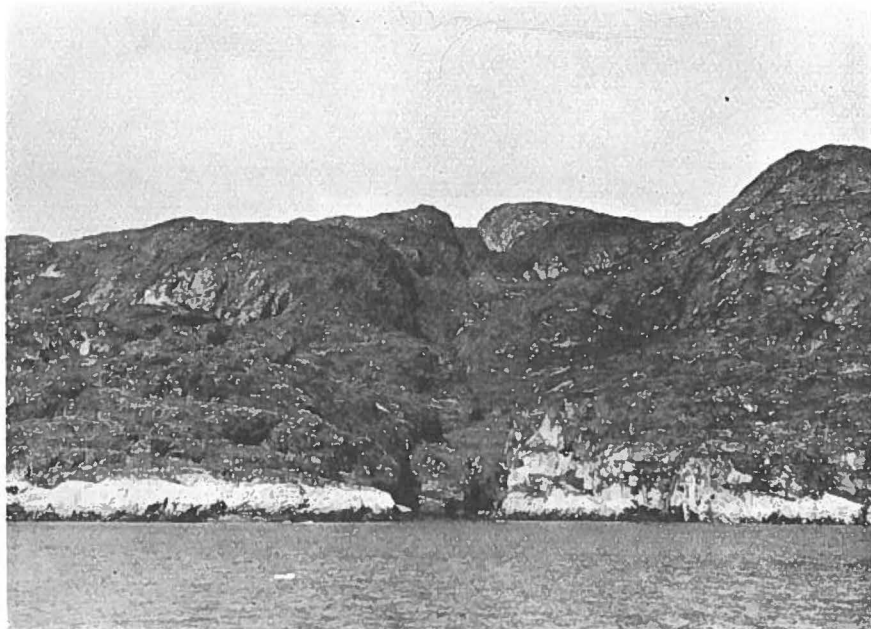


Fig. 43. Dyke of essexite diabase on the northern bank of Brede Fjord, Kanertek Island.

to their weathering colour and their tendency to crumble into gravel. Thus they often form large furrows or small valleys (fig. 43), frequently with a calciphilous flora, a very striking feature in southern Greenland. CROMMELIN has shown that this tendency to disintegration causes them to be very conspicuous in the sand samples. Owing to their content of titan-augite they form an important element for the characterisation of the younger sediments (CROMMELIN 1937).

In most cases the dykes of this group intersect the black dykes (cf. fig. 45, 46), for instance in the area near Arsuk, on Sanerut, and in Kobberrmine Bay, at Tavdlorudit, Ika Fjord, and Ivigtut Fjord, North of Brede Fjord (fig. 43), Hollænder Island, Julianehaab, and farther south; thus they run in directions varying about NW—SE. However, there are exceptions to this rule, for instance at Arpagfik,

between Brede Fjord and Skov Fjord, at Torsukatak and Sarkamiut. Thus the distribution is regular in its broad features only. It is of importance that precisely in this area, which forms the continuation of Tunugdliarfik, the diabase dykes extend parallel to the direction of the fjords, as at Narsak.

The dykes are mostly broader than the black dykes, often some 30—40 m, occasionally up to one hundred metres broad. Many of them extend over several kilometres, thus from points offering extensive

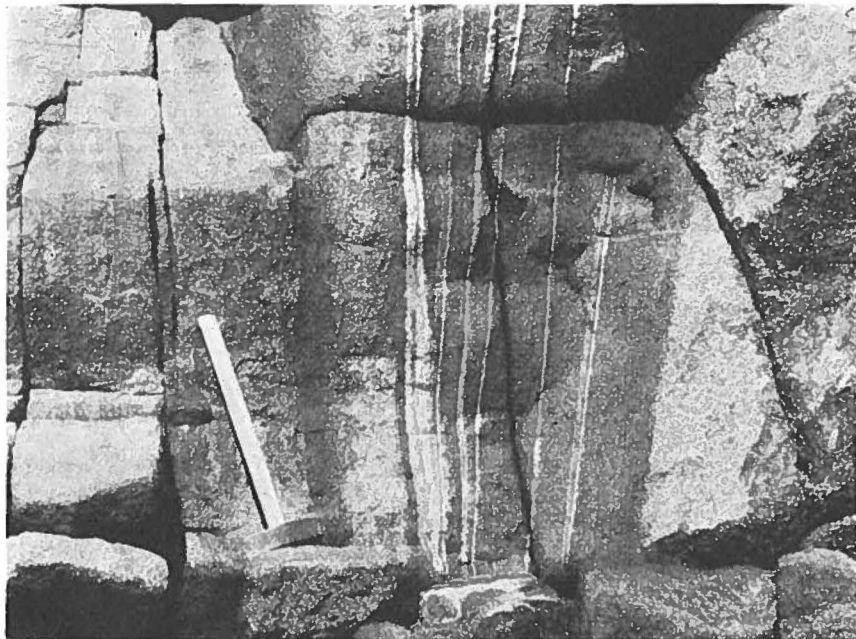


Fig. 44. Banded diabase. The coast north of Pudlatit.

views large dykes can be traced over dozens of kilometres (fig. 45, 46). Others terminate very rapidly; in such cases they are usually arranged *en echelon*, so that at the end of one the beginning of the next one is soon found. The distance between the large parallel dykes is usually much larger than between the smaller dark dykes. In some regions this interval is of a certain size, so that a certain periodicity will result, which is very distinctly visible from places offering a good view. The broader the dykes, the greater is usually the distance between them; but it decreases towards the younger granite massifs. On the whole they show a different rule of distribution from that of the preceding group.

As a rule the diabases do not exhibit glassy contacts with the wall rock. They are generally more fine-grained towards the margins,

but have not, apparently, chilled margins like the dark dykes. In several of the dykes bubbles were observed along the lines of contact; in these, as also in fissures in the dykes, vesicles with calcite crystals may form. Such vesicles were observed by A. JESSEN (1896) on an island off Sydproven, and are now found in many places. In the majority of the dykes a marked flow-structure is observable, appearing either in the form of streaked or banded structures (fig. 44). In these schlieren and parallel



Fig. 45. View from the Gule Fjæld towards the northeast. In the foreground, the top made up of diabase, which cuts off dark dykes to the right and left; in the background the Kvanit Fjord, which cuts through the high flat landscape, above which some broad mountain massifs project; the high flat landscape forms part of the western high area (cf. p. 124); it extends in below the inland ice which is seen in the background.

bands, lumps of labrador-felspar may develop. In some dykes, notably at Brede Fjord, the flow-structure is older than some large patches which resemble the so-called diabase-pegmatites (ESKOLA 1936). Here the pegmatitisation spreads across the fluidal structure; this does not flow round it, but disappears at the patch and continues on its other side. It must accordingly have formed after the magna of the dyke has ceased to move. In other cases the pegmatitisation and minor movements have apparently alternated. Possibly stronger movements, too, have alternated with this process, giving rise to the banded and streaked structures, but at present it is difficult to ascertain.

The diabases form ladder-vein structures to an even greater extent than the black dykes. The jointing is partially parallel with the adjacent walls, partially it runs at right angles to it. In one system of transverse joints minor movements may take place in large dykes, giving rise to mylonitic films and mineral transformations. In these dykes melting of the adjacent rock is a much commoner phenomenon than in the



Fig. 46 a.

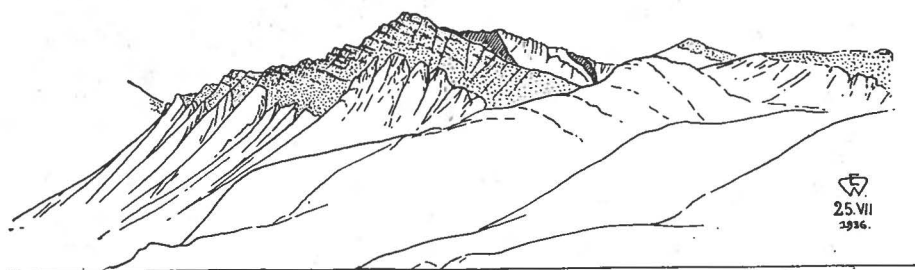


Fig. 46 b.

Fig. 46. Gule Fjæld north of Arpagfik Fjord is built up of a large diabase dyke which cuts through the basement and the older black dykes. a) seen from the head of the fjord: b) from the southern bank of the fjord. Diabase = dotted, black dykes = shaded.

preceding group. In large dykes projecting corners, or the roof, if the dyke dips downwards, may be strongly affected. The molten material may then appear either as very thin veins in the neighbouring rocks, or in most cases in the diabase (fig. 47). These diabase-granites are very frequently met with; they may form small intrusion-breccias with the diabase.

To sum up: The black dykes intruded into a much cooled rock; the widening took place largely in the direction NW—SE; the brown dykes intruded into a rock already heated; the widening trended largely NE—SW. The black dykes appear in certain zones; the brown dykes are broader, but occur at a certain distance from each other. Thus the



Fig. 47. Breccia consisting of diabase and granite which has been melted from the wall-rock, and forms veins in the diabase. Hollænder Island.

two groups differ from one another not only by their contents but also by their behaviour.

c. The importance of the younger dykes.

The importance of the young dykes is of divers kinds: First, it is of chronological interest. By tracing the dykes which belong positively to the Gardar Formation, beyond their actual area it is possible to obtain time marks throughout the whole of southern Greenland and possibly still farther. Thus it is a point of the greatest importance to trace these dyke systems beyond the area in order to find out whether they terminate in another formation or possibly in another orogenic zone. It is this system which allows of a definite correlation of the formations of the Gardar period beyond the Tunugdliarfik area, and offers a more reliable basis for the classification.

Secondly, the young dykes are of importance kinematically; that is to say, from these dykes it is possible to reconstruct in some degree the movements to which the whole rock mass was subjected during the Gardar period. Widening took place throughout the known area. This part of the Gardar period in southern Greenland cannot, therefore, be defined as an orogenic period with narrowing, but a period of relaxation and widening. It is not very probable that

compressive movements of a regional character should have taken place in the immediately adjoining areas, (but this does not exclude local compressions through interference). Possibly compressions took place after the close of the Gardar period, but no positive proofs are available. On the other hand it is quite possible, and even probable, that the Gardar period in the neighbouring areas also corresponded to a widening with the formation of basins; thus a geosyncline might form in case of a greater supply of material. The basin which received the material missing between the Ketilides and the Gardar Formation must, at any rate, be of geosynclinal dimensions. But it is as yet uncertain on which side this should be looked for. Very probably this problematic formation has been folded and granitised and thus included in the crystalline platform.

Thirdly, they are of petrological interest. However, I shall not here enter into a discussion of these questions, but shall merely briefly mention their relation to the young granites and syenites. For this purpose the latter group will be dealt with.

d. The group of younger granites and syenites.

This group has been very scantily investigated. The first observations recorded were supplied by GIESECKE; EBERLIN, KNUTSEN, and A. JESSEN have given valuable contributions. USSING marked the occurrences on his sketch map (1912, pl. 1), but gives no description or discussion. GIESECKE called attention to the younger age of this group; with an acuteness amounting to genius he even termed it "regenerated granite". EBERLIN records observations in three places, on the basis of which he regarded the granite as younger, viz. the occurrence of inclusions of the surrounding gneiss or garnetiferous granite (KNUTSEN and EBERLIN, pp. 252—253). This is not quite decisive according to recent experience, since the late-Ketilidian granites may also contain such inclusions. Their relation to the younger dykes is decisive. These are in many cases brecciated and transformed. This determines the chronological place of the group: most of its massifs are younger than the diabase group. Some basic dykes are younger than the granites. Outside the granite occurrences it may be difficult to distinguish them from the other basic dykes.

The younger granites and syenites are present in a large number of massifs within the area investigated. Here I shall only discuss some observations which may be helpful in illustrating the problem of the structural classification, disregarding the various other observations.

The petrography of the massifs is but little known so far. CROMMELIN (1937) gives a number of interesting data regarding their minerals. Without entering into a mineralogic-petrographic description, I must

mention some textures which would seem to give important information. Hitherto no chemical analyses have been available of these rocks, and a more detailed examination of them is therefore required and planned. In the following the massifs visited will be briefly described in the direction north to south. The following massifs are found within our area:

- a) the Kungnat massif;
- β) the Nunarsuit massif;
- γ) the Sydproven massifs; under this heading we may include several small massifs round the mouth of the Unartok and Lichtenau Fjords;
- δ) the massif in the interior of Unartok Fjord;
- ϵ) the Frederiksdal massif.

The massifs are found in two areas separated by a broad belt, in the middle of which Kagsimiut is situated. It is this indentation in the coast of South Greenland which is seen on all maps of the region; here it will be referred to as the Kagsimiut depression or the Kagsimiut gulf (cf. pp. 125-126). To the west of it begins the western series of massifs, including Nunarsuit and the Kungnat massif, continuing in the governmental district of Frederikshaab in a series of massifs. The eastern area comprises the whole of southern Greenland from N. Sermilik to the southernmost cape and up the east coast.

The Frederiksdal massif and the Nunarsuit massif are the two largest massifs, although only parts of them are known; they extend towards the sea and disappear below the water. So far only a rather small part of these large massifs has been visited, so a thorough investigation may be expected to yield much fresh information. The following data should therefore be regarded as a first contribution.

a) the Kungnat massif.

This massif forms the highest summit within the area of Arsuk, attaining a height of 1400 m. It is fairly round and of a diameter of 5-6 km. It rises into the migmatite zone north of Arsuk Fjord (figs. 2, 48). The granite is red, mostly coarse-grained, but of a varying size of grain; in the interior it is very coarse-grained, like pegmatite, but in addition fine-grained varieties occur without any visible regularity of distribution; conditions at the margin enable us to form an idea of it. The coarse portions are filled with miarolitic cavities, which may develop into druses. These cavities may occupy a comparatively large part of the volume of the rock, which in such case is like a sponge; these varieties form large lumps of irregular shape. A large part of the granites falls readily into gravel; however, not all beds have this property; it would seem that the cavities are of a certain importance in that respect. On closer examination small fissures radiate from each of the cavities

into the surrounding minerals, partially following the cleavage. It is along these small fissures that the rock will crumble. The fine-grained rocks which do not contain such cavities, are more resistant. Aplitic dykes, which seem partially to impregnate the adjacent rock, may therefore stand out like walls (see figs. 2 and 3 in CROMMELIN 1937).

The granites are divided into large massive beds of varying thickness, being thicker in the interior of the massif than at its margins. It



Fig. 48. Kungnat massif, seen from the Gule Fjæld north of Arpagfik Fjord.
Below the fog, the basement; above it, younger granite.

is this bedding which sets its stamp on the mountain forms, which will consequently be of quite a different character from that of the surface of the ancient basement (cf. fig. 56); the latter is on a small scale very irregular. Now the glacier will carry away the detached fragments, now erosion will remove the crumbling portions and only to a small extent the larger blocks. The mountains therefore look as if they were "cleaned", because but few smaller particles are strewn about; only large blocks or gravel remain. Hence this topography is recognisable even from a distance. The massifs are of importance for the sediment-petrography (CROMMELIN 1937) because of the special minerals they supply.

As regards appearance and colour the granite most closely resembles the Obnäs granite or the Onas granite of Finland, i. e. the type

which J. J. SEDERHOLM called the third group of granites. Some of the contact phenomena also recall those described by BORGSTROM (1931) from Tarmviken (Onas archipelago, Southern Finland).

The contacts are of different kinds; in the first place, transitions from the more granitic migmatites to the Kungnat granite occur. The

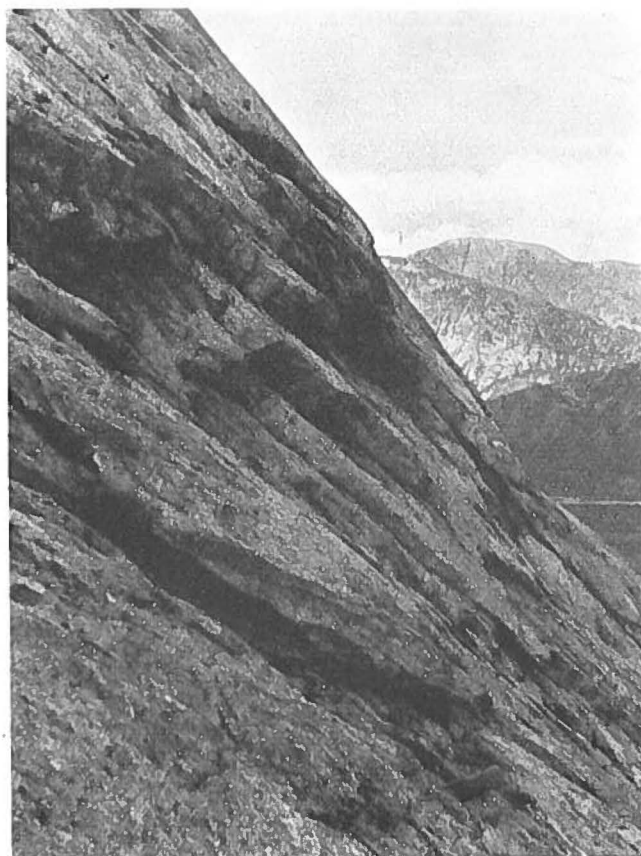


Fig. 49. Upright bedding-planes in the younger granite on the eastern side of Kungnat, near the contact.

diabases, too, may pass into a darker variety of the granite. The hornblendes are biotitised, the potash feldspars are beginning to settle, turning redder and larger; the dark minerals merely fill the interstices between the feldspars, lending to the rock a more or less dark tint, which may disappear later. The quartz will gather and form idiomorphic individuals. At the transition from gneissic to granitic rocks they seem to gather around small cavities, whence they grow into the rock and individualise towards the cavity. The diabases need a longer time to

become transformed; they still stand out like walls in the marginal zone. When the contacts are parallel they form a boundary.

Certain Ketilidian migmatites form another type of contact. The granitic portions are first transformed, and the darker fragments will begin to float in the younger granite. This type develops into the next one, in which the fragments have been broken up and the whole mass has moved. The individual fragments no longer bear the same relation to each other, but have been turned and displaced in relation to each other. Accordingly it is an intrusion breccia. It must have flown along the contact, so that the fragments moved against each other. In these

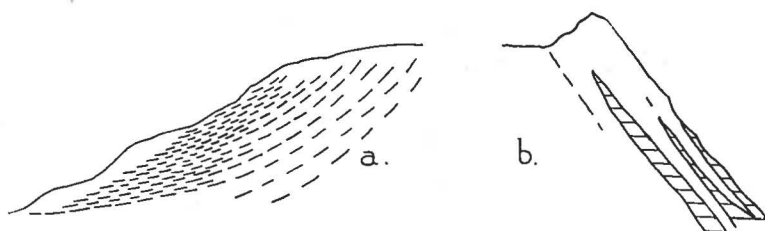


Fig. 50. a) Diagram showing the distribution of joints in the marginal zone of the Kungnat massif; in the surrounding migmatites they are close-set and flat, rising in the younger granite, and at the same time the intervals between them increase. b) In the eastern edge of the massif tongues of migmatite extend into the granite; their internal structure does not correspond to their external shape; they are assumed to have been bent upwards during the formation of the dome.

agmatites the granite forms the matrix. It often shows interesting mineral textures. These two types occur where the granite intersects the migmatites across the strike. The next type shows one further stage of development; a large part of the matrix has been replaced by fluorite, so it is a kind of fluorite-agmatite. The streaky or augen structure is often maintained in the fluoritisation. In company with the fluoritised patches there occur cassiterite and other minerals belonging to this association.

At most contacts the granite has a pegmatitic character. It is traversed by fine-grained dykes of spotted granite and very thin dark veins. The beds are not of the same thickness everywhere; in the agmatitic and neighbouring rocks they are less thick (fig. 49) than farther into the massif. A similar bedding is met with in the migmatites outside the massif. This bedding runs across the usual joints, it is even less thick and soon disappears outwardly. The beds rise towards the marginal zone of the massif, in which zone it is more than 45 degrees (figs. 49, 50). In the massif the beds form a large, not entirely regular dome (Pl. 5). Many remnants of the migmatitic rocks apparently still remain on the top of Kungnat; unfortunately, however, time did not allow of an

ascent of the peak, so only the appearance and the erratics are indicative of the presence of migmatites.

The bedding might be interpreted in analogy with the classical interpretations by CLOOS (1936) as the last traces of the upward movement of the molten mass. The granites from which CLOOS's results were gained, are shown by his descriptions and samples to be of a different character. Hence it is not certain that his interpretations are immediately transferable to granites of quite a different kind. Similar cases to that of the Kungnat granite and several of the younger massifs of southern Greenland have been treated by MIKKOLA (1928) and KANERVA (1928); the former studied the Nattanen granite of Finnish Lappland, which is very like the Kungnat granite, the latter studied the Rapakiwis of western Finland, which show several points of resemblance, notably to some of the massifs to be dealt with later. Both authors arrive at the result that it is the bedding which is conspicuous in the first instance, whereas the traces of the two other directions are so much alike that they cannot be distinguished from one another in the field. The degree of symmetry of these joint-systems is accordingly higher than in the general cases, especially in those investigated by CLOOS. Both Finnish investigators nevertheless associate both the horizontal and the vertical joint systems with the flow of the molten mass; but MIKKOLA is very critical and cautious in his expressions. In such massifs which have cooled very rapidly, the cooling might be assumed to be a concurrent cause of the bedding. If so, the fissures may be supposed to be controlled by the tensions and in some degree to give a picture of them. The distribution in the marginal zone speaks in favour of something of this kind. Conditions are at any rate not so clearly defined here as in the classical cases analysed by CLOOS. I shall revert to this question below.

β) The Nunarsuit massif.

This massif occupies a large part of the islands Nunarsuit and Alangorsuak; it extends far seawards in the Kitsigsut islands, but its outward boundary is not known. It has a width of at least 23 km in an E—W direction, and a length of nearly 25 km in a N—S direction. Its highest summits are Kidtlavat, attaining nearly 800 m in Nunarsuit, and Agnikitsorsuak on Alangorsuak, attaining 670 m. The mountains are very wild and jagged and with fantastic shapes. To the west the islands represent part of the strandflat.

The contact can be observed in the large islands. I visited it at Malene Mountain on Nunarsuit in the area south of Helene Harbour; on Alangorsuak it could be studied north of the Sound Knækket across the island and in the mountains west of Agnikitsorsuak towards "Røde Top" and "Lyse Nes" near Josva Mine. These contact-localities differ greatly.

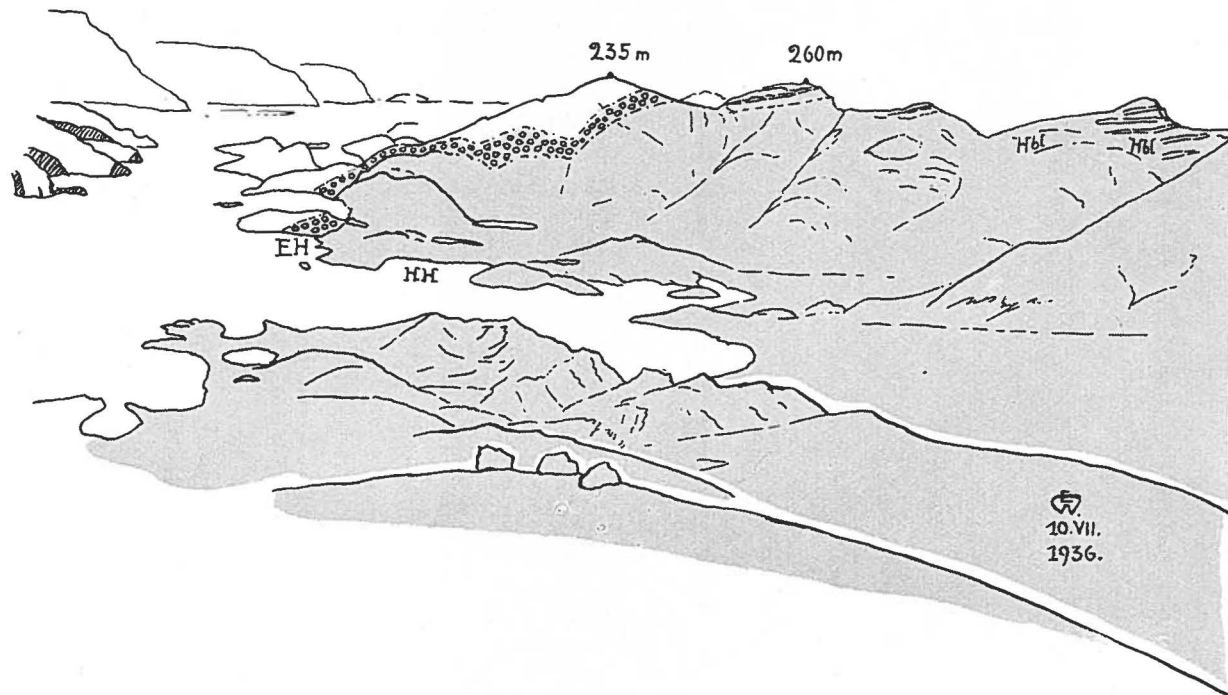


Fig. 51. Sketch of the area round Helene Harbour, Nunarsuit. White = migmatites with dark younger dykes; grey = younger granite; with circles, Rapakiwi, at the top 260 m and farther to the right the amphibole-granite (Hbl) with the pegmatitic zones. E H = Emma Harbour; H H = Helene Harbour.

At Malene Mountain and partially at Kobbermine Bay there is a transition. At Malene Mountain it is very gradual. At the base of the mountain the rock has in part the character of a Julianehaab granite, partly of a younger granite. The secretion forms and veins with acicular hornblende are alone indicative of younger granite; however, one has to walk for about half a kilometre before the quartz, too, becomes idiomorphic and the rock acquires the characteristic texture and the typical red colour;



Fig. 52. Rapakiwi between Helene Harbour and Emma Harbour, Nunarsuit.

at the same time it begins to crumble. The bedding begins with a thickness of 30—40 cm, increasing to 2—4 m. It dips towards the N and NE, forming undulating planes with undulations of a length of many hundred metres. Two orthogonal perpendicular joint-systems are found, the same as in the surrounding Julianehaab granite.

On either side of the Knækket in Torsukatak conditions are more instructive and more complicated. Here the basement is made up of granites and migmatites with particularly many dark dykes. Some of them may almost be called small massifs; this is especially the case with a diabase dyke of ossipitic type, like those found in southern Finland and in the Åland archipelago. It extends from Emma Harbour to Bangs Harbour. Below this diabase and below the granitic basement a layer of varying thickness extends up to summit 235 m (cf. fig. 51). This summit consists of red granite with Rapakiwi texture. The feldspars are

ovoid in shape and the quartzes are idiomorphic; they are embedded in a red ground-mass, which is fine-grained near the contact, but becomes coarser towards the interior. The ovoids have no plagioclase rings (fig. 52). The rock much resembles many West Finnish and Åland Rapakiwi types. When the ground-mass becomes coarser, the rock loses its Rapakiwi habitus, turning into a granite of the Onas-Obnäs type. The Rapakiwi has a thickness of 2—20 m. Where diabase is present, the contact bends down, whereas in the granites and the migmatites it swells up (fig. 53). At the large ossipitic diabase the contact is kinetically influenced; the granite seems to have flown below this roof.

The transition from the granite and the migmatite takes place through the formation of a very fine-grained ground-mass, often with

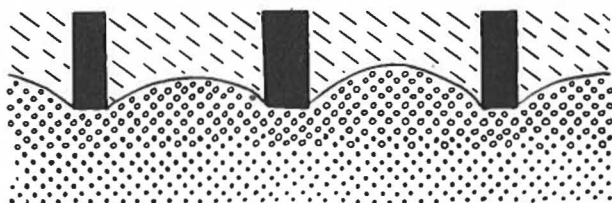


Fig. 53. Contact between Rapakiwi and migmatite with basic dykes. Black = basic dykes in the migmatites; rings = granite with Rapakiwi texture; dotted = Helene granite.

no visible boundary towards the adjacent rock; in this mass the quartz will gather, it turns milky, and forms idiomorphic individuals. The ovoids begin to appear in the ground-mass, in which biotite darker than that of the Julianehaab granite occurs. In some cases the transformation of the biotite of the Julianehaab granite into Rapakiwi biotite may be observed; it may also arise from hornblende. Accompanying the Rapakiwi and in part replacing it there occur spotted granites, which in Finland also are known to occur in association with Rapakiwi (WAHL 1925). At Josva Mine the late-Ketilidian white granites have been transformed at a great distance from the contact; the biotites are bleached or pyriticised; the feldspars are much kaolinised. A similar kaolinisation by deep-seated younger granite massifs is found in eastern Finland also; but there it has in part been interpreted in a different way (FROSTERUS 1928, VÄRYNEN 1929).

Below the Rapakiwi there follows, with a transition, the granite which characterises the surroundings of Helene Harbour, and which can be traced from this point over wide stretches both towards the north and south; it will be termed the Helene granite. It forms a layer of varying thickness below the Rapakiwi, and extends through the whole massif from Kobbermine Bay to the isthmus of Malene Mountain.

It is of the Onas-Obnäs type (SEDERHOLM 1926) and corresponds as facies to the granites of the third group in Fennoscandia. It is coarse, with idiomorphic quartz, big red feldspars, which very readily fall to gravel. The large, rather flat cirques occurring between the sharp mountain crests near Knækket, a type of topography which extends through Nunarsuit, are due to this circumstance; it already attracted the attention of the mapping expedition (GARDE 1894). Not



Fig. 54. Migmatites transformed into hornblende granite, in part pegmatitic. Near summit No. 3 at Helene Harbour.

only the shape, but also the surface of the ground is characteristic; it is covered with coarse gravel; where no marine sediments occur, or finer material transported there by rivulets or the wind, only a very sparse vegetation is found. The finer particles are blown away, and only the coarse gravel will remain. The Helene granite contains as a dark component usually biotite, biotite and hornblende, or dark hornblende. The highly biotitic types are situated towards the outer part of the massif; however, the distribution does not seem to be regular everywhere. In the lower part it passes into the next type.

This granite might be termed micropegmatitic amphibole-granite; the amphibole is sometimes arfvedsonitic. These rocks are transformation products of pre-existing rocks. It can be distinctly observed how the transformation proceeds along the joints; relicts may often be found

in the interior of the blocks. Here we find again quartzites and greenstones, as found farther north, but not directly outside the contact. At the mountains immediately west of Helene Harbour relicts occur which form mountains with intermediate transformation zones. The material transported there has often been crystallised along the joints into a very coarse pegmatite with large amphiboles. In this rock, too, the transformation of the quartz of the gneiss into the more idiomorphic



Fig. 55. Tuluvaralik; the surface forms of the syenite contrast strongly with those of the Julianehaab granite and of the migmatites (cf. fig. 56).

quartz of the granites may often be observed. Owing to its different original material the granite exhibits a peculiar spotted and banded appearance (fig. 54), even after everything has been transformed. It seems remarkable to any one coming from the more homogeneous interior. But it can only be explained if one comes from the less transformed zones.

To the west, near Peru Harbour, this zone is underlain by dark, partly amphibolitic syenites. The latter are intersected by broad pegmatite veins with amphiboles up to 20 cm long. The pegmatite dykes are much more individualised here than farther out, where they vanish gradually towards the surroundings. The conditions could not be traced farther westward. The Kidtlavat mountains, which could be observed at a distance from several sides, seem to be built up of many different

rocks in no quite simple way, and therefore promise very interesting results.

Tuluvertalik, the largest of the inner Kitsigsut islands, was visited by the author. It has previously been described by GIESECKE (June 19—23, 1806, and August 7, 1809) and GARDE (1896). GIESECKE mentions syenite and veins rich in iron-ore, and records the finding of zirkonite. The syenite is mostly striped and dark-coloured. It falls



Fig. 56. The surface forms of the migmatitic granite in the skerries at Julianehaab, Julianehaab's Umanak.

readily to gravel. The waves wash rich ore products out of the sand. They were examined by CROMMELIN (1937). Several kinds of dyke occur in the syenite. The oldest are the magnetite-amphibole dykes. They often run in zigzag and have been subjected to movements. Younger are the fine-grained dykes of a syenitic character, the aplites and pegmatites, the latter with very large felspar individuals. They pierce the syenite as large dykes. Kitsigsut and Kidtlavat appear to form a large dark syenite nucleus in a large shell of red granites. The syenites, too, are rich in variations.

Thus neither as regards structure nor composition is the Nunarsuit massif a single massif, but a complex. The granites form a shell, while the syenites and other, more basic rocks form one or several nuclei within it. In the northern parts the granite margins are 5—10 km broad.

If its lower boundary is assumed to be almost parallel to the outer contact, the thickness will prove to be 1500—3000 m. These granites are largely distinct reaction-products between the pre-existing rock and the material added later. The nuclei seem to be the governing portions of the massif; they are surrounded by a shell of mixed rocks. In these granitic rocks, too, there is a jointing which to a great extent cannot be due to the flowing, since they are transformed in situ. These rocks



Fig. 57. Bedding of the Nunarsuit granite. The beds are 1 to 1.5 m thick. Bay behind Angnikitsorsuak, on the island of Alangorsuak.

obtain a new jointing system which deviates from the preceding one, and form thick beds (fig. 57). It is natural, in addition to mechanical tensions, to assume here a release of tensions by cooling.

Large and important parts are as yet unknown, so interesting results may be expected from a further investigation.

γ) The Sydprøven massifs.

Several smaller massifs in the outer parts of Lichtenau and Unartok Fjords will be included in one unit, since they are very probably connected in the depths. The individual parts are found in the following places (fig. 58):

- 1) The peninsula of Sydprøven and the islands southwest of it;
- 2) The island Tugtutuarsuk and the southernmost part of the island Unartok;

- 3) the southwest side of Unartok Fjord, at Niakornak and thence to Kanajormiut, and the western part of the island Angmalortok.
- 4) the northern part of Sermersok.

As will be seen from the sketch (fig. 58), the boundaries given by USSING are not quite satisfactory; this must be due to an erroneous interpretation of A. JESSEN's map (1896). A. JESSEN marks the area near the settlement Issua and the surroundings of Lichtenau as "gabbro". At Lichtenau these basic and ultra-basic rocks no doubt belong to the Ketilidian cycle. In re-drawing the map USSING placed them with the younger rocks. It is very probable that the rocks at Issua, too, belong to the Ketilides, as they form the continuation of the very basic rocks of the migmatites in the southernmost part of Tugtutuarsuk.

- 1) The Sydprøven peninsula and the islands to the southwest.

Near Sydprøven a strandflat extends towards the south from the mountain Kingitok. In the mainland it is nearly 3 km broad. However, only a portion of it is occupied by the younger granite, the remainder is made up of Ketilidian migmatites and basic rocks. The granite further comprises the islands Sagdlia and Uvigerdliat west of Sydprøven. The visible part of the massif has a length of nearly 3 km and a width of 1.5 km. As already stated, USSING indicates it beyond Lichtenau; but it does not even extend to the large cove which bounds the Sydprøven peninsula. In this massif no heights rise above the strandflat; it appears as a low, hilly landscape with lakelets and bogs from which the edges of the immense crumbling beds are seen to project. The beds are mostly flat, but seem to be less flat at the main contacts. The bedding structures continue some distance into the migmatite. This is especially distinct in the coast between Sydprøven and Lichtenau.

The Sydprøven granite is generally very coarse-grained, whitish-grey and friable. Usually it contains big, white feldspars, which, as a rule, show no Rapakiwi textures. The quartz may be idiomorphic, but it is mostly granulated. A very large part of the massif is filled with inclusions, or must be considered the transition zone between the granite and the migmatites of the Ketilidian group. Only at some few points of the northern boundary is there a sharp line of demarcation.

The transition is initiated by the formation of big feldspars in the gneisses and amphibolites, which gradually gather into large clouds (fig. 59). The quartz gathers into accumulations, which to begin with have very irregular boundaries and often a dark marginal zone, but subsequently more or less idiomorphic individuals will develop from them. The very basic and very fine-grained acid rocks are less affected.

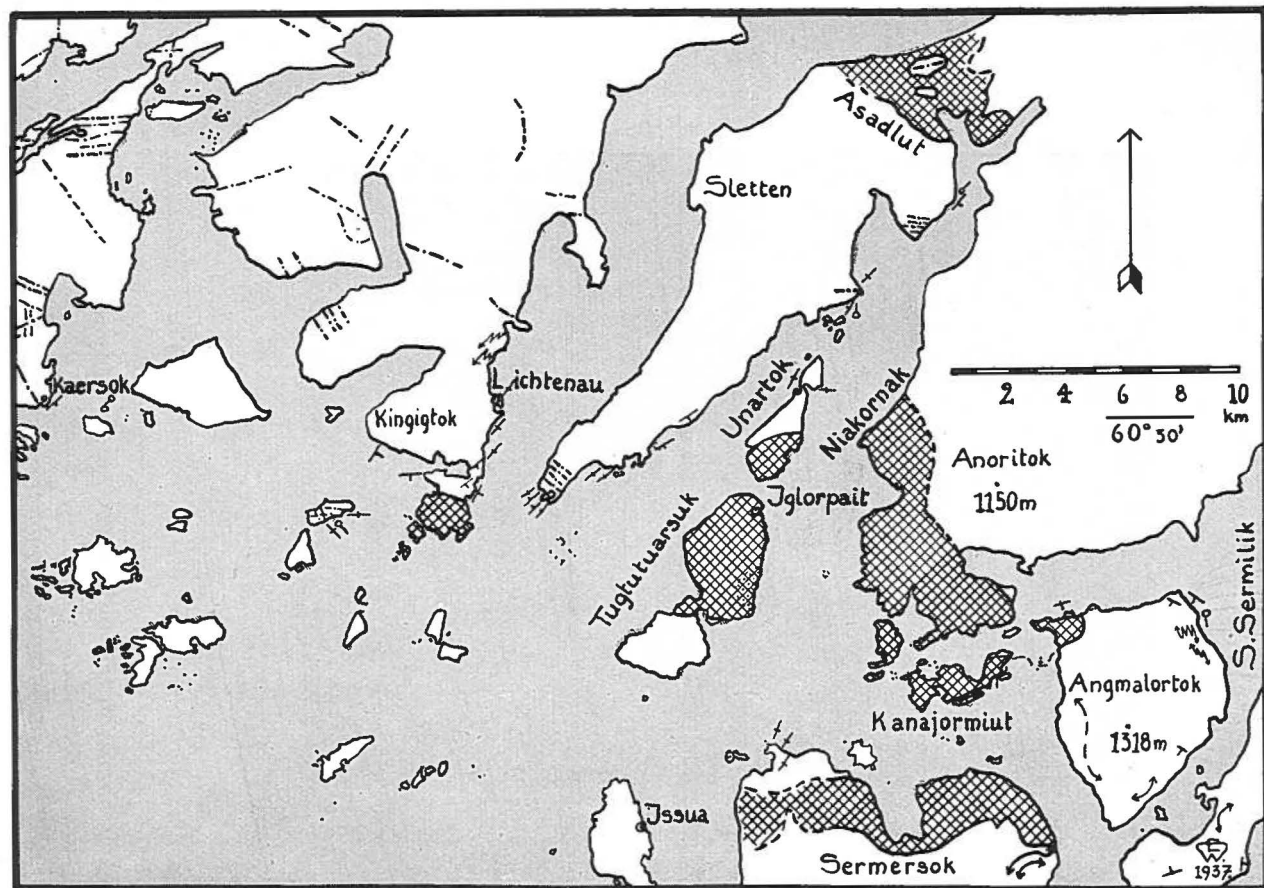


Fig. 58. The Sydprøven massifs (hatched); the syenitic nucleus on Tugtutuarsuk are further dotted. Marks indicate the direction of the migmatites. The stipled lines show the directions of the more important younger dyke systems.

When the transformation proceeds along all routes, there remains a swarm of inclusions whose orientation is still retained. The migration and crystallisation of the feldspars take place along the "s" planes and joints, presenting a regular network. The agmatites arising in this way



Fig. 59. The imbibition of the Ketilidian migmatites and transformation into younger granite. The shore near the harbour of Sydproven.

are accordingly not moved intrusive breccias, but agmatites in situ. It is only the substances which have migrated, not the armature of the rock.

The diabases, too, have been transformed; at first they were biotitised, and subsequently feldspatised. Large parts of the massif apparently represent a boundary zone. No deeper parts of the massif are accessible.

2) and 3), Tugtutuarsuk and the southwestern side of Unartok Fjord.

These occurrences are probably directly connected. They are separated from the preceding one at the surface through the occurrence

of Ketilidian migmatites on the islands situated between the Lichtenau Fjord and Unartok Fjord. It may, however, be taken for granted that they are connected in the depths. The occurrences (2) and (3) have a visible width of 14 km and a length of 11 km, which increases to nearly 18 km if we assume its direct connection with the occurrence in the northern part of Sermersok. The occurrences are shown in fig. 58. The highest point of the massif is nearly 300 m near Markaksuit.



Fig. 60. Rapakiwi with exogenic fragments, at various stages of transformation. Tugtutuarsuk.

The contacts are visible in the isthmus of Tugtutuarsuk, on Unartok Island and on Angmalortok. On the mainland they are for the most part covered by Quaternary formations, but are visible in the Kanajormiut archipelago. So many inclusions occur, some of the size of some dozen metres, that they, too, must be regarded as contacts.

The rocks differ a good deal throughout the area. Some of the most interesting types were found on Tugtutuarsuk. Along the margins of the migmatite-granite there develops, even at a distance, a spotted granite, the biotites gathering into small spots. The hornblende, too, may be biotitised and form small spots. Gradually large feldspars will form in them, which may be round or with rounded edges. Very often they exhibit round zones with inclusions. Originating from the light-coloured Ketilidian migmatite-granites, a light-grey granite will

develop, often with Rapakiwi texture; starting from the dark portions and the dark-coloured dykes, a brown Rapakiwi will form. The pattern of light and dark in the pre-existing rock is still vaguely preserved, like an indistinct photograph. In the actual Rapakiwi zone, which is mostly of a brown colour, a great number of fragments are found (fig. 60). The ovoids also form in the fragments; in this way they turn gradually into Rapakiwi. In fig. 60 shadows of fragments at different stages of dissolution will be seen. In many fragments a vermicular system of thin quartz veins will first form. In others the quartz gathers into round aggregates of grains; at a later stage they form regular intergrowths with the feldspars. Small fragments may have a light-coloured edge, like the ovoids. The Rapakiwi does not seem to occur without the presence of fragments. Some of these breccias are packed breccias. They are accordingly not agmatites in situ, but the elements have moved against each other.

The Rapakiwi belt at Tugtutuarsuk is underlain by a syenite of a similar type to that found at Tuluvartalik (p. 104). As in the Nunarsuit massif, it is penetrated by pegmatites, which consist largely of quartz with some feldspar, biotite, and hornblende. The feldspars may be very big and surrounded by a granophyric margin of quartz and feldspar. But not all dykes have parallel walls and crystallised out without movement. In some dykes movements take place during the whole development, which constantly break up the dyke again, allowing the addition of fresh material. A kind of dyke breccia will develop (fig. 61). At the first supply of fresh material a brown Rapakiwi will form, by which the syenite will be transformed into Rapakiwi, which on a subsequent transformation passes into white Rapakiwi. Thus the brown and white colours of these Rapakiwis originate in a different way from those of the outer portions of the Rapakiwi belt. If syenitic material is abundant, it will be brown, if it decreases, it will be white. In other dykes the individual phases are less distinctly separated than in this: in the centre the Rapakiwi is light-grey, at the margins it is brown; between them the ovoids have light-coloured margins. On further movement it may in these dykes pass into a light-coloured, fine-grained, streaky granite. The last displacement zones contain quartz veins 2—3 cm broad, with strictly parallel side walls, which also intersect the ovoids.

Thus we obtain the following general picture: towards the outer as well as towards the interior parts of the Rapakiwi-zone Rapakiwi will be formed at a certain stage of the development whenever fragments are present, or breccia zones will receive the necessary additional supply. They may be formed with endogenous (syenite) or exogenous fragments.

The pegmatitic solutions will ascend to the Rapakiwi belt, but are transformed there into Rapakiwi.

Almost the same observations may be made between Kanajormiut and the mainland. The whole archipelago is traversed by broad swarms of fragments, and in association with them occurs the more marked

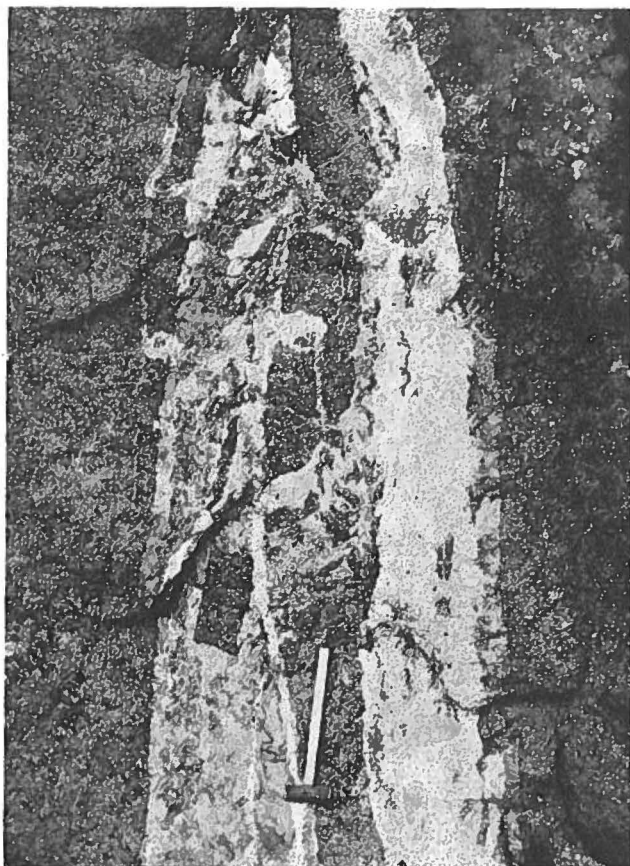


Fig. 61. Brecciated zone in syenite, with transformation into Rapakiwi at various stages. Tugtutuarsuk.

Rapakiwi texture. Mostly brown rocks contain a great number of the fragments of the Sermilik group. On Niarkornak the granite is very coarse. The feldspars are 3—5 cm in size, and the quartz almost idiomorphic. The feldspars are generally not round, but may be so in some places. In some feldspars a ring of epidote will form below the edge. Circles of other inclusions occur, too. The rock is so friable that it is difficult to secure a sample. The large beds slope towards the depression filled with Quaternary rocks, in which the contact must be found. On the top there occur many fragments of migmatite, greenstone, granites,

and aplitic and quartzitic rocks. The whole mass is more like the type of Sydprøven. The entire area from Niakornak to Kanajormiut belongs to the marginal zone of the massif. It is much broader than on Tugtutuarsuk. Here, as in the Nunarsuit massif the nuclei do not seem to be concentric. Conditions and the rock types seem to change with the thickness of the surrounding granitic shell. Thus the distance between the outer contact and the inner contact seems to be of some importance. In places where they occur close to one another, conditions are most interesting. Studies of the erratic blocks show that essexitic rocks are probably still found in the interior of the massif.

4) Sermersok.

In the northern part of the island the younger granites form a narrow belt, whose boundaries have been ascertained at some few points only. Possibly young granites are found in the interior of the island, too. Mostly they are very coarse light-grey granites, of the Sydprøven type. In the Kuaniarsuit Mountain, which is a well-known landmark, the horizontal bedding is very distinct.

On the western side of the bay the mountains rise to altitudes of several hundred metres. They are filled with fragments throughout their whole height. This shows that the fragment-filled zones may be extensive not only in width and length, but also in height. Hence it cannot be inferred from the presence of fragments that the contact is found at a few metres' distance; it may be distant several hundred metres in the terrain. This is of importance for the localities situated in the strandflat.

δ) The massif in the interior of Unartok Fjord.

The massif extends round the northern bay in the interior of Unartok Fjord, issuing from the mountains Asadtlut. It is nearly 3 km in diameter, and attains altitudes of 900 m. The boundary towards Lichtenau Fjord has not yet been ascertained. This massif is not indicated on A. JESSEN's and USSING's maps.

The rocks vary greatly. They are mostly coarse light-grey strongly crumbling granites. The variation is due to the highly mixed state of the pre-existing rocky substratum. All stages of transformation are to be found, ranging from the different basic and acid Ketilidian rocks to many younger dykes, so that a rich variation arises. The most striking feature of the landscape is the strongly marked horizontal jointing. In fig. 62 and in pl. 2, fig. 2 it is seen from the southeast; it is even distinct on the western side; the boundary is seen in fig. 62. At the boundary the granite passes into the Ketilidian migmatites, and for this reason the jointing is less distinct. It passes into certain horizontal

joints in the migmatite, which, however, do not usually play a part in the landscape. Thus the most conspicuous joints do not run parallel to the contact, but have a different orientation. If it were not for this immense mountain wall, but we had to deal with a wooded territory or a lowland, as in the strandflat or in Fennoscandia, these well-marked horizontal joints might be regarded as proofs that the contact runs in the same direction. This has been assumed in Fennoscandia

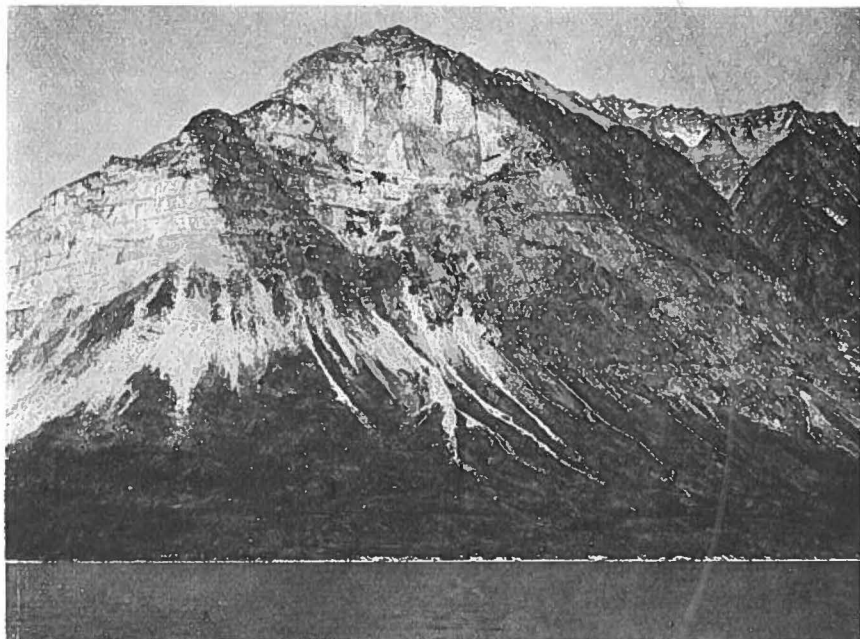


Fig. 62. Massif in the interior of Unartok Fjord, seen from the east. The flat bedding extends right to the boundary towards the migmatites. In the centre, the shadow of a previous darker dyke.

scandia (MIKKOLA 1928, KANERVA 1928), and it is quite understandable. However, this case, as also others in southern Greenland, more especially on Sermersok, shows that the question is in need of a revision. In the younger massifs of southern Greenland, especially in that here described, these joints are much more similar in function to the phenomena known as ladder-veins. This may be assumed to be largely due to the cooling. This limits in some degree the application of the so-called granite-tectonic methods (CLOOS 1936). Thus it should be examined in each case whether the method is applicable in its classical form, i. e. whether the case corresponds to the conditions for which the method was devised.

In the middle of the picture (fig. 62) a dark stripe is seen to cut across the massif; the stripe consists of a darker variety of granite. This shows that the granitisation has taken place without great re-

volutions. The darker and more basic granite varieties cannot be regarded as formed by differentiated parts of the magma; they are conditioned by the pre-existing basement rock. Thus we must be cautious in affixing the label of crystallisation-differentiation to all rock varieties. In the present case the acid and the basic varieties seem to have been formed simultaneously. The large mark, too, shows that there has not, probably, been very strong movements during the cooling of the massif. Only near the contacts do there seem to have been some movements. The massif contains no rocks other than the various granitic varieties; the nucleus is probably more deep-seated.

ε) The Frederiksdal massif.

The large southern massif will be called after the most important settlement situated within it. It begins at the mouth of Tasermiut Fjord and extends all the way to the northwestern islands of the Cape Farewell archipelago. It has a length of nearly 45 km and a width of at least 36 km; it is bounded by the sea, so its outward boundary is not known. The greater part of it lies at sea-level, but at Frederiksdal it attains altitudes of nearly 800 m. So far the massif has only been very little investigated, so we must be content with some few observations.

At the mouth of Tasermiut the mountain Tateratkasik is built up of brown syenite and granite with pegmatite dykes arranged cross-wise and pegmatitised zones of movement, recalling those of Tugtutuarsuk. Round the zones the rock is transformed into a whitish-yellow Rapakiwi. Younger dark dykes occur, too, surrounded by a whitish-yellow aureole.

In the skerries between Tasermiut and Iglokasik grey Rapakiwi-like granite is widely distributed (fig. 63). It is mentioned by A. JESSEN (1896, p. 145). The ovoids may be up to 10 cm, and have often a light-coloured margin. So-called anti-Rapakiwi occurs also. Previous metabasites also exert their influence, forming brown Rapakiwi. Moreover ossipitic rocks occur and are metamorphosed. Huge zones with abundant fragments extend like clouds through the skerries.

At Herjolfsnes fine-grained, brownish-red, friable granites occur in addition to the Rapakiwitic rocks. These granites are traversed by zones abundant in fragments. In the fine-grained granites very large feldspars will form in the groundmass, which are only visible when glittering; they are filled with the small mineral grains of the granite. On the further development the feldspars seem to be able to arrange the inclusions in zones and pass into ovoids. At the same time large milky-blue idiomorphic quartzes are formed. Syenites and more basic rocks occur, too, and such rocks are further met with in the surroundings of Frederiksdal. TORNEBOHM describes a hypersthene gabbro from this place,

and hypersthene was also found by CROMMELIN in the sand samples collected there (1937). However, it has not yet been decided whether it originates from older basic masses analogous to those from Lichtenau. The rocks at Frederiksdal vary greatly, many different fragments, both from the migmatitic series and the syenitic series, being found.

At the southernmost landfast point of Greenland dark, coarse granites occur, often as Rapakiwi, with feldspars 7—8 cm in size, which

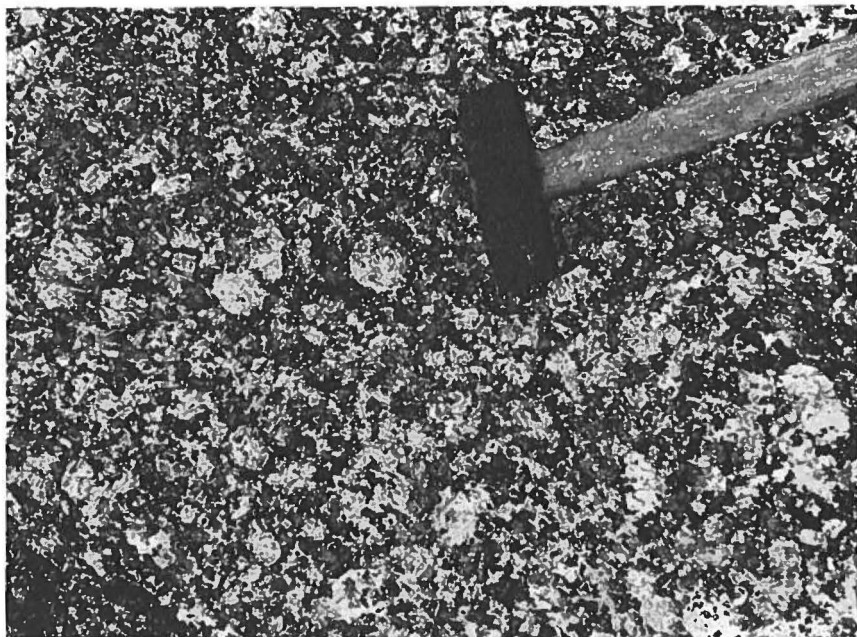


Fig. 63. Rapakiwi in the skerries of Iglokasik.

may contain circles of inclusions. They are often rich in magnetite. Swarms of fragments are embedded in the rock. The formation of the characteristic milky-blue quartzes is especially distinct here.

This massif, too, appears to contain a nucleus of rocks of a syenitic and an essexitic stamp, surrounded by a granitic shell.

It proved impossible in the summer of 1936 to visit the two smaller massifs in Tasermit. Judging from erratics, the rocks are very similar to those of the massifs which have been briefly described above. In the interior of S. Sermilik, too, must be found a massif of younger granites which supply blocks with ovoids of a size of about 5 cm.

Summary of the younger granites.

A number of structural features will appear from the brief descriptions of the younger granite massifs given above.

They are younger than some of the diabases, and form large domes. They are not piercing in the sense that the molten masses have pushed aside the pre-existing basement rock. On the contrary, it must be assumed that a very large part of the basement is metamorphosed, at any rate as regards the granitic outer parts. Whether the rocks of the nucleus are intrusive, cannot yet be decided, but it seems probable. The granitic rocks are younger than the syenitic, more basic nuclei. The rocks both outside and inside the granitic zone are metamorphosed into granites. A typical feature of them all is their horizontal bedding, their many miarolitic cavities, and their crumbling. Although I shall not here enter into mineralogic-petrographical questions, a geochemical characteristic should be mentioned, viz. their fluorine content. Smaller and larger patches of fluorite are found both in and outside the granites. They may be metasomatic, as in the Kungnat granite (p. 97), or occur mostly as coatings on joints, or in transverse zones. Notably these small fillings in joints are found throughout the whole area, so that it is impossible to enumerate the individual localities. They are especially abundant in the surroundings of Arsuk Island, Ivigtut, Taylor's Harbour, Ikafjord, and Kujartorfik. On the latter island a very interesting occurrence was observed; several veins of fluorite ascend through Julianehaab granite of a younger generation. Round these veins the granite has been transformed into a granite of the Helene granite type. The feldspars are big and of a deep red colour, the quartzes are gathered and milky-blue. Thus the different stages of the transformation are concentrated round these veins; this shows that it has probably some connection with the content of fluorine.

In the skerries between Torsukatak and Sarkamiut joints with a little fluorite are found in many places. They are usually of a red or yellow colour, while the intermediate granite is grey; the shores therefore obtain a peculiar mottled appearance. Furthermore, the fluorite is found in the surroundings of Brede Fjord, near Julianehaab, and south of that place. It has already been recorded from Tunugdliarfik (p. 80—81). It is fairly common farther south, too, but as far as has hitherto been ascertained never in large quantities.

Best known is the famous occurrence of cryolite at Ivigtut. It belongs to the later phase of the Gardar Formation and is understandable in connection with its other manifestations; however interesting it might be to discuss these relations here, there are various reasons for not doing so.

The content of fluorine must play a role in the formation of the younger granites, and in the development of their different textures, of which the Rapakiwi is the most remarkable. A great number of theories as to the formation of the Rapakiwi texture have previously

been advanced. Some are to the effect that it is the result of a cooling of a molten mass with partial re-melting. (WAHL 1925, VON ECKERMANN 1937). The most remarkable of these theories is that of WAHL, who explains the ovoid shape as a result of a reduction of the gas pressure and the connected conditions. Another group of theories explain the Rapakiwi texture as being more related to the metamorphic phenomena. J. J. SEDERHOLM strongly emphasized the fact that the ovoids also developed in the inclusions and in the adjacent rocks. DRESCHER-KADEN (1935) and BACKLUND (1937) consider the texture a metamorphic phenomenon. BACKLUND points out that it is the molasse from the Sveco-Fennidic orogeny which has been transformed into the Rapakiwi rocks, which should, then, be an indicator of pre-existing molasse sediments.

On the basis of the observations made in South Greenland it is possible to take a standpoint to some of these hypotheses; the Rapakiwi texture is found in those parts of the massifs in which inclusions are present as also where they are about to disappear, or have just disappeared. This speaks in favour of a metamorphic origin and controls the localisation of these rock types in the massifs: they occur where the boundary moves agmatitically, that is to say, advances with an agmatitic front. Such agmatites are found when the roof is much jointed or in other ways contains beaten tracks along which the volatile components may prepare for action. The fluorine content must there have caused different conditions of viscosity. Various signs indicate that the molecular mobility was at first greater than usual, larger crystals being able to get their material from the surroundings. Subsequently the mobility decreased very rapidly. Whether this took place by release of pressure, as assumed by WAHL, or whether it is merely a characteristic feature of the fluorine-bearing matter, we shall not here decide. That the rather high content of zirkon may be of importance, may merely be suggested.

BACKLUND's hypothesis that the Rapakiwi texture is the result of a transformation of molassic rock types was not confirmed in South Greenland. These granites have resulted from very different original rocks of very different ages, thus Ketilidian rocks, but also various younger dykes and the syenitic series, which belong to the same group. The only visible trace of their origin is that those originating from acid rocks are mostly light-coloured, whereas those originating from basic rocks are brownish. However, this rule is not without exception; the brown rocks, too, may turn into a lighter colour upon a later additive transformation. It would be interesting if the Finnish Rapakiwi rocks also, which have hitherto contributed most considerably to the Rapakiwi problem, could be investigated from this point of view. ESKOLA (1930) has set forth interesting hypotheses concerning

the crumbling of the Rapakiwi, which may in part be confirmed in South Greenland.

The inferences which the South Greenland occurrences in their present state of investigation suggest, may be summarised as follows: the Rapakiwi texture occurs in the agmatitic front, which forms a shell round the syenitic massifs. This shell has, as a rule, the shape of a flat dome, but may exhibit a number of protuberances. The partitions between these growing protuberances are absorbed, but for some time yet they will form swarms of fragments extending like fog banks through the granitic zone. The nucleus contains syenitic and more basic as well as anorthositic rocks. So far no large occurrences of these rocks have been found, but the block content of the moraines indicates their presence. In most massifs the granitic shell seems still to remain in the place in which it was formed; in doming the roof it may escape through fissures; however, so far no examples of a far-going migration have been found in Greenland. EBERLIN (1889, p. 253) states that near Aluk, at the southeast coast, and in the interior of Lindennov Fjord the younger granites and syenites occur in mushroom-shaped bodies, that is, laccoliths. The level of the present topography in Southwest Greenland does not permit of making investigations at the base of the massifs. The only comparable case was found in the surroundings of Helene Harbour, where the upper lamina is partially underlain by a lamina, more than 100 m thick, of less transformed basement rock. The level distribution in the older basement seems to be characteristic of Southwest Greenland also. It should not, however, be confused with the level bedding, as has been done in Fennoscandia, where the topographic conditions did not allow of a more comprehensive vertical survey.

It is quite possible that a number of features of the Finnish Rapakiwi massifs can be explained in a similar way; notably the massifs of south-western Finland, which I studied in 1930 under the kind leadership of Professor ESKOLA, exhibit many points of resemblance. The many different rocks in the vicinity of Lappeenranta, which I visited repeatedly in the agreeable company of Dr. LAGERCRANTZ, and which have now been described by HACKMANN (1934), show a number of analogies. The occurrences of Rapakiwi in Drivdalen, Trollheimen and Orkladalen, Norway (CARSTENS 1926, WEGMANN 1926), and their association with other granites and with anorthositic rocks would seem to be interpretable in a more satisfactory way on the basis of the observations made in South Greenland. It would be tempting to compare the younger granites of South Greenland with the Swedish rocks described by v. ECKERMANN (1936, 1937). Since, however, I do not know the latter from personal inspection, and v. ECKERMANN has chiefly studied them from mineralogical and petrochemical points of view, whereas I

gave more attention to the structural aspects, conditions do not yet seem ripe for a more detailed discussion. The characteristics enumerated by v. ECKERMANN (1936, p. 264) for the corresponding granitic groups agree largely with those of South Greenland: "Both granites are characterized by their lack of accompanying pegmatites. Both are conspicuous by their titanium and fluorine content. Both develop in their acid differentiates plagioclase shells around orthoclase-phenocrysts, and granophyric or poikilitic textures". In a new, very interesting paper v. ECKERMANN (1937) sets forth a theory comprising both the basic and the acid members of the Rapakiwi series. All these are supposed to have been formed in the lower stories of the earth's crust and to have made their way upwards by way of faults or similar canals. According to this theory the magma fractions which subsequently compose the rocks should be formed at a depth at which their formation cannot be observed. The theory is based entirely on physico-chemical considerations. It is therefore easy to defend, because all the reactions which are required later in order to secure agreement with conditions at the surface, can be transferred to that unknown depth; it may be compared with a portmanteau (WEISMANN, v. BUBNOFF 1931), from which, on a given occasion, all that is unpacked which has previously been packed up for the occasion. Thus it is a very ingenious theory, because it evades all difficulties. However, when the greatest connoisseur of the Swedish Rapakiwi massifs feels compelled to resort to such a theory, it may perhaps be assumed that the Swedish massifs show a number of other properties which are different from those of the Finnish, Norwegian, and South-Greenlandic ones, and it would therefore be exceedingly interesting to discuss these differences.

In the occurrences of South Greenland the transformations are particularly striking. When such an eminent petrologist as v. ECKERMANN does not pay special attention to them in Sweden, it is reasonable to assume that these phenomena have left no distinct traces in the Swedish rocks. This is possibly due to the circumstance that, as on Hogland (KRANCK 1928), they are formations which have reached much nearer to the surface of the earth than in other regions. Hence it should not be regarded as impossible that part of the development which v. ECKERMANN transferred to depths where no living man can ever control them, took place at depths which are visible in Finland and South Greenland. This is only a suggestion which might account for the incredible variation in descriptions and theories in this field. If they are grouped according to certain depths, a number of the differences will be understood. The fact that many observers have generalised their observations from one level making them apply to all the other levels, must necessarily create disagreements.

One further remark may be added in regard to the absence of pegmatites from the Rapakiwi group pointed out by v. ECKERMANN: in the more deep-seated Rapakiwi masses, also, pegmatites are of rare occurrence; but they are found in Finland. In South Greenland they occur where the deep-seated nuclei crop out. The pegmatites pierce the sub-Rapakiwian rocks in abundance, and Rapakiwi texture is found together with them. In other cases they reach the Rapakiwi zone and there disappear into the granites. Thus pegmatites are not absent from the Rapakiwi, but the pegmatitic material forms part of this rock. When this material was overtaken by the cooling in the supply canals, it crystallised out in the form of pegmatite, since it had no time to react with the wall rocks. The lack of pegmatites must accordingly be interpreted in a different way. We arrive, then, at a hypothesis which explains conditions in other massifs also:

The pegmatites were added to the marginal zone, which is now the granitic zone. At its outer side the surrounding rocks, at the internal side the nuclear rocks, were transformed, and the granitic shell developed in situ. Fluorine played a certain role in this process. If these Rapakiwi granites are compared with the usual types of granitic series, the difference is mostly that the pegmatites and granites of the latter are more separated. If the last solutions intrude into the already cooled granitic rocks, they will crystallise out as pegmatites. Only in the interior parts of granitic areas, which are the last to be reached by the cooling, the lichors do not crystallise in dykes, but may still react upon the granitic material. In this way the late granites arise (WEGMANN 1935, pp. 335, 342—343). In their outward appearance these granites show certain points of resemblance to the rocks of the Rapakiwi group. Very typical in this respect are the late-Karelidian granites of eastern Finland; the same applies to the late-Caledonian rocks occurring in the Stauning Alps in East Greenland (WEGMANN 1935) and at the boundary between Trøndelagen and Nordland in Norway.

This explanation of the absence of pegmatites in the Rapakiwi rocks also accounts for the relation of these rocks to the ore content. Among the many occurrences of Rapakiwi in Finland, only one large ore-deposit is found, viz. at Pitkäranta near the Ladoga Lake (TRÜSTEDT 1907). The Rapakiwi, therefore, is not generally regarded as "ore-friendly". Under special conditions only ore concentrations may be met with; such special conditions are furnished by the limestone layers at Pitkäranta (Finland) and the fairly calcareous greenstones at Josva Mine (South Greenland). If no such possibilities for concentration are present, the material concentrated in the pegmatitic solutions will be distributed again and diluted in the Rapakiwi rocks. This also accounts for their content of rare substances and minerals. That this hypothesis

will involve even more mineralogical and petrographical consequences, will be discussed in another place. The mineralogical investigations carried out by FERSMANN and especially by POPOFF (1928) on Rapakiwis should be interpreted in this way, rather than as due to crystallisation of an intrusive magma.

The tectonic significance of the Rapakiwi massifs is very different according as WAHL's, v. ECKERMANN's, or similar hypotheses are adopted or the observations made in South Greenland and in southern Finland are taken into account. If they are interpreted as reaction products lying more or less in situ, we may thus observe the transformations so to speak in the workshops in which the rocks originate. Only part of the material has been added. The new product may in some cases continue its migration. The problem as to how the mass secured room, and consequently the tectonic development of the whole portion of the earth's crust during this period, will be different too.

It is not my intention to present here a fully elaborated working hypothesis for the genesis and tectonic importance of the Rapakiwi rocks; for in doing so, I should have to enter into a more detailed discussion of the Fennoscandic conditions than I have done; but I believe I have shown that South Greenland may give important contributions to the problem. At the same time some features of the tectonic development of South Greenland during the latter part of the Gardar period can be studied.

3. The relations between the Tunugdliarfik massifs and the younger granite and syenite massifs.

A direct contact between the alkaline massifs of Tunugdliarfik and the younger granite massifs has not hitherto been found. Thus no direct proof of their relationship is available. Yet we have certain clues to a hypothetic parallelisation:

Both groups of rocks are younger than most of the diabases. Both are accompanied and succeeded by fluoritic exhalations. The latter fact, however, need not mean that they are strictly synchronous. According to v. ECKERMANN's observations the fluorine content is exhibited by both the Råtan granite and the Rapakiwi group; but they are of different ages. In Finland both the granites of the third group and of the Rapakiwi group show this content of fluorine; here, too, there is a difference in age.

It is quite probable that in South Greenland the two groups belong to the same cycle, only their position within it is doubtful.

A further clue is given by the parallelism of development of the younger granite massifs with those of the essexite series, notably

in the nordmarkitic and arfvedsonite-granitic members. The resemblance is particularly marked at Helene Harbour. That the development of the rocks of the massifs in the Gardar Formation follows a course but slightly different from that located in the Ketilidian rocks will easily be understood. But in the Narsak rocks, where the portion of the digested basement rocks is of great importance, the resemblance is more marked. If it is assumed that the Rapakiwi rocks correspond to the



Fig. 64. Dark dyke younger than the nordmarkite and the arfvedsonite-granite in the Kusinga Valley near Narsak; the lava is very rich in bubbles, seen as lines of white spots. The margin of the dyke is glassy.

last members of series which correspond to the essexite series, and it is further assumed that they are fairly synchronous, the transformation into alkaline rocks would have occurred in the succeeding episode, though more accurate determination of this difference in phase is not possible. Functionally the formation of the Rapakiwi rocks shows a certain similarity to that of the alkaline rocks; in the formation of new rocks a fixation of volatile constituents takes place. These volatile constituents may belong to the same cycle; their first activity resulted in the explosions in the lower Igaliko sandstone; subsequently there followed their transformative activity in the formation of the alkaline rocks. The former were rather explosive, the latter more corrosive, which is due partly to a difference in the composition, partly to the liability to reaction of the surroundings.

The last manifestations of the cycle are dykes which are younger than the younger abyssal rocks. A number of them occur in the region of Narsak (Fig. 64). Small veins are recorded from the Kungnat massif. In the bay south of Angnikitsorsuak the granite is traversed by a diabase dyke. Similar dykes are found on Sermersok. Dykes of this type have been recorded from the mouth of Tasermiut and from other localities in the Frederiksdal massif. The dykes at Narsak and Kusinga were richer in gasses. The remaining dykes sometimes seem to behave like lamprophyres.

The igneous manifeststions have now come to an end. The area contains no more marks of later deposits or volcanic outbursts; the hot springs at Unartok have a different meaning (A. JESSEN 1896).

V. LATER DEVELOPMENT

In view of the fact that no sediments of younger age occur, it must be assumed that the area has since that time been elevated, so that it became an area of supply and not of accumulation. Thus the material transported during this period must be investigated if we are to discover any features of its history. The sediments of the Davis Strait have not yet been investigated, so we cannot form an idea of events on the basis of their composition and sequence. We must therefore be content to study the forms of terrain which have resulted from the removal of the material. The marks are found in the physiography of the country. I shall refrain from giving a description of it, but merely treat some few traits which may contribute to connect the history of the area with the development of Greenland. The post-glacial formations and the discussion of the most recent subsidence of the land will be disregarded. Interesting views on the transportation of sediments and its characterisation are given by CROMMELIN (1937).

To find out the early history we must glance at the large features of the relief. They will be briefly discussed here. In these features the fjords and valleys are details of the first order, which, again, are succeeded by lower classes. They owe their modelling to the activity of the glaciers and the running water, and are traces of the most recent episodes in the life of the area. The altitudinal groupings of the area fall naturally into two high areas separated by a lower zone.

The western high area begins at Nunarsuit and Alangorsuak (altitudes ranging from 600 to 800 m) continuing in western Sanerut (highest summit 945 m), Tavdlorudit, Arsuk Storø (757 m), Arsuk Island (910 m), and Kungnat (1400 m). The view from the Gule Fjæld (940 m, North of Arpagfik) (cf. Fig. 45) towards the north and east shows that at an altitude of 700—900 m there is a wide plateau, a fairly level landscape, such as is found in many parts of the Norwegian mountains. In this "vidda" there occur a number of broad mountain massifs, in part made up of younger granites, which rise for some hundred metres above the undulating landscape. The fjords cut their way into it, dividing it into smaller areas. Where the fjords, their valleys, and the glacier

cirques approach each other, more alpine forms with narrow crêtes and pointed summits will develop. This is the case near the coast (cf. Fig. 48). In the interior the inland ice rests on this flat surface, but descends into the valleys. The high massifs form peninsulas and nunataks in the inland ice. Previously the inland ice seems to have covered larger portions of the high landscape, but it did not spread to its outermost parts, which were consequently sculptured by more local glaciers. The result



Fig. 65 The slope of the eastern high landscape towards the lowland of the Kagsimiut depression, near Akuliarusersuak in Lichtenau Fjord. Looking towards the northwest.

is that these outer portions (Nunarsuit, Alangorsuak, the western part of Sanerut, Arsuk Island, Arsuk Storø, Kungnat and Sermersut) bear a certain resemblance to the Lofoten.

This levelled landscape descends towards the southeast, being very low in the interior of Kobbermine Bay. From that point it rises somewhat towards the east, but does not exceed 550 m. Only around the innermost N. Sermilik does the terrain rise again to altitudes of more than 1000 m, in some places more than 2000 m. At the same time the topography again assumes an alpine character. Between these two blocks, a stretch of lowland seems to extend below the ice, as will appear from GARDE's famous expedition on to the inland ice (GARDE 1896, pls. VI and VII). This lowland also extends towards the south. In its centre lies Kagsimiut, and it may therefore be called the Kagsimiut

depression. The depression is also traceable in the coast line as a whole. Along this stretch as far as the island Sermersok no more high mountains occur at the coast. A high rock wall is traceable northward from that island, as shown in the sketch-map (pl. 7). It begins with altitudes of nearly 1400 m, very near the sea; at Anoritok the summits rise to nearly 1200 m, at Lichtenau Fjord to nearly 1800 m (Fig. 65), and at Igaliko to 1750 m. Where the fjords and valleys cut into this cliff, alpine forms will result, usually beginning behind the cliff, which

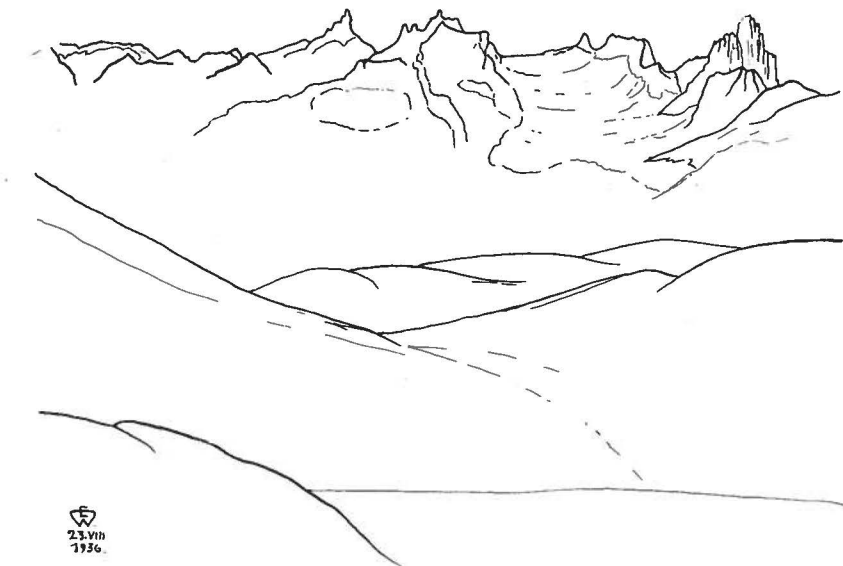


Fig. 66. High jagged peaks, rising above the main zone of distribution of the glaciers on Sermersok Island. View from the interior of Unartok Fjord.

is not generally of alpine form, (pl. 2, Fig. 65); behind this margin the forms are sharp, mostly aiguille-like (Fig. 66). Their disintegration is very active; they are not very resistant, and cannot, therefore, be very old. In cross-section the valleys are very dissimilar in both areas. Farther towards the interior a top-level appears, from which the summits were cut out. This again is an ancient levelled landscape. Above it a few massifs rise up, from which the highest summits have been cut out. This high landscape extends right across the land to the fjords of the east coast. A belt with low passes from one fjord to the other extends along the cliff. West of this line of passes the Ilimausak massif rises to 1450 m (Fig. 67) and the Redekammen to 1210 m. They are surrounded by a number of lower mountains. The whole landscape has been covered by the inland ice, which has modelled it. In many places, however, an ancient level remains at an altitude of about 600 m. The valleys and fjords occur at rather short intervals, so the level is much dissected. In the

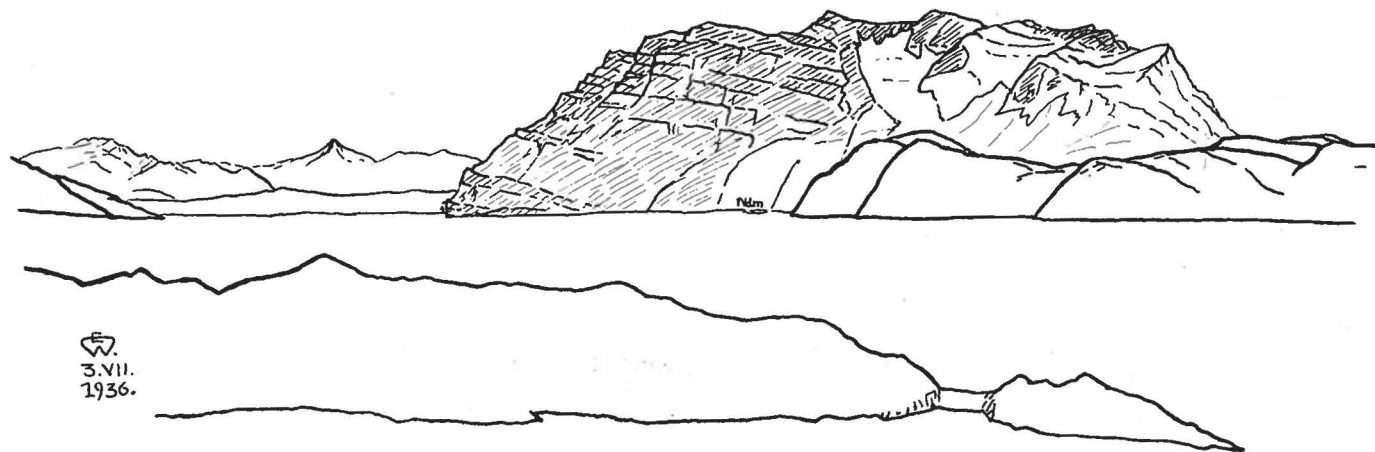


Fig. 67. Sketch drawn from the eastern cape of the island Kanertek at the mouth of Torsukatak Sound in Brede Fjord. To the left N. Sermilik Fjord with the high mountains in the background and the lowland of Kagsiarsuk in the middle. In the centre, the massif of Ilimausak (sedimentary and volcanic series are shaded; Ndm = nordmarkite). To the right the island of Tugtotoq, consisting of Ketilidian granites, with a distinctly lower top-level than the massif of Ilimausak behind.

southern part of Sermersok it is very distinct north of Cape Egede. A lower level occurs at about 300 m (cf. Fig. 67). In the northern parts of the Julianehaab district, in particular, it is still distinctly visible in many places.

This landscape is intersected by the most pronounced level, the ancient strandflat, elevated less than 100 m above the sea, and accordingly exceedingly distinct over wide stretches. (Figs. 68, 69, pl. 2).



Fig. 68. Strandflat near Nanortalik. Formed in the eastern high area. At the fog a view of the Tasermiut (Ketils) Fjord. View from Sigsarigsok.

It cuts across both higher and lower levels. The strandflat is well known from the coasts of Greenland. It was described by KORNERUP for the Holsteinsborg district, and the account was accompanied by very typical figures (KORNERUP 1881). It is mentioned by NANSEN, too. LAUGE KOCH coupled certain portions of it with the sub-Mesozoic peneplain in the areas round Disko Bay. Many theories about the genesis of the strandflat have been set forth; GUYAN (1935) has given a complete resumé of them. Usually it is assumed to be glacial, interglacial, or pre-glacial. As it exhibits nearly the same altitudes throughout the area, there have hardly been larger differential elevations since it was formed. The deepest level is that of the sea-banks which skirt the west coast of Greenland over great distances. They are assumed by many authors to correspond to the deepest eustatic level (PENCK 1936), that is to say, the

level when the greatest quantity of water was bound up in the glaciations of Quaternary times. On that assumption it is tempting to regard the emerged strandflat as equivalent to the level of the sea when the large glaciations had melted, that is to say, it would be interglacial.

The first peneplain (summit level) was elevated several times, at such a rapid rate that erosion could not keep pace with it and preserve the topography with about the same altitudinal differences between mountain summits and valleys. During these uplifts the whole land-

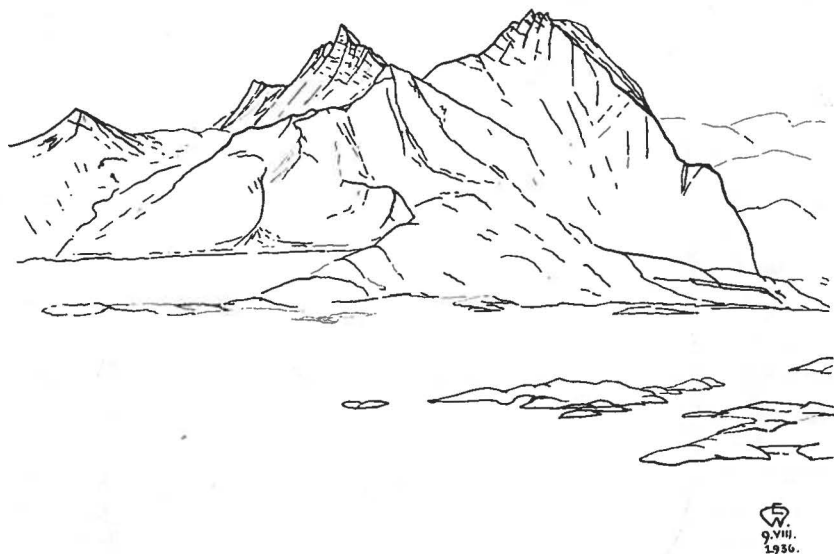


Fig. 69. Kungnat, with the low skerries of Arsuk in the foreground, which here forms the strandflat, cut in the western high area. Drawn from the top of Arsuk Storø.

scape was domed. At Kobbermine Bay the strandflat level extends below the ice. The warping is younger than the earliest peneplanation but older than the formation of the strandflat; it has the direction N-S. The Kagsimiut Gulf is the most visible trace of the depression between the two upheavals. When we speak here about a depression, it does not mean that the area has subsided, but only that it is a lower-lying area. On the contrary, it is highly probable that this area, too, has been elevated, though not so much as the adjacent areas. That it has not subsided later to any great extent is shown by the fact that the strandflat has not been more deformed than that it exhibits almost the same altitudes throughout the area.

On the orographic map of Greenland many traces of this north-south warping of the ancient peneplains can be seen. In East Greenland these tendencies commenced as early as the Devonian time (BÜTLER 1935,

WEGMANN 1935), but were succeeded by compressions. This warping is especially distinct in Mesozoic and Tertiary times between Liverpool Land and the Stauning Alps. North of Davis Sound only the western part of the syncline is landfast, the remaining part lies below the sea. To the south of Scoresby Sound, the syncline is filled with basalt. Its western part dips towards the east in the interior of Scoresby Sound, its eastern part dips towards the west at Cape Brewster (WAGER 1934). The whole syncline strikes towards the Blosseville Coast. The subsidence continued after the *mise-en-place* of the basalts. Synclines with similar directions are found on Iceland and in the sea off Northeast Greenland, where they were discovered by TROLLE (1935). A further down-warping of the early peneplain seems to occur west of the Angmagssalik district, where the top-level lies below the ice, and the latter descends towards the coast. Davis Strait farther west was formed by a similar down-warping.

It seems reasonable to connect the down-warping at Kagsimiut with the north-and-south directed domes which seem to dominate a good deal of the topography of Greenland. No accurate dating is obtained in this way, because these peneplains, even where they can be dated, are of different ages (WEGMANN 1935, p. 45—46), but it fits into the tendency to motion which prevailed in Mesozoic and Tertiary times. These domes and the intermediate basins are assumed to have played a very important role in the formation of the inland ice.

Adherents of the isostasy theory will note that a series of younger granitic masses occur in both high areas of South Greenland. Their specific gravity is lower than that of the rocks of the basement, both because of their composition and owing to the many pores found in them. When large masses of these rocks spread in the depth, these zones must become lighter (WASHINGTON 1922). In that case the movements would be upheavals; warping, then, is merely a descriptive expression. I shall revert to these problems in another connection.

VI. CHRONOLOGICAL PARALLELISATION

The only traces of fossils were found in red chert from the Igaliko sandstone. STEENSTRUP discovered sponge-spicules in it under the microscope which it has not hitherto been possible to account for stratigraphically. It has therefore been attempted to parallelise the formation by means of comparisons. The Igaliko sandstone has been placed in very different periods, as follows:

- 1) pre-Cambrian (JOHNSTRUP, DAWSON, LAUGE KOCH);
- 2) Devonian (GIESECKE, SUSS, USSING, BACKLUND);
- 3) Permian (PINGEL).

That is to say these sediments have been parallelised with all the formations which are represented in the northern hemisphere by red terrestrial deposits. All these deposits are fairly similar to one another, so it must be regarded as very difficult to parallelise them on the basis of their facies.

If as a further basis for comparison we take the association with the volcanic rocks, a comparison with all three will be possible, but the Permian will not be very probable.

- 1) Pre-Cambrian: It may be compared with different formations:
 - a) North Greenland: LAUGE KOCH (1935) records huge beds of diabases above the Thule Formation.
 - b) in East Greenland the lower parts of the Eleonore Bay Formation contains ophitic diabases (WEGMANN 1935).
 - c) in North America the Cambrian is underlain by red sandstones which are partially referred to Cambrian, partly to Keweenawan (STAUFFER 1927): but the great volcanic outbursts in Keweenawan time occurred below these red sandstones; even DAWSON¹⁾ compared the Igaliko sandstone with these red sandstones.

¹⁾ DAWSON (1886, pp. 9—10) compared the Igaliko sandstone to the red sandstones which underlie his "Silurian system", and which are now largely regarded as pre-Cambrian; in his description he refers them to the Silurian system, but mentions that they have also been regarded as Devonian and Permian.

- d) Fennoscandia: Jotnian and Hoglandian; both in Finland and Sweden the sediments of these formations are interbedded with rich series of basic and acid rocks. They bear a great resemblance to the Greenland rocks.
- e) Fennoscandia and Scotland: Caledonian zone; Torridonian, Greenlandian, Eocambrian; mostly only such igneous formations as penetrate are mentioned; in the Bossekop series only volcanic products are recorded (HOLTEDAHL 1918).
- 2) Devonian. a) East Greenland. Here BÜTLER (1935, 1936) has ascertained two main periods of volcanism, viz. the lower Cape Fletcher Series and the upper Cape Graah Series, which have been examined petrographically by A. RITTMANN. Both extrusive and plutonic rocks are found. (NOE-NYGARD's paper (1937) on this subject is to a great extent based on BÜTLER's investigations).
- b) Scotland; volcanic and plutonic rocks are found both in the lower and the upper series (READ 1935).
- c) Norway; the Devonian of western Norway contains comparatively few volcanic rocks (KOLDERUP 1928).
- d) North America; Devonian volcanism is found in the Dalhousie complex (HOWARD 1926).

The immense Devonian sandstone series with volcanism seem only to occur where they have been formed in an internal molasse-basin (in relation to the Caledonian belt). Thus they depend to some extent on the orogenesis, both as regards their sedimentation and their volcanic development. The sedimentation is greatly influenced by the intra-Devonian movements, as demonstrated by BÜTLER (1936).

The question then arises: is the Gardar Formation to be considered a late-Caledonian internal molasse basin? This gives rise to the problem about the connection of the Ketilides. LAUGE KOCH (1936) has set forth the supposition that the Caledonides of East Greenland continued across the Julianehaab district. Such a connection seems difficult to demonstrate at present, and according to the most recent investigations is hardly probable. The facies of the Ketilidian and the Caledonian series differ greatly, and show no points of resemblance. The facies might be assumed to change along the route from East Greenland to South Greenland; but no transition has been observed in the intermediate area (KNUTSEN and EBERLIN 1889, WAGER 1934). It is far more probable that the Ketilides belong to a middle pre-Cambrian cycle.

As will be seen from the brief description, the disturbances of the Gardar Formation do not resemble the Devonian movements in East Greenland. BÜTLER has ascertained a series of fold-

ing phases between the Kongeborgen and Hudson Land, East Greenland. In the southern area also (Wegener Peninsula and Canning Land) the Devonian strata are folded, as may be seen from the photographs published by NOE-NYGAARD¹⁾ (1934). The whole tectonic style and character of the movement of the Devonian of East Greenland differ from those of the Gardar Formation. It might be objected that differences were to be expected over such wide distances; however, the Old Red of Scotland, situated at an even greater distance, shows great similarities in principle to the East Greenland series. At any rate, the Gardar Formation is not directly comparable to the intra-Caledonian molasse basins.

If the Devonian is maintained, as done recently by BØGGILD (BØGGILD, etc. 1935) (unfortunately, however, without a statement of his motives), it must be compared with the fault zones of the old rejuvenated blocks, as for instance the rejuvenated blocks of Central Europe. A comparison in a functional respect with Limagne (JUNG 1936) within the French central massif might give some structural information. The framework there is Hercynian, whereas sediments and volcanism are Tertiary, in part Quaternary. Thus there is an immense difference in time between the two activities, the younger formation is not associated with the Palæozoic orogenesis (its late formations are Stephanian and Permian), but with the Tertiary activities at a time when the Paleozoic structures were dead. A certain functional similarity is shown by the chemical conditions of the eruptive rocks; an explanation of this fact will be given below.

The similarity with the East Greenland Palæozoic is accentuated through the occurrence of alkaline rocks south of Davy Sound and at Kangerdlugssuak. Their stratigraphic position, however, has not yet been established.

3) Permian: The Oslo area; the plutonic rocks of the Julianehaab district and those of the Oslo district have been compared by many authors; but it is only some few types, occupying but little space, which agree. Neither structure nor movements (HOLTEDAHN 1935) show great similarities, especially if the whole of the south Greenland area is considered.

It has also been suggested that the alkaline rocks might be of Tertiary age, like those of western Scotland. This is hardly probable. If they belong to the same cycle as the younger granites, they are older than the upper peneplain, which is Tertiary, in some parts possibly Mesozoic.

¹⁾ His photographs show a very peculiar case in the history of geological investigation, viz. that the photographic camera has detected more than the geologist at work, since NOE-NYGAARD denies in his text and diagrams (pp. 80—81) the folds recorded by his camera and reproduced in his figures and plates.

The best object for comparison with the Gardar Formation is the Fennoscandic Rapakiwi belt (SEDERHOLM 1932; v. ECKERMANN 1937). The South Greenland area includes along the west coast the Frederikshaab and Julianehaab governmental districts, being accordingly nearly 400 km broad in a north-and-south direction; possibly it is even broader, as it may extend into the Godthaab district also. As regards the extension in an east-and-west direction a similar figure will be arrived at. Thus we are not concerned with a merely local phenomenon, but a regional formation. If the superficial extension of the individual massifs is less than the average of the Fennoscandic ones, it may be due to the depth of denudation. The distribution of the basic rocks in the Hoglandian-Jotnian cycle shows many points of resemblance to that of the Gardar Formation. If the parallelisation is based on a discussion of similarities, that is to say, if the same method is adopted as was used by USSING, no certain result will be obtained either; but there seem to be reasons for correlating the South Greenland Gardar Formation with the Hoglandian-Jotnian cycle of Fennoscandia. On the other hand, it falls within the Keweenawan period on the North-American continent. The Keweenawan Formation is of geosynclinal thickness; the Gardar Formation is supposed to correspond to it as a smaller accumulation.

Yet another argument may give some hints: the Gardar Formation is a period of widening in South Greenland. If it is assumed that the neighbouring areas showed the same tendency, and periods with similar tendencies are looked for in East Greenland, two periods will be found, viz. the young pre-Cambrian one and the post-Caledonian one, during which the aforementioned (cf. pp. 129—130) broad synclinal zone was formed, and whose widening is evidenced by the many basalt dykes (WAGER 1934). If the latter is assumed to correspond to the formation of the Kagsimiut depression, it is natural to correlate the two former, and to regard the young pre-Cambrian as a period of widening in Greenland. Nor is it perhaps quite casual that the zones of widening in which sediments have accumulated, are in Northeast and Southeast Greenland, largely parallel to the directions of widening in South Greenland. Accordingly the widening cannot be a local, but must be a regional phenomenon.

Since the time of WEGENER all regional tectonics relating to Greenland have been followed with great attention by adherents of the theory of continental drift. It may, therefore, be necessary to say a few words about it. In a previous paper the present author outlined the unity of the Caledonian mountain chains round the Skandik, not only as contemporaneous but also in regard to the development of the transverse sections (WEGMANN 1935). Similar connections have been pointed out for the

Devonian (BÜTLER 1936) and the younger formations (ALDINGER 1937). Recently HOLTEDAHL, too, has accepted this working hypothesis (HOLTEDAHL 1936). If we imagine the pictures of the Caledonian folding and the migrating Caledonian geosyncline rolled back like a film (WEGMANN 1935), the Rapakiwi belt would extend across Fennoscandia and southern Greenland in continuation of each other. Where its continuation is found in Canada, is not known; possibly the Mugford Formation of Labrador belongs to this cycle.

Certain relations may be pointed out between the deep-seated massifs of the Gardar Formation and the anorthosite-bearing districts of southwestern Norway (BARTH 1936) and the Adirondacks (BALK 1931). The similarity should here be sought not so much in the interpretation which has been given of their *mise-en-place* but in the structure and the types of the rocks; a further comparison will be necessary in the petrographic description. The petrographical comparison with the rocks of the Kola Peninsula has previously been discussed (RAMSAY, FERMANN, BACKLUND 1932). In recent years exhaustive regional-tectonic investigations have been carried out by POLKANOFF (1935), which have quite recently been compiled by v. BUBNOFF (1937). It cannot be denied that there are a number of similarities, but also great differences. As regards the age of the alkaline rocks they are correlated with those of the Oslo district, but not without controversy.

The stratigraphic conditions do not yet seem to have given any clues for a parallelisation. The Ketilides cannot be directly compared with the Caledonides of East Greenland; they should probably be referred to one of the pre-Cambrian orogenic cycles. The Gardar Formation may be referred either to the young pre-Cambrian or to the Palæozoic. Possibly, however, the eruptive and sedimentary manifestations of the Gardar Formation are distributed over longer periods, so that they cannot as a whole be directly parallelised with one of the periods mentioned, but should be referred to several periods. It is necessary, therefore, to arrive at a better division within the Gardar Formation than it has hitherto been possible to make. A comparison with objects more thoroughly studied will be very helpful for this purpose.

Unfortunately the investigations have not so far allowed of a definite parallelisation. As will appear from the above, this aspect of the question is hypothetical. But the recent investigations have shown definitely how the parallelisation can be carried out; we can trace the network of the basic dykes of the Gardar Formation to the east and west, and investigate in which formations it ends. This must be one of the main items on the programme for further investigations.

VII. SUMMARY AND SOME GENERAL CONSIDERATIONS

In the preceding account an attempt has been made to class the rocks of South Greenland on the basis of their structural development. This has been divided into two main cycles, viz. the Ketilidian and the Gardar Formation cycles.

The Ketilidian cycle begins with the formation of a geosynclinal series which can be divided into

- a) a lower sedimentary series, the so-called Sermilik group, and
- b) an upper, mainly volcanic series, the so-called Arsuk group.

These two series have been folded, and the structure arising in this way has been granitised to a great extent. The result is the Julianehaab granite and its different variations. The movements during the granitisation have been briefly described.

After the granitisation there followed a period of strong erosion, which denuded the mountain chain right down to the broad masses of migmatites and granites. The hypsogenous movement seems to have accompanied and succeeded the granitisation. A new accumulation begins on the deep-cutting peneplain. This initiates the cycle of the Gardar Formation, which consists of the following main divisions:

- a) the Igaliko sandstone; in its lower portion a volcanism of a more explosive character begins with an abundance of gases decreasing towards
- b) the porphyry formation, which is an almost purely volcanic formation of great thickness.

Volcanic feeding channels are traceable nearly throughout the whole area; they constitute an important indicator of age for the whole of southern Greenland. These formations are intruded by the essexite series, a series of plutonic rocks embracing the essexite-gabbro passing into nordmarkite and arfvedsonite-granite. Outside the Tunugdliarfik area this series is probably represented by diabases. They are succeeded by a series of syenitic intrusive rocks, which are surrounded by a shell of younger granites and Rapakiwi rocks. They form a large number of

massifs in South Greenland. In the Tunugdliarfik area the whole edifice, the basement, the sandstone, and the lava formation as also the essexite series, are transformed into the alkaline rocks, the series of nepheline-syenites.

The development may be tabulated as follows:

The Gardar Formation	$\left\{ \begin{array}{l} \text{porphyry} \\ \text{formation} \\ \text{Igaliko} \\ \text{sandstone} \end{array} \right\}$	essexite series	$\left\{ \begin{array}{l} \text{nepheline-} \\ \text{syenite series} \\ \text{Rapakiwi} \\ \text{series} \end{array} \right\}$
large hiatus			
The Ketilides	$\left\{ \begin{array}{l} \text{Arsuk} \\ \text{group} \\ \text{Sermilik} \\ \text{group} \end{array} \right\}$	folding $\rightarrow$ granitisation $\rightarrow$ Julianehaab granite	

In southern Greenland the earth's crust has preserved the traces of two cycles. At present too little is known about the earlier ones to include them in this consideration. Each cycle begins with a depression and an accumulation of sediments and volcanic basic products. In the first cycle this period is succeeded by a folding activity, presumably with a narrowing of the whole zone; in the second cycle the widening continues. In both cases the basic rocks are followed by intermediate and acid rocks; they are largely mixed rocks, i. e. some constituents originate from pre-existing rocks, some have been added later. In the former cycle rocks of a calco-alkaline type arise, in the latter rocks of a more specially alkaline type. Twice the migmatite front rose in the crust, but produced very different series of rocks. In other regions this phenomenon has been explained by the assumption that a different magma from that occurring below the continents was found below the geosynclines. Other geologists merely assume a different tendency of differentiation, but the same kind of magma. Other authors, again, assume that the rocks recur in the course of each orogenic cycle, partially in a magmatic state. On this hypothesis the variability is much greater from the beginning, since magmas of many different kinds may form; and they may develop in many different ways.

At the beginning of the cycle the acid crust must have been rather solid down to the depths from which the basic material was derived; it pierce the upper crust in the form of dykes giving off part of its heat to the wall rock; at each new intrusion the temperature of the crust will rise, especially when the dykes occur at small intervals. The thermal gradient in the crust will become steeper. In the Gardar cycle it can be

observed that the basement at the time it was intruded by the diabase dykes must have been warmer than at the time of formation of the porphyry group; the meltings along the margins become increasingly frequent.

If a more or less horizontal position of the isotherms is assumed from the beginning of the cycle, it will be disturbed by the intrusion of the swarms of dykes; the isotherms rise in domes around these swarms (fig. 70), in which melting may take place at smaller depths than outside them. It is from these domes of the isotherms that the granitisation starts. But why, it may be objected, will different products result in the different cycles? In both cases swarms of basic dykes at first penetrated the old basement of granitic composition; in both cases the transforma-

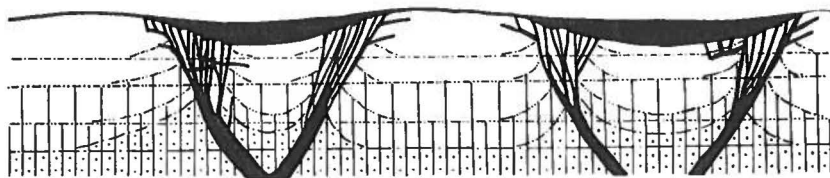


Fig. 70. In an old basement the isotherms are nearly horizontal (indicated by lines and points). Through the intrusion and solidification of the swarms of dykes (black) the isotherms rise in the neighbourhood. They will not remain parallel planes any longer, but surfaces with considerable differences of altitude. These differences will exert some influence on the next folding or faulting, whose intrusions will continue in the same manner. In this way the differentiation between zones with mobile infrastructure and more rigid blocks will arise.

tion front will rise into the new material; what is the cause of the difference? There seems to be two reasons: The first cycle began with a widening of the crust corresponding to the depression and the opening of the dykes; but subsequently the zone narrowed again. In this way the earlier basement rocks, with admixtures from below, will develop into magmas. A large part of the earliest basement becomes palingenous. Its deeper portions will melt again and subsequently crystallise. If it receives an addition of fresh "blood", normal granites will result; if not, it will become a granulitic series.

By folding, parts of the basement will subside to greater depths than those to which their chemico-mineralogical composition is adapted. The result will be a certain readaptation. Certain substances will make their way upwards, soaking through the mass of the folded chain. These easily migrating substances and volatile compounds will be distributed over large rock masses and thereby become comparatively diluted. The masses which rise in the form of magmas will in this case be of a mixed origin. It is not very probable that large parts of the sialic crust will have originated through differentiation of the subjacent basaltic magma.

The Ketilidian orogeny may be divided into two successive acts: first a widening, and subsequently a narrowing. If likewise we divide the Gardar period into two acts, the zone will be widened during both acts. Thus the difference between the Ketilidian and the Gardar developments consists in the different tendency of movement during the second act. These developments result in the formation of very different igneous products.

If we assume that the sialic blocks are underlain by increasingly basic layers, and that at a certain depth they form a latent melt, this melt will intrude into the interstices between the blocks when the blocks slide from one another. In the first phases there will be merely some syntaxis and mixture at the deepest parts of the sialic crust. Gradually as the wall-rocks of the chief canals of ascent grow more heated (cf. fig. 70), more and more of the wall-rocks will rise to higher temperatures, at which they may react with the stream coming from the depth and will mix with the surrounding magma. At the same time the development will take place in a different way, which I shall here treat only very schematically: During its ascent between the blocks the magma will be subjected to a constantly decreasing pressure, so that the volatile compounds will move upwards and will carry with them through gaseous transfer a number of other components. These components will gather in the upper parts of the ascending magma. If this is still at a high temperature, both parts will react and form new rock types.

Thus the development in the widening zones and the narrowing zones will follow very different courses. The difference is that in the latter the molecular migration takes place under high pressures and into foreign material, viz. into the folded basement and the new material of the orogenic cycle. In the magma-lamellæ between the sialic blocks the transferable compounds will move under a lower pressure; they will soak into material of a similar composition to that from which they have emigrated, as long as syntaxis on a large scale is not taking place. But such a syntaxis will not assume the same size as below a narrowing zone. The volatile components with their suite will leave different traces:

- 1) they may gather in the upper, still warm parts of the same magma and react with it;
- 2) they may intrude into a hot wall-rock and react with it;
- 3) they may intrude into the already cooled part of the same magma and crystallise there as pegmatites;
- 4) they may intrude into colder wall-rocks and crystallise there as pegmatites.

Case 1) is that which occurs in the magma-columns between the basement blocks during the ascent of the magma and prior to its cooling. Case 2) occurs in the widening zones and narrowing zones when the isotherms rise. In regard to volume this case predominates to a great extent in the narrowing zones. Cases 3) and 4) occur when the cooling-front descends. Thus the volatile components will appear in very different forms according as they meet an advancing or a receding cooling-front.

The connection between the state of movement of the crust, widening or narrowing, seems clearly evidenced through the cycles of southern Greenland. The Ketilides represent the example of a narrowing zone and an intensive migmatitisation. The Gardar Formation shows an example of a zone of widening with the attendant phenomena.

If the development of the magma-columns between the basement-blocks represents the normal types of differentiation of magmas originating from the simatic layers with little or without contamination, we arrive at the following considerations: the magmas of the deep-seated basalts will, under conditions like those of the higher crust, turn by differentiation into alkaline rocks and highly alkaline solutions, but not into normal granites. If this is right, alkaline rocks must appear wherever the basaltic differentiation was not disturbed by sialic contamination. We can get a proof of this in another way: It is now generally assumed that over wide areas of the Pacific no sialic crust is found. LACROIX has shown that no granitic differentiation products are found in this area of the Pacific but only alkaline series. It is clear that there, too, different tendencies are found. But the similarity between the rocks of this part of the Pacific and the rocks of the widening zones show, that there is a distinct difference between the formation of the rocks of the sialic crust on the one side, and the alkaline series on the other side, as pointed out before (WEGMANN 1935). It was a great pleasure to me to learn, when discussing petrographical problems with Dr. RITTMANN, that in an entirely different way and quite independently he had arrived at similar conclusions; I can only regard it as a promising prospect of this working hypothesis, and I thank Dr. RITTMANN for his kind permission to mention it here.

If we proceed along these lines, we may ask: how, then, were the granitic basements formed? The first intermediary and acid crusts in the history of the earth were not calco-alkaline granites. It must be assumed that the first crusts were gradually transformed through subaeric transformations, and through erosion and sedimentation in the course of many cycles they were gradually transformed into the material which later formed the granitic basements. The migmatitisation and the palingenesis played a great role in this respect. This is perhaps the reason for the comparatively good agreement existing between the

composition of the calco-alkaline series and the bulk composition of a large part of the more usual sediments. In each orogenic cycle it would be even more similar if no other factors intervened. Thus all the ancient granitic folding zones in the pre-Cambrian areas are not by far first cycles. (Some of the oldest leptites may to some extent be exceptions). There must have been many transformations which created this on the whole uniform sialic basement, already seen in the earliest known folding zones. It is this basement which is put into circulation at each new orogenesis both supra-crustal and infra-crustal (WEGMANN 1936). Thus the granites are the metamorphic products of the orogenic cycles. The processes by which it is regenerated in each new cycle are different from the differentiation and metamorphic processes in the large alkaline masses and the uncontaminated basalts. The filled gaps in the widening zones are like test-holes through the sialic crust down to the sima. The events in these test-holes may throw light on the conditions of our earth at the inception of geologic times.

In the light of these considerations the problem of the growth of the continents obtains another meaning. The differentiation through transportation (between erosion and sedimentation) on the one side and the migmatitisation have played a principal rôle in the genesis of the sialic crust. Where subaerial weathering cannot act upon the products of the simatic differentiation, viz. below the oceans, no greater sialic masses can develop. Thus the problem of the "constancy of the oceans" appears from another angle. On one side we have the simatic type of differentiation, on the other the sialic cycles, which through sedimentation and migmatitisation govern a circulation whose principal conditions are: a subaerial relief and a subcrustal burial with rising temperatures. Between the extreme types of simatic differentiation and the sialic cycles there are many combinations and transitions. When explaining the economy of the earth's crust it seems practical to have these extreme types in mind. Then the functions of the intra-continental orogenic zones and of those at the margins of the continents will be understood in a different way. The threads of these considerations will be followed in another paper.

The development of the geosyncline with its widening is therefore something different in a magmatic respect from the development of the folding range, which corresponds to a narrowing of the zone. It has also been claimed that the differentiation below a geosyncline is unlike that below a continental basement. This does not seem to be a sufficient reason; in the geosynclines there is usually a basement below the new material. It is possibly thinner than below the higher areas, but it is at any rate so thick that it will be visible in most mountain chains either in folds or nappes or in a palingenuous form. On the hypothesis

set forth above, it is not the basement but its tendency to move which is the cause of the difference. The tendency to move is not a direct influence either, but acts indirectly in that it facilitates or weakens the possibility for contamination and assimilation. These possibilities cause the great variation in the differentiation series known. An example has been given in the above, viz. how Rapakiwi and similar granites were formed between the syenitic and essexitic rocks and the ancient basement. RITTMANN (1936) has come to similar results on studying series of volcanic development; he shows how the Vesuv magma develops through assimilation of lime and dolomite. DALY assumed that the assimilation of calcareous matter was the main cause of the formation of alkaline series originating from calco-alkaline rocks. We cannot accept his postulate in this general form.

In these final considerations I have discussed some general questions and have thus necessarily diverged from the individual features of the development of South Greenland. It is not my intention to compel the facts to fit one formula. To some extent earlier investigators, partly compelled by the terminology, have clothed the development of mountain chains in one uniform and the magmatic development in another, contrasting them with each other, and much of the diversified reality has thus been lost. It may be objected that it can only be apprehended by systematisation; but the longer we apply the same scheme, the more do we become slaves to it, and the more definite will it seem to be. It is only by trying new systematisations which may lead to new syntheses that we shall be able to detect such aspects of the phenomena as could not be expressed by the earlier formulas. The new system, too, is a pattern which will one day have to be altered. If the systematisation ranges over too wide a field, its individual parts will be deprived of all their special properties so that very little of the phenomena, that is, of the mountains and rocks, will remain. For the field geologist who is to apply these formulas as working hypotheses, they will vanish like air. The ideal working hypothesis would be: a maximum of unity in a maximum of diversity; however, these are contrasts which can only be united by a compromise. Some geologists incline to one side, others to the other side. In recent years it has been attempted from many quarters to render uniform the development of mountain chains; the next object will probably be to work out again the more individual features which lend to each orogenic zone its own physiognomy.

Bocksriet, Schaffhausen, May 6th, 1937.

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B. C. G. F. = Bulletin de la Commission géologique de Finlande, Helsinki-Helsingfors.

G. F. F. = Geologiska Föreningens i Stockholm Förhandlingar, Stockholm.

PLATES

Plate 1.

Section of Chart No. 148 of the southern part of Greenland, by kind permission of the Kgl. danske Søkort-Arkiv of Copenhagen.

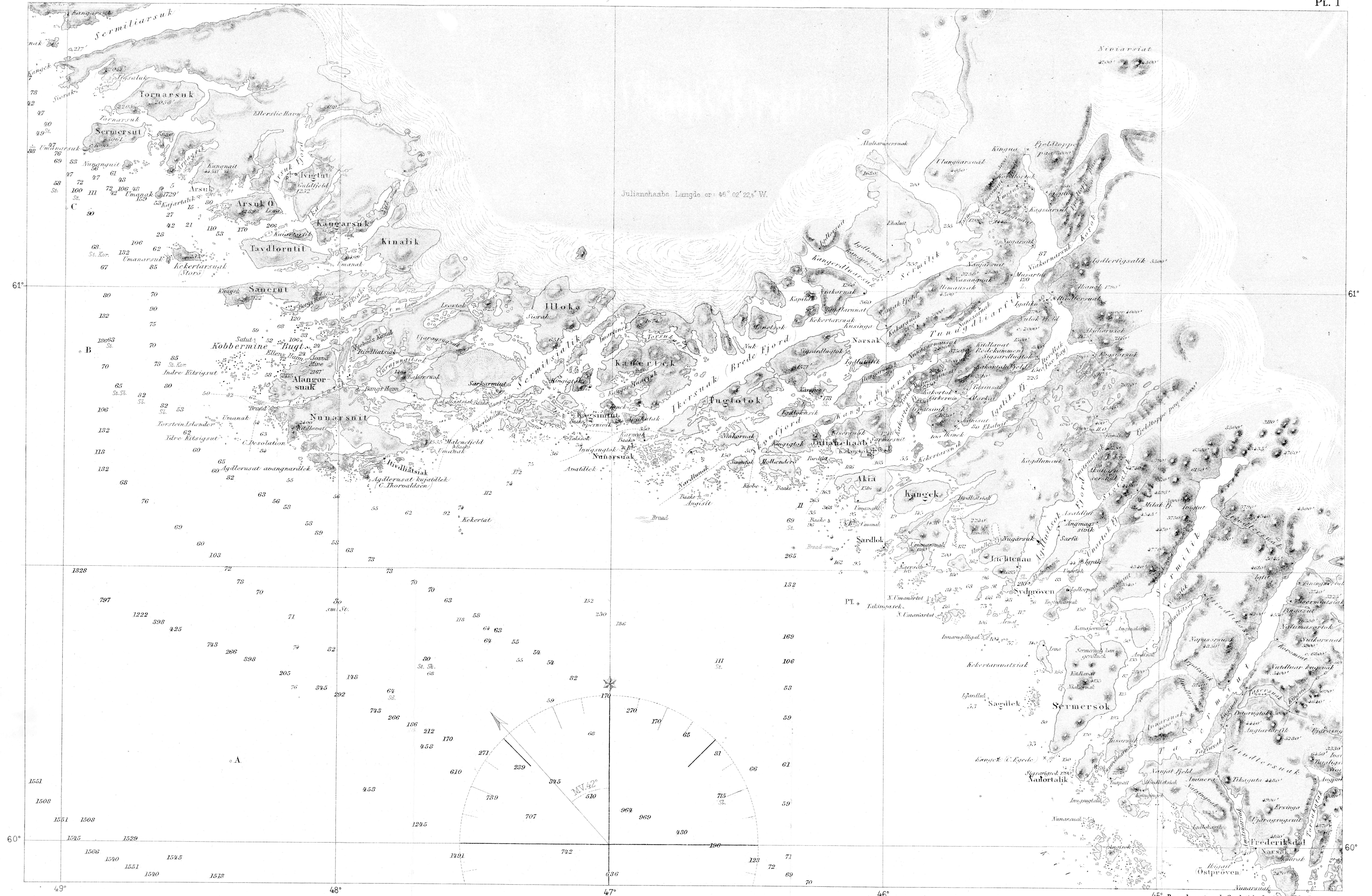


Plate 2.

- Fig. 1. Natsinguak and Nugluartukasik (985 m), seen from the skerries at Iglokasik, showing the folds in the Sermilik series. The lowland in the foreground is made up of younger granites, largely Rapakiwi, and corresponds to the level of the strandflat (cf. p. 128).
- Fig. 2. View from Niakornak towards the interior of Unartok Fjord. To the right, the lowland, which rises in the Asdlut peaks, forming the high mountains round the interior of Unartok Fjord. These, again, have been cut out from a high peneplain, remnants of which can be observed in the top level. In the centre, with the flat-lying joints, is the massif of the younger granites. The whole landscape inside the Asdlut peaks bears the stamp of a young and very active relief.



Fig. 1.

1. IX.
1956.

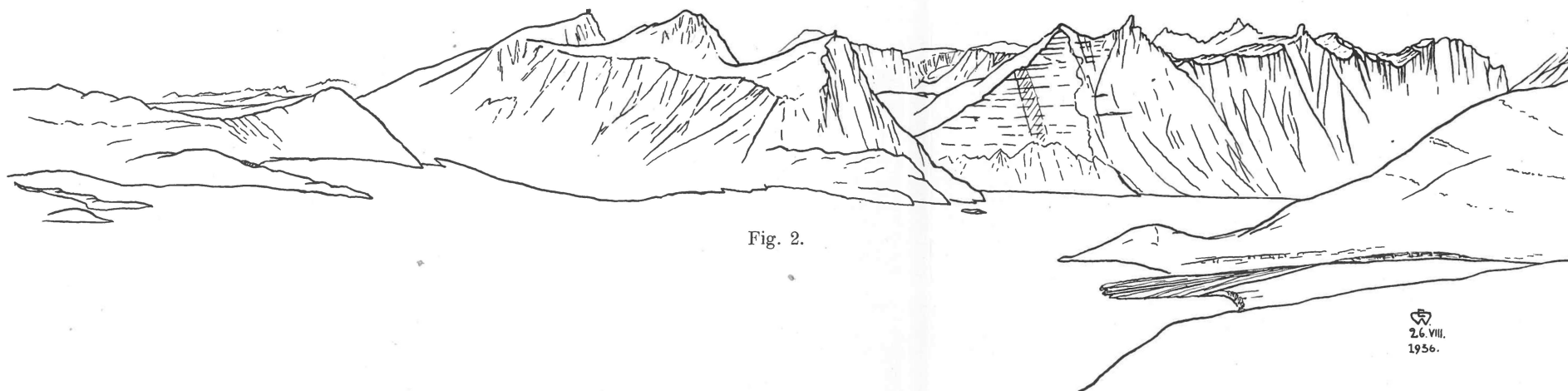


Fig. 2.

2.6. VIII.
1956.

Plate 3. .

The region near Taylor's Havn (T) and Weber's Havn (W).

Fig. 1. Seen from the east coast of Arsuk Island.

Fig. 2. Seen from the cape at the entrance to Ika Fjord.

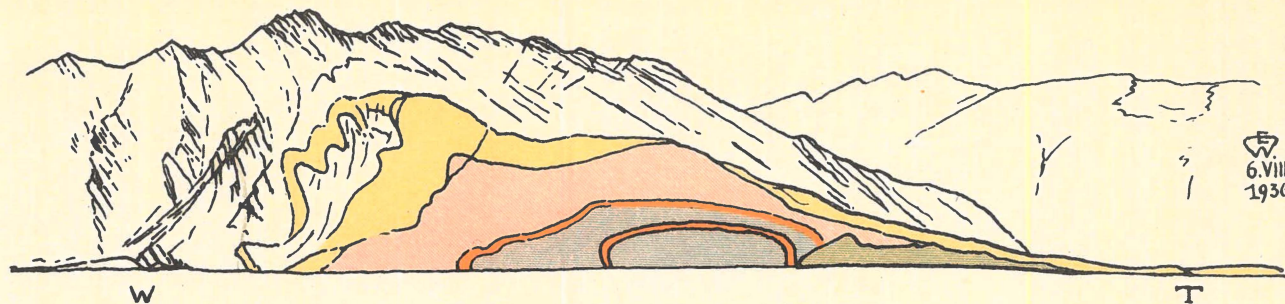


Fig. 1

- Pyritic schists*
- Dark schists*
- Dolomite and dolomitic limestone*
- Gneissic schists*
- Quartzites*

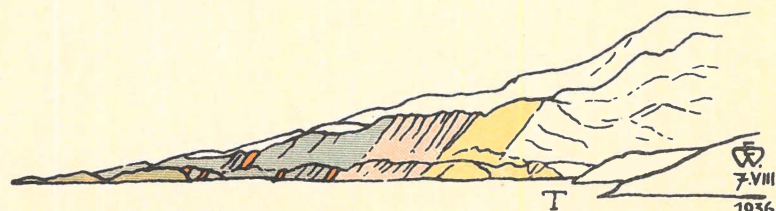


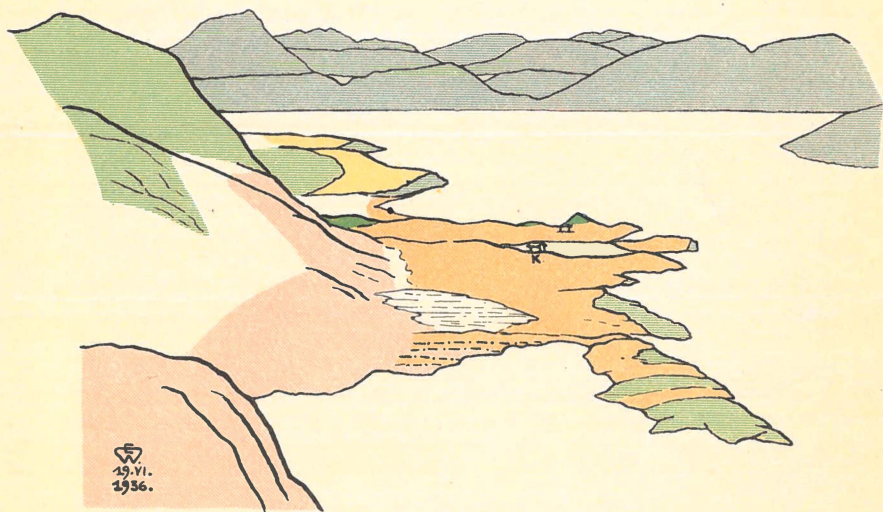
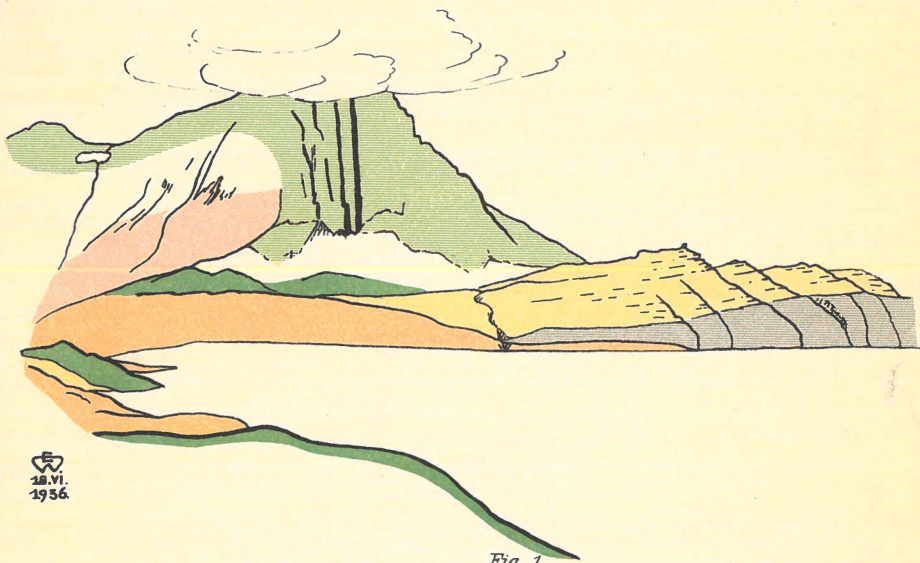
Fig. 2

Plate 4.

The surroundings of Narsak.

Fig. 1. Looking from the sheep-farming station towards the bay south of Narsak.

Fig. 2. Looking from the mountain north of Kusinga Valley towards Panernak and Narsak. K = the church of Narsak, behind which the harbour is seen, on the other side the sheep-farming station. Conditions at Panernak, roughly outlined in the foreground, are actually much complicated.



	Nordmarkite		Essexite		Porphyry Form.
	Breccia		Quartzite		Ketildian Basement

Plate 5.

The Kungnat Massif.

Gray = younger granite; white = Ketilidian basement.

- Fig. 1. View from the northern shore of Arsuk Island, showing the boundaries of the massif.
- Fig. 2. View from Ininguit, showing the dome-shaped arrangement of the joints (cf. fig. 48—50, 69); probably portions of older rocks are found in the top region.
- Fig. 3. Seen from Kajartalik; many dark dykes in the basement.

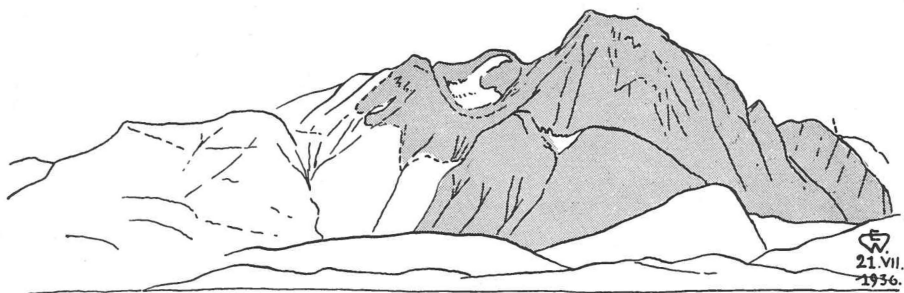


Fig. 1.

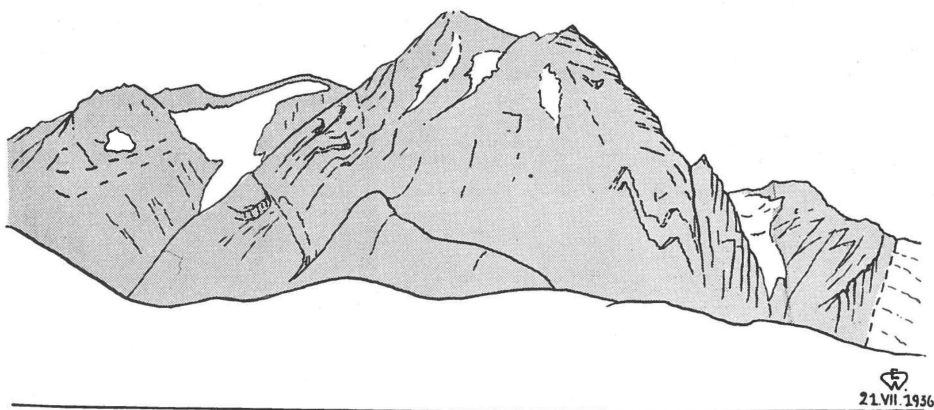


Fig. 2.



Fig. 3.

Plate 6.

Diagram showing the distribution of the Gardar Formation.

- 1) Igaliko sandstone (supposed areas below the ice with interrogation marks).
- 2) Porphyry formation.
- 3) Important swarms of younger basic dykes.
- 4) Younger granites, Rapakiwi, syenites, nordmarkites, essexites, etc.
- 5) Nepheline-syenites.

To the east the boundary of the highland is marked by a line; to the west the axis of the western high area is indicated.

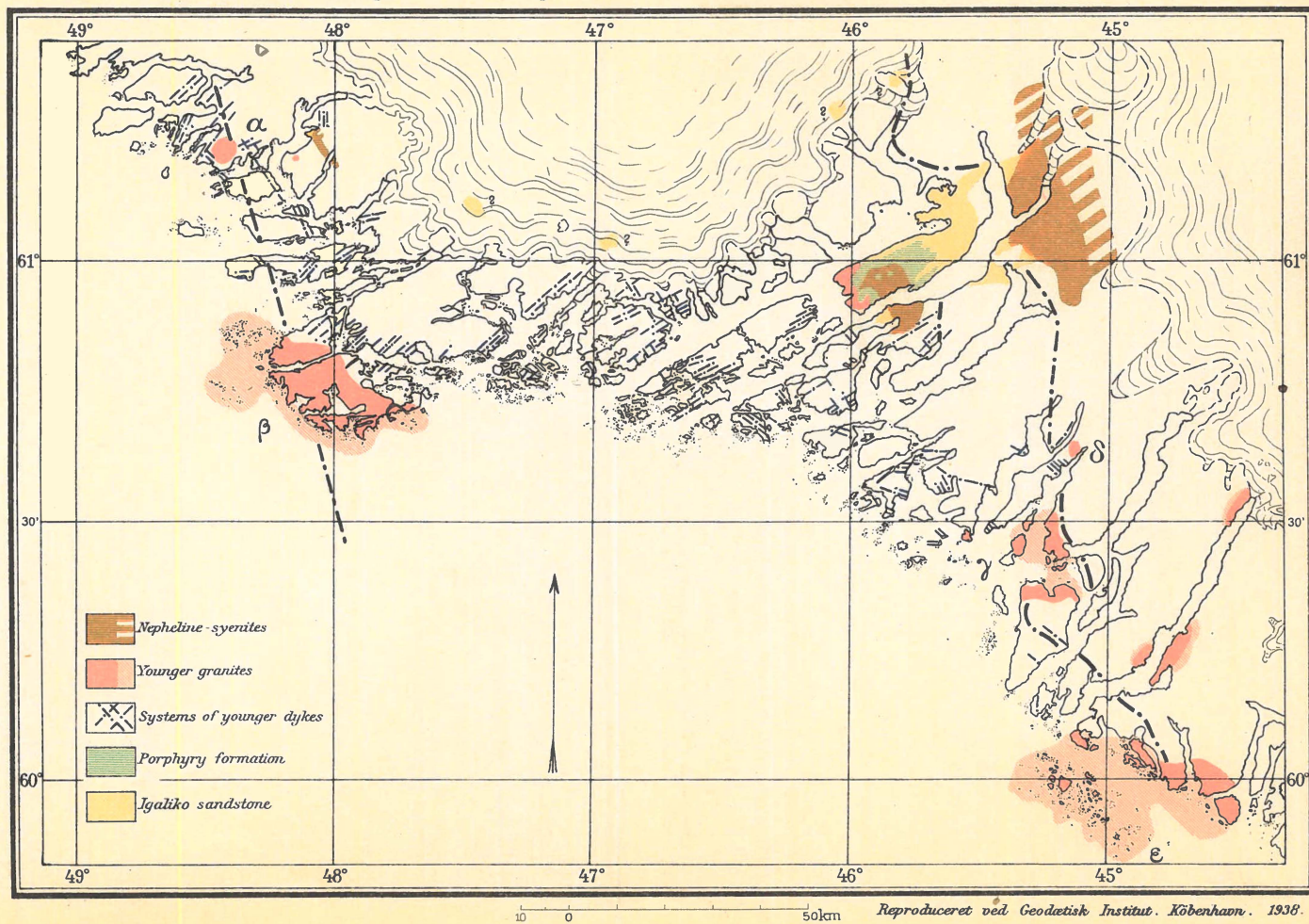


Plate 7.

Diagrammatic sketch showing the altitudinal conditions.

The eastern high area of southern Greenland, to the west bordering on the cliff (cf. p. 126) = brown.

Along the cliff a zone of low passes leading from one fjord to the other (cf. p. 126) = arrows.

The zone of the passes separates the massifs of Ilimausak and Redekammen from the eastern high area; the massifs extend over 1000 m.

The lower areas of Julianehaab and Kagsimiut without special indication.

The zone with the high jagged mountain-forms, cut out of the western high area (p. 124) = pink.

Axis of the western high area = —·—·— line.

The strandflat cutting all the preceding elements unconformably from the seashore (p. 128) = blue.

Altitudes in metres.

