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ON THE CRYSTALLINE COMPLEX OF LIVERPOOL LAND

BY

E. H. KRANCK

WITH 22 FIGURES IN THE TEXT, 2 PLATES AND 2 MAPS

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI A/S
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INTRODUCTION

The geological research work in the Arctic has until of late years mainly had the character of preliminary surveyings, covering large areas which only to a very limited extent have been mapped or which in many cases had never before been visited. In such circumstances detail fieldwork has been carried out only in a few cases, generally only in the vicinity of the winter-stations of the expeditions.

The only region of greater extent in the Arctic where the geology is comparatively well known also in comparison with the settled parts of the world is the section of East Greenland called King Christian X. Land. This country has during several years been systematically surveyed by a number of Danish expeditions under the leadership of Dr. LAUGE KOCH, and in addition also by a great number of foreign expeditions. Here the investigations have reached a stage which makes it possible to adopt methods of working belonging to a more advanced type of research than those used in the majority of the Arctic regions. This also holds good with regard to the petrography of the crystalline rocks of East Greenland.

The Danish expeditions mentioned above, particularly the biggest of them, The Danish Three Years' Expedition to King Christian X. Land, devoted considerable time also to the crystalline rocks. This part of the program has been carried out under the leadership of professor H. G. BACKLUND of Upsala, who visited Greenland in the summers 1929—1934 and who has already published a number of papers on the subject. Prof. Backlund has worked out the program of the petrographic investigations followed by him and his fellow-workers.

Also the following lines fit into this research-program, giving some results of the investigations on Liverpool Land during the summer 1933, when I had the opportunity to take part in the fieldwork, thanks to the courtesy of the leader of the Three Years' Expedition and of Prof. Backlund.

The program of these investigations was above all to collect as many data as possible about the petrography and structural geology of the

crystalline area of Liverpool Land in order to gather comparable data between this region and the crystalline areas earlier explored in the northerly parts of East Greenland. Contemporaneously also a number of theodolite-measurements and field mappings were carried out.

The present paper does not form a complete treatment of the results of these investigations. It merely gives a description of some field-observations, completed with brief laboratory-investigation of the rock-specimens collected. I have only slightly touched upon questions dealing with the relationship between the different crystalline areas of Greenland, questions which will in the future be treated by BACKLUND.

Instead comparatively much space has been devoted to the structural geology and the tectonics of the area. Also in that respect the results, however, are far from definite and in many points are to be regarded only as contributions to the discussion about the problems treated in the paper. The methods and principles of the tectonic investigations of crystalline areas of a more or less Archaean type are, as is known, still a matter of debate, particularly in the Scandinavian countries, and some of the points of view put forward in the following diverge in some respects from those hitherto generally adopted.

I have therefore tried to keep apart the theoretical conclusions and the observations, which has made a number of repetitions necessary, but which, it is to be hoped, will make the paper easier to read.

I here desire to lay stress upon the fact that the main part of the observations treated in the paper and also a good many of the specimens described have been collected jointly with the other members of the expedition, and that the conclusions and interpretations of the geology have generally been discussed already in the field. Therefore in almost every point I owe thanks to these gentlemen, more particularly to Professor BACKLUND, for the positive results which the paper possibly may contain. On the other hand, I alone am responsible for all errors and mistakes.

Finally, I wish to thank the leader of the expedition, Dr. LAUGE KOCH, and the leader of my party, Professor H. G. BACKLUND, who made it possible for me to carry out this investigation. To Dr. KOCH I am particularly obliged for placing at my disposal the topographic map of Liverpool Land worked out from the air-photographs taken by the aviators of the expedition, and for subsidies towards analyses and other expenses of the investigation.

During the preparation of the material Professor BACKLUND has given me the benefit of his great experience of the geology of Greenland, both as regards directions and advice.

To Dr. NAIMA SAHLBOM in Stockholm, who has been kind enough to carry out a number of rock-analyses, I am also greatly indebted.

In conclusion I desire to thank the other members of the party, Mag. scient. A. NOE-NYGAARD, Mag. phil. TH. SAHLSTEIN and Ing. S. H. HASSELBALCH for good collaboration and comradeship in the field work, Mag. SAHLSTEIN also for collaboration in the preparing of the collection. He has undertaken the petrographic investigation of some of the rock-types, which will be described by him in separate papers.

Helsingfors, 6th April 1935.

A. OUTLINES OF THE GEOLOGIC MAP OF LIVERPOOL LAND

Liverpool Land in East Greenland (King Christian X. Land) is situated between 70°30′ and 71°35′ N. and is crossed from north to south by the meridian 22° E. of Grenwich. The name Liverpool Land was proposed by OTTO NORDENSKJÖLD (29.) to comprehend the strip of land about 25 km broad between the inlet of Scoresby Sound and the inlet of King Oscars Fjord (Davy Sound). It is bounded in the east by the Arctic Sea, and in the west by Carlsberg's Fjord and Hurry Inlet. Between the heads of these two fjords the natural boundary between Liverpool Land and Jameson Land can be drawn along the broad valley between these fjords (Klitdalen). With the exception of the westernmost parts from the watershed east of Klitdalen westwards, and of some small areas east of the northern third of Hurry Inlet, the rockground of Liverpool Land consists of crystalline rocks of varying composition.

Earlier explorers (SCORESBY, OTTO NORDENSKJÖLD (29.), ROSENKRANTZ (21.)) have referred this crystalline complex to the Archaean. LAUGE KOCH has later on owing to a cursory survey of the crystalline formations of East Greenland (21, p. 59), supposed that the section east of the old sedimentary rocks are of later date, probably Caledonian, and he therefore assumes that also the area here in question might belong to the same group.

Actual observations in Liverpool Land have, however, until now been far too few to give evidence of any decisive importance. Most of the available data derive from NORDENSKJÖLD, who made a number of landings on the coast of Hurry Inlet and at a number of places on the south and west coasts (29, 30.), during the Carlsbergsfondet Expedition of the year 1900. These observations did not afford any possibilities of determining the regional distribution of the collected rock types, and NORDENSKJÖLD only draws the general conclusion that Liverpool Land as a whole consists (with the exception of the inner parts of Hurry

Inlet) of crystalline rocks of Archaean type. In the year 1924 ROSENKRANTZ amplified these observations with a few observations from the southernmost part of the region.

In connection with the explorations by the Danish Three Years' Expedition to King Christian X. Land of which Dr. LAUGE KOCH was leader, Liverpool Land was visited in the summer of 1933 by Prof. H. G. BACKLUND and his companions. Landings and also land-traverses were made on several localities, particularly in the south, from both the east and the west coast. In the following chapters a number of field-observations and rock-types collected during this journey will be described, and in connection with these descriptions some general questions concerning the geology of the rock-ground of Liverpool Land will be discussed.

It may already here be pointed out that the observations, in spite of many new contributions gained by the last investigations, are still very scattered and too insufficient to allow of the drawing of any accurate geologic map of Liverpool Land containing more than the main features, but in comparison with most parts of the crystalline areas of the Arctic, this region must after all be considered as comparatively well known, and therefore the compilation of even a very approximate map added to this paper seems to be justified.

A short summary of the regional geology of Liverpool Land according to our present stage of knowledge will be given before entering on a detailed description of the localities visited.

The southern coast of Liverpool Land consists entirely of composite migmatitic gneisses, for the most part probably paragneisses, but with a very prominent granitic component. They generally have the character of vein-gneisses, penetrated by numerous younger cross-cutting dikes and veins of pegmatite and aplite. The colour is on the whole pinkish or grayish. The tectonic deformation is everywhere conspicuous, particularly farther west in the region of Cape Hope. In the south-easternmost section of Cape Tobin it is less prominent. The pitch and the axial direction of the differential-folding in this area runs from north-east to south-west.

If we follow the eastern coast of Hurry Inlet in a northerly direction we meet with gneisses of another type already some km north of Cape Hope. They are alternating pure gray gneisses and darker coloured garnetiferous gneissic rocks with abundant eclogitic inclusions. The tectonic deformation is very strong, stronger than in the foregoing group, and with a generally north-southerly axial-trend. The granitization is less conspicuous and is mainly represented by dikes and veins of several generations. In these gneisses the pitch generally trends north to south.

North-east of Cape Hope a mylonite-zone was found. This is probably

situated on the contact between the gneisses of the south coast and the gneisses of Hurry Inlet. Here the rocks are rolled out into mylonitic schists, in which the garnetiferous gneisses and the eclogitic fragments generally have the character of granulite (the name used in accordance with the German nomenclature) resembling the granulites of Saxony and other localities. The extension of this interesting zone is unfortunately not known. Farther east from the innermost part of Rosenvinge Bay, ROSENKRANTZ reports limestone, and in the region farther to the northwest MALMQVIST (personal communication) has found granite in contact with limestone containing skarn-minerals and graphite.

North of the Hurry Inlet gneisses, which in their typical shape were found so far north as only a couple of km south of the southernmost of the two big glacier valleys of the east coast ("Gubbedal"), migmatitic gneisses occur with amphibolite inclusions which seem to increase in number northward. According to BACKLUND the northernmost section of this gneiss-region consists for the most part of dark greenstone, penetrated by granitic dikes and veins.

From this region as far as the innermost part of Hurry Inlet, a large very uniform area of pink granite extends. Its northern contact is situated in the next valley north of NORDENSKJÖLD's "Kalkdalen", Bodal. One might say that eastwards the granite extends as far as to the central watershed of Liverpool Land, at least one Swedish mile from the east coast.

On the whole the Hurry Inlet granite is unaffected by tectonic movements. Only at the northern contact there are to be seen traces of faults and brecciations of evidently recent age (*cf.* p. 47). At least in the central parts the rock is very pure, but shows on the other hand, especially in the more peripheric sections, abundance of inclusions derived from older formations, both such of gneissic character and such of diorite and basic igneous rocks, thus forming typical migmatites. In Sødal Valley several thick layers of limestone were observed, included in the granite, and still farther eastward gneisses and rocks of dioritic composition are to be found, all rock-types which occur on the east coast.

North of the Hurry Inlet granite, gneissic rocks are found, but of a type which differs widely from the gneisses farther south which were described in the foregoing. They can generally be defined as a migmatitic gneiss in which the granitic component prevails. The latter is of a coarse-grained pegmatitic character. The colour of these gneisses is whitish. The dip is generally very steep and the strike is varying; also the dip of the folding-axes is often steep and much more irregular than on the south coast. Mineralogically the gneisses are mostly biotite- and biotite-garnet-gneisses. The granitic component is tectonized in a considerable degree, and consequently older than the Hurry Inlet granite.

About 8 km from the northern end of Hurry Inlet in a northeasterly direction (Hodal Valley *cf.* p. 71) one meets with migmatites of the same granite, but with diorite as the base-component. The migmatite is gradually replaced by pure diorite or granodiorite, traversed by granitic veins. This diorite area continues underneath the ice-cap covering the interior parts of Liverpool Land, and is evidently of considerable extent.

The crystalline rock-ground around the northern end of Hurry Inlet is cut by numerous basic dikes mentioned already by NORDENSKJÖLD. During the excursions in the summer of 1933 a great number of these dikes were found. They generally belong to two different types: 1. Ouachitite-dikes (older) of the type described by NORDENSKJÖLD (29.) and 2. basalt-dikes. The first-named generally have a north-easterly — south-westerly strike, the latter mainly strike in the direction north-south, but apparently less regularly than the former. These dikes will be described in detail elsewhere.

The coast-plain in this region consists of unaltered sediments belonging to three different formations, separated by unconformities.

1. The oldest consist of phyllitic and quartzitic rocks and also of limestone occurring in some of the hills west of the plain and in some outcrops on the shore. (*cf.* the map). They are penetrated by quartz-porphyry-dikes probably belonging to the Hurry Inlet granite. The last named granite also contains inclusions of limestone and schist which might belong to the same formation. BACKLUND refers these sediments to upper Cambro-silurian, and has used the name The Hurry Inlet formation in order to keep them apart from the following groups.

2. The next formation can be studied at the edge of the coast-plain in the foothills of the mountains between the mouth of Kalkdalen and the Bodal Valley. Here a coarse, red-coloured conglomerate occurs. It consists mainly of granite-pebbles, deriving from the Hurry Inlet granite. These pebbles are often but incompletely rounded and the matrix gives the impression of a weathering product. Also quartzporphyry pebbles have been found. It is evident that this conglomerate is formed almost *in situ*. In the northernmost localities Backlund also observed phyllitic pebbles (*cf.* 1).

3. In the strand-flat and also on the Fame Islands there are sandstone and conglomerate of a polymict character, containing pebbles of all the formations mentioned above (*cf.* the map). They correspond to the Eotriassic sediments of Jameson Land.

There evidently exists an unconformity between the arcose conglomerate and these Eotriassic sediments. BACKLUND supposes the age of the firstnamed to be Devonian, a conjecture which seems very probable (*cf.* p. 118).

The Fame Islands consist, as the earlier expeditions named in the

foregoing have pointed out, for the most part of a coarse-grained porphyric or coarse ophitic dolerite, probably of the same age as the mighty sills on Jameson Land.

Like the west coast the eastern coast of Liverpool Land, the original Liverpool Coast of SCORESBY, presents several different formations, but it is remarkable that none of the formations of the west coast are found on this side. This remarkable assymmetric structure was evidently observed already by NORDENSKJÖLD. Of particular interest is the large distribution of granodioritic rocks.

After passing Cape Svainson, south of Cape Hodgson, we still find gneissic rocks evidently more or less similar in character to the gneisses of the south coast as far as to Cape Hodgson. Here they dive underneath homogeneous granodiorite which composes the point. On the west side of the point gneisses with flat lying, slightly folded layers again are visible up to the inlet east of Lille Fjord, where diorite again occurs. Also here it is underlain by gneiss. With the exception of its southern end, the small cliffy "Raffles Island" is composed of homogeneous diorite, with some big hornblenditic inclusions of a type which is found in abundance also in other parts of the diorite-complex. Rathbone Island is composed of the same granodiorite. From Lille Fjord northward the coast-mountains all consist of the same uniformly gray rock until Glasgow Island, where gneissic formations again appear. This granodiorite-area is in other words very big, measuring about 20 km in length, and probably extends eastwards to the boundary of the Hurry Inlet granite. It is very probable that the dioritic inclusions found in the last-named rock in the uppermost parts of Sødal Valley are deriving from the diorite of the east coast.

The granodiorite is crossed by numerous pegmatite- and aplite veins, which in all probability derive in part from the granodiorite itself, but in part belong to the younger granites of Liverpool Land.

Another granodiorite-area, though far smaller in extent, was found in the region of Cape Smith, north of the inlet of Store Fjord. It extends from Polyp Harbour (*cf.* the map) in the South, to the fjords south of Cape Topham (Inder Fjord) in the North. The rock type here offers the most striking similarity with the granodiorites of the southern area. The plutonic rock here only occurs around the outer parts of the fjord; farther inside one meets with gneissic rocks.

Neither of these areas is probably in direct connection with the diorites found north of Hurry Inlet. The lastnamed possibly extends as far as to the granite area of Store Fjord, described below, in which case the inclusions in the granite would be remnants of an assimilated part of the granodiorites. — From this short review it is clearly to be seen that the rock-group in question forms a very important element of the earth crust of this part of East Greenland.

One of the most conspicuous sections of the east coast is formed by the gneisses which lie north of the granodiorite-area of Cape Hodgson — Glasgow Island. At Glasgow Island the white colour of the steeply upfolded layers indicates the existence of limestone or dolomite. Farther northward mixed gneisses of very prominent granitic-migmatitic character compose the bulk of the mountain walls.

The layers seem to be folded into recumbent folds which have been flattened out into an almost horizontal position and the first impression therefore is that one has to do with layering of sediments of different colours, alternating black, gray and pink. Basic inclusions are very numerous. Also dikes occur in abundance, of basic (diabasic) and granitic composition. The last named belong to several generations.

On account of the impossibility of getting close enough to the coast, due to coast-ice, the northern contact of these gneisses could not be determined with absolute exactitude, while also its character is still a matter of uncertainty. However, it is to be found somewhere at the first big fjord (Mariager Fjord) north of Cape Greg.

From this fjord northward fairly pure igneous granite is found extending up to some km south of Polyp Harbour and also forming the bulk of the rock ground in the region of Store Fjord. This granite will in the following be called the Store Fjord-granite. The granite has generally a more deep-seated habit than the Hurry Inlet granite. It is light grayish or pinkish, comparatively uneven, with alternating fine-grained and more coarse-grained varieties. Schliers and inclusions of different character, mostly of dioritic composition, are very numerous and in many places the cliff-walls can be designated as eruptive breccias. On the whole the rock is of more or less syntectic origin, but after all has an undoubtedly igneous character. It can be compared with the so-called Hangö granite of the Archaean of South Finland (Sederholm 44, 45). Needless to say, dikes and veins of all kinds are found in the granite-complex, which also in this respect differs from the Hurry Inlet granite.

In the innermost parts of Store Fjord there occurs a granite of the same type as the Hurry Inlet granite. The contact with the foregoing rock was not determined, but it seems to occur as dikes in the last-named, which circumstance, in addition to the definite difference in the petrographic character indicates that we here really have to do with another, and after all more recent formation. The rock is fairly coarse-grained, often porphyric, and has the same bright pink colour as the granite of the west coast of Hurry Inlet. The granite extends to the watershed between Store Fjord and Klitdalen, and composes the base on which rest the Mesozoic sediments west of Store Fjord.

Gneissic rocks occur within the Store Fjord region only in the broad

valley which ends in the Store Fjord Valley on the south coast opposite its northern arm. This valley will in the following be called Frydendal Valley. It is characterized by splendid terminal- and edge-moraines deposited in its lower parts.

The walls consist of banded gneisses which on the west side extend to the crest of the mountains: on the east side they only form the lower part, the upper consisting of grayish granite, so far as can be judged from below. Owing to the horizontal position of the schistosity the gneiss recalls the gneisses of Cape Greg and contains also mainly the same elements. They differ, however, in being more mylonitic and fine-grained. Besides normal gneisses, layers of quartzitic composition and also of limestone are found. Amphibolitic layers are very abundant.

In the cliff-walls, opposite the end of the valley and in the innermost valley from the north on the north shore of the Store Fjord (Skarndal) there are seen inclusions of this gneiss in the younger granite, measuring several hundred meters in diameter. It has been folded into numerous small differential-folds, of a style which does not occur within the gneiss-complex *in situ*. It has also suffered a certain amount of recrystallization, due to the influence of the granite.

Similar gneisses were also found inside Polyp Harbour.

On the contact with the gneisses the Store Fjord-granite has developed a characteristic coarse porphyric marginal structure, with generally rounded phenocrysts measuring up to 3 cm in diameter.

Within the fjords north of Cape Topham one meets with gneisses which in many respects recall the white gneisses north of Hurry Inlet. They are upfolded in a steep position, and are for the most part highly granitized. The most prominent feature of the complex is a big limestone anticline, which seems to be cut off by granite and at the contact gives rise to diopside-hornblende-garnet skarn, or highly garnetiferous sillimanite-gneisses, of very irregular "schliery" appearance. These upfolded gneisses, with limestone layers and dark basic inclusions, and numerous pegmatite-veins, compose, so far as could be seen from the sea, the coast northward as far as to the northernmost part of Liverpool Land. A black (hornblenditic?) rock composes its northern point (C. Newton).

A landing at Murray Island proved that we here still have to do with gneisses, and of a type which greatly resembles the mylonitic gneisses of the Frydendal Valley of Store Fjord. The chief difference is that the gneisses here mainly dip at a steep angle.

According to this short review we can divide the rock-ground of Liverpool Land into the following subdivisions.

1. The gneiss-complex of the south coast. (Cape Hope, Scoresby Sund, Cape Tobin, Cape Svainsson).

2. The garnet-pyroxene-gneiss area of Hurry Inlet.

3. The granite-area of the east coast of Hurry Inlet.
4. The migmatite-gneiss area north of Hurry Inlet.
5. The granodiorite areas of the east coast of Liverpool Land.
6. The banded gneisses of the east coast (extending from Glasgow Island to the granite-area of Store Fjord).
7. The granite-area of Store Fjord.
8. The gneiss-areas of North Liverpool Land (Store Fjord, Polyp Harbour, Cape Topham, Murray Island).

In the following description of the field observations and of the rock-specimens investigated this general division will be used.

The summary given above has shown that Liverpool Land as a whole can be characterized as a migmatite-area, where all formations of supercrustal origin have been intermingled with granitic rocks to an extent which often makes it difficult to keep the two rock-types separate. Rocks with preserved sedimentary structure were nowhere to be found except those of innermost Hurry Inlet (No. 2 on the map), and it is, therefore, only possible to distinguish between gneissic rocks and plutonic rocks. In the following the former of these rocks will be dealt with first.

The Contact between the Crystalline Base and the Sediments West of Store Fjord.

From the west end of Store Fjord a broad valley leads through the mountainous western coast-region of Liverpool Land up to the even high-plateau which forms its westernmost part, and which gradually descends westwards towards the Klit Valley (Klitdal).

The plateau is covered with mesozoic sediments which rest on the crystalline base forming the mountains of the east coast.

In order to investigate the contact between these two formations, the author made a traverse along the valley over the watershed between the Klit Valley and Store Fjord.

The valley forms the direct continuation of the fjord. Compared with the valleys of the outer east coast, it is very open and particularly in its upper part shows a very mature appearance. The rockground consists, as far as to the height of land, of bright pink granite, partly coarse porphyric, partly also fine medium-grained. Fissures filled with green epidote are very abundant. Dikes of Ouachitite were found by Backlund and Sahlstein farther east, and several pebbles of these rocks were observed in the valley.

The height of land lies about 7 km from the end of Store Fjord 200 m above the sea. The rock-ground is here still granitic, of the same type as around the inner parts of Store Fjord. Already about 500 m

west of the watershed the streamlet has dug itself a canyonlike valley with about 30 m steep walls. Here one enters the sedimentary terrain of west Liverpool Land. The walls of the canyon consist of soft sediments, resting on a crystalline base visible in its bottom. The lowermost strata immediately on the crystalline rock consists of a very coarse, partly almost conglomeratic, red-coloured arkose, with pebbles of granite and



Photo E. H. K.

Fig. 1. The contact between the Eotriassic sediments and the crystalline base, (visible at the bottom of the valley, with walls of sandstone) W of Store Fjord.

quartz, and also containing a fairly big amount of gneissic material. The pebbles are but incompletely rounded.

Higher up comes more fine-grained, bright brick-red sandstone, interbedded with fine-grained, almost slaty layers. No fossils were found. The sediments are characterized by light, whitish, bleached spots. On the whole they resemble the sandstone underlying the basalt of the Fame Islands in Hurry Inlet. Abundant ripple-marks and old sun-cracks are seen.

Like the sediments the underlying Crystalline is highly weathered and very soft to a depth of at least $^1/_2$ m. Nevertheless, the original texture is fairly well visible on the erosion surface uncovered by the stream. There are still visible aplitic veins and "Schliers" of older included rocks. Under the microscope all components except the quartz are completely turbid and opaque. However, on account of their shape,

which is still preserved, the rock can be definitely identified as the red granite found in the end of Store Fjord. The contact with the sediments is visible on fig. 1, p. 16.

Farther south-westward, in the next valley, the higher strata of the sediment-formation were found. Here there are alternating red and gray sandstone-strata (about $^1/_2$—1 m in thickness) interbedded with calcareous strata containing abundant lime-concretions. The formation, which is traversed by numerous layers of gypsum, has a very gentle westerly dip. These characteristics correspond to those of the "Gyps-formation" of ROSENKRANTZ (37.). In this part of Liverpool Land the eotriassic layers consequently rest immediately on the Crystalline-basement.

On both sides, (north and south) of the valley continuing the Store Fjord Valley the mountains rise to a height of about 7—800 m. The sediments cover the very gentle slopes up to 350—400 metres. These conditions are very interesting, because they clearly prove that the Store Fjord Valley is older than the eotriassic sedimentation, and that it was cut into the prae-triassic land-flat. It is evidently the same land-flat which we have seen uncovered along the eastern coast of Hurry Inlet.

B. THE GNEISSES OF LIVERPOOL LAND

The Gneiss-area of the South Coast.

The Colony of Scoresby Sound—Cape Hope.

On these localities the bedrock mainly consists of the same type of gneiss. The principal rock-types are the following:

1. Gray biotite-hornblende-gneiss. The rock has partly a very pronounced schistosity, but is in other places almost without any parallel structure, and resembles a hornblende-diorite. The most conspicuous component is the hornblende in fairly big (3 mm), well individualized crystals, which stand out clearly in the pale, somewhat grainy foundation. Biotite is more common in the schistose than in the non-schistose varieties. In more granitized sections microcline is the dominating light component and the rock grades into a syenite.

2. Biotite schist, through interbedding with pegmatite-veins parallel with the S-surfaces, giving rise to vein-gneisses. The schists are generally fine-grained, dark grayish or brownish in colour. Owing to tectonic movements the lighter layers are often broken and drawn out into lenses or form "Augengneiss"-like rocks.

3. Light-coloured, whitish or pinkish gneisses, consisting for the most part of felspar and quartz, and colourless mica. They grade into typical sericite-quartzites.

4. Here we have abundant pink layers of aplitic gneisses composed mainly of potash-felspar and quartz; the potash-felspar is often highly dominant.

5. Hornblenditic and amphibolitic inclusions and "Schliers".

These gneisses are penetrated by numerous veins and dikes of pink granite, pegmatite and aplite, which partly have the character of layers between the schist-packets, partly cut through the schistosity. The granite has soaked the schist-complex as a whole, until probably no one of the primary components has been able to keep its primary composition

unchanged. Particularly potash-felspar has evidently been added in considerable amounts.

Already the field researches furnish good evidence of the originally sedimentary character of the basal gneisses, and we shall in the following see that this assumption is supported by microscopic investigation.

It has already been pointed out that strong tectonical movements have had a share in the origination of the gneisses of the south coast. Their present shape is in fact mainly the result of these movements, in conjunction with the granitic injection. The bedding in the gneiss is at least in detail mainly secondary, caused by the pinching out and flattening of the rock-masses and the primary bedding is with certainty untraceable within the investigated parts of this complex. The tectonic style, taken on a small scale, is characterized by horizontally outdrawn differential folds, formed by strong, more or less horizontal gliding in a semiplastic state. The horizontal cleavage prevails, but also steep dips are found. Along the shear-planes the schists exhibit often very good cleavage, mainly due to the orientation of the micas and other femic components along the shear-planes. However, this cleavage is not so well developed in all parts of the gneisses, and is generally less prominent in the gray hornblende-gneisses than in the acidic quartzitic and aplitic types. (*cf.* also p. 92).

A typical feature of these gneisses is the existence of laminated quartz, forming very elongated thin films, parallel with the schistosity, which have often been folded at the continued movement. They have frequently been described from tectonized rocks, where the crystallization has been contemporaneous with the movement (*i. a.* 56). The grains are orientated parallel with the S-surface, with the main-axes of the cuartz (q.) at right or at least at steep angles to S.

Basic veins are common. They are, however, all more ancient than the granite veins, and have like the last-mentioned at least in some degree been influenced by the tectonic movements. Most of them have been broken and represent only fragments of the original vein. They generally have an amphibolitic composition. An interesting group is represented by veins with an eclogitic composition, with garnet and pyroxene as main components. (*cf.* SAHLSTEIN 40). They have been observed both at Scoresby Sound and also at Cape Hope. Especially at the latter place it was found that the vein-character was well preserved. At Scoresby Sound the occurrence can also be interpreted as fragments or inclusions. These scattered observations are of importance because they prove the genetic relationship between the gneisses of the south coast of Liverpool Land and the gneiss-complex of Hurry Inlet, with garnet-bearing rocks as one of the main elements.

Here mention must also be made of the deposit of crystalline lime-

stone described by ROSENCRANTZ (37.) from the north-west corner of Rosenvinge Bay, which evidently belongs to the same formation, but represents another horizon. Limestone has not been observed in the gneisses described above, unless in the form of hornblenditic alteration-products.

Cape Tobin.

The third point where the writer has had the opportunity to make personal aquaintance with the gneisses of the south coast was Cape Tobin, visited by NORDENSKJÖLD, who, however, limited himself to stating the occurrence of gneissic rocks of normal Archaean type (*cf.* 29).

The general impression given by the gneisses of Cape Tobin is almost the same as that of the rocks from the vicinity of the colony of Scoresby Sound. Also here the strong tectonization with an almost horizontal folding-axis is prominent and the pink colour is predominant. The tectonization here has given rise to slightly softer forms of the differential-folds. Evidently mylonitization plays a far less important part and on the whole the rock-mass seems to have been more plastic until the last stage of folding, this possibly depending on the more advanced stage of granitization (*cf.* p. 94). Particularly in the easternmost section the dip is steep, partly vertical, on the west shore of the cape more or less horizontal. Figs. 2 and 18 give a good idea of the gneisses and their folding-style.

The rock-components forming the basal-constituents of this migmatite are generally the same as those at the colony of Scoresby Sound. The quartzitic rocks, however, play a less important rôle, and the gray gneisses are dominant. Here they have a still more plutonic outer aspect than on the foregoing locality, and in the field it is almost impossible to decide whether they should be classified as ortho- or paragneisses. On account of the analogy with the foregoing, the latter assumption is, however, more probable, although we can hardly reckon on any chemical resemblance with sedimentary rocks. This question will be further discussed later on (p. 92).

Cape Svainson.

A short landing at a small cove north of Cape Svainson showed that the gneiss here is of a slightly different aspect than on the foregoing localities, although there still are many similarities. Also here the granitization gives the rock-ground its character. The schistosity is mainly stronger and gives rise to a very distinctive cleavage, resembling the flaggy cleavage of for instance several rock types of the Moine-gneisses of the Western Highlands of Scotland.

Here the primary composition was undoubtedly quartzitic. Certain layers in fact consist of pure sericite-quartzite, but they are interbedded with layers of aplitic gneiss, originated at the injection process. Dark

micaceous schists and hornblende-bearing schists were not found, and consequently the original rock has here been a more or less pure sandstone, in contrast to the more slaty character of the eastern localities.

On the landing-place a big basic inclusion was investigated, which is easily visible from the sea on account of its black colour. It consists of a hornblenditic or perhaps rather a coarse amphibolitic rock. In the central parts it is comparatively unaffected by tectonization, but in the marginal parts, in contact with the surrounding gneisses, it has been drawn out, and shows the same conspicuous linear schistosity as the gneiss itself. Evidently this basic rock, forming a mass of about 200 m in diameter, represents a basic intrusion of ophiolitic character. Also the possibility of an altered limestone must be taken into account, but is less probable, as will be shown later (*cf.* p. 27).

The observations quoted above indicate that the rocks of the south coast of Liverpool Land are paragneisses, which in the direction north-east to south-west change from quartzitic to slaty rocks. Farther north psammitic and pelitic schists probably underlie the quartzitic schists, while crystalline limestone has also been found. This is visible also in the cliffs south of Cape Hodgson.

Petrography.

As has been pointed out in the foregoing chapter, the gneisses of the Scoresby Sound colony show quite a varying mineralogical composition. They have, however, some features which can be considered as typical of all the rocks of the gneiss-complex in question. We have firstly the important rôle played by the potash-felspar and secondly the abundance of cyanite, constituting a type-mineral. True, these two components are not to be found in every rock, but are probably present in all cases where the chemical composition makes their origination possible.

Of the rocks which with certainty can be considered as paragneisses, the quartzitic schists are those of the simplest composition. Their main components are quartz, microcline, muscovite and generally also plagioclase in varying quantities. Quartz forms at least 60% of the rock. The mineral is always recrystallized, evidently contemporaneously with the movement, and the granulation therefore is conspicuous, but has nowhere received the character of a mylonitization. The best indication of recrystallization is given by the muscovite films which in general lie strictly parallel-orientated, in many cases following an earlier shear-direction. They often have been embedded in big later crystallized quartz grains[1]). The quartz and also the felspar grains

[1]) Sahlstein believes that also here the mica generally is orientated at the last movement, but also points out the strong postkinematic recrystallization.

have always very uneven sutured margins. The first-named generally is slightly undulose with strong recrystallization of the last-named, while the former preserve an orientation given by kinetic movements. The different behaviour of the mica and the quartz is a very common feature among the schists of Liverpool Land and is best illustrated by the structure-diagrams worked out by SAHLSTEIN (42.). The structural orientation of the mica generally reflects fairly well the macrotectonics of the rock-complex.

The micaceous vein-gneiss consists of a fine-grained dark brownish-gray mica-schist and thin pink pegmatitic strata, which are often broken, with the fragments drawn out into lens-shape.

The mineral-constituents are quartz, microcline, plagioclase (oligoclase), muscovite, biotite (generally subordinate), cyanite and chlorite. The latter generally as an alteration product of biotite.

The structure is granulitic, generally lamellated with bands of elongated quartz-grains and felspar alternating with layers rich in femic components. The last-named are, as usually is the case in rocks of that type, more sheared than the first-named, depending on the higher degree of newcrystallizations in the salic constituents, particularly of the quartz. The last-mentioned mineral often forms rather big, sutured grains with slight undulations. Of particular interest are the elongated grains, named in the foregoing as originated by means of crystallization connected with movement. If we do not take into account the undulation, the optical orientation of these grains is uniform in the whole grains, with a at about right angles to the foliation. There are often seen fine ruptures indicating a slight displacement in the crystal parallel with the same direction. In many cases the crystals also have been later granulated and appear in that case as polysomatic agglomerations. Sometimes there also can be seen spots with an intense granulation of almost mylonitic character within the big quartz-grains. They are on all sides included in the host-crystal, in the same way as the mica-flakes, and evidently represent remnants from a still older granulation. This granulation seems to belong to the same stage of deformation of the rock, in which, at least in many cases, the present parallel-orientation of the mica originated. These remnants are very elucidatory as regards the explanation of the lamellar quartz. At least in some cases it has undoubtedly been formed from crushed and outdrawn old quartz-grains by a process which can be compared with the collective crystallization of big crystals at the cost of small ones. The potash-felspar seems as a rule to be a microcperthite. The lamellation is generally insignificant. As in all gneisses of the south coast microcline-gitter structure is absent. The plagioclase is generally clear, with Albite- and Carlsbad-

lamellation, sometimes a little dull. The decomposition is due to saussuritization. Microperthitic intergrowths are often seen.

Biotite forms pale yellowish flakes; it is generally altered into light greenish chlorite and sagenite. Muscovite forms long plates, especially along shearing-cracks and flagplanes. Both the micas show a tendency to alter into potash-felspar. Iron ore and cyanite are generally present in a few small grains. Garnet is sometimes present in small, light pinkish, rounded grains.

The quantitative composition of this rock varies of course very much in every slice, depending on how much of the different layers happens to be included. The thickness of the layers is as a rule a few cm. (Quartz and potash-felspar can be considered as the dominating felsic components with about 30—60 and 10—25 vol %). Sometimes the plagioclase is about as important as the microcline. Muscovite is about as common as the felspars.

Closely related to these gneisses and occurring interbedded with them are the cyanite-gneisses, consisting of quartz (c. 50%), microcline (c. 40%), cyanite (10—20%), muscovite, plagioclase (up to 20%) and in small quantities sphene, magnetite and zircon.

The structural features are generally the same as in the gneisses described in the foregoing. The type-mineral, cyanite, is mainly grouped along planes of shearing, where the small blunt-ended crystal-grains are clustered together to dense aggregates (size about 0.05 mm). These polysomatic agglomerates could be interpreted either as having been formed at a disintegration of big crystals, or as having crystallized contemporaneously with the shear-movement. The latter suggestion seems to be the more probable. These elongated agglomerations are generally surrounded by muscovite, which mineral originates on the coast of the cyanite, evidently through a reaction with potash-felspar. Another reaction-product of interest on the contact between cyanite and microcline is a colourless garnet, which is seen growing from the cyanite-agglomerations within the felspar. The composition of this garnet cannot be determined on account of the small size of the crystals, but because of the absence of Mg,Fe-minerals in the rock, it can be concluded that it must be a Ca,Al-garnet. So far as can be estimated from its position and shape this garnet is formed later than the shearing and the origination of cyanite and muscovite in the rock.

Another type of cyanite-gneiss consists of the same minerals, but with the addition of abundant biotite, with muscovite in a subordinate position and with a few small grains of pink garnet embedded in the quartz-felspar foundation. In the slices investigated, the tectonization was less conspicuous than in the muscovite-rich gneisses.

The mineralogical composition of the gneisses described above,

indicates with a certain amount of feasibility that they represent altered psammitic layers rich in alumina, which by granitization have been enriched in felspar.

The gray hornblende-gneisses of the south coast are more difficult to interpret as to their original character, particularly because the contact studies, owing to strong deformation, do not give any indications about the igneous or supercrustal character of the rock. Their mineralogical composition is: plagioclase, representing the most

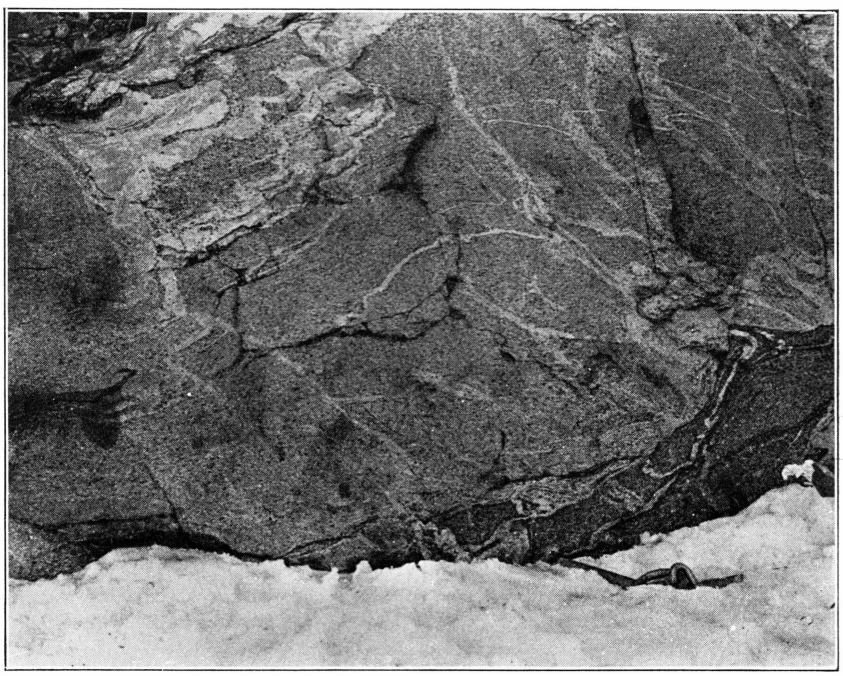

Photo E. H. K.

Fig. 2. Almost massive gray paragneiss with aplitic veins. Cape Tobin.

important salic component, forming about 30—35% of the rock, potash-felspar (5—20%), quartz, generally less than potash-felspar, hornblende (20—30%), biotite (5—20%), titanite (5—10%) and apatite. Also cyanite has sometimes been observed.

The most striking difference between these and the psammitic gneisses is the high percentage of hornblende and sphene and the comparatively high content of plagioclase (oligoclase, 25% An). The composition corresponds equally as well to that of an orthogneiss as to that of a paragneiss. The structure is completely granoblastic, with irregular boundaries between the components, which are all comparatively evenly distributed in the rock. Only the coloured minerals are in some degree clustered together along certain zones. In some varieties the

schistosity is fairly well developed. in others the parallel structure is insignificant. The only mineral which is slightly idiomorphic is hornblende, which occurs in comparatively big crystals containing an abundance of inclusions and evidently representing blastic grains rather than primary crystallization-products. The colour is the common grass-green — brownish-green — yellowish. The yellowish-brown biotite-flakes are always at least to some extent parallel orientated and contribute to the gneissose appearance of the rock. The plagioclase shows twinnings according to the Albite- and Carlsbad-laws. Myrmekites in cauliflower-projections abound.

If we exclude plutonic origin of this gneiss as less probable, on account of the great variability of rock-types there are two possibilities left. The first that it is formed from a (supercrustal) amphibolitic rock which at the granitic injection has soaked great quantities of felspar and quartz and in this way has gradually been altered into the diorite-like — sometimes syenite-like — rock here in question. The structure and general habit highly resemble migmatitic rocks which the writer has seen to be formed in the same way in orther parts of the world. (Compare the interpretation of the origin of the garnet-pyroxene gneisses of Hurry Inlet, p. 40).

The other explanation is that the rock derives from comparatively lime-rich sediments, e. g. a pelitic rock which has been completely recrystallized and enriched in granitic solutions. We have in fact among the so-called pelitic schists of the injection complexes of North Scotland, of Scandinavia, Canada etc., several occurrences which offer striking similarities. This interpretation is favoured by the sedimentary character of the bulk of the gneisses in south Liverpool Land, and the absence of igneous rocks of supercrustal origin.

The bulk of the aplitic gneisses are of course real orthogneisses, occurring as layers between the other rocks and following the general strike-direction. They consist mainly of quartz and potash-felspar, with plagioclase in smaller amounts, and some films of mica (biotite and muscovite) as the only mafic component. The tectonization of these gneisses is generally less advanced than in the para-gneisses and belongs evidently to a later phase of movements than that which has caused the bulk of the schistosity in the gneiss-complex.

Of igneous origin are also the amphibolitic inclusions, and the pegmatitic and aplitic dikes which, however, do not offer anything of particular interest in addition to the data furnished by every migmatite-area.

More interesting are the basic garnetiferous dikes consisting of garnet, pyroxene (monoclinic and rhombic), hornblende, plagioclase, biotite, iron ore and titanite. They completely

correspond to the eclogitic rocks of Hurry Inlet and therefore will be mentioned here only quite briefly. Their structure is decidedly blastic with very sutured margins between the components, which are all greatly filled with inclusions. Reaction seams of different kinds between the components are exceedingly abundant. This feature seems to the author to be good evidence of the secondary character of the present minerals, or at least of the major part of them. The dikes have probably originally consolidated with another mineral-composition and have later, due to the metamorphosis, been altered into garnetiferous rocks. This alteration will be further discussed in another connection (p. 43).

The gneisses of Cape Svainson show about the same petrographic features as the gneisses from Cape Hope and Scoresby Sound. Here the quartzitic gneiss predominates, together with aplitic gneiss. The tectonization is conspicuous also under the microscope and is shown especially by the very consequent parallel-orientation of the mica. On the other hand, the recrystallization of the salic components is fairly complete and mylonitic structure is as a rule not present in the rock, although a certain degree of cataclase is far from rare (Fig. 3, Pl. 1).

The basis inclusion has a typical amphibolitic composition with dark green hornblende ($c:\gamma = 16°$) plagioclase (36% An), dark brown biotite, muscovite, titanite and apatite. Occasionally also calcite occurs. In the undeformed sections garnet occurs as rounded, fairly big grains. In the contact-zones with the surrounding gneisses the mica becomes more abundant, the structure is more gneissic and the hornblende is lighter green in colour. In order to solve the question as to whether this rock is of igneous origin or not and whether it can be compared with the eclogitic inclusions of Hurry Inlet an analysis was made by Dr. N. SAHLBOM with the following result (p. 27).

The composition corresponds to several gabbros and metagabbros and has a pronounced igneous character. As later will be seen the rock offers several similarities with the basic garnetiferous rocks of Hurry Inlet and the south coast of Liverpool Land. The supposition as to ophiolitic origin therefore seems to be well justified.

The Garnet-Pyroxene-Gneiss area of Hurry Inlet.

Field observations.

The southernmost part of the west coast of Hurry Inlet rises very gradually from the shore up to a height of about 600 m, at which altitude the highest crests of the landscape are cut by an almost horizontal old peneplane in which the young fjords and the steep almost alpine summits

Table 1.

SiO_2	46.74		
TiO_2	2.88		
ZrO_2	none		
Al_2O_3	14.77	Norm.	
Fe_2O_3	3.11	Or	8.89
FeO	11.00	Ab	24.25
MnO	0.18	An	23.20
MgO	6.52	Di	9.65
CaO	8.45	Hy	2.34
BaO	trace	En	1.80
Na_2O	2.83	Fe_2SiO_4, Fa	12.45
K_2O	1.50	Mg_2SiO_4, Fo	10.04
P_2O_5	0.53	Mt	4.63
S	0.17	Il	0.61
Cl	0.17	Py	0.24
H_2O+	1.28	Ap	1.34
$(H_2O\div$	0.25)	Cl	0.10
$(O = Cl_2\ 1{\cdot}54)$	100.11		99.74

Amphibolite, Cape Svainson, Liverpool Land, Anal. N. Sahlbom. G = 3.04.

and ridges of the eastern coast have been sculptured. The main sky-line of the west slope represents an erosion surface, older than the peneplane mentioned above, and dips underneath the sediments of Jameson Land with a gradient of 3—4°. Although, taken as a whole, it has the character of a plane, the terrain is far from level. It is traversed by numerous small stream-valleys, generally with steep walls cutting through the rock-ground, and giving rise to a hilly landscape with well developed glacial topography. The relative heights are 100 to 200 m. The valleys offer good opportunities of studying cross-sections of the bed-rock.

Also in this region the rock-ground is of a very complex composition and resembles, particularly at first sight, in many respects the migmatitic gneisses of the south coast. But on the other hand there exist several very striking differences, which make their separation from the gneiss-area of south Liverpool Land quite justified.

Also at Hurry Inlet strong mechanic influence is conspicuous, and in a still higher degree than in the gneisses described in the foregoing chapter. It has given rise to a well developed schistosity or banding, with for the most part flat-lying stratification, recalling that of the south coast; locally also a steep folding is noticeable. The linear schistosity is generally very pronounced and the pitch has as a rule a more or less horizontal position, though forming gentle culminations and depressions, which in some degree also are visible in the topography. On the whole, the consequent horizontal position of all the structures is a prominent

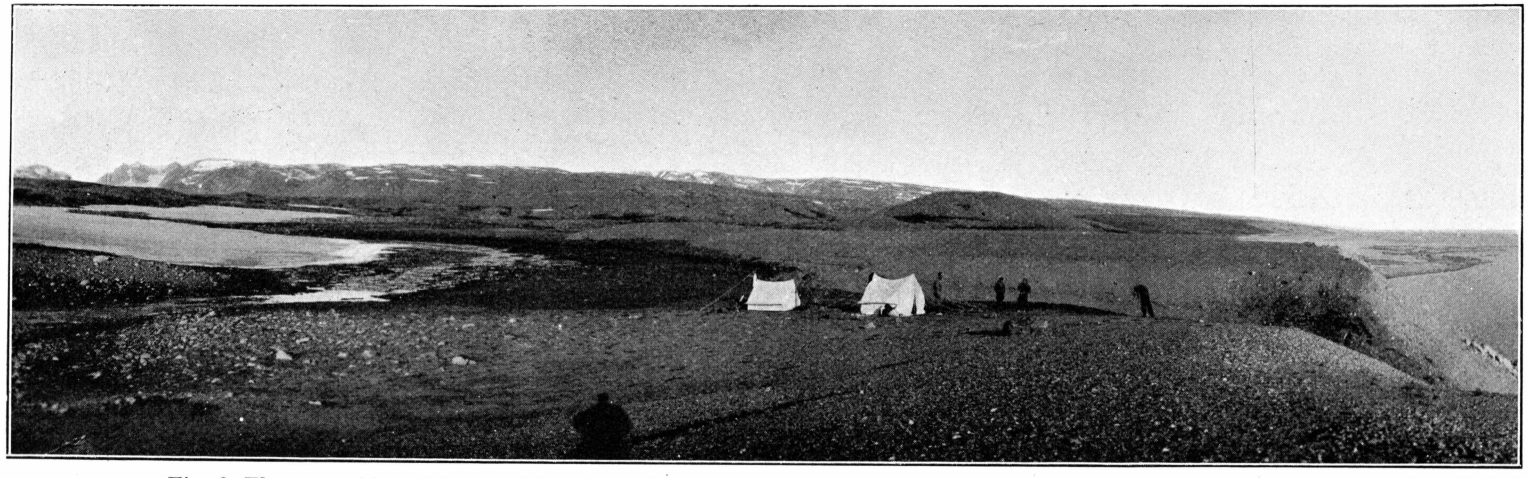

Fig. 3. The west side of Liverpool Land seen from a point north of the outlet of Nøkkedal River in Hurry Inlet. The even crests on the right-hand side consist of garnet-pyroxene-gneisses, the steep summits to the left of granite. Photo E. H. K.

feature of the complex. In addition to the evidently very advanced stage of metamorphism (both tectonical and chemical) this gives the gneisses in question their character.

The principal rock-types composing the complex are the following:

1. Gray gneiss. The type which is probably most important as to volume is a light-gray-coloured, comparatively fine-grained gneiss, with thin dark gray layers and whitish, aplite-like veinlets or "tails". At the tectonical deformation the latter have been cut off and bent into complicated folds of almost ptygmatic aspect. The internal (differential) movements have in part gone so far that the veinlets receive the character of



Photo Th. Sahlstein.

Fig. 4. Gray, highly deformed psammitic gneiss, composing the base of the eclogite breccias of Hurry Inlet.

small "Augen" in the gneiss. Macroscopically this rock often resembles a strongly deformed granite-gneiss, but the quartz-content is too high to justify such an interpretation (Fig. 4, p. 29). It occurs in layers, often hundreds of metres thick, frequently with embedded strata of darker colour with hornblende, pyroxene, garnet and other femic components visible to the naked eye. Banded mica-gneisses also occur. In the pure gray gneiss the size of the grains generally is too small to allow of identification without microscope.

2. Dark gray garnet-pyroxene-gneiss. The other main type is a dark grayish, generally more coarse-grained gneiss, sprinkled with crystals of femic minerals, often arranged in bands or seams. There is often an interbedding of dark and whitish layers giving the gneiss a stratified appearance. Pyroxene and hornblende and red garnet are visible in every specimen and sometimes also an abundance of black mica. Figs. 6 and 7 give a good idea of the rock-type in question. There is often a kind of selective crystallization, into strata with big garnets in a dom-

inantly white, felsic base and strata with less garnet and abundant pyroxene (amphibole) with less felsic components.

3. Eclogitic rocks. Finally we have basic rocks of eclogitic composition, occurring as limited masses within the gneisses described above. They are dark rocks, generally without visible light components, with red garnet and dark green pyroxene as dominating minerals. Basic rocks also occur entirely without or with only small quantities of garnet. Some of them have an amphibolitic composition (*cf.* p. 39), but within the typical Hurry Inlet gneisses there is always a certain amount of pyroxene.

4. Pegmatites and aplites. We further have to mention the numerous pegmatitic and aplitic veins of the region as rock-constituents which do not belong to the gneisses proper.

The two first described gneisses seem to alternate rather irregularly; the basic types forming layers infolded in the more felsic ones. They can often be traced over considerable distances in the same horizon. The eclogite occurs as inclusions in the gneisses, sometimes measuring several hundreds of metres, sometimes being quite small in size. As a rule these inclusions seem to occur within the pyroxene-hornblende-gneisses, and if they occur within the gray gneiss they are always surrounded by a rim of dark garnetiferous gneiss forming a kind of corona (*cf.* fig. 43) with a gradually diminishing amount of dark components, from the boundary of the eclogite inclusion outwards. They resemble the coronas around basic inclusions in migmatitic assimilation rocks. The form of the eclogite masses is either lens-like outdrawn, or angular. In many cases the eclogite-inclusions form real breccias and there can hardly be any doubt that the brecciation has occurred after the consolidation of the basic rock.

Greater masses of pure eclogite have not been found, and the occurrence in that respect evidently greatly resembles the Norwegian eclogites described by ESKOLA (11.) and also some of the Alpine and Saxonian localities (*i. a.*, 51, 58).

In comparison with the surrounding gneisses the eclogite-inclusions appear as astonishingly massive and unaffected by tectonic influences. Only in the boundaries, where the salic components are profuse, is there a pronounced schistosity, but in the central parts there are even under the microscope hardly any signs of tectonization. This, however, does not depend upon the fact that the basic inclusions have taken less part in the movements than have the gneisses, but rather upon the tremendous power of resistance against mechanic deformation of such ultrabasic rocks, as compared with quartz and felspar-rich rocks, especially under the physical conditions in which the deformation in Liverpool Land has taken place. The massive structure as a rule is well preserved, also where the inclusions are very small, if they do not contain any felspar. On the

other hand, there are rock-types which as to their chemical composition can be referred to the eclogites, although they contain in some degree plagioclase, which shows a well developed parallel-structure. In some cases the massive structure may depend upon the eclogitic composition having originated contemporaneously with the last stage of deformation (*cf.* p. 42).

In its peripheric sections and evidently also in the lowermost horizons of the garnet-gneiss complex the character of the rock-ground is in some degree different. We here gradually enter a formation of another origin. On the shores of Hurry Inlet there occurs a fine-grained gneiss which closely resembles the so-called leptitic gneisses of Scandinavia. It is a fine-grained gneiss which obviously before the last recrystallization has undergone a mylonitization, with dark "Schliers" and inclusions. A similar gneiss-type was found on the north side of the garnet-gneiss complex, in the northernmost of the deep cross-valleys within the area. In the bottom of this valley there occurs a typical migmatitic gneiss of Archaean aspect, consisting of a fine-grained granite-gneissic base with dark inclusions and traversed by a network of aplitic veins. It shows typical assimilation-phenomena at the boundary between the older components and the intruding granitic rock. Basic inclusions are present in abundance. They have about the same shape as the angular eclogitic inclusions in the garnetiferous gneisses, but the mineralogical composition is for the most part amphibolitic. Only a few eclogitic inclusions were found. The rock-formation was evidently strongly tectonized contemporaneously with the granitization.

In the upper parts of the cliff-walls of the same valley typical garnet-pyroxene-gneisses occur, obviously resting on the migmatite-gneisses.

The writer got the impression that the garnet-pyroxene-gneiss-complex as a whole forms a comparatively thin sheet upon the migmatites, and measures probably nowhere more than 3—400 m in thickness. The field observations are unfortunately still too scarce to give a definite answer to questions as to the field-position of the formation, but there are, as later will be seen, also other facts which point in the aforesaid direction.

Also eastward the garnet-pyroxene-gneisses gradually change into more normal migmatite-gneisses containing hornblende and garnet.

An interesting contact zone was found at the south side, on the contact between the garnet-gneisses and the gneisses of the south coast, and is likely to throw light on the tectonic relation between the two rock-complexes. Here, north-east of Cape Hope, on the edge of the small areas of triassic sandstone described by Rosencrantz, we found a typical thrust-zone, where the rock-types of the garnet-pyroxene-

gneiss area occur in a still more advanced stage of tectonization. They are rolled out in an extremely complicated manner, and folded into numerous small, partly standing, partly recumbent folds, bent towards the south. Both the layers poor in garnet and the garnetiferous gneisses with ultrabasic inclusions are represented. Only the last-mentioned have sometimes still preserved their former character. Besides the eclogites, there are present also amphibolitic inclusions which generally contain some garnet. The other rocks have been altered into typical tectonites. Of particular interest is the rock which is formed at the tectonization of the garnetiferous gneisses. These are altered into rocks which both

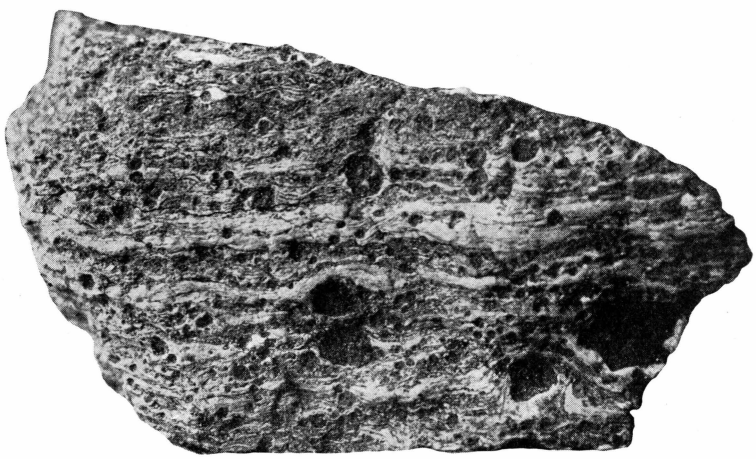

Fig. 5. "Granulite-like" mylonite-gneiss north-east of Cape Hope. About $^1/_2$ of natural size.

macroscopically and in thin-section show a very close resemblance to the granulites of, for instance, Saxony. (The name granulite is here used in the German sense of the word). The felsic components, both the quartz and the felspar, are drawn out in thin ultramylonitic bands which have been bent around the often "rotated" red garnet-grains. Fig. 5 gives an idea of the macroscopic character of these rocks. There is no doubt that this mylonite-zone belongs to the garnet-pyroxene-gneiss area. Besides by the observations quoted above, this conclusion is supported by the fact that also within the garnet-pyroxene-gneiss area of Hurry Inlet there sometimes can be seen structures resembling those of the locality here described, although the deformation has never gone so far.

The south eastern boundary-regions of the garnet-pyroxene-gneiss area were touched by Dr. MALMQUIST and Ing. EKLUND during the excursions 1933 in connection with ore-prospecting. Their collection of rock-specimens, which the writer had the opportunity of looking through

in Upsala, shows that we here (north and north-west of the Colony of Scoresby Sound) have to do with garnetiferous gneisses which seem to be in less degree mechanically deformed, but instead are to a considerable degree affected by granitic injections. They resemble in many respects real injection-gneisses or migmatites and are rather to be referred to the gneisses of the south-coast. The great rôle played by basic, hornblenditic rocks is conspicuous. Also eclogites, mostly altered into garnetiferous hornblendite, are represented. On the whole hornblende-gneisses (not unlike Lewisian gneisses) play a great rôle compared with mica-bearing rocks. The granitization was partly a lit-par-lit injection with assimilating pegmatites, partly it is represented by younger crosscutting veins and dikes. The first-named seems to correspond to the later granitization (*cf.* p. 106) on the south coast. The granitization is here mainly later in comparison with the tectonization and the latter therefore is less prominent.

Petrography.

The gray gneiss of the Hurry Inlet region consists in its purest form of quartz, plagioclase, orthoclase, biotite, magnetite, titanite, apatite and zircon, the last-named in very small quantities.

Quartz is the dominating component, forming about 50—60 vol. % of the rock. The structure is granulitic. The mineral-grains are irregularly limited, often with sutured margins, and on the whole the size of the grains lies for all main-components within the same limits (0.5—0.05 mm). On the other hand, there are grains of each mineral in every magnitude. A remarkable feature is the often almost total absence of undulose structure in the quartz and the scarcity of myrmekite-structure.

Plagioclase (about 20% An) occurs abundantly and represents the felsic mineral second in importance, with 15—25 vol. %; in several cases still more. Potash-felspar is remarkably rare and is found only in a few small grains; in many sections it is absent. This fact is of importance in comparison with the para-gneisses of Scoresby Sound where microcline was present, generally in great quantities, in almost every specimen. Here the mineral is limited to certain veinlets and aplitic layers. Biotite (5—10%) occurs as small seams of greenish-brown colour, sometimes altered into chlorite. The orientation is far less regular than in the gneisses of the south coast and the seams give the impression of having been disturbed by late recrystallizations, or of representing crystallization in varying conditions. Magnetite is an important component and is in some specimens represented in quantities as great as, or even greater than the biotite. It has a completely xenomorphic appearance. Small quantities of green hornblende are often seen particularly in the mica-rich varieties.

Of the accessory components apatite and more particularly

titanite are abundant. Rutil was found as a couple of small slightly rounded prisms.

The properties given above agree fairly well with a paragneiss of impure quartzitic composition.

In order to decide the question whether this gneiss is to be referred to the paragneisses, or if it is an orthogneiss, an analysis was made by Dr. NAIMA SAHLBOM with the following result.

Table II.

	1	2
SiO_2	78.63	79.66
TiO_2	0.60	—
ZrO_2	0.05	—
Al_2O_3	8.91	9.21
Fe_2O_3	2.12	3.57
FeO	1.03	0.08
MnO	0.04	trace
CaO	2.12	0.10
MgO	0.62	0.64
Na_2O	1.33	0.22
K_2O	3.83	4.49
P_2O_5	0.05	0.02
H_2O+	0.46	1.84
($H_2O\div$	0.10)	..
	99.79	99.86

1. Psammitic gneiss. Hurry Inlet. N. Sahlbom. analyst.

2. Lower "Bundsandstein" slightly argilliceous. Heidelberg. (From Rosenbusch, Elemente der Gesteinslehre).

As shown by the rock given for the sake of comparison, the analysis corresponds well with a psammitic rock, and proves definitely that we here have to do with ancient sediments, and not with granitic gneisses.

The potash for the most part belongs to the biotite, and the iron to magnetite, in some cases also to hornblende.

(In contrast to these gneisses the aplite-like gneisses of the boundary regions of the complex often are practically free of mica. They are composed of a fine granulitic mixture of quartz and plagioclase and also potash-felspar. In addition there are tiny flakes of a sericitic or chloritic mineral).

With an increasing percentage of the dark components the mineralogical composition becomes more complicated. In the transitional types grading into the dark gneisses, quartz and plagioclase are still the dominating minerals, but with increasing quantities of biotite. In addition they contain small grains of garnet, green hornblende, augite and

andalusite; as accessory components also magnetite, titanite, apatite and small crystals of rutile.

The dark garnet-pyroxene-gneisses, occurring generally in connection with the eclogites, contain mainly the same minerals, but with an excess of femic components. Here green hornblende and garnet, or pyroxene and garnet, with or without hornblende, are the dominating minerals, forming more than 50% of the rock. The size of the grains is somewhat bigger than in the foregoing rock. The pyroxene

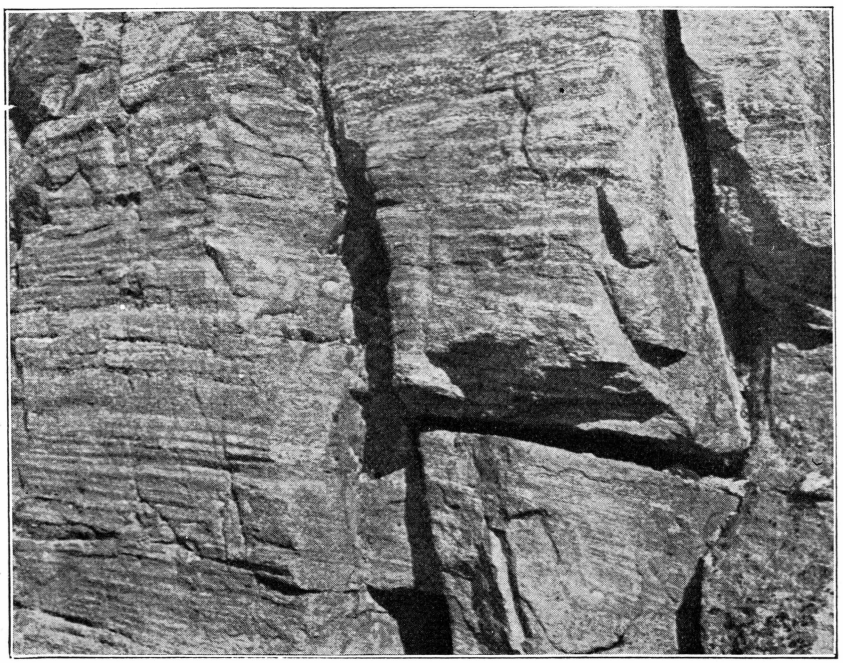

Photo E. H. K.

Fig. 6. Banded garnet-pyroxene-gneiss with well developed linear schistosity. Height about 3 m.

is partly rhombic, partly monoclinic. The latter is a light greenish augite with $\gamma : c = 42°$. The composition of the garnet in this rock was not determined with greater exactitude, but some determinations of the refraction-index give about 1.76—1.77, which points to a fairly great percentage of the pyrope-molecule. The pyrope-percentage seems to increase with increasing basicity of the rock.

The structural features of these rocks are very typical. As already has been pointed out, there always is a strong parallel-structure in the gneisses, when studied in the field (Fig. 6 and 7).

In section under the microscope this structure is less prominent. The micro-structure obtains its character through the very irregular

forms of the grains, none of which have any individual crystal-development, and through the great frequency of rounded inclusions, of diablastic character.

Typical intergrowth-structures are found in abundance. If we begin with the coloured minerals, the pyroxene always contains rounded inclusions of plagioclase (or quartz). Also the hornblende is rich in inclusions, but generally not in the same degree as is the pyroxene, particularly the rhombic type. The last-named has as a rule an almost spongy appearance. A symplectitic intergrowth is formed of magnetite and hypersthene and also of hornblende and magnetite. Hypersthene also forms celyphitic coronas around garnet, evidently representing a reaction-product of the latter.

A very typical diablastic structure, which seems to be limited to the rocks here in question, is an antiperthitic mixture of plagioclase and orthoclase. The former mineral is always the host. It has the composition of an oligoclase with c. 25% An and has a well developed Albite-twinning-lamellation. The mineral-grains are filled up with orthoclase-inclusions, generally angular in shape, resembling as to form some types of graphic structures. The crystal-surfaces of the inclusions have evidently been orientated according to certain surfaces of the host-minerals, and as a rule they form a singular optical unity, which shows the same extinction of all the inclusions (*cf.* fig. 2. pl. 1). In many cases the inclusions make up more than 50% of the volume of the host-mineral. The writer's general impression is that the orthoclase in some way replaces the plagioclase. There exists no constant relation between the amount of oligoclase and orthoclase in the grains; in that respect the phenomenon corresponds to normal antiperthite. Pure plagioclase-grains have in no case been found within these rocks.

Antiperthites of this type have often been described, particularly in garnetiferous gneisses (granulites) related to the rocks here in question.

Besides these intergrowths there also can be seen abundant myrmekitic intergrowths of quartz and plagioclase, showing the common cauliflower-like shape.

After all, it is quite obvious that a great number of reactions between the different minerals of the rock have occurred, which only for the less part have been finished, and that there hardly exists any equilibrium in the present stage of its development. The minerals found correspond fairly well with the paragenesis occurring in the big aureoles around intruding plutonites in the deeply eroded crystalline sections of the earth-crust.

The reactions which more or less directly can be observed in the rock are the following:

1. Replacement of augite and hypersthene by green hornblende.

2. Garnet alters into rhombic pyroxene (kelyphite), but also into hornblende. Here the alteration-product first originated is a light bluish-green amphibole (*cf.* the investigation of Th. SAHLSTEIN 40).

3. Growth of plagioclase at the cost of garnet. In connection with this reaction, there is found crystallization of fine-grained magnetite.

4. Biotite alters into titanite and chlorite (sometimes also into muscovite, but on the whole the last-named mineral is very rare within the gneisses of Hurry Inlet.

5. Andalusite is replaced by felspar.

There can on the whole be traced a tendency to an alteration of the present minerals corresponding to the garnet-zone of metamorphism into hornblende-bearing rocks of the type which we have found represented in the eastern boundary regions north of the Colony of Scoresby Sound (p. 32). This tendency seems to coincide with an increasing influence of granitization: that is to say an advancement of the isothermic surfaces and contemporaneously an addition of water to the rocks. In connection with the increasing degree of metamorphism cyanite is formed instead of andalusite in the eastern parts of the complex.

As earlier has been pointed out, the granitic influence within the typical garnet-pyroxene-gneisses on the whole is not conspicuous and the content of potash-felspar is low. On the other hand, the dark gneisses, compared with the light gray gneisses, have a comparatively high content of this mineral. We have in them the intergrowth of plagioclase and orthoclase and the high content of biotite, proving that the potassium for some reason has been enriched in the more basic part of the rock-complex. This recalls the often observed high potassium-content in pelitic gneisses (e. g. in the Scotch Highlands) generally interpreted as a primary adsorption of this element in clay-sediments (Fig. 1, Pl. IV).

The eclogitic rocks of Hurry Inlet have been described in detail by TH. SAHLSTEIN (40.) and it is therefore not necessary to dwell on them in this connection. They are of the composition well known from eclogite-localities in other parts of the world, red pyrope and green pyroxene being the dominating, in many cases the only components.

The following main-types can be observed:

1. Garnet-augite-rock consisting of garnet with dominating pyrope, light greenish augite and small quantities of quartz. The structure is the same as in eclogites described from other localities with rounded grains of garnet embedded in the pyroxene.

2. Garnet-pyroxene-plagioclase-rocks consisting of these minerals with an addition of small quantities of quartz, biotite, titano-magnetite and rutile. Besides the pyroxene, which is partly rhombic and partly monoclinic, hornblende is generally present, often in considerable

quantities. Also andalusite has been observed. The garnet is more almandine-rich than in the pure eclogite but contains still more pyrope than the first-named molecule, according to the index of refraction. These varieties grade into the dark gneisses described in the foregoing. Also the structure is in many respects similar (Fig. 1 and 2, Pl. 1).

In the pure eclogites there generally can be seen different kinds of alterations and reactions between the principal components. Between garnet and augite there is generally a thin rim of light green amphibole (smaragdite). In some varieties the garnet is completely altered into this mineral. Contemporaneously the augite is transformed into symplectite with numerous inclusions of quartz or plagioclase. The monoclinic augite often seems to be replaced by a hypersthene.

In certain varieties — possibly where the granitic influence has been conspicuous — the pyroxene and also the light green amphibole alter into common dark green hornblende.

In other words, the reactions resemble those of the garnetiferous gneisses. The eclogite-minerals crystallized earlier become instable at the continued metamorphism and alter at first hand into the minerals of the gneisses.

The reaction-rims described from the garnets of pure garnet-pyroxene-rock are not found around the corresponding mineral of the varieties rich in plagioclase. Here the alteration of the garnets has the character of a gradual replacement by felspar with a contemporaneous crystallization of iron-ore. This may depend on the more almanditic composition of the mineral.

In order to give an idea of the chemical composition of the eclogites of Hurry Inlet three analyses taken from SAHLSTEIN's above-named paper may be quoted. As a comparison the analysis of the garnetiferous amphibolite of Cape Svainson is given (see p. 39).

No. 2 represents the eclogitic inclusions from Scoresby Sound with garnet, rhombic and monoclinic pyroxene, green hornblende and plagioclase as main components, and with further a considerable amount of biotite and quartz. No. 3 is an eclogite from Hurry Inlet with fairly abundant hornblende. No. 4 is a pure eclogite.

The difference between the amphibolite and the hornblende-eclogite is not great, and there can hardly be any doubt about the close relationship between them. The table gives an idea of the change in the composition of the rock-series, with an increasing percentage of hornblende, and probably also of the change which the eclogites have suffered with an increasing influence of granitic intrusions (*cf.* p. 45). The increase of potassium with an increasing percentage of hornblende is in that respect very elucidatory. Very remarkable is the high percentage of chlorine which is far too high to be contained in the apatite. It lies close

Table III.

	1.	2.	3.	4.
SiO_2	46.74	45.56	48.80	53.24
TiO_2	2.88	2.60	1.30	0.44
ZrO_2	n.d.	trace	trace	none
Al_2O_3	14.77	16.10	16.60	5.90
Fe_2O_3	3.11	5.59	5.03	5.70
FeO	11.00	9.15	5.80	6.58
MnO	0.18	0.20	0.18	0.25
MgO	6.52	6.54	8.58	16.49
CaO	8.45	8.60	11.57	10.49
BaO	trace	0.05	trace	none
Na_2O	2.83	2.67	3.01	0.40
K_2O	1.50	1.38	0.83	0.17
P_2O_5	0.53	0.86	0.38	none
S	0.17	none	none	none
F	n.d.	none	none	none
Cl	0.17	0.34	0.14	0.14
H_2O+	1.28	0.72	0.50	0.40
$(H_2O \div$	0.25	0.15	0.12	0.10
	100.12	100.36	99.72	100.26
$O = Cl$	0.03	0.08		

1. Amphibolite. Cap Svainson. G = 3.04.
2. Eclogite, Scoresby Sound.
3. Eclogite, Hurry Inlet.
4. Eclogite Hurry Inlet. G = 3.363. Anal. N. Sahlbom.

at hand to suppose a content of scapolite, but in spite of careful investigation the author has not been able to find this mineral or any other chlorine-bearing mineral. SAHLSTEIN has also failed to find any definite explanation of the derivation of this component. We so far have to combine it with some of the mafic minerals of the rock.

Finally, we have to mention the petrographic character of the amphibolitic inclusions described from the contact-zone of the valley on the northern edge of the garnet-pyroxene-gneiss-area (p. 31). The composition and structure of these inclusions do not differ from those of a normal amphibolite in other migmatitic-areas. The only signs which bring to mind the rocks described above are small remnants of augite, which for the most part have been altered into hornblende. The augite, which is in most places difficult to recognise, seems to be a clino-augite of the same type as in the dark gneisses and in the eclogites. This observation points to the possibility that also these inclusions originally had a composition corresponding to that of the last-named, but have here suffered a higher degree of alteration. The surrounding gneiss is

here a potash-rich, normal migmatite. The chemical composition of these inclusions is probably about the same as analysis 1, Table III.

The Origin of the Garnet-Pyroxene-Gneisses of Hurry Inlet.

The findings given by the field observations will be used first in the interpretation of the origin of the formation described in the foregoing, and seem to give the key to the problem.

If we compare the mode of occurrence of the eclogite and the garnet-pyroxene gneisses, it is quite obvious that there exists an intimate relationship between the two. The gneiss regularly forms the rims of the eclogite. Only in a few cases have eclogite-fragments been observed without this contact-zone, and in these cases the fragments were very angular and the gneiss had evidently been comparatively slightly influenced by internal movements. As a rule, the contact-gneiss-rim is broad compared with the size of the eclogite inclusions, and is generally bigger in diameter than the first-named. In many cases it appears as if the eclogite, some tiny remnants excluded, had been completely altered into garnet-gneiss, which in such cases occurs in layers attaining 10 m or more in thickness (*cf.* fig. 6 p. 35).

In the foregoing has been shown that the bulk of the gneiss-formation of Hurry Inlet and also of the south coast of Liverpool Land as a whole must be regarded as consisting of highly metamorphosed psammitic and pelitic sediments. The included eclogite-masses must evidently be regarded as originally igneous rocks, rich in magnesia. Like eclogites described from other parts of the world, their composition corresponds to the basic and ultra-basic intrusions which often have been found in the orogenetic zones of the earth-crust, in the Alps, in North America and in the Caledonian folding-zone of Norway and other places. These rocks seem to intrude in connection with the orogenic movements as "ophiolites" or "Grüne Gesteine", forming lenses and sheets between the layers between which they are deposited. There is every reason to use the same interpretation with regard to the basic rocks here in question from Hurry Inlet.

On the other hand, the field-investigations make it apparent that the basic inclusions in their present shape represent the result of a high degree of metamorphosis and in many respects can be compared with the inclusions within migmatitic rocks. This opinion was expressed both by BACKLUND and the present author already in the field and on the whole the laboratory-investigations have supported same.

It has already been shown that the present position of the rocks is not the primary one, but that they have been rolled out and brecciated during movements which must have taken place after the ultrabasic intrusions already had been consolidated. They now appear as partly

angular, partly outdrawn lens-shaped fragments in the gneiss, often forming breccias, which highly resemble such of eruptive origin. These ultrabasic fragments lie within a dark gneiss which evidently at least in most cases has been originated through reactions between the surrounding gneisses and the basic igneous rock.

On account of the sedimentary character of the surrounding gneisses, these reaction-zones can hardly be explained in the same way as the coronas around basic inclusions in a normal assimilation complex. Another alternative would be that the intruding basic rocks might have affected the gneiss at the intrusion. This is, however, less probable, on account of the greater volume of the reaction-rock in comparison with the eclogite-inclusions. The eclogite ought in such case in many places to have completely soaked into the surrounding gneisses, leaving only some small remnants unaltered.

The only possibility left is that the reaction has taken place between the eclogite and the gneiss after the consolidation of the first-named and, as we shall see, in connection with the general metamorphosis of the rock-complex as a whole.

The character of this metamorphosis is shown by the mineralogical composition and by the structure of the formation. The typical mineral of the gneiss-complex of Hurry Inlet is garnet, and it is present in every rock containing the necessary content of alumina and Mg, Fe. The formation of this mineral has here taken part in the same movement which has caused the banding of the gneisses and the brecciation of the eclogites. The garnets of the first-named have usually the typical rotated appearance-often described in the literature as an indication of the synkinematic appearance of the mineral. Already in the field the outdrawn shape of the garnet-agglomerations and the parallel arrangement of the other dark minerals is conspicuous, with the later formed, or less resistant, felsic layers bending around the resistant mafic components. Often the parallel-structure bends around bigger fragments of eclogite, sometimes also forming a kind of rotational whorls, indicating that the parallel-striation has been formed contemporaneously with the brecciation. Schistosity formed earlier is often broken up, and fragments with an older parallel-structure have been infolded in a younger movement. The schistosity first originated, forms an angle with the younger one.

The field-relations consequently indicate that the present character of the gneiss-formation is the result of a contemporaneous powerful tectonic action and a new-crystallization, both together representing a long development with varying physico-chemical conditions, changing at every point — and probably also in the complex as a whole — with the kinetic development of the rock-complex.

The minerals of the dark gneisses represent a paragenesis which

has often been explained as caused by a pure regional-metamorphosis. On the other hand, the minerals garnet, andalusite and disthene are very characteristic members in the contact aureole of the great intrusive bodies of the Archaean in which the crystallization obviously has been caused by a rising temperature, possibly supported by the high pressure (*cf.* WEGMANN, KRANCK, 54, 23, BUDDINGTON 7, RAGUIN 34, a. o). In the latter case the alteration may most conveniently be called a pluto-metamorphosis. It is evidently on the whole very difficult to keep apart the conceptions regional-metamorphism and contact-metamorphism in deep-seated areas where an intense injection of plutonic rocks has taken place. According to the opinion of the author, most of the mineral paragenesis belonging to this zone may as well be regarded as contact-minerals originated through the action of the intruding plutonites, in particular granites, as regional-metamorphic rocks originated on account of changing physico-chemical conditions, although the last-named of course will be influenced by the injection.

Herewith the question arises whether the garnet of the eclogite is originated during the same cycle of metamorphosis as the garnet of the gneissic rocks. The first-named is a fairly pure pyrope with almandine as a subordinate component; the latter is a garnet comparatively rich in almandine but in the more basic varieties still with a considerable percentage (abt. 50%) of pyrope. Pyrope has been interpreted as a typical high-pressure-mineral, which is crystallized from a silicate-magma, consolidated in the innermost parts of the earth crust or in corresponding conditions in mountain-folding regions. (11, 13, 50.). This conjecture is mainly based on the theoretical calculations of the molecular-volume of the mineral-combination pyroxene-pyrope, but experiments carried out in order to prove the correctness of the theory have failed to give any satisfactory results. There is, however, no reason to call in question the possibility of this mode of origination. But on the other hand the author thinks that in the case here in question it is quite possible to assume, also for the pyrope an origin which corresponds more to that of the almandite-rich varieties of the garnet-group.

At Hurry Inlet we consequently either have to interpret the eclogite as formed from an eclogite-magma before the regional-metamorphosis had begun, or as formed in connection with the last-named. In the first case, the crystallization of the garnet in the basic inclusion of the complex would belong to another stage of the development, and be of another age than the garnets of the gneisses. The conditions in field, however, give no support to such a supposition; instead everything points to the synchronic origin of the present mineralogic composition of the rock-complex. As we have seen, the composition of the garnets of the gneisses

and of the eclogite is different, but there exist all transitions between them. Also in the more basic gneisses the pyrope-content seems to be comparatively high. The author therefore is of the opinion that the explanation of the mineralogical composition of the garnet-gneisses ought to be used also in connection with the eclogites of the area.

The origin of the garnet-pyroxene-gneisses can in most cases investigated be explained as depending on reactions between the ultrabasic rocks and the paragneisses, in connection with strong differential



Photo E. H. K.

Fig. 7. Inclusion of eclogite in gray gneiss with reaction-rim of garnet-pyroxene-gneiss.

movements along the contact. These movements have always gradually brought new rock-masses into contact with each other. More particularly where the eclogite-inclusions have been rotated between gneiss-masses has this process been very effective and can to some extent be compared with the accumulation of snow around a rolling snow-ball, but in the opposite direction, viz. not giving rise to an accumulation, but instead to a peeling off of the basic rock (*cf.* fig. 7.).

In order to understand the mechanics of the deformation we have to take into account the fact that the gneissic rock was in some degree plastic; the ultrabasic rocks again maintained a high power of resistance against mechanic stress. The more volatile components and also compon-

ents with a low melting-temperature were squeezed out and were crystallized in different layers. During this selective crystallization, which has been described under the designation metamorphic differentiation (ESKOLA, 12.) especially the light components quartz and felspar were separated from the dark ones. Often the garnet has crystallized in very big, rounded crystals surrounded by salic bands (Fig. 8).

Similar phenomena are often seen in gneisses of Archaean type in regions where the mineralogical composition has originated contemporaneously with tectonic movements within the rock-masses.

Besides the mechanical mixing, named above, also granitic injection — a normal migmatitization — has contributed to the complicated

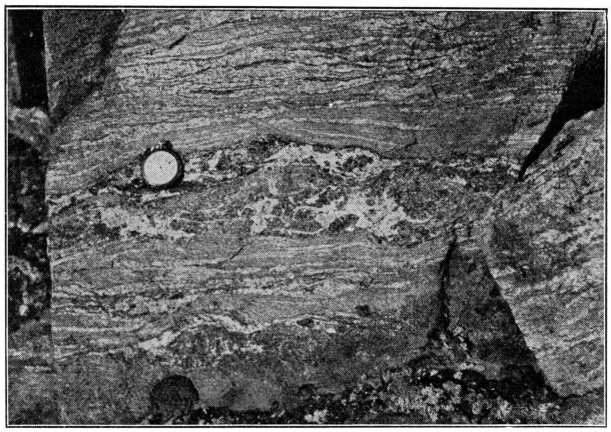

Photo TH. SAHLSTEIN.

Fig. 8. Detail of the cliff on fig. 6 p. 35 showing the differentiation into light bands with big garnets and fragments of eclogite and dark, more fine-grained bands.

character of the rock. In spite of the migmatite-like appearance of the gneisses, granites after all play a comparatively less important role than in the gneisses of Scoresby Sound. The veinlets of the gray gneiss might in most cases as well have the character of venites in which the potash-felspar-quartz component has been squeezed out in the way suggested by HOLMQUIST (20.). Especially in the dark gneisses the light veinlets in many cases have an almost pegmatitic appearance and probably belong to a prae-kinematic injection.

Broadly speaking, the gneiss-complex now in question has only vague traces of injection-structure left. The original granitization is widely covered by late metamorphic structures mainly of tectonic origin.

The mineralogical composition of the gneiss-complex has according to the observations quoted above been ruled by a strong shearing stress in addition to a rising temperature, probably also metasomatic reactions,

which have caused the intense recrystallization in the rocks. This recrystallization has also affected the micro-structures of the rock. The great abundance of diablastic inclusions and reaction rims reminds one greatly of contact-metamorphic rocks. Also the peculiar antiperthitic intergrowth of orthoclase and plagioclase is evidently dependent on the particular physico-chemical conditions during which the recrystallization has happened. The orthoclase has for some reason crystallized entirely with the plagioclase, possibly due to a high temperature at the first stage of the crystallization. At the beginning of the crystallization this might have given rise to mix-crystals of potash- and lime-soda-felspar containing an abnormal amount of the first-named component[1]).

According to the foregoing, the sequence and events at the origination of the interesting garnet-pyroxene-gneiss complex of Hurry Inlet can be summarized in the following way.

1. Intrusion of an ultrabasic magma in a complex of paragneisses of psammitic and partly also pelitic character, which already in some degree had been metamorphosed and injected by granites.

2. The basic magma consolidated with a mineralogical composition about which nothing is known with certainty. After the consolidation the whole complex was tectonized and contemporaneously affected by thermic metamorphosis and the composition also in some degree was affected by injected granitic material. The gneisses were thereby drawn out with intense differential movements and partly mylonitized. The basic — ophiolitic — rocks were at first brecciated and thereafter altered into eclogites. During the tectonization and recrystallization they were mixed and reacted with the surrounding gneisses, originating pyroxene-hornblende-garnet-andalusite rocks, a. s. o. In the easternmost parts the andalusite partly seems to be replaced by cyanite, probably due to the vicinity of intruding granites which have caused a higher temperature.

In the outermost zone the continued metamorphism leads to hornblende-rich rocks.

3. The gneisses have afterwards been penetrated by a system of granitic and pegmatitic veins and have also in some degree been injected a new by granitic material.

The development reminds one in many respects of that described particularly in the Crystalline area of Austria, *i. a.* of the Moravic "Tayakuppel" which in great detail has been kinetically analysed by WALDMANN (51.).

As to the metamorphism we evidently have to reckon with two

[1]) Other authors, *i. a.* Waldmann, have regarded these structures as eutectic; on the other hand *i. a.* Sederholm (p. 127, 45) has laid stress on their "metamorphic" character, a conjecture with which the present author agrees.

stages of alteration. The first is represented by the eclogitic rocks and the garnetiferous pyroxene-cyanite-andalusite-gneisses. They dominate in the sections of the area where the granitic injection is less prominent. The second is represented by the hornblende-bearing rocks and corresponds to the amphibolite or migmatite-phasies. Both can be regarded as due to the influence of the same plutonic intrusion.

The first type of alteration is mainly thermolytic and pneumatolytic (the extremely high content of Cl in the rocks!); the latter has originated at a more intimate granitic metasomatosis (migmatitization).

The explanation of the origin of the eclogites and related rocks of Liverpool Land given above differs in some respects from the generally used interpretation (ESKOLA 11., FERMOR 13., WALDMANN 51., a. o.) which is based on the supposition of an original, igneous character of these rocks also with regard to their mineralogical composition.

The conclusions brought forward in this paper are mainly founded on observations in the field, but as the author has tried to show, they can also be verified by the petrologic investigation. Except for a few later corrections already the first acquaintance in place gave rise to practically the same general opinion about the origin.

The principal difference from the general interpretation is the supposition that the eclogitic composition here is the result of a later metamorphosis and does not represent a primary crystallization from a basic magma. Concerning the physico-chemical conditions, in which this alteration took place, the explanation given above does not differ in any high degree from the explanations given earlier. Undoubtedly also here there had been a high pressure which obviously had the character of shearing-stress. On the other hand also a pneumatolytic and thermolytic influence has contributed to the reactions in the rocks. Possibly the shearing stress locally may play the same role as a pressure of hydrostatic type. The opinions expressed by the author about the character of the mineral-paragenesis agree in many respects with those put forward by SEDERHOLM in his classic investigation of the migmatitic rocks of southern Finland (46., p. 125), and also with the opinions of several Swiss geologists (HERITSCH, WIESENDER a. o.) concerning the origination of the eclogites of the Eastern Alps.

The eclogites of Norway (Grytingvaage in Selje) described by ESKOLA undoubtedly offer several similarities with the eclogites of East Greenland, both as to the mode of occurrence and as to the composition. They also lie within a tectonized gneiss as fragments, generally surrounded by reaction rims. The main difference consists in the composition of these rims, which in the Norwegian occurrence are composed of pure hornblende-rocks, whereas on Greenland they are pyroxene-garnet-bearing rocks, grading locally into hornblende rocks.

Another difference is the igneous character of the surrounding gneiss of the Norwegian locality.

Comparison with these Norwegian rocks is of peculiar interest, as they also represent a Caledonian occurrence of about the same type as those here described.

The White Gneisses North of Hurry Inlet.

The gneisses north of the granite-area of Hurry Inlet differ widely from the gneisses of south Liverpool Land. They also can generally be characterized as migmatitic gneisses, partly biotite-gneisses, partly garnet-gneisses. The granitic component is dominant and is as a rule of a rather coarse pegmatitic appearance. The dip of the schistosity is generally steep; the folding is irregular and of the "disharmonic" highly plastic type often found in deep-seated granitization areas (*cf.* 8, 54.). In this respect the complex cannot be compared with anything on Liverpool Land, except may, be in its northernmost parts (Cape Fennia). The general impression is that we have to do with a very deep-seated formation, in which the magmatic movements have played a rôle at least as important as that of the mechanic tectonization.

In the neighbourhood of Hurry Inlet sediments evidently form the bulk of the base-rock. Limestone is a common component and is found in small, but sometimes also considerable "schliery" inclusions in the gneiss, together with amphibolite and mica-schist inclusions. The limestone was already mentioned by Nordenskjöld in "Kalkdalen". Northward, as already stated, diorite is the bulk component of the migmatite (p. 11).

Like all migmatites these gneisses are of a very varying chemical composition even within a small area, with granitic minerals composing the main-mass. They are petrologically of interest on account of the coarse crystalline structure, which shows that the rock has avoided the strong tectonic disintegration of the mineral components described from the foregoing localities. In spite of this the rocks show numerous traces of interior movements appearing as local shear zones and slopes, which, however, do not lead to any complete destruction of the older structures. An exception in that respect is furnished by the rocks in the neighbourhood of the contact with the Hurry Inlet granite. Dislocation to a considerable extent has taken place here and has in some degree also deformed the gneisses, giving rise to mylonites and breccias. On the contact the weathering is always very strong and minerals like felspar and mica are dull and indeterminable.

Mineralogically the gneisses are characterized by potash-felspar, plagioclase and quartz with biotite, muscovite, red garnet, together with titanite, magnetite (titano-magnetite) apatite and sulphides in

small quantities. The white felspar predominates and gives the whole rock its colour.

A common feature seems to be microcline gitter-lamellation in the potash-felspar, which is generally perthitic. The plagioclase is often saussuritized. It has the composition of an oligoclase, rich in albite.

Particularly in varieties influenced by mechanic deformation the garnet is more or less completely altered into chlorite and muscovite, sometimes also into biotite. The mineral is often rotated, showing that there have been movements at, or after, its crystallization. In cases of alteration mica-flakes are arranged in spiders on the plan where the garnet crystals originally have been situated.

The contact between the gneiss and the Hurry Inlet granite obviously represents an old movement zone, where transversal dislocation has occurred at several stages of the geological development of the rock ground. The latest of these movements have cut off a number of the ouachitite and diabase-dikes traversing the contact. We find at several places in the valleys dikes which are seen on the one side of the gorge of the stream, but which are lacking on the opposite side. The movements have not taken place along one single slope, but along a system of several slopes, which probably have been used at different times.

The main result of the vertical movement was that the granite area and probably also the sediments west of it have sunk down in comparison with the gneiss. The gneisses therefore have been eroded to a deeper level, and consequently have a light-coloured, comparatively unweathered appearance. The granite-area has been sheltered from the erosion and the red, weathered, old surface is still preserved and shows the strong contrast in colour between the two formations. This movement was probably late, as will be shown later, probably Postdevonian (p. 118).

The Banded Gneisses of the East Coast.

Field observations.

The banded gneisses of the east coast will in the following for the sake of brevity be called the Cape Greg gneisses, after the locality where they have been studied in detail. So far as we know, the petrological and structural features found here can be considered as typical of the whole gneiss-complex, from Glasgow Island up to the vicinity of Store Fjord. Along this coast-section, so far as can be estimated from the sea, the cliffs are made up of the same strongly banded rock with flat layered banding, from a distance resembling a sedimentary bedding. Fig. 9 illustrates the appearance of the mountain walls of the region better than any description.

A closer examination of the rocks of which these mountains are built up shows that they are completely crystalline gneisses of varying composition. In many respects they resemble the gneisses of the south coast, but also distinguishing features can easily be detected. The most conspicuous among these is the lively variation in composition and colour. The different layers rarely reach a thickness of more than 10—20 m. On the other hand, they are of very great horizontal extension and can be followed for several kilometres along the cliff-walls, if they have not been suddenly broken or bent by foldings and thrusts.

Further, the gneisses of this complex are more granitized and completely recrystallized (paracrystalline). Generally they are comparatively coarse-grained, while there is a lack of primary structures, which could give information about the original composition and origin of the rocks. Also the chemical composition is evidently highly altered, owing to granitic injections. The granitic constituents, or more correctly gneisses of granitic composition, do in fact constitute the bulk of the complex.

The relationship between the tectonics and the rock-textures marks another important difference from the southern gneisses. The gneisses of Cape Greg are on the whole completely new-crystallized since the last tectonic movements of the region, and only certain layers possess signs of cataclastic structures and mylonitization. Unlike the dikes of Scoresby Sound, the very numerous veins and dikes of pegmatite, granite and aplite which traverse the layered gneisses are unaffected by late movements. This does of course not necessarily mean that they have been injected after the complete settling down of the orogenetic action within the rock-ground. On the contrary, as later will be shown, most of them have been injected contemporaneously with the orogenetic phase and they are therefore usually folded and broken by thrusts and slopes, but the cataclastic structures originated have later been removed by new-crystallization on a grand scale. (*cf.* p. 102).

Broadly speaking, the Cape-Greg-gneisses consist of alternating layers of pink granitic or pegmatitic gneiss, coarse biotite gneiss, whitish quartz-rich sericite gneiss and dark amphibolitic gneisses. These gneisses contain big inclusions of an amphibolite which evidently is of igneous origin and has once intruded in veins or sills between the gneisses. It forms very conspicuous angular fragments, unevenly distributed in the cliff walls. Still younger are the basic veins in which an ophitic diabase structure has been partly preserved. But these have also been broken and bent in the orogenic movements.

All these rocks are traversed by pegmatites and aplites. There are, however, several generations of them in existence, which indicates a long time of injection and possibly different phases of injections. The

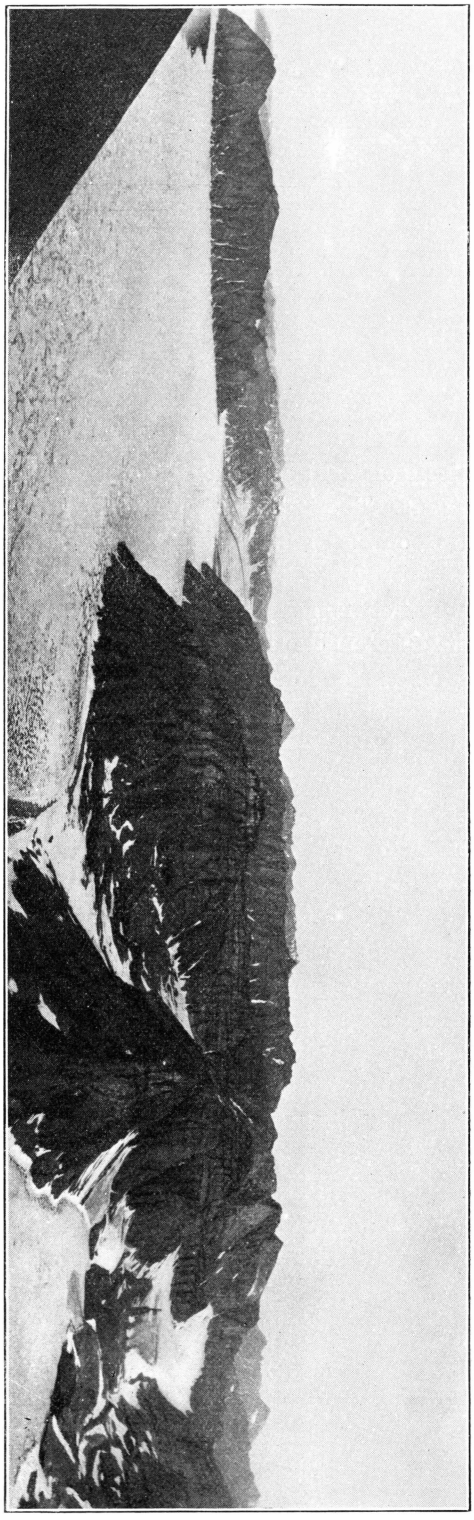

Fig. 9. Horizontal gneiss-layers at Cape Greg. Looking S.

Photo E. H. K.

more ancient intimately correspond to the general regional granitization of the complex.

Limestone was not observed at Cape Greg, although some of the gneisses contain lime as a by-constituent, but possibly some of the amphibolites are originated from limestone or lime-rich sediments at the metamorphism. On the other hand, we have already pointed out the occurrence of limestone in the southernmost contact of the gneiss-area at Glasgow Island.

The mineralogy of the Cape Greg gneisses is on the whole very

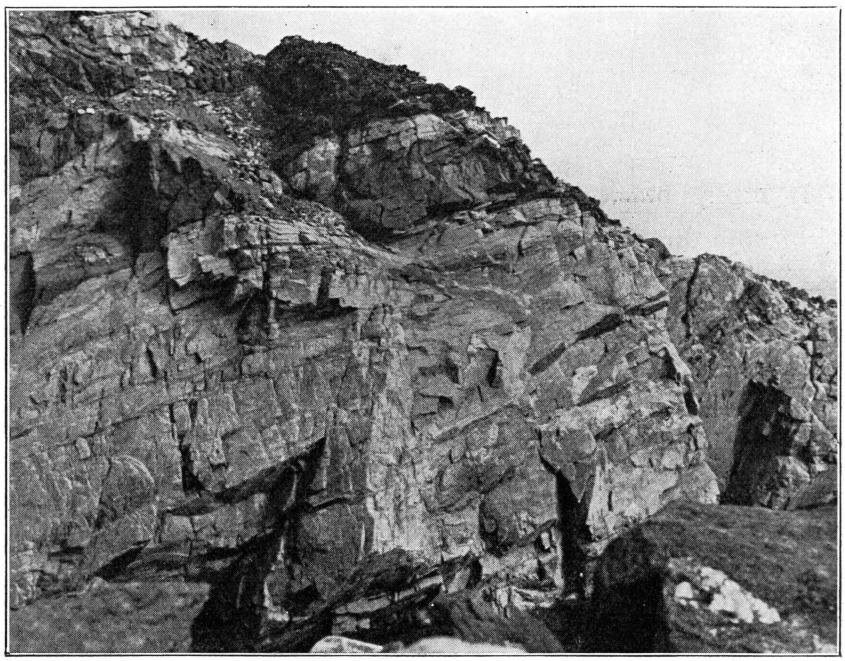

Fig. 10. Deformed quartzitic and aplitic gneisses of the highest crest of the Cape Greg cliff. Height of the rock wall about 4 m. Photo E. H. K.

simple. It corresponds to that of a Precambrian migmatite-area or injection complex with an advanced stage of granitization. Microscopically, pink potash-felspar, quartz and white plagioclase dominate, together with black biotite, and in the basic parts also hornblende. Garnet is common, although not conspicuous.

The most interesting objects of study within this area are the tectonics and the kinetic conditions, which, however, will be dealt with later on. (p. 101).

Petrography.

The most common of the gneisses of Cap Greg will be briefly described in the following:

1. Pink biotite gneiss. The mineralogical composition is oligoclase rich in albite (c. 20 % An.) about 45—55 vol. %, microcline 35—45 %, biotite 10—35 %, quartz 5—10 %, titanite, apatite, and iron ore in small quantities. The structure is granulitic and shows in thin-section no distinct orientation of other minerals than in some degree dark brownish biotite films. The recrystallization is generally complete. Cataclastic structures are visible only in exceptional cases, and more rarely than in any other part of Liverpool Land. Macroscopically the hand-specimens often show a well developed parallel-structure, depending mainly in the distribution of the mafic components (Fig. 3, Pl. 2).

The plagioclase occurs as fairly big grains with Carlsbad and Albite twinning lamellation. The potash-felspar is a perthitic microcline. the mineral is often seen growing on the coast of the lime-soda-felspar. Myrmekite is present in abundance.

In other words, the composition of these gneisses gives no indications as to the primary character of the rock. It could as well be derived from a paragneiss as from a granitic orthogneiss. There are, however, also certain more fine-grained banded biotite gneisses with a very pronounced parallel-orientation, containing lamellated quartz as the main component, which more resemble paragneisses, and sometimes grade into mica schists. Owing to the interbedding on mica-rich aplitic layers and quartz films, their composition is very difficult to estimate quantitatively.

Gray hornblende-biotite-gneiss. This gneiss differs from the foregoing through its whitish-gray colour and the content of green hornblende. The structure is mainly of the same granulitic, rather coarse, crystalline type. Mica and potash-felspar occur in about the same proportions as in the pink gneisses. The cryptoperthitic microcline often shows gitter-lamellation. The quartz-content is often high and attains about 30 vol %. Of the accessory minerals titanite is more abundant than in the gneisses free from hornblende. On the whole, it is evident that this gneiss is comparatively rich in lime.

This gray gneiss generally occurs in separate layers, often containing amphibolitic inclusions.

In many respects this gneiss resembles the gray gneisses of the south coast, but it is still less cataclastic and more recrystallized under the microscope and even-grained in hand-specimen. Biotite generally plays a greater role than in the last-named localities, and generally the rocks at Cape Greg are less like dioritic rocks and remind one more of banded migmatites.

Aplitic gneiss. Those rocks which have a mineralogical composition corresponding to an ordinary microcline-aplite and which in all

probability are tectonized aplitic layers can be regarded as aplitic gneisses. Like the other gneisses of the complex, they occur as horizontal layers. They differ from unaltered aplites on account of the granulitic structure. The mineral-boundaries are very sutured and inclusions and intersertal-structures are numerous. The composition is microcline (45—50%), quartz 25—35%, plagioclase 10—15%. The very subordinate dark components are represented by pale brown biotite, titanite, apatite, iron ore and light pinkish garnet in small rounded grains. Also some small grains of orthite were observed.

Quartzitic gneiss, composed mainly of rather coarse-grained quartz, muscovite, less biotite and in still less degree felspar, (oligoclase and microcline). The schistosity is generally well developed, due mainly to the parallel-orientation of mica-films.

Banded gneiss of arteritic character, composed of alternating mica-rich darker layers and aplitic layers.

Amphibolitic gneiss-layers. Amphibolitic layers play an important rôle in the gneiss complex of Cape Greg and contribute perhaps more than any other component to the layered appearance of the cliff walls of the coast. They have the typical mosaic-structure of the high metamorphic basic rocks of this group with parallel-orientated, elongated crystals of green hornblende as type-components. The quantitive composition is pale brownish-green hornblende about (40—50%), oligoclase (20—35% An) with comparatively insignificant twinning lamellation (25—30%). Quartz is abundant (about 15%). Potash-felspar is present only in small quantities. A typical constituent is red garnet in fairly big crystals, surrounded by a broad white rim of plagioclase and quartz. The mineral seems to alter into plagioclase, with which mineral it forms resorbed contacts. In connection with the resorption small grains of iron ore are formed, evidently containing the iron-percentage of the garnet. Biotite is often very subordinated. Titanite is completely lacking, and iron ore is but sparingly found.

The rock probably is an altered lime-rich sediment and not an eruptive greenstone.

Igneous greenstone generally occurs in the form of big fragments in the gneisses. Petrographically they completely resemble the greenstone described from Cap Svainson. The inclusions are massive in the central parts, schistose and micaceous in the marginal parts. The main component, dark green hornblende, forms 45—55% of the rock. The mineral is generally very rich in small inclusions of iron ore. Titanomagnetite also occurs abundantly in big irregular grains, partly surrounded by reaction rims of titanite. The light minerals are represented by plagioclase in rather irregular, clear grains. Titanite plays a great rôle and also apatite is abundantly present. Biotite is generally

subordinate, but occurs in some types in greater amount, particularly where the schistosity is conspicuous.

The rocks which have been briefly described above make up the bulk of the gneiss-complex. Besides, there are also numerous granitic veins and dikes, which microscopically offer less interest.

The younger basic rocks, which occur as cross-cutting dikes, and which have only slightly been influenced by tectonic alteration are at least in part still of diabasic character. A specimen of these dikes will be described in the following, on account of its mineralogical composition, which offers some peculiarities of theoretical interest.

Diabase Inclusions in the Gneiss of Cape Greg.

The rock specimen here in question is of a fine-grained diabase which microscopically in every respect resembles a common, fine-grained diabase or basalt. It derives from one of the dikes which have been broken up into angular fragments during the latest tectonic movements in the rock-ground, but which are completely unaffected by interior movements causing cataclastic structures or orientated recrystallizations. The rock has instead to a considerable degree been influenced by a thermic metamorphosis and probably also to a certain extent by hydrothermal processes (Fig. 2, Pl. 2).

In its present shape the rock consists of a net-work of ophitic plagioclase-lests embedded in mafic minerals. The felspar-crystals show several features which probably are due to heating until very near melting point. They are always dull, owing to being filled up all through with tiny inclusions. The cleavage is almost absent, but instead irregular fractures of glassy appearance are to be seen. The bi-refraction is abnormally low. According to the extinction the composition of the mineral should be about 30% An. The small inclusions are frequently more abundant and bigger in the central parts of the crystal, and often almost absent in the peripheric parts. Under great magnification their bi-refraction and a high refraction-index, but no crystal-form, can be stated, also the colour is on account of the diminutive size not determinable. Probably they are some Al-mineral, possibly mullite?

Of the minerals composing the mass between the plagioclase-lests, augite is the only one which fits into a normal basaltic composition. Also this component is, however, altered in a way which shows similarities with the foregoing. The crystals are so filled up with small dark inclusions that the augite often has an almost blackish colour. The refraction index is lower than in normal augite; the bi-refraction is still high, but the colours seem to be slightly abnormal. The small inclusions are plainly needle-shaped and resemble the ilmenite needles which can often be observed in the augites of gabbros and similar rocks. They

are arranged according to the directions of cleavage (also 001). $\gamma : c = c. 38°$. A considerable part of the space between the plagioclase-lests is filled with minerals which evidently are of entirely secondary origin. They are for the most part zonary-arranged and have grown as reaction rims around other minerals, and on the boundaries between different crystals. At least some of these minerals seem to form alteration-products of olivine; others again have grown on the coast of augite, which mineral, however, as we have seen, for the most part still is identifiable.

The main types of these polysomatic grains are the following. 1) Aggregates of tiny brown biotite seams. 2) Aggregates of light bluish-green amphibole. 3) Aggregates of a colourless mineral, which according to the optical properties probably is a lawsonite or margarite?. The last-mentioned mineral forms radially built aggregates in the centre of a field between the plagioclase lests; around this field follows a zone of very small-grained, pale biotite, while outermost a contact-zone towards the plagioclase is composed of colourless garnet. Garnet is also found along the contact between plagioclase and augite, amphibole and the biotite aggregates. In other words, it represents the normal contact-product between felspar and the mafic minerals, and forms at least 1—2% of the rock.

Titanite is abundantly present in big, idiomorphic, light brownish crystals with sharp cleavage, as is also the case with apatite, forming long prisms which have not been influenced by the metamorphosis. Magnetite forms big black grains often surrounded by broad flakes of reddish-brown biotite.

Several rules determining the distribution of the different minerals can consequently be observed. Augite is never seen occurring in direct contact with plagioclase; there is always a rim of biotite between both these minerals. This is also to a certain degree the case where the other mafic components are concerned. We have the following zonar arrangements, written in the order in which the minerals follow on from the kernel of the aggregate outwards (towards the felspar).

Lawsonite (margarite), biotite (amphibole), garnet, plagioclase.
Magnetite, biotite, garnet, plagioclase.
Augite, biotite (amphibole), garnet, plagioclase.

The mineral-composition described above can hardly be interpreted as a primary crystallization. The origin of these mineral-zones is evidently to be referred to a comparatively rapid thermic-metasomatic-metamorphosis of the basalt (propably an olivine-basalt), in connection with the last granitic intrusions. It evidently demonstrates certain tendencies towards a chemical equilibrium which was never reached, however, owing to the shortness of the time of heating. The minerals therefore

belong to different stages of the alteration, corresponding to different temperature-conditions. As already pointed out, water, and probably also alkalies, has evidently been added to the original rock-components.

At the first stage of metamorphosis the Mg, Fe-bearing minerals (augite, olivine) reacted with the felspar, with the addition of some potassium and water originating biotite. The mica in many respects corresponds to olivine in waterfree diabases and is, as known, often found in basic dike-rocks as the source of an excess of magnesia. Here the secondary character, however, clearly appears from the mode of occurrence. Possibly the origination of amphibole is in part still earlier. This mineral can be regarded as a reaction-product of augite.

A later stage of alteration, corresponding to decreasing temperature, is the origination of garnet. At this stage the metamorphosis was purely thermal, without any addition of water. The biotite originated at the foregoing stage reacted with the felspar, a reaction which evidently is closely related to the well known reaction.

$$\text{anorthite} + \text{olivine} = \text{garnet}.$$

All the "transformations", given above are well known to the geologists familiar with research-work in metamorphic areas, but they are seldom found all together within such a limited space.

The alteration, however, did not stop with the formation of garnet, but was further continued when the temperature was lowered again. At this stage probably the bulk of the bluish-green amphibole was crystallized. It has also in some degree been formed on the coast of garnet, and is consequently mainly later than that mineral.

The origination of lawsonite is probably also to be referred to the same stage. Augite was evidently transformed into Mg, Fe-mica and a high-temperature Ca-silicate. Lawsonite has often been described from glaucophane-bearing schists and related metamorphic rocks and it therefore lies close at hand to refer its origination to the light bluish-green hornblende, which, though not a real glaucophane, must after all represent a related amphibole. In this connection it may be mentioned that SAHLSTEIN has found a probably similar light amphibole together with lawsonite in altered eclogite-rocks from Hurry Inlet.

There exists a very interesting agreement between the different alteration phases within this diabase and several wellknown basic rocks which sometimes have been interpreted as primary crystallization-products, sometimes as metamorphic-rocks.

Stage I is characterized by the reaction augite + alkali-felspar = biotite + quartz. The reaction is found in all granitic injection areas where granite at comparatively high temperature is found in contact with basic rocks, and it is also found in a great number of igneous rocks

as primary crystallization. Its origin was evidently due to increasing temperature and the presence of water.

Stage II shows the typical reaction biotite + felspar = garnet. Here we find correspondence with the eclogites and similar garnet-bearing rocks. Unfortunately, the diminutive size of the garnet made it impossible to determine its composition.

Stage III shows light green amphibole and lawsonite (margarite) as type-minerals. They evidently closely correspond to the glaucophane-schists. The origin of this paragenesis is generally explained as the result of a regressive metamorphosis (decreasing temperature).

It is of course not necessary to point out the interesting comparison between the rock here in question and the eclogites and garnet-pyroxene rocks of Hurry Inlet. We here have the indisputable proof that garnet is formed through thermal-metamorphism from basic igneous rocks in exactly the way argued by the interpretation of the origin of the eclogites of Hurry Inlet. Unfortunately, the material was not sufficient to allow of any closer investigation of the different minerals, but in view of the great theoretical interest of the interpretation of the other metamorphic rocks of Liverpool Land the rather detailed description given above seems to be justified.

The Gneisses of Store Fjord.

The only gneiss-area of importance in Store Fjord is the occurrence in the Frydendal Valley in the inner parts of the fjord (*cf.* the map Pl. 3). Here we meet with rocks of the same composite appearance as on south Liverpool Land, with interbedding of different types of gneisses and crystalline schists. Taken from the bottom upwards the cliff-wall of the west slope consists of:

1) Fine grained gneisses of reddish colour, consisting for the most part of microcline, plagioclase and quartz, with a small amount of mica.
2) Gray gneisses mainly consisting of plagioclase, quartz, mica and hornblende. They are interbedded with amphibolitic gneisses and dark amphibole-plagioclase-mica gneisses etc. (to 200 m).
3) Mylonitic sericite-quartzite in several thin layers interbedded with gneiss (to 400 m).
4) Reddish banded gneiss resembling No. 2.
5) Crystalline limestone with an abundance of big quartz-dikes. In the last-mentioned horizon we have several big lenses of hornblenditic greenstone. The crest of the wall again consists of gneisses. The thickness of the whole formation is about 800 m.

On the opposite side of the valley only the lower part of the rock-ground is composed of gneisses, the upper half consisting of granite.

The same reddish gneisses seem also to form the mountains farther up the valley.

SAHLSTEIN, who made an investigation in these parts, found no gneisses in the northernmost of the side valleys, from the west, but instead came across granitic migmatite consisting of dominating pink granite with inclusions of gabbro and diorite-material, resembling those in the Store Fjord granite. In other words, the gneiss-area comprises only the narrow ridge between the two valleys. It evidently forms a piece of the rock-ground which is bounded by slopes, possibly originated in connection with the granitic intrusions. This conception is supported by the petrographical character of the gneisses and also by their kinetic structure.

The Store Fjord gneisses differ from the gneisses described in the foregoing, above all on account of their conspicuous post-crystalline structure, which in several cases has the character of a mylonitization. There is in most specimens a decomposition of the mineral-grains ("Kornzerfall") which is later than the last recrystallization. The horizontal schistosity is still more dominating than in the gneiss of Cape Greg and, with the exception of some very flat zig-zag-folds, no folding is seen. Instead, the different layers are often pinched out and cut off in the form of slides (BAILEY) and the greenstone fragments have an elongated lens shape. In other words, the structures of the Store Fjord gneisses have received their structures in connection with strong, and probably comparatively late horizontal movements. It is a peculiar fact that the granitic injections have not in a high degree influenced this gneiss as in the case of the gneisses of Cape Greg. Only the big inclusion on the opposite side of the valley has been altered into hornfels-like schists.

Evidently the explanation of this circumstance has to be sought in the tectonical conditions, which are here still too little known to allow of any further discussion.

The petrology of these gneisses does not offer anything of interest in addition to what has already been mentioned. They evidently are, or have been, paragneisses of about the same composition as the gneisses of Scoresby Sound. Of the gneisses described from the southern parts of Liverpool Land they closely resemble the rocks found in the lowermost parts of the garnet-pyroxene-gneisses of Hurry Inlet, where the garnet-bearing phase is replaced by granite-free rocks belonging to the amphibolite-phase (p. 32).

In the femic gneisses there is often seen pyroxene in addition to hornblende (diopside); also epidote is fairly abundant as a vein-filling or alteration product of hornblende or pyroxene.

The Gneisses of North Liverpool Land.

Polyp Harbour—Cape Topham.

The dioritic rocks of Polyp Harbour and Cape Smith will be described elsewhere (p. 73—74).

The gneissic rocks of this locality appear in the cliff walls as almost horizontal layers of the same highly deformed type as in the Store Fjord region (p. 57). Here, however, the influence of injecting granite is very much stronger and the structure is characterized by an almost complete recrystallization. All the rocks are comparatively coarse-grained.

As to the composition, the dark layers of amphibolitic composition are of wide extent. Also limestone is present, and has evidently earlier been still more abundant. The fact is that an abundance of "skarn"-rocks, composed of hornblende and diopside and sometimes also garnet and scapolite, is found in the moraine-material in the small glacier-valley ending in Polyp Harbour. Also basic rocks with a structure which could be interpreted as tectonized pillow-structure were observed. Besides these basic constituents, gray gneisses, both biotite-gneisses and hornblende-gneisses, compose the bulk of the formation, which is cut by a network of veins and veinlets from the intruding granite. Typical assimilations showing the gradual change from schistose rocks to almost massive rocks which can hardly be distinguished from the granodiorite form the zone between the plutonic rocks and the gneisses.

On the whole, also compared with other regions on Liverpool Land, the last-mentioned have a striking resemblance to the oldest Archaean schists.

The petrography of these rocks does not offer anything differing from other assimilation-complexes of this type.

The granodiorite north of Polyp Harbour forms the mountain-walls of the coast as far as to the sound south of Trekanten Island and also the outer part of this sound (Tvær Sound). The same rock forms the south side of the island up to the westernmost point (Cape Hilding) where the contact with the para-gneisses is found. In the upper parts of the mountain walls on the south coast of Tvær Sound the striped appearance of the rocks indicates that the diorites are covered with altered and partly assimilated gneisses, the layers being mainly in steep positions. Conditions are evidently the same as were observed already at Polyp Harbour. The diorite injects from underneath the older rocks which still form a cap over the former. Farther west the horizontal position still seems to dominate underneath the diorite-massif.

At Cape Hilding there are excellent opportunities for studying the contact-conditions. Here the basic rock is partly an amphibolite, partly limestone. It is penetrated by the granite occurring as the contact-

variety of the granodiorite-massif, forming eruptive breccias with sharp-edged fragments (*cf.* fig. 11, p. 60).

The contact with the limestone is very interesting. The granite has assimilated the limestone, which occurs as rounded fragments with unmistakably corroded edges and beautiful reaction rims. The latter show a zonar structure, with coarse-crystalline hornblende as the outermost zone, and red garnet and diopside nearer the limestone. Where the granite has penetrated the limestone it becomes a coarse-grained horn-



Photo E. H. K.

Fig. 11. Eruptive breccia consisting of amphibolite fragments penetrated by granite. W. point of Hildegaard Island.

blende-granodiorite, consisting of almost exclusively white plagioclase (andesine) in broad xenomorphic grains and dark hornblende, pale green under the microscope. Also contact rocks rich in mica with bronze-yellowish flakes of biotite, together with pale brownish amphibole, form the characteristic components.

The amphibolite occurring together with the limestone is most likely an old supercrustal greenstone, probably related to the amphibolitic schists of Polyp Harbour. In some places structures recalling porphyritic structures with small white plagioclase phenocrysts were observed.

All the contact rocks have a completely para-crystalline structure and show no signs of post-metamorphic deformation.

On the south coast of Cape Topham the gneisses are more or less migmatitic and have been cut by numerous broad dikes of pegmatite. They are particularly well visible in the steep cliffs composing the cape. From here northward the folding becomes more intense, with steep dip of the schistosity. In the inner parts of the fjords the rocks were studied at Cape Fennia (*cf.* the map). We have westward, opposite the point, a



Photo E. H. K.

Fig. 12. Migmatite-gneiss with "Schliers" of garnet-fels. Cape Fennia, west of Cape Topham.

big anticline with limestone or dolomite, and it therefore was of interest to study the gneisses in its vicinity. Also here the granitization was very strong and the granitic rocks evidently have assimilated the dominating part of the original sediments. The latter remain only as assimilated fragments and "Schliers". They have partly an amphibolitic composition but more especially farther up the mountains they consist for the most part of red garnet, forming garnet-fels with only insignificant quantities of other components. These garnetiferous fragments have generally an elongated, bent or folded form, showing how plastic the rock was during the intense granitization. Elongated "Schliers"

of very garnet-rich gneiss are also to be seen and broadly speaking it seems as if the garnet here in many places plays the same rôle as hornblende and biotite in other migmatites of this appearence. The aspect of this rock is shown by fig. 12 p. 61.

Unfortunately, the time which could be spent at this place was too short to allow of more than quite a superficial orientation and it therefore seems to be of less interest to enter upon the petrology of the rock-types, especially as similar rocks have been found by BACKLUND in great abundance in the inner parts of Scoresby Sound.

It is, however, fairly obvious that these garnet-gneisses have originated at the assimilation of lime-rich sediments in granite and can be compared with "skarn"-rocks. Besides the garnet, the gneisses also contain an abundance of sillimannite. They are generally traversed by shear-planes, indicating deformation in connection with the metamorphosis.

Murray Island.

Murray Island was visited already by O. NORDENSKJÖLD (29.), who stated the occurrence of gneissic rocks. We had the opportunity of making some observations at the eastern end of the island and of completing the data furnished by the first-named explorer.

The cliff walls of the island consist of banded gneisses, in hand specimen resembling the gneisses from Store Fjord. They are, however, highly folded, with mostly a steep position of the dip. The axial-position is horizontal. The rock is rich in microcline, and therefore generally of a pinkish colour, but with abundant dark bands and inclusions. Of these more especially the amphibolitic inclusions are conspicuous. They are partly massive, partly outdrawn and schistose. The macrostructure of the rock is characteristic on account of the strong linear schistosity, which in section parallel with the axial direction often gives it a striped appearance.

Pegmatites are abundant. They penetrate the old schistosity, but are themselves highly folded and deformed, indicating several stages of alteration and movement.

Of the gneiss-varieties the following are the most important.

1. Pinkish gneiss. The composition is quartz, plagioclase, microcline, biotite, titanite, titano-magnetite, apatite. Muscovite and sagenite are sparingly found.

The structure is granulitic, (Fig. 4, Pl. 2), with indications of a considerable degree of movement after the last recrystallization. Parallel-orientation of the mica is always seen. The microcline, occurring as evidently later injected filling between the other components, has always a well developed gitter-lamellation. On the whole the rock, both

macroscopically and under the microscope, resembles the so-called leptites of the Scandinavian Archaean.

2. Pinkish aplitic gneiss. Quartz and microcline are the dominating components. Plagioclase occurs sparingly. The structure is the same as in the foregoing. The quartz is here partly recrystallized as "lamell-quartz", forming elongated grains along the shear-planes.

3. Hornblende gneiss. The dark minerals represented by common hornblende and biotite are here abundant, but still occur in smaller quantities than felspar and quartz. Microcline is still of importance. Also here mylonitization is apparent.

4. The amphibolitic inclusions have the same composition and structure as similar rocks described from other parts of the region.

C. THE PLUTONIC ROCKS OF LIVERPOOL LAND

The Granodioritic Rocks.

Mode of Occurrence.

Along the eastern coast of Liverpool Land, as we have seen, there is a great abundance of plutonic rocks deriving from lime-sodium-rich magmas of a composition lying between diorites and lime-sodium granites. They generally are medium-grained to coarse-medium-grained, pure gray coloured, sometimes light pinkish, and generally show only slight traces of pressure. The greatest body of these rocks reaches along the coast from the region of Lille Fjord near the south end of Liverpool Land and to Glasgow Island in the north. Another great occurrence was found in the region inside Cape Smith, north of Store Fjord. A similar rock occurs also at Cape Hodgson, south-east of Lille Fjord.

The discovery of granodioritic rocks within the area of Caledonian mountain building in East Greenland is interesting on account of the very distinct position which the rock-family in question possesses in mountain-folding-zones.

Owing to the shortness of the time of investigation the mode of occurrence and the shape of the rock-masses could not be determined with certainty, but all observations available indicate that the granodiorites of Liverpool Land represent more or less lens or sheetlike bodies within the earth-crust, rather than batholites. They have all been at least in some degree influenced by orogenic movements and may be classified as late-synkinematic intrusions. Traces of granitization and an abundance of granitic, pegmatitic and aplitic veins indicate reaction with younger granite.

The biggest of the granodiorite masses was more closely investigated only on Rathbone Island, from which locality most of the rock-specimens studied derive. The northern contact was touched at Raffles Island. Here the gneisses slope underneath the diorite at a comparatively steep angle. The contact shows signs of strong movement and shearing in the diorite along the contact plane. This shear-structure and mylonitization does not extend more than some tens of metres within the diorite.

In other words, the contact also shows the features of a tectonic contact and not of a purely intrusive contact.

The northern contact on the coast inside Glasgow Island could not be reached because of the ice, which closed the entrance to the coast. Seen from the sea, the mountain wall gives a fairly good picture of the contact conditions (*cf.* fig. 20, p. 102). Also here the contact obviously has been disturbed by tectonic movements. The gneisses on the north side of the contact are folded into a steep anticline with a white kernel, obviously consisting of limestone. Farther north the folding is still very strong, but the folds are overturned to the north. (*cf.* fig. 20, p. 102). It is possible that the steep folding close to the contact is partly caused by the big mass of igneous rocks which have been pushed up against the less resistant gneisses and schists. The main folding after all seems to be of an earlier date.

Traces of movements in the granodiorite were also observed within the rock-mass at Rathbone Island, where the rock is partly almost gneissic, partly highly jointed and crushed up.

The small massif at Cape Hodgson dips westwards and also northwards underneath the gneisses. There was no opportunity to investigate the contact more closely, but the position of the gneisses at the contact indicates movements also here after the mise-en-place of the diorite.

So far as could be ascertained the diorite of Cape Hodgson only forms the outermost point, and does not stretch farther inland.

The granodiorite massif north of Store Fjord was only very superficially investigated, and its general shape can not yet be determined. The contact shows a strong granitization caused by a later intruded microcline-rich granite, forming a syntectic boundary zone, which in some places has the character of a volcanic breccia.

Also the diorite-area north of Hurry Inlet shows similarities with the rocks mentioned above. It is penetrated by a microcline-granite as veins and by pegmatitic and aplitic dikes. The basic rock is in part completely migmatitized and assimilated. (*cf.* p. 71).

Before entering upon the question as to the relation between all these granodioritic rocks, a petrological description of the rock-type of the different localities will be given, beginning with the most southerly occurrence at Cape Hodgson.

The Granodiorite of Cape Hodgson.

The rock is coarse-medium-grained, and gray-coloured. The dominating components, visible to the naked eye, are black hornblende and white felspar.

In many places there is also seen a very typical reddish kernel in

the big felspar grains, which give the whole rock a light pinkish aspect. The rock is strongly affected by tectonic movements, the felspar grains and quartz-grains being pinched out and crushed. Sometimes there is a distinct pitch, striking about 205° with a dip of 0—5°. The direction is remarkable, as differing from the general axial-trend of the gneisses of south Liverpool Land. It coincides with the pitch of the gneisses on the east-coast of Hurry Inlet. As will be seen later, also other observations from the diorite-areas of the southern west-coast show the same direction of deformation. The cataclastic structure as well as the position of the contact, points to an east-westerly tectonization after the consolidation of the granodiorite masses. Hornblenditic inclusions are abundant.

The Granodiorite of Raffles Island.

The small rocky Raffles Island consists for the most part of granodioritic rocks. The contact with the underlying gneisses seems to pass its southernmost point, where complicated foldings and tectonic parallel-structure are visible in the cliff-walls. The diorite at the contact is highly deformed. The normal undeformed type recalls the foregoing. Porphyric varieties with big, light pinkish phenocrysts of felspar occur in abundance. A characteristic feature of this occurrence is the great number of black inclusions of coarse-grained hornblendite and irregular veins of very coarse-grained diorite-pegmatite. The latter is very poor in quartz and obviously derives from the dioritic rock.

Under the microscope the granodioritic rock of Raffles Island shows an almost eugranitic or hypidiomorphic structure, in some degree disturbed by later movements, which have given rise to narrow granulated rims around the bigger mineral grains. In connection with this granulation myrmekite-structures are seen. The principal components are: plagioclase, microcline, quartz, dark green hornblende and biotite. Apatite and titanite occur in abundance, the latter often forming reaction-zones around grains of titano-magnetite.

The microcline occurs partly as irregular grains, growing in the spaces between the other mineral-components, partly as big phenocryst-like grains, measuring up to about 5 mm in diameter. Also the last-named do not have sharp boundaries and seem to grow on the coast of other components, particularly plagioclase, which often is found as fragments in the big microcline-grains. The mineral is unaltered, but with a slight brownish turbidity. A well developed microcline "gitter structure" is always noticeable, and, especially in the bigger grains, also a fine perthite structure. Both these structures obviously have a certain relation to the mechanical stress which the rock has suffered.

Plagioclase also occurs in more or less irregular grains, generally elongated, parallel with MP. The mineral is sometimes slightly saussur-

itized. It has always a fine Albite twinning-lamellation, more rarely twins after the Carlsbad-law. Myrmekite-structure in the crush-zones grows with the convex side towards the potash-felspar grains. The composition is c. 17—18% An, in part probably more An-rich. Zonar-structure is wanting. The quartz grains are undulatic and xenomorphic.

Hornblende dominates among the dark minerals, which generally are clustered together. It is of a common brownish-green to grass-green type with $\gamma : c = 16°$, $2E = -58°$. The outermost edge is sometimes more bluish, with a smaller angle of extinction. Small remnants of augite, partly altered into hornblende, are sometimes seen in the innermost parts of the grains. They form only a very small percentage of the grains, but are of interest, because they prove that the consolidation of the rock began with pyroxene. The biotite is yellowish-brown, generally chloritized. Epidote is quite a common component, which occurs together with the other femic components, being the latest crystallized amongst them, and often growing around hornblende-grains.

The quantitative composition is shown by the following table.

Table IV.

		Norm.	
SiO_2	57.79		
TiO_2	1.30		
Al_2O_3	16.30		
Fe_2O_3	2.87	Qz	12.18
FeO	3.41	Or	17.74
MnO	0.08	Ab	23.20
MgO	3.93	An	23.18
CaO	6.97	Di	3.61
BaO	0.12	Hy	1.85
Na_2O	2.71	En	9.50
K_2O	2.98	Il	2.42
P_2O_5	0.67	Mt	4.18
S	0.09	Ap	1.68
$H_2O +$	0.62		99.54
$H_2O -$	0.13		
	99.98		

Granodiorite, Raffles Island. Anal. N. Sahlbom, G = 2.75.

The rock gave upon geometrical analysis the following composition:

Quartz	12.61
Plagioclase	38.61
Potash-felspar	18.00
Hornblende	26.50
Biotite	2.14
Magnetite	2.14
	100.00

The tectonized diorites from the same locality have mainly a similar mineralogic composition. Only the biotite is almost completely chloritized and epidote has been in some degree originated on the coast of hornblende. The structure has undergone a complete transformation. The rock is traversed by shear-zones along which the mineral-components have been highly granulated.

The big grains are more or less lens-shaped or broken up into outdrawn agglomerations of smaller grains. The most resistant component is the hornblende, which on the whole has preserved its original composition and shape. An increase of the bluish amphibole-variety indicates, however, new-crystallization also of this component. The titanite is granulated and rolled out like strings of beads. The felspar has been the most resistant of the colourless components, being only divided into smaller grains. The mineral has lost most of its twinning-structure. The microcline is characteristic on account of the lack of perthite structure. The quartz is not only completely crushed up but also for the most part recrystallized as elongated narrow bands along the crush-zones. The resistance in respect of the mechanical deformation appears generally to be the reverse to the sequence of crystallization in this type of rocks. The quartz is the latest mineral to crystallize, and possesses the lowest power of crystallization, but is the first to be destroyed at the deformation. On the other hand, it is also the first mineral to recrystallize, and therefore sometimes is found as comparatively big individuals, together with fine granulated felspar, in rocks which have reached a certain stage of tectonization. These phenomena can be studied in abundance in rocks of different kinds in the crystalline of Liverpool Land. Zircon was sometimes observed in this diorite.

The hornblenditic inclusions of Raffles Island consist for the most part of brownish-green hornblende. $\gamma : c = 17°$. Apatite occurs abundantly as small rounded grains irregularly scattered in the rock. Titanite is partly growing in the spaces between the hornblende crystals like a ground mass, generally in some degree altered and turbid, dark brown in colour. The fresh mineral is almost colourless. Oligoclase and quartz occur only in small quantities.

This coarse-grained hornblendite represents a rock-type which is commonly found in and evidently genetically connected with granodioritic rocks, and which generally has been interpreted as a magmatic differentiation product deriving from the same magma. On the other hand, it offers great similarities with hornblendites originated from lime-rich sediments or pure dolomitic limestones included and assimilated by granitic magmas. The latter explanation must be borne in mind also with regard to the hornblendites here in question.

The Granodioritic Rocks of Rathbone Island.

The rocks of Rathbone Island evidently belong to the same igneous body as the rocks of Raffles Island and are petrologically very similar.

The steep unweathered cliff walls of the island offer splendid opportunities of studying the rocks in field. The first impression is that of a mixed rock, formed of a darker base, cut by veins consisting of lighter-coloured material. Sometimes the rock looks almost granitic; sometimes it is darker in colour and purely dioritic. Under the microscope the difference is less distinct. Also here hornblenditic inclusions abound. The

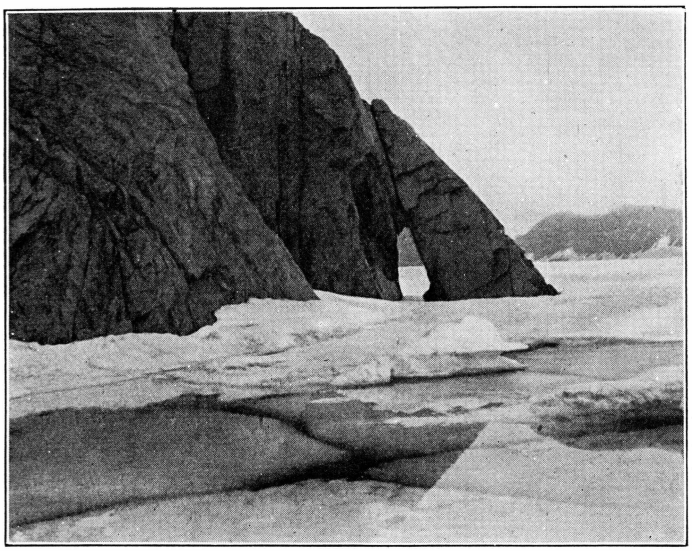

Photo E. H. K.

Fig. 12. Highly jointed Granodiorite-cliffs on Rathbone Island.

rock varieties differ not only in respect of colour, but also structurally. There are both even-grained and coarse-medium-grained rocks, finer-grained varieties and coarse-porphyritic rocks of the same type as described from Cape Hodgson.

The whole rock-mass is crossed by pink-coloured aplitic veins of varying size, ranging from some cm to several m in thickness. They have sharp edges towards the boundary rock, and evidently belong to a younger eruption series deriving from the same magma. The dip of the veins is for the most part northerly (about 45°).

The granodiorite of Rathborne Island is in general less deformed than the rocks on the foregoing localities, probably due to a more central position in the massif, but it nevertheless shows traces of a powerful tectonic influence. The rock is in an extremely high degree jointed, sometimes almost brecciated, the joints representing differential thrusts

and slopes, generally filled with mylonitic material and clustered together with bright green epidote. On account of this brecciation the cliff-walls are loose and dangerous to climb. A more thorough deformation, giving rise to differential-shearing, leading to parallel-structure and beginning schistosity was observed on the westernmost point of the island. Mylonitic structures comparable to those described from the foregoing localities have, however, not been observed here; the inner parts of the granodiorite mass have obviously been too resistant to allow of any complete mechanical transformation, with pseudoplastic reaction ("Durchbewegung") of the rock.

The mineral-components are mainly the same as in the foregoing. The grains are more sharp-edged, and particularly the dark, blunt hornblende crystals stand out very sharply against the white basements of felspar and quartz. Pink felspar occurs only in the porphyric varieties. Titanite is sometimes uncommonly abundantly present in sharp bright brown crystals, well visible also to the naked eye.

Under the microscope the structure is hypidiomorphic granular to eugranitic. The crystallographic form of the mineral grains is, as a rule, badly developed, except in the case of the titanite and partly of the apatite. The plagioclase grains are slightly idiomorphic. The mineralogic composition is: plagioclase, microcline, quartz, hornblende, biotite, epidote and titanite. In the light-coloured, more granitic varieties the hornblende is wanting. Titanite, titano-magnetite and apatite are all present.

The plagioclase is in some places clear, in other samples altered into saussurite with abundant carbonate. The composition differs with the acidity of the rock. In the normal type with hornblende it is 32 % An; in the light coloured variety without hornblende (from the W.end of the island) it is 26—27 %.

Twins according to the Carlsbad and Albite laws. A typical feature is the absence or insignificance of the zonar-structure, indicating comparatively abyssal conditions during the consolidation.

In some samples there is an abundance of calcite, lying in allotriomorphic grains between the other minerals, sometimes also occurring as a fine matrix scattered all over the rock.

Pyroxene was not found in the samples investigated, but there is hardly any doubt that it is present in the granodiorites of Rathbone Island.

As already pointed out, epidote is for the most part to be regarded as a secondary product in the fissures, but is also seen in small quantities within the rock, constituting a late-magmatic mineral.

The quantitative composition of the main-type is probably about the same as of the rock of Table IV.

The Dioritic Rocks of the Hodal Valley N. of Hurry Inlet.

In the north-easterly direction from the northern end of Hurry Inlet the expedition struck a large diorite area forming the high cliffs around the uppermost part of a broad valley, running in the upper part in a north-westerly direction. It is called Hodal Valley (Fig. 14, p. 71). The dark colour of the mountain slopes farther to the north and northwest indicates that the rock-type continues in that direction under the ice cap, covering the inner part of the land.



Photo E. H. K.

Fig. 14. Upper end of Hodal Valley, surrounded by diorite-mountains.

The rock is medium-grained, dark gray, on the weathered surface usually brownish. It is penetrated by numerous veins of pegmatite and aplite. Nearer to the southern contact the influence of the neighbouring granite is very strong and leads to a complete migmatization, with large scale development of igneous breccias, with resorbed fragments of diorite lying in a pegmatitic and aplitic ground-mass. On the other hand, the gneissic component in the migmatite-complex north of Hurry Inlet is clearly older than the diorite, in which inclusions of schistose fragments can be seen at several places. In other words, the age-relation of this diorite is quite clear.

Microscopic investigation shows that the granodiorite of Hodal Valley in many respects resembles the dioritic rocks described in the

foregoing. In spite of the dark colour we also here have to do with granodiorites or diorites comparatively rich in potash-felspar and quartz. The structure is mostly eugranitic, sometimes slightly hypidiomorphic. Particularly the dark components show irregular corroded edges (Fig. 4, Pl. 1).

The most remarkable difference from the granodiorites of the south-western parts of Hurry Inlet is the abundance of augite, which represents one of the main components of the rock. The other constituents are plagioclase, microcline, quartz, hornblende, biotite, iron ore, titanite, apatite.

The mechanical deformation is comparatively strong, with granulated zones around the mineral grains. Myrmekite occurs in great abundance. The plagioclase of the rock-series has the composition c. 27% An, in other samples it is slightly more Ab-rich. The grains are generally very broad in the direction perpendicular to c. Albite and Carlsbad-lamellation is well developed. Zonar-structure is almost completely lacking. In the plagioclase-grains there are often seen very tiny needle-shaped inclusions, orientated partly parallel with P, M and probably the ground-pyramid; the needles cut through the twinning-lamellation, and consequently seem to be of later origin.

The potash-felspar is characteristic on account of the absence of perthite-lamellation and microcline-twinning, and is a homogeneous orthoclase. It contains very highly resorbed small fragments of the plagioclase and has grown on the coast of the surrounding minerals. Quartz occurs in fairly great quantities. As generally is the case, it has suffered more than any other mineral through mechanical deformation and is always more or less crushed up and often completely granulated and undulose.

The augite is generally surrounded by green hornblende. The grains are light greenish, with almost no pleochroism. The extinction is about $\gamma : c = 37°$, and indicates the composition of a diopsidic augite. Jointing parallel 001. (2E c. 25°). The amphibole is for the most part a common hornblende. In samples where the contact influence of the granite was stronger, the augite has partly been altered into chlorite, partly (probably still later) into bluish amphibole with small angle of extinction ($\gamma : c = 5°$) and with the axial-plane perpendicular to OlO. The absorption is $X > Y > Z$, blue, grass-green, yellowish. These properties point to an amphibole rich in alkalies. On the other hand, similar amphiboles have often been proved to be alkali-poor hornblendes, and it lies close at hand to regard the mineral here in question as being of the same kind. It nearly corresponds to the s. c. smaragdites of the basic rocks. The light bluish hornblende often alters into common dark green hornblende, this evidently occurring when the metamorphosis is continued. The outer-

most edge consists of solid dark hornblende, the interior parts of light, porous amphibole.

The biotite is dark reddish-brown to light yellow, in the granitized varieties there is seen a peculiar intergrowth of felspar and mica, bringing to mind symplectitic structures. The biotite contemporaneously alters into chlorite.

The quantitative composition of the rock is shown by the following analysis:

Table V.

SO_2	55.72		
TiO_2	1.25		
Al_2O_3	17.35	Qz	4.20
Fe_2O_3	3.19	Or	15.59
FeO	2.99	Ab	35.32
MnO	0.07	An	21.14
MgO	3.66	Di	4.96
CaO	7.07	Hy	0.92
BaO	0.16	En	9.10
Na_2O	4.23	Il	2.42
K_2O	2.64	Mt	4.64
P_2O_5	0.88	Ap	2.20
S	0.02		100.49
H_2O+	0.52		
$(HO_2\div$	0.25)		
	99.75		

Granodiorite, Hodal Valley north of Hurry Inlet, Liverpool Land. Anal N. Sahlbom. G = 2.78.

The following table gives the mineralogical composition determined by geometrical analysis.

Quartz	6.75 %
Plagioclase	48.39 -
Potash-felspar	7.24 -
Hornblende	22.60 -
Augite	4.62 -
Biotite	10.40 -
	100.00 %

The Granodiorite area of Cape Smith.

The granodiorite rock of Cape Smith reminds one very much of the foregoing. It is macroscopically a comparatively light, often pure gray, medium-grained rock; in the porphyric varieties the kernel of the phenocryst is reddish, in the same way as in the southern diorite areas. The microscopic structure is also very similar, with the same main-

components in chiefly the same proportions. The mechanic influence is obviously less powerful, and granulation is rare in the normal types. The composition of the plagioclase is on an average 27—28% An; in types with zonar-structure the innermost part has 30% An, the outermost 27%. Augite is abundantly present; it has the same properties as in the foregoing. The two amphibole-types described from Hurry Inlet occur also here (in the dark green $\gamma : c = 18°$, in the light bluish $\gamma : c = 11°$).

The rock contains numerous small dark inclusions of amphibolitic composition. The analysis Table VI gives the chemical composition of the rock.

Table VI.

SiO_2	58.45		
TiO_2	1.48		
ZrO_2	trace	Qz	9.35
Al_2O_3	17.93	Or	16.77
Fe_2O_3	3.83	Ab	34.08
FeO	1.39	An	21.92
MnO	0.04	Di	1.28
MgO	2.12	Hy	1.86
CaO	5.98	En	5.40
BaO	0.04	Il	2.88
Na_2O	4.03	Ap	6.00
K_2O	2.94	He	1.16
F	none		100.50
H_2O	0.88		
H_2O	0.10		
	99.71		

Granodiorite, Cape Smith, Liverpool Land. Anal. N. Sahlbom. G = 2.75.

The Contact between the Granodiorite and Microcline-Granite at Polyp Harbour.

The rocks occurring on the contact between granodiorite and microcline-granite can be studied at Polyp Harbour. In the steep cliff walls on the north side of the bay the rock-ground consists of pure granodiorite; higher up, in the glacial-valley ending in the bay, gneissic rocks of composite character occur, and the same gneisses are found also high up in the mountains, on the coast, and in the cliff walls farther south. All these rocks are penetrated by granite, forming migmatitic rocks of different aspect. In this connection especially those rocks are of interest which originate in places where the granite is intruded into dioritic rocks. As was pointed out before, such intrusions are common along the original contact-line between gneisses and granodiorite; a rule that holds true not only in the crystalline of Greenland, but which can be observed in every crystalline area of the same type. It generally is favoured by

movements along the less resistant zone of inhomogenity between the granodiorite mass and the neighbouring rock.

The existence of a movement-zone at Polyp Harbour, and strong movements in connection with the granitic intrusion can plainly be read from the rock-structures. Where the younger granite has affected the diorite, the last-named gradually loses its even-grained, homogeneous structure and becomes distinctly foliated, recalling a gneissic rock. A microscopical investigation shows that this structure partly can be explained as a fluidal structure, partly as a mechanical schistosity, or, more exactly, a structure originated by contemporaneous shearing and injection. The felspar and particularly the quartz are disintegrated, and often originate myrmekite. The augite is more resistant, but alters in the marginal parts into bluish amphibole.

In the contact-zone porphyric structures are very common; the potash-felspar occurs as big, well individualized phenocrysts, often attaining several cm in length, generally with twinning according to the Carlsbad-law. Under the microscope the boundaries of these crystals are far from sharp. The phenocrysts generally contain inclusions of the other minerals, and there is strong reason to interpret them as a comparatively late crystallization. Microcline twinning-structure and perthitic bands can generally be seen within the shear-zones particularly in small grains. The plagioclase in these rocks has still about the same composition as in the unaltered diorite, 27—30 $^0/_0$ An.

A further stage of the tectonic development is demonstrated by the "Augengneisses", macroscopically coarse-grained gneissic rocks with big lens-shaped microcline grains, often up to 5 cm in size, in a gneissic ground-mass. Under the microscope the coarse structure disappears and the rock, including the biggest felspars, turns out to consist of comparatively small highly granulated agglomerations of small mineral individuals. The big phenocrysts or idioblastic crystals are evidently originated in connection with rotation and collective growth of the first-mentioned microcline crystals.

At this stage of development the rock is gradually enriched in potash-felspar; the dark components, augite and hornblende, alter into biotite, quartz has recrystallized, often in elongated grains along moving-planes, and the rock is in many respects comparable to a normal "Augengneiss".

The development of the granodiorite within the contact zone is in other words granodiorite → porphyry-granite → "Augengneiss". Where the injection is less conspicuous or more gradual one gets common banded gneisses instead of "Augengneiss".

Summary.

As we have seen in the foregoing the granodiorites of Liverpool Land compose a very well defined group of intrusions. Their mineralogy is characterized by the composition: plagioclase (24—26° % An), microcline, quartz, biotite and hornblende, the lastnamed component often occurring together with augite. The pure hornblende-diorites seem to be more common than the pyroxene-bearing types. Pure biotite-diorites without hornblende and with an increasing percentage of potash-felspar represent transitions towards granitic rocks.

The rocks here in question differ from normal diorites in the comparatively high potash-content also in varieties poor in quartz, which consequently grade into monzonitic types, although real monzonites have not been found.

On the whole, the chemical composition shows only small variations and the more acid or more basic types have only a subordinate importance within the diorite areas. Also the rocks of the different areas are very similar. The three analyses (Table VII) representing the main-areas of Liverpool Land were chosen in order to demonstrate rather the differences than the similarity of the magmas. In spite of this they resemble each other in every respect, and could well represent the same undifferentiated igneous body, giving strong support to the theory of the consanguinity of all the granodiorites of Liverpool Land.

Table VII.

SiO_2	58.45	57.79	55.72
TiO_2	1.48	1.30	1.25
ZrO_2	trace	n.d.	n.d.
Al_2O_3	17.93	16.31	17.35
Fe_2O_3	3.83	2.87	3.19
FeO	1.39	3.41	3.19
MnO	0.04	0.08	0.07
MgO	2.12	3.93	3.66
CaO	5.98	6.97	7.07
BaO	0.04	0.12	0.16
Na_2O	4.03	2.71	4.23
K_2O	2.94	2.98	2.64
P_2O_5	0.64	0.67	0.88
S	n. d.	0.09	0.02
F	none	n. d.	n. d.
H_2O+	0.88	0.62	0.52
$(H_2O\div$	0.10	0.13	0.25)
	99.71	99.85	99.75

1. Granodiorite, Cape Smith.
2. — , Raffles Island.
3. — , Hodal valley.

The classification of these granodiorites according to the systems generally used for igneous rocks offers some difficulties on account of the transitional position between the lime-soda series and the potash-series. The term granodiorite has here been used mainly on account of the high percentage of potash-felspar which brings about the correspondence of the analyses with the granite series of NIGGLI (Gesteins- und Mineralprovinzen) although the low silica-percentage would justify the name diorite. The molecular-proportions, reckoned according to NIGGLI, would place the rocks within the yosemitic magmas; on the other hand, the bulk-composition corresponds very closely to the average of the dioritic rocks according to ROSENBUSH-OSANN (Elemente der Gesteinslehre, 1923).

The comparison of the dioritic rock of Liverpool with the Trondhjemite-series of the Norwegian Caledonides lies close at hand. As a matter of fact, very similar types of the analyses published have been described, particularly by W. M. GOLDSCHMIDT (17); *i. a.* the hypersthene-mica-diorite of Mallestuen may be mentioned. On an average, the dioritic rocks of the Scandinavian Caledonides are more Ca, Na-rich. This may at least depend on a different position within the orogenic folding-zone. The Scandinavian rocks seem on the whole to be more tectonized, i. e. to be earlier intruded in comparison with the orogenic movements, which may have given rise to a more complete differentiation into lime-natron- and potash-rich varieties. In spite of these differences, a parallelization of both the rock-series seems to be very natural.

The granodiorites of East Greenland show a very close resemblance to the diorites of the Cordillera of America, particularly the Andean diorites, which possess the same transitional position between the lime-soda and the potash-series, with adamellitic granites and other rocks leading towards the latter (24). The examples given could easily be multiplied by rock-provinces from the Alps, from Central Europe, from the Archean of Scandinavia and North America and other places. On the whole the granodiorites of East Greenland fit well into the series of lime-soda-rich intrusives which regularly occur in connection with mountainfolding of geocynclinal (alpine) type.

Granitic Rocks.

The Older Granite of Store Fjord.

The microcline-granite which has given rise to the migmatitization of the older schists and evidently also has influenced the granodioritic rocks occurs in most places as pegmatitic or aplitic masses or as strongly palingeneous gneisses. Pure granite is found only in certain areas. One of the best explored regions, and also probably the largest,

is that around Store Fjord. With the exception of one small area on the southern shore, in the inner part of the fjord, the mountains around the fjord consist of more or less pure granitic rocks, light gray to light pinkish in colour. The rock is as a whole far from homogenous, containing numerous inclusions of darker coloured material, and is penetrated by a network of aplitic and pegmatitic veins. The whole complex can with certainty be regarded as highly syntectic.

There are, however, also big masses of pure microcline-granite, partly fine-grained, partly medium-grained, more often porphyric.

The inclusions consist for the most part almost exclusively of dioritic and hornblenditic rocks. A problem which can hardly be definitely solved is whether these inclusions are really derived from included igneous rocks, or if they partly can be interpreted as altered sedimentary rocks. As will be shown in the following, both possibilities must probably be taken into consideration, even though the igneous type dominates.

The porphyric granite (N. shore of Store Fjord) is in hand-specimen characterized by the sharp phenocrysts of microcline, generally developed as Carlsbad-twins, reaching a length of about $1^1/_2$ cm. The ground-mass is fine-medium-grained with pink felspar, quartz and black biotite as the dominating components visible to the naked eye.

The structure is eugranitic. Granulation can be observed in some degree, but generally the structure is unaffected. The quartz grains are only slightly undulous. The rock is comparatively unweathered, and only a slight turbidity, depending partly on beginning saussuritization in the plagioclase, partly on an iron-oxide pigmentation, is sometimes noticeable.

The mineral-composition is: microcline, plagioclase, quartz, biotite, titanite, titano-magnetite, apatite, zircon. The microcline has generally a fine perthite-structure and well developed microcline-lamellation; both the potash-felspar of the phenocrysts and that of the basement have irregular boundaries and contain inclusions of the plagioclase which has crystallized earlier. The plagioclase is an oligoclase with about 22 % An. and a very fine, sometimes insignificant, Albite-lamellation, often combined with twinning after the Carlsbad-law. The titanite is light reddish and occurs in great quantities, mainly around the iron-ore-crystals. The mica is greenish-brown, in some degree chloritized, and containing sagenite. Around tiny zircon-grains a small pleocroitic corona is visible. Myrmekite is present in abundance. The quartz grains are generally small and lappy.

On the whole, the rock shows the typical properties of a Precambrian palingenous granite, such as the granites of the second group of SEDERHOLM in Finland.

The fine-grained type differs both on account of the more



Fig. 15. View of the inlet of Store Fjord, seen from the mountains on the north shore. The cliffs consist of granite. Photo E. H. K.

hypidiomorphic structure, (which, however, never is so conspicuous as in the youngest granites of the tract described in the following) (p. 82) and on account of the varying composition of the plagioclase. The latter is sometimes zonary-built with an anorthite-rich kernel, always more or less resorbed and surrounded by an outer zone of an Albite-rich plagioclase. The kernel contains about 30% An., the outer (bigger) zone 22—24%, that is to say the same as in the foregoing type. The fine-grained varieties have evidently crystallized more rapidly than the coarse-grained ones. The kernel is generally in some degree altered, evidently owing to unstable conditions during the later phase of crystallization, and contains rather big crystals of muscovite, orientated after the cleavage planes of the plagioclase.

The dioritic inclusions in the granite of Store Fjord represent a complete magmatic series, from pure dioritic rocks without microcline to potash-rich granodioritic varieties. They sometimes occur in comparatively big solid bodies, in other places they occur as small fragments, which have been more or less assimilated by the granite. The dioritic component often shows a parallel-structure, which gives it a gneissgranitic character. This structure may partly depend on an earlier tectonic influence, but is certainly for the most part developed in connection with the granitization, at which the included rock was becoming soft and was easily drawn out into semifluidal parallel-structures. Under the microscope there is to be seen a slight granulation, but this is never conspicuous.

The composition in the pure dioritic inclusions corresponds closely to that of the granodioritic rocks described before, although the quartz- and microcline-content sometimes is lower. The plagioclase is slightly zonar, with about 30—32% An in the basic kernel and 24—27% in the outer zone; the latter properties also depend on the degree of granitization, the plagioclase being more Ab-rich in the fragments where the potash-felspar is abundant. Augite occurs always together with amphibole of the two kinds named before. The primary amphibole is a dark brownish-green hornblende. At the granitization both the augite and the hornblende named above are altered into a bluish amphibole, generally in some degree spongy in appearance, as it never completely fills up the volume of the altered augite, numerous quartz-grains filling up the rest of the space. Contemporaneously iron-oxide is also found, evidently depending on a lower content in the secondary amphibole than in the original augite-grain. Sometimes the mixture between bluish amphibole and quartz has the character of a symplectite. Another alteration which also seems to depend on the contact-influence of the granite is the formation of reaction-rims of titanite around the numerous grains of titano-magnetite. Particularly where the ore-grains lie within

biotite-flakes this reaction is conspicuous; the ore grains being surrounded by a crown of sharp-edged crystals of titanite. The biotite is evidently in some degree instable against the granitization; it is often highly corroded and surrounded by clear rims of new-crystallized potash-felspar and quartz. Myrmekitic intergrowth of plagioclase and quartz is also present. Plagioclase is corroded by potash-felspar, the latter generally with perthite-structure. The quartz contains microlitic needle-shaped intergrowths.

This general description proves that the diorites included in the granite of Store Fjord do not differ in any mineralogical respect from the granodioritic rocks of Liverpool Land, and there is strong reason to interpret the granite-region of Store Fjord as a highly granitized diorite intrusion, where the dioritic rocks for the most part are assimilated by granite. It seems natural to connect this diorite with that described from the region north of Hurry Inlet, which in fact continues in a direction pointing towards the Store Fjord region.

It is of course impossible to decide with certainty if there also exist other assimilated rocks among the fragments in the syntectic granite-area of Store Fjord. The ultrabasic hornblenditic rocks are strongly

Table VIII.

	1.	2.	3.
SiO_2	68.80	69.66	68.67
TiO_2	0.38	0.31	0.33
ZrO_2	trace	—	—
Al_2O_3	15.98	14.42	16.88
Fe_2O_3	1.63	0,98	0.34
FeO	1.47	1.30	1.44
MnO	0.04	0.02	trace
MgO	1.02	1.15	0.64
CaO	2.52	1.40	2.70
BaO	0.06	—	—
Na_2O	3.03	4.26	4.16
K_2O	3.80	4.32	3.84
P_2O_5	0.44	0.30	0.20
H_2O+	0.66	0.94	0.79
H_2O-	0.20	0.25	0.15
	99.74	100.01	100.14

Norm of I.	
Qz	30.30
Or	22.60
Ab	25.63
An	10.08
Cd	3.28
Hy	0.92
En	2.50
Il	7.60
Mt	2.32
Ap	1.00
	106.23

1. Microcline-granite, Store Fjord, Liverpool Land. Anal. N. Sahlbom. G = 2.65.

2. Granite ("Zweiglimmergranit"), Ättestupan, Franz Josefs Fjord. Anal. N. Sahlbom. Meddelelser om Grönland, 87,4, p. 91.

3. Pink granodioritic granite (Variety of the "Centralgranite of Finland"), Island Puutsaari, Lake Ladoga, Anal. L. Lokka. Geologisk översiktskarta över Finland. D.". Nyslott, p. 115.

reminiscent of the hornblendites which are often found in migmatite areas where limestones have been affected by granite, but we have earlier described also such inclusions in the granodiorite areas.

The chemical composition is shown by the analysis Table VIII, p. 81.

According to a geometrical analysis, the percentage of the principal minerals of the mode is about the following:

Quartz	23.51 %
Plagioclase	42.04 -
Microcline	27.02 -
Biotite	5.82 -
Titanite	1.19 -
Magnetite	0.42 -
	100.00 %

The composition is characterized by the comparatively low percentage of silica and the comparatively high sodium-percentage. The content of plagioclase is slightly higher than that of potash-felspar, and the rock in that respect grades into the granodioritic (adamellitic) rocks. It corresponds fairly well with the granite of Ättestupan in Frans Josefs Fjord described by BACKLUND as Caledonian (No. 2, Table 8). As a comparison a granite belonging to the Central-granites of Finland is given (No. 3, Table 8). As has been pointed out, before these granites have a geological position recalling that of the granite here in question.

The Younger Granite of Store Fjord.

In the westernmost part of Store Fjord the granite has a character which distinguishes it from the granite of the eastern parts of the region. In the cliff-walls the warm reddish colour is conspicuous and reminds one at first sight of the granite in the inner part of Hurry Inlet. This colour seems, however, to depend on the close neighbourhood of the overlying younger sediments, indicating the vicinity of the old Pretriassic weathering surface. On the other hand, a closer examination proves that the difference between the granites of both ends of the fjord is not only dependent on a higher degree of weathering, but also on the fact that we here have to do with a different, and after all a younger intrusion. The contact between both granites was not investigated, but the older granite is cut by dikes and veins, obviously deriving from the younger rock.

Microscopic investigation gives strong support to the supposition of a difference in age between the granites. The younger one has regularly a less altered character and shows no traces of tectonic influence. The quartz, which occurs in about the same quantities as in the Store Fjord granite, is only slightly undulating and never granulated. The structure

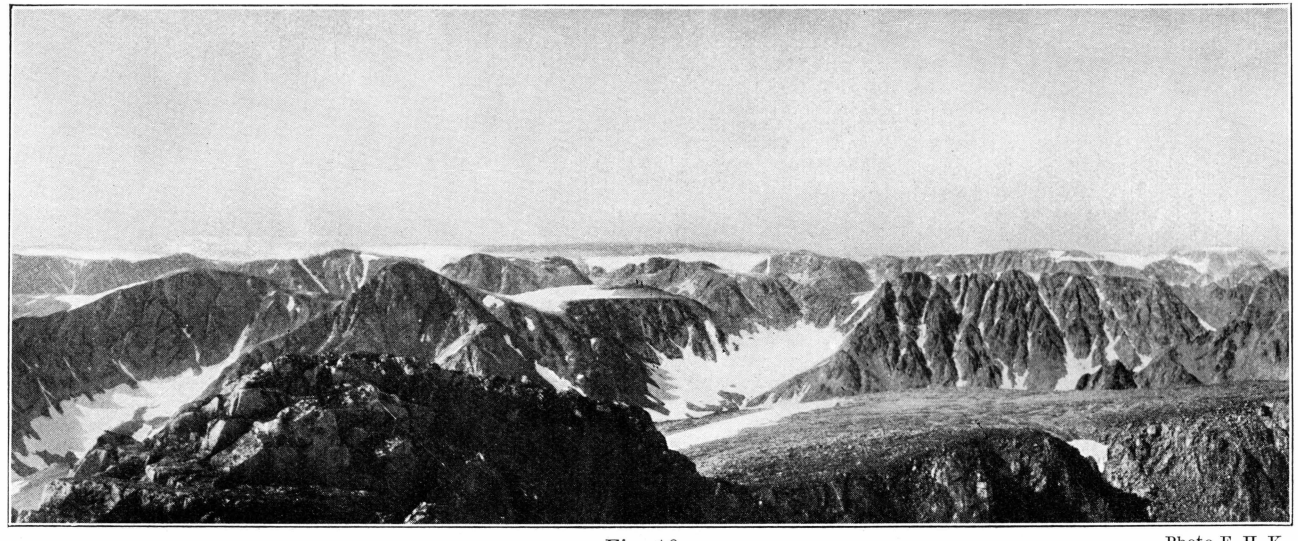

Fig. 16. Photo E. H. K.

View northward from the mountains on the north shore of Store Fjord, showing remnants of an old uplifted land-surface cut by younger valleys. The rock-ground consists on the right-hand side of the Store Fjord granite, on the left of younger granite.

is hypidiomorphic, with generally unusually sharp and rectilinear edges of the grains. The felspar grains in especial are crystallographically well developed. A striking difference between this granite and the Store Fjord granite exists with regard to the phenocrysts of potash-felspar in the very common porphyric varieties. Here the phenocrysts really give the impression of having been originated comparatively early and have developed sharp crystal-surfaces. They, however, sometimes also contain resorbed inclusions of still earlier originated plagioclase. The dark components are represented by brownish-yellow mica, generally partly or completely chloritized, and green hornblende (γ:c = 16°.5) with slight pleochroism. Titanite occurs as sharp-edged idiomorphic small crystals, zirkon as tiny, blunt-ended prismatic grains. Apatite is seen only in small quantities. Calcite and epidote are present, especially in fissures in the rock. The base between the hypidiomorphic grains mainly consists of late crystallized quartz, but never or very rarely of microcline, as in the Store Fjord granite. The composition of the generally zonar-striated plagioclase is in the outer parts an Ab-rich oligoclase; in the kernel the percentage is 32% An. The potash-felspar is a cryptoperthitic orthoclase.

All these characteristics correspond intimately, as will be shown in the following, with those of the granite of Hurry Inlet.

A granite of this type was found so far westward as on the watershed between Store Fjord and Klittdalen, at the contact with the overlying Mesozoic sediments.

The Hurry Inlet Granite.

The granite-area on the east coast of Hurry Inlet north of the Sødal Valley is as a whole the purest granite area of Liverpool Land, with the most characteristic and easily distinguishable rock-types. The area is very extensive, at least 400 square km, and it therefore is quite natural that a great number of varying types can be found within it. Although the normal granite has a very pure aspect, there exist many evidences that an anatexis on a great scale has taken place also in connection with the intrusion of this rock-type. It could be studied particularly well in the inner parts of Liverpool Land at the upper end of the Sødal Valley, where the granite contains inclusions of considerable size and in great amount, both of older igneous rocks, more especially dioritic ones, and of sediments. Among the latter the fragments of limestone are important. Also amphibolitic greenstones of different types can be seen, probably partly deriving from highly metamorphosed lime-rich sediments.

Also in regions where the granite is almost pure, as e. g. in the region west of the north end of Hurry Inlet, there always occur "Schlier"-like

inhomogenities, evidently representing highly absorbed traces of assimilated exotic material.

Very pure even-grained granite, however, seems to compose the bulk of the area. There can be distinguished at least three main types: 1) Fine-grained pale pinkish to grayish granite; 2) coarse porphyric granite, with big pink-coloured phenocrysts of potash-felspar in a groundmass recalling the foregoing type, and 3) a coarse medium-grained porphyric granite, with smaller, but more numerous, phenocrysts, and with less difference between phenocrysts and groundmass. In the region around the north end of Hurry Inlet the granite is bright pink in colour, but the colour becomes farther south lighter and lighter. In the southern and inner parts gray or almost gray types predominate. The first-mentioned region is evidently very near the old Pretriassic surface (here partly Predevonic) the same weathering-surface mentioned already from the region west of Store Fjord, and the red colour also here may depend on surface weathering. All the different varieties of this granite possess a number of structural features which make it easily distinguishable when compared with the older granites of Liverpool Land.

First of all, the absence of tectonic influence is a characteristic feature which proves that the granite is completely post-tectonic. Only in the contact-regions, particularly at the north contact, have late dislocations caused local deformations in the rock. Another attribute is the structure, which in all varieties is characterized by very sharp-edged grains and by considerable amounts of idiomorphic forms of the components, both of the phenocrysts and of the groundmass. The more leucocratic composition, with mica as dominating femic component, makes the separation from the other granitic and granodioritic rocks of the region very easy. The structural features indicate that the Hurry Inlet granite is more hypabyssic, consolidated at a comparatively insignificant depth compared with the other plutonites of Liverpool Land. Such features are: 1) The even-grained homogeneous aspect, 2) the strong zonar-structure of the plagioclase, and 3) the general character of the contacts with other rocks, which, in spite of the syntectic features named above, are more often sharp and well defined than is the case with the older granites of Liverpool Land. On account of the structure the Hurry Inlet granite always gives an impression of, brittleness and has a very good jointing.

The mineral-composition varies in some degree in different areas, especially where other rocks have been assimilated. The pure and even-grained granite in the tracts around Sødal Valley is free from hornblende and contains almost no tinatite; in the regions farther north both these components are present, possibly depending on a higher degree of anatexis.

The granites of Nøkkedal Valley (Fig. 1, Pl. 2) are for the most part coarse-porphyric, the phenocrysts 2—3 cm in length. The mineral-components are perthitic orthoclase, plagioclase, quartz, biotite, small quantities of magnetite, apatite and zirkon, sometimes also muscovite. In the upper part of the valley, on the edge of the glaciers, there was found a fine-grained, very homogeneous variety of the same mineral-composition, with some interesting structural features. The idiomorphic growth of the components is here particularly conspicuous, and also the quartz, which was the last mineral to crystallize, has at least in some degree its own crystal-form. The plagioclase is characterized by the uncommonly big difference between the composition of the inner parts and of the peripheric parts. The first-mentioned was in some grains determined at 44 % An, the very basic kernel is surrounded by a rim with 40 % and the peripheric part is about 28 % An. The existence of the anorthite-rich plagioclase in the pure granite and quartz-rich rock evidently depends on the rapid cooling, which also has caused the strong zonar-composition. The instable character of the anorthitic plagioclase is indicated by an alteration which can be observed in the kernel of most of the mineral grains. The felspar is scattered with small muscovite flakes, regularly orientated after the direction of cleavage. Another typical feature is myrmekitic intergrowth of quartz in the plagioclase, sometimes filling up the whole grain, which nevertheless has the outer idiomorphic form preserved. The potash-felspar is a perthitic orthoclase with slight undulation. The femic minerals are very subordinated and are here represented only by yellowish-brown biotite in small blunt flakes, and some tiny ore-grains. Zirkon occurs sometimes in abundance, apatite is almost entirely absent.

The typical features described above are less well developed in the syntectic varieties; here the general migmatite-structure dominates. Where hornblende enters amongst the components titanite and apatite are generally also found and in basic inclusions are sometimes very abundant. Here also sulphides and carbonates can often be seen. Augite is present in some of the inclusions in the upper parts of the Sødal Valley, and the general features and alteration-series correspond to these described from the diorite intrusions in Store Fjord. In other words, it is hardly possible to conclude by aid of the microscope which one of the two granite generations of Liverpool Land has caused the migmatization, except of course in tracts where the tectonic influence has been strong, and the kataclastic structures have not been destroyed by later recrystallizations.

The quantitative composition of the younger granite was investigated by means of analyses.

All the granites treated above represent types well known from a

great numer of petrographic descriptions from different parts of the world.

As both the analyses prove, the granite of Hurry Inlet has a very homogeneous rock-mass. In spite of being taken from different regions the coarse porphyric type only about four km from the coast, the fine-grained, gray type about nine km from the interior parts of Liverpool Land — they show an almost astonishingly close resemblance. The igneous body has evidently only in an insignificant degree been differentiated at the consolidation, a circumstance which agrees well with the field observations.

Table IX.

	1.	2.	Norm	1.	2.
SiO_2	70.83	70.73	Qz	33.40	26.82
TiO_2	0.18	0.36	Or	25.28	25.28
ZrO_2	0.02	none	Ab	27.80	27.80
Al_2O_3	14.63	15.36	An	7.85	10.59
Fe_2O_3	2.28	0.81	Cd	2.00	1.40
FeO	1.18	1.17	Hy	—	0.79
MnO	0.02	0.02	En	0.70	2.20
MgO	0.51	0.88	Il	0.32	0.76
CaO	1.80	2.40	Mt	3.35	—
Na_2O	3.31	3.31	Ap	0.66	0.67
K_2O	4.32	4.36			
P_2O_5	0.30	0.29			
H_2O+	0.66	0.50			
$(H_2O\div$	0.18	0.13			
	100.04	100.1'		101.36	96.31

1. Granite, fine-grained, Hurry Inlet, Liverpool Land. Anal. N. Sahlbom. G = 2.65.

2. Granite, coarse-porphyric, Hurry Inlet, Anal. N. Sahlbom. G = 2.65.

The chemical composition Table IX is characterized by the comparatively high amount of alumina and the very low magnesia content. It corresponds to a group of granites which is very common also within the Precambrian of Scandinavia, with about 70% silica and about 14—15% alumina, generally belonging to SEDERHOLM's groups II and III. This holds good also regarding the Store Fjord granite. This rock type is well known also in the Caledonian mountain-chain of Scandinavia. (BACKLUND, 2, 3). The correspondence with many of the Highland-granites of Scotland will be pointed out elsewhere.

On the whole, the Store Fjord granite varies very little from the younger granite, although there seem to be some distinct specialities.

The silica is lower Al_3O_2, MgO is higher. Instead both CaO and Na_2O are lower. It therefore at first seems strange that the plagioclase of the Hurry Inlet granite is in its kernel more anorthite-rich than the plagioclase of the Store Fjord granite. This, however, evidently depends on the same conditions which have caused the strong zonar-structure of the first-mentioned granite. The consolidation started at a comparatively high temperature and the cooling thereafter was rapid. These circumstances are often met with in hypabyssal rocks from which the volatile components have escaped at an early stage of crystallization.

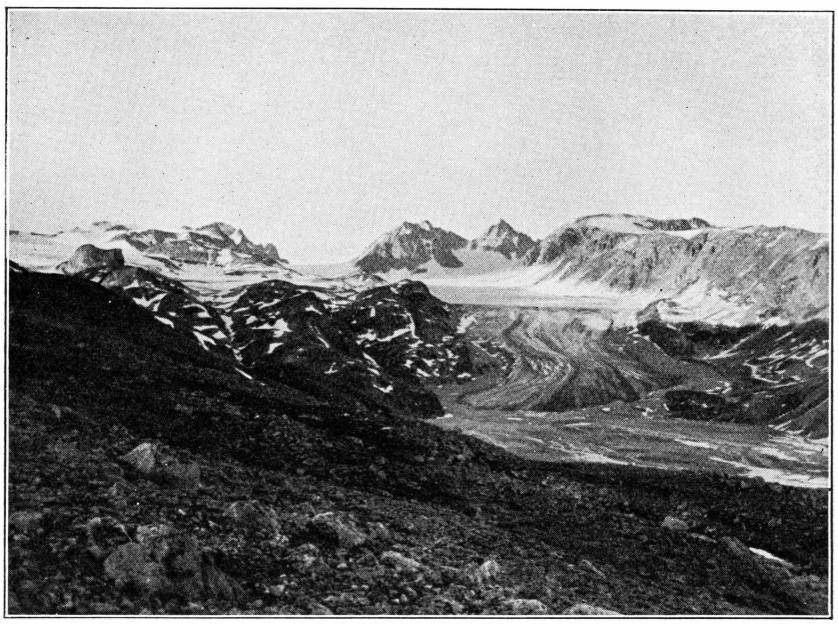

Fig. 17. The uppermost part of Nøkkedal Valley, surrounded by cliffs consisting of the Hurry Inlet granite. Photo E. H. K.

In another connection attention has been drawn to the fact that, the Store Fjord granite evidently belongs to the same cycle of intrusions as the granodioritic rocks (p. 106). In fact, certain features can be traced in its chemical composition which support the supposition of consanguinity. A comparison of the molecular proportions, particularly using the numbers of NIGGLI, gives a close resemblance to the adamellitic rocks, a rock group forming the intermediate member between granites and diorites in the diorite-granite differentiation series. This type of granites have been described also from the Trondhjemite-opdalite series of Norway (GOLDSCHMIDT).

Finally, we have to compare the granites of Liverpool Land with the granites of the other parts of East Greenland. Microcline-granites

and syntectic granites deriving therefrom, of exactly the same type as the granite treated above, have already been described in great detail by BACKLUND from the northern fjord-area of East Greenland, and there can hardly be any doubt that they generally belong to the same phase of intrusion. Of course, there are extant several variations due to the partly syntectic character of the rock, but in spite of this the similarities are unmistakable. It is as yet too early to decide if they can be connected with the two groups of granites described above; before this can be done all the collections of the Three Year Expedition will have to be investigated. BACKLUND will probably treat the problem of the magmatectonics of the region as a whole.

D. TECTONIC AND KINETIC OBSERVATIONS ON LIVERPOOL LAND

Method of Investigation.

The stratigraphic relation between the formations described in Liverpool Land has in the foregoing received only very superficial treatment. This is due in part to the localities investigated being still too few and sporadic, which makes a connection in detail impossible. Further, it is necessary to treat the tectonic conditions of the region as a whole, before any stratigraphical conclusions can be drawn. In this case also the tectonics are known only in a few places and the general conclusions have in many respects the character of a working hypothesis, which may give some directing points for future research work in East Greenland.

The problems with which the tectonic investigation has to deal on Liverpool Land are the following:

1. The traces of the orogenetic movements within every locality, beginning with the differential movement and its style, up to the great forms. Where the last-mentioned can be directly studied, the investigation naturally begins from the "grand style" and goes further into detail, as far as to microscopic structure analyses, but in many cases, particularly within the injection complexes with their complicated foldings, the opposite way may be preferable.

2. The relation between the rock-textures and the tectonic style.

3. The sequence of the events which have developed the tectonic forms, that is to say, the tectonic development of Liverpool Land. Here the sequence has to be found for every locality, and investigations thereupon made as to the possibility of connecting the sequence of movements of different regions. In this way also stratigraphic connection may be possible in certain cases, giving the necessary aid to the still too uncertain method of contact studies.

4. Finally, we have to consider the possibilities of fitting in the

tectonics of Liverpool Land within the structures of the northern parts of East Greenland.

Good help in the investigation is afforded by the magmatic intrusion, which intimately coincides with the tectonic events, as has often been pointed out, from Greenland particularly by BACKLUND. The questions dealt with above are in most points identical with those treated by the last-named author in his papers on the geology of the Crystalline of East Greenland.

Before entering on the detail-analyses of the different localities it may be useful to give a short summary of the tectonics of both coast sections on the eastern and on the western coast of Liverpool Land, so far as they are known. These sections cut the general axial-trend of the main-folding of the gneisses at an angle of on an average about 40°, in the central parts around Cape Greg about 90°, and the coast-line therefore gives a fairly good cross-profile of the formations.

On the east coast the dominating element is formed by the granodiorite-area; in the south limited by the paragneisses of the south-coast, in the north by the gneisses of Cape Greg. Seen from the sea, the folding in the last-mentioned formation is very strong and directed northward with lying folds; in the former the deformation also is considerable although the visible folds are less conspicuous. The folds seem here mostly to be directed southward, in other words away from the granodiorite-mass.

North of the Cape Greg-gneisses follows the granite-area of Store Fjord, with post-orogenic granitic injections cutting through the folding of the gneisses. As a typical gneissic element we here have the gneisses of the Frydendal Valley and of Polyp Harbour, representing strongly tectonized elements.

At Polyp Harbour, up to Cape Topham, granodiorites again appear, partly cutting through the gneisses, and with large granitic margins. From the fjord-area inside Cape Topham (S.) the gneisses, which generally seem to be of the same type as in the region of Store Fjord, have been folded into steep anticlines and synclines, and therefore generally show a very steep dip of the schistosity. This tectonic style continues up to the north end of Liverpool Land.

The southernmost part of the coast of Hurry Inlet is occupied by the garnet-pyroxene-gneisses of Hurry Inlet with generally horizontal schistosity. They do not correspond to any of the formations found on the east coast. This is the case also with the granites of Hurry Inlet, which compose the following formation northward. After this completely postkinematic intrusive body, follows the migmatitic gneiss north of Hurry Inlet, which as to its general tectonic character in some degree

resembles the gneiss from the regions south of Cape Topham, but which cannot with any certainty be connected with any other formation.

Farther north, the western boundary of Liverpool Land was met with, west of Store Fjord, but here was only found a granite which corresponds in every respect to the young granite of Hurry Inlet.

The feature which strikes the explorer accustomed to migmatite-regions of Archaean type is the dominating, more or less horizontal schistosity, pointed out already by BACKLUND (1) from the northerly parts of the Caledonian mountain-folding region of East Greenland. With but few exceptions, the folding-axis is also, if not horizontal, in every case very flat. This position can be explained either as depending on an original horizontal primary layering, which at the granitization has been altered into crystalline schist-layers, or else on the origination of horizontal shear-movements during the orogenic events of the region.

In the following the conditions at the localities treated in the foregoing will be discussed more in detail.

The Gneisses of the South Coast.

The tectonics of this complex are too complicated to have allowed of anything but a very superficial orientation at some short landings particularly on account of the comparatively low coast with drift-covered hills, which give but few larger cross-sections visible at a long distance. The observations here are therefore mainly limited to the small-scale kinetics and the relation between the injection and the differential-movements within the localities visited.

The gneiss-layers of the south-coast seem to form a number of big, for the most comparatively low anticlines and synclines and between them areas with more complicated small-foldings. The type of folding is characterized by the fact that flat-lying schistosity dominates. By the side of this general position of the layers, also steep or vertical dips have an extensive distribution in certain strikes, while dips of the more gentle slope of 30°—60° are rare. In other words, the folds have a shape which is reminiscent of the Jura-Mountains, according to the interpretation of BUXTORF, with "Koffertfalten" and small overthrusts. This comparison of course relates only to the shape and not to the tectonics in general.

The strike is mainly north-east—south-west, which also gives the main-direction of the folding-axes of at least the small folds. The position of the last-named is nearly horizontal, though slightly undulating, forming flat depressions and culminations. A longitudinal-profile from Cape Hodgson southwards gives a north-easterly pitch as far as Cape Svainson; at Cape Tobin it is on an average south-westerly;

west of Rosenvinge Bay it is almost horizontal and at Cape Hope again north-easterly.

In the region of Cape Svainson—Cape Hodgson the cross-profile gives a rather steep folding, which also is found in the easterly parts of the peninsula of Cape Tobin. Steep positions of the dip predominate. On the westerly part of the last-named peninsula, up to the neighbourhood of the colony of Scoresby Sound, the layers are rather flat and here seem to form a (possibly several) dome-like fold which can be traced

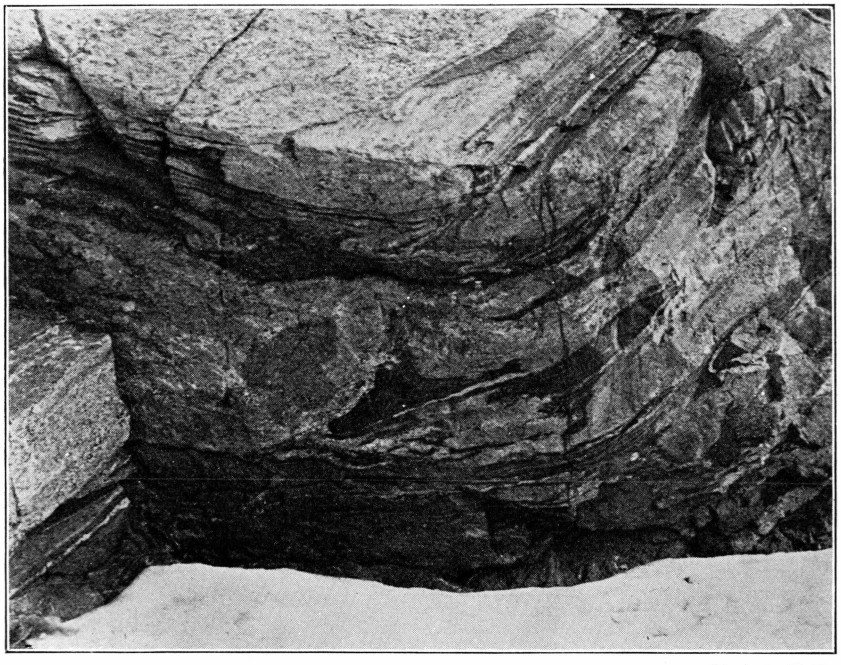

Fig. 18. Photo E. H. K.
Differential folding in gneiss from Cape Tobin. Height of the rock about 2 m.

as far as to the east coast, north of the diorite occurrence of Cape Hodgson. In the neighbourhood of the colony there are a number of small, partly rather steep folds. In the innermost parts of Rosenvinge bay a very steep upfolding of the strata is seen. In the north-westernmost section, seen at Cape Hope, the schistosity generally lies flat, but with strong small folding.

The data given above, however, only indicate the main lines of the structure, and evidently represent only the latest stage of the folding. The style described above corresponds to a rather superficial folding, where the plasticity of the rock-material was comparatively small, and coincides badly with the highly granitized character of the rock-ground.

The explanation of this contradiction is, however, found during the detailed investigation of the kinetics of the region.

It has been shown (p. 21) that the gneisses of the south coast represent a typical injection complex with a strong granitization of an old sediment formation. As in every complex of that type, we also here have a very complicated differential-folding, often with very soft forms recalling flowage, which were formed in connection with the granitization. The two photographs, Fig. 2, p. 24 and fig. 18, p. 93, give a better idea of the character of this folding than does any description. Fig. 2 in especial demonstrates a type of deformation which undoubtedly has taken place in material which posessed a comparatively high degree of plasticity. The pictures are taken from Cape Tobin, but the same style is found, though less abundantly, at Cape Hope and at other places. The plasticity is evidently connected with the granitization, which has lowered the resistance against the orogenic forces, both by raising the temperature and by addition of more fluid material. Similar conditions have been described from Greenland by BACKLUND (2.) and from migmatitic regions in Scandinavia, particularly by SEDERHOLM 45, 46, WEGMANN (54.) and the author (23). The synchronism between the movement and the injection can be seen from the behaviour of the aplite and pegmatite veins. They are partly intruded *lit par lit* between the rolled-out gneisses and have been deformed together with the latter.

In part the veins cut the gneiss-layers, but have nevertheless been deformed by the continued folding. This type of folding has generally only slightly affected the rock-structure, and has not given rise to mylonitization and conspicuous parallel-structures.

In certain areas, more particularly in the region of Cape Hope and the Colony of Scoresby Sound, but also on other localities, we find as the typical feature a strong linear-schistosity, combined with a pronounced shearing, which is seen both in the gneissic and in the granitic elements, and even in the youngest pegmatites of the region. It is quite evident that after the last granitic injections a fairly strong interior movement occurred, a movement which after all was not intense enough to remove all the older structures, but which as the last one has given the complex those features which at first sight perhaps may be most conspicuous. Such linear structures have generally been connected with a comparatively high brittleness and less fluid character than lamellar-structures and particularly the types of structures described in the foregoing. The last-named seems consequently to belong to an earlier stage of the tectonic development of the rock-ground than the former.

The linear structure is generally more developed in certain strikes. At the colony of Scoresby Sound it is *e. g.* well developed in the hills behind the settlement, but is scarcely noticeable in the coarse gray

gneisses farther westward. This depends partly on the lower resistance of the granitic gneiss, but also on the greater activity, in certain sections of the gneisses, of the last movements to which it is due. The action seems to be stronger where the great folding described above is characterized by comparatively small dimensions. Here kataclastic structure sometimes is clearly visible under the microscope, although real mylonites are lacking. At this stage the flaggy habit of some of the gneisses originated (*i. a.* Cape Svainson). The deformation caused by the latest movements, which also have influenced the youngest pegmatites, often has more the character of a brecciation than of a deformation with origination of parallel-structure and glide-planes.

In other words, we can distinguish at least two different deformations, one plastic, coinciding with the granitic injection, and one semiplastic, which broadly speaking is later than the last-mentioned or contemporaneous with the last pegmatite veins of the region. We need not say that these deformations were gradual and may belong to the same great folding cycle. The latter of these two deformations seems mainly to be connected with the simple great folding of the region.

We still have to deal with the question whether the sediments were deformed already before the granitization of the area took place. It is rather difficult to answer this, on account of the length of the last period of granitization and the possibility of several phases of granitic injections. The petrographic description, however, shows that the last crystallization, giving rise to *i. a.* the lamell-quartz, is probably later than the orientation of at least a part of the biotite, which probably reflects an earlier stage of deformation (p. 22).

In every case the deformation of the gneisses is so strong that only an intense internal shearing (Durchbewegung) can have given rise to it, and this means that the present position of the layering of the gneisses, also where they lie more or less horizontally, is not the original one. They have probably been tectonized and recrystallized in a considerable degree already before the occurrence of the last movement, which is responsible for their present position.

Of some importance is further the date of the origin of the type mineral of the region, the cyanite of the paragneisses. The mineral is orientated along shear-zones within the gneisses, and the grains have evidently been in some degree removed after their first crystallization. In other words, the mineral is at least slightly older than the latest movements and probably coincides with the later stage of the granite-injection, when the rocks already in some degree had lost their plasticity. The eclogitic composition of the basic dikes of the area probably can be referred to the same stage of development. They are also only slightly

influenced by the tectonization, less than the eclogites of the garnet-pyroxene-gneiss area farther north.

We have in the foregoing left out of consideration the question about the direction of the movement. The observations give in fact no definite answer to this. In most places where overturned folds have been observed they have the plane of folding inclined toward the south-east, which indicates that the movement, at least at one stage, was going on in that direction. This, however, may be a local folding-direction depending on the inhomogenity of the folded material.

The tectonic events of the gneisses of the south coast can be summarized in the following points:

1. Early post-granitic tectonization. The structures originated are covered by later movements, except for some general features.
2. Granite-injection-phase of long duration with contemporaneous folding.
3. Injection of cross-cutting pegmatite and aplite-veins.
4. Late and post-granitic movements, connected with strong recrystallization, but with semiplastic style of folding. A southerly direction of folding was probably the rule during the earlier stages of this phase.

The Garnet-Pyroxene-Gneiss of Hurry Inlet.

The tectonic structure of this area has been the subject of discussion in connection with the treatment of the origin of the garnetiferous rocks It was found that the present structures have probably originated in connection with strong, almost horizontal movements in the rock-ground. So far as can be judged from the character of the gneisses, these movements were younger than the main-movements in the area described in the foregoing chapter.

Taken as a whole, the garnet-pyroxene-gneiss area consists of comparatively flat-lying schist-layers, with local foldings. The pitch is generally flat, but undulating in detail, forming a number of culminations and depressions, of dimensions rarely extending more than some hundreds of metres. The axial-dip is nowhere more than 5—15°. Of great interest is the general axial-direction, on account of the variation from that of the gneisses of the south coast. (p. 26). In the last-named it was north-east—south-westerly; in the gneisses now in question it was determined as north—south over all (a great number of determinations). This direction also corresponds to the linear-structure and the pitch of the differential-folding of the gneisses.

It has already been mentioned that the typical garnet-pyroxene-gneisses with their very characteristic mineralogical composition are

underlain by more normal migmatitic microcline-gneisses. These gneisses had, on the localities where they were observed, the same north-southerly axial-direction, showing that they tectonically still belong to the same complex.

The character of the tectonic movements is elucidated by the detail-tectonics and the microscopic structures of the area. Compared with the gneisses described before, they show a still more pronounced out-drawing of all the structures. It is particularly well visible in the gray gneisses, in which all the veinlets have a tendency towards an elongation along the plane of schistosity. Excluding the young cross-cutting veins, structures forming a greater angle with the general shear-direction are remarkably rare. Differential folds are therefore almost absent, with the exception of the small ptygmatic folding of the veinlets in the gneisses. The formation is iu other words flattened out in a still higher degree than in the foregoing region. It is of importance that mylonitic structures and other structures depending on a disintegration of the rock-constituents after the last crystallization are far more common than on the south coast. (*cf.* the structure-analytical investigation by SAHLSTEIN (42). However, also here they are limited to certain zones, and typical "paracrystalline" (*cf.* SANDER 43.) structures are far from rare, forming rather the rule than an exception. The behaviour of the mica-flakes has been pointed out in the foregoing (p. 95.) and is shown in the most elucidatory way in the structure-diagrams of SAHLSTEIN (42).

The combination of a pronounced rolled-out structure on the one hand and the absence of visible differential-folds on the other, can only be explained as depending on a strong tangential movement, with shearing under a considerable stress, at which all the small folds and older cross-cutting veinlets have been fitted in the same dominating parallel-orientation. It is here impossible to decide in which direction the movement has gone: east to west or west to east.

An extreme development of the shearing is found in the granulite-zone north-east of Cape Hope (p. 31). Here the deformation has given rise to schistose rocks where the less resistant components have either been completely mylonitized — in such places the movement was more rapid than the recrystallization — or then new-crystallized in grains orientated along the shear-planes. In the latter case the new-crystallization kept pace with the movement (*cf. i. a.* WENK 57. and the author 23.). The schist-zone here in question is evidently a thrust-plane where the movement has continued after the mainpart of the complex had reached a comparatively high degree of rigidity. The movement was undoubtedly later than the granitization which has influenced particularly the eastern parts of the gneiss-complex.

The situation of this mylonite-zone on the boundary of the garnet-pyroxene-gneisses and the migmatitic gneisses of the south coast at a low altitude, only about 100 m above the sea-level, leads to the conception that it forms the lower border of the first-named formation.

A closer examination of the mylonitic layers gives support to the suggestion that the movement here lasted after it had ceased in other places. In connection with the mylonitization, we have also a coarse breaking up of the gneisses into big fragments, which again have been enfolded and outdrawn at the continued tectonization. Also in these fragments the rocks are often exceedingly strongly tectonized — before the brecciation —. The same conditions are, as we have seen earlier (p. 45), found also in the normal garnet-pyroxene-gneisses, but there the structures point to a far more gradual deformation.

Before entering on the question of the relative age of the movements, the mechanics of the igneous intrusions of the area have to be considered.

The probably synkinematic intrusion of the eclogitic greenstones has already been pointed out (p. 40), and also the later transformation of these ultrabasic rocks.

Within the garnet-pyroxene-gneisses the granitic injection plays a much less prominent rôle than in the gneisses of the south coast. The absence of injections of the common synkinematic character can be explained in two different ways. 1. The gneiss-complex has never been granitized. 2. The structures originated at the granitization have been removed at the last strong tectonization.

A complete absence of granitization can hardly be combined with the petrological character of the rock-types described in the foregoing (p. 33). Many of the veins with potash-felspar and quartz are without doubt of igneous origin, but have been altered in the way assumed in 2. In the marginal parts of the complex, particularly in the eastern section northwest of Scoresby Sound, we have mentioned rock-types influenced by a strong granitization.

But on the other hand, if we examine the mineralogical composition of the great majority of the rock-types, it undoubtedly is difficult to explain under the assumption of an intense addition of granitic material, at least in comparison with the other gneisses of Liverpool Land. The scarcity of potash-felspar and the dominating rôle played by quartz seem to indicate a fairly complete preservation of the original sedimentary composition, also if we take into account the possibility that the felspar partly has been altered into biotite.

The field-observations consequently indicate that the complex as a whole has been influenced by a granitization, but that only the marginal parts have been to any considerable degree injected by granitic material.

The scarcity of injections in the typical garnet-pyroxene-gneisses depends upon their position in the outer parts of the contact aureole. A contributory circumstance has possibly also been that the gneisses represent one or several thrusts and the rocks in a certain degree are allochtonous, and have in part later than the underlying formations been influenced by the intruding plutonites. In any case the influence of the last-named on the garnet-pyroxene-gneiss complex has mainly been a rising of the temperature. This in addition to the strong contemporaneous shear-movements has caused the strong metamorphosis of the rocks.

We here enter upon the question as to the cause and time of the metamorphosis which has given rise to the present mineralogical composition of the rocks of the region.

The author has already before pointed out the possibility that the great granodioritic intrusions and related granites differentiated from the same magma, though not necessarily intruding at the same time, might be the agents giving rise to the mineral-combination here. There are several reasons pointing to this. First of all the same type of metamorphosis seems to be abundant, mainly in the surroundings of the granodiorite-mass of the east coast, which we can assume also extends underneath the gneisses of Hurry Inlet. If we further take into account the granitic rocks which seem to belong to the same cycle of intrusion the zone of activity becomes still more extensive.

In this zone we have the eclogites and the garnet-pyroxene-gneisses of Hurry Inlet with garnets (pyrope-almandine), hypersthene, andalusite and other minerals, the gneisses of the south coast with cyanite and garnet and the limestone north of Rosenvinge Bay with skarn minerals and graphite.

Where the paragneisses have been intruded by the granite itself hornblende-bearing varieties with almanditic garnet predominate. Also the cyanite seems mainly to belong to the innermost aureole, whereas the combination mentioned above mainly belongs to the outer zone where the shear-movement was strong in comparison with the recrystallization.

The granites intruding in the boundary-zones of the gneiss-complex of Hurry Inlet are probably for the most part later than the granodioritic intrusions (*cf.* p. 107). The relation of the last-named rocks to these gneisses is, however, evident on account of tectonic observations. There exists, as already mentioned, a fairly strong tectonization in the granodiorite, which after all is conspicuous only in its marginal parts. At Cape Hodgson, on Raffles Island and on the west end of Rathbone Island the pitch of this deformation was clearly north-southerly, *i. e.* coinciding with that of the Hurry Inlet gneisses. The granodiorite has therefore

been affected by the same late phase of deformation as the last-named, and consequently intruded before or in connection with the earlier stages of this movement. The deformation of the south coast is evidently older, but it is quite possible that the main part of the granitization coincides with that of the Hurry Inlet gneisses, although the tectonization here has continued after it had ended in the southern gneisses.

This opinion about the tectonic position of the garnet-pyroxene-gneiss area of Hurry Inlet is illustrated by the schematic stereogram, fig. 19.

Of the post-kinematic intrusions the numerous pegmatitic and aplitic veins are the most important. They have not taken part in the tectonic events of the region and must therefore at least for the most

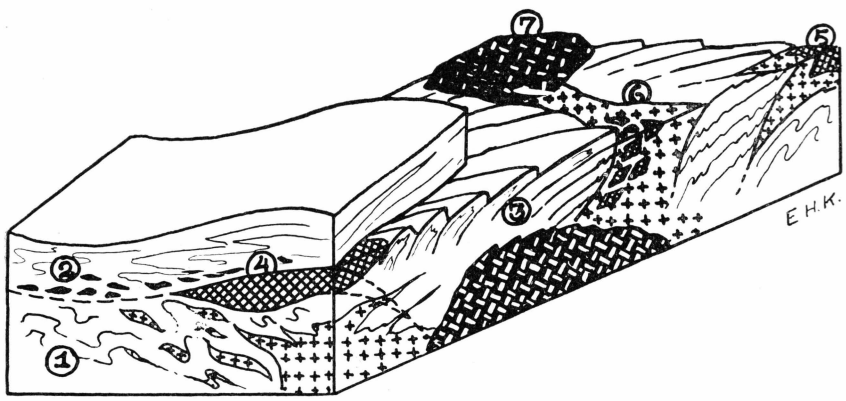

Fig. 19. Schematic stereogram illustrating the tectonic relation between the rock-formations of South Liverpool Land, according to the explanation given in the text. 1. The migmatite gneisses of the south coast. 2. The garnet-pyroxene-gneisses of Hurry Inlet. 3. The gneisses of Cape Greg. 4. The granodiorite of Rathbone Island. 5. The granodiorite of Cape Smith. 6. The Store Fjord granite. 7. The Hurry Inlet granite.

part be referred to granitic injection later than those of the south coast. The petrographic character indicates their relationship with the Hurry Inlet granite north of the gneiss-area. In every case there is a great hiatus between the intrusion of these pegmatites and the earlier injections which have been intruded before the tectonization.

Of post-kinematic dikes of basic composition we only have to mention one single diabase-dike from the coast of Hurry Inlet in the northern part of the area, but several more will undoubtedly be found in the future.

According to the opinions expressed in the foregoing, the tectonic development of the garnet-pyroxene-gneiss area of Hurry Inlet can be summarized as follows:

1. An old complex of psammitic sediments was tectonized and partly injected by granitic solutions. This, the first phase of orogeny, can evidently be parallelized with the migmatitization of the gneisses of the south coast, although the granitization at Hurry Inlet was less prominent.

2. In connection with tectonic movements (beginning of the second phase of orogeny) ultrabasic greenstones were intruded, and consolidated as deep-seated rocks (ophiolites).

3. A new orogenic action, (from E. to W.) in continuation of the foregoing, rolled out the granitized psammitic gneisses and broke up the resistant basic rocks into pieces, forming big breccias. The ophiolitic intrusions are followed by synkinematic intrusion of granodioritic rocks (on the west coast) and granite. In connection with these plutonic intrusions and the strong tectonization the rocks of the complex were metamorphosed. The ultrabasic greenstones were altered into eclogites, the gneisses into garnet-pyroxene-gneisses.

4. In certain zones, particularly in the undermost parts of the gneiss-complex, the movements continued as over-thrusts and gave rise to *i. a.* the granulites north-west of Cape Hope.

5. Post-orogenic intrusions of granite- and pegmatite-veins, probably deriving from the Hurry Inlet granite mass.

The Tectonics of the Gneisses of Cape Greg.

The foregoing formations have been treated in comparatively great detail, in order to bring forward the questions which in the present state of our knowledge of the geology of Liverpool Land can be at least in some degree cleared up.

The same problems meet the explorer also in the other parts of the region and in the following can therefore be described more shortly. Concerning several questions we may refer to what has been mentioned in the foregoing.

North of the diorite area between Raffes Island and Glasgow Island a gneiss-area occurs which from the tectonical point of view is the best exposed of the investigated sections of Liverpool Land, mainly on account of the splendid profiles afforded by the steep cliff-walls of the east coast.

The position of the layers and the tectonic style of the coast between Glasgow Island and Cape Greg is shown in Fig. 20. The main-folding has the character of a system of recumbent folds turned over to the north. They have been rolled out in an extremely high degree, lying in the northerly section almost horizontally, and therefore from a short distance appear as a horizontal stratification.

The position gradually changes from south to north. At the southern contact with the granodiorite massif at Glasgow Island, the folding has

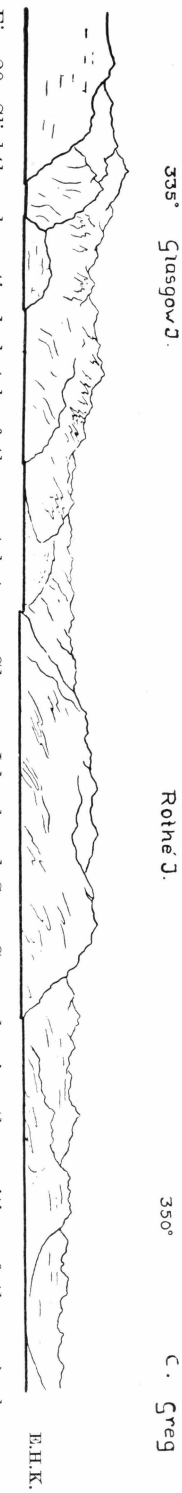

Fig. 20. Slightly schematized sketch of the coast between Glasgow Island and Cape Greg, showing the position of the gneiss-layers.

given rise to a number of composite anticlines with an almost vertical position of the plane of the folds. Towards the north they are gradually turned over until they at Cape Greg become horizontal, and farther north have in part the character of flat downfolds (BAILEY). The highly outdrawn condition of the folds is best illustrated by Fig. 20, p. 102.

The style reminds one in some degree of the Helvetic nappes of the Alps on a small scale but must, as the kinetic conditions indicate, be explained in a slightly different way.

When studied in detail, complicated small-folding is found in several cases, though in most instanees it is almost covered by the strong parallel-schistosity. The structure of the rock always shows a lamellar schistosity — in contrast to the gneiss-areas described before-linear structures are here almost absent. In hand-specimen the strong recrystallization (paracrystalline) structures give the gneisses an almost massive, granitic appearance. Fig. 21 shows the typical, small-tectonic style of the gneisses of Cape Greg, at a place where the out-rolling is very strong.

In these gneisses the big fragments of dark amphibolite are very conspicuous. On account of the sharp edges of the inclusions they resemble at first sight eruptive breccias. However, a careful study of the excellently exposed cliff-walls at Cape Greg, gives a good demonstration that this brecciation is purely mechanical, and only indirectly connected with the granitic injections. The tectonic style proves that the gneiss-layers were very plastic during the orogenic events which have given them their present position. It lies close at hand to connect this plasticity with a mobilization through synkinematic granitic injections on a large scale, mainly in the form of an intimate lit par lit injection, combined with an intense metasomatic replacement of sedimentary material through microcline, quartz and other granitic minerals. Nowhere within the area does one meet with pure granite, a circumstance which several authors (WENK 57.) with good reason have regarded as evidence of synchronity of the tectonization and the injection. Therefore also the

last recrystallization and the movement generally were contemporaneous; the former in most cases continued after the finishing of the latter, and gave rise to the coarse crystalline structures of the Cape Greg gneisses.

Compared with the acidic gneisses, which are very mobile, particularly at a high temperature, basic amphibolites were much more resistant and were broken up — in the same way as we already have found from the eclogite-area of Hurry Inlet, where, however, the tectonization was very much stronger (p. 26). The fragments drifted with the flowing differential flowage gneisses and were arranged in rows or seemingly irregularly scattered within the layered gneisses. Fragments from originally the same amphibolite-layers can therefore be found several hundreds of metres from each other and often in different horizontal layers (*cf.* fig. 15).

The gneisses contain a great number of granitic veins of several generations, the older ptygmatically folded, the younger cutting straight through the formation. During a later stage of the injection, when the rigidity of the complex already was fairly high, the pegmatite-intrusions have often taken place in connection with so-called boudinage structure (4. fig. 15). The importance of these structures in metamorphic rocks has been excellently elucidated by WEGMANN (55.), CORIN (9) and also RAGUIN (34) and it is therefore not necessary to enter upon this question here.

During the last stage diabasic dikes have intruded, which have been but slightly influenced by the deformation.

In Fig. 15 the kinetic development of gneisses of the Cape Greg type has been illustrated through some cross-sections in slightly schematized drawings.

Stage 1. The basal formation was folded in connection with lit par lit injection of pegmatite.

Stage 2. Plastic deformation of the mobilized gneisses. The structures are drawn out into almost horizontal layers. The less plastic greenstones are brecciated.

Stage 3. The rolling-out of the formation is continued, with differential-movements and origination of new S-surfaces, along which new granite- and pegmatite-veins find their way. The older pegmatites are ptygmatically folded on account of shortening of the vertical dimension. Intrusion of cross-cutting basic dikes.

Stage 4. Semiplastic deformation with boudinage structure in the schist layers, and origination of flaggy cleavage along S-surfaces. Intrusions of young post-tectonic pegmatites.

This type of kinetics within migmatite-areas is of course not restricted to Greenland. The interpretation given above mainly coincides

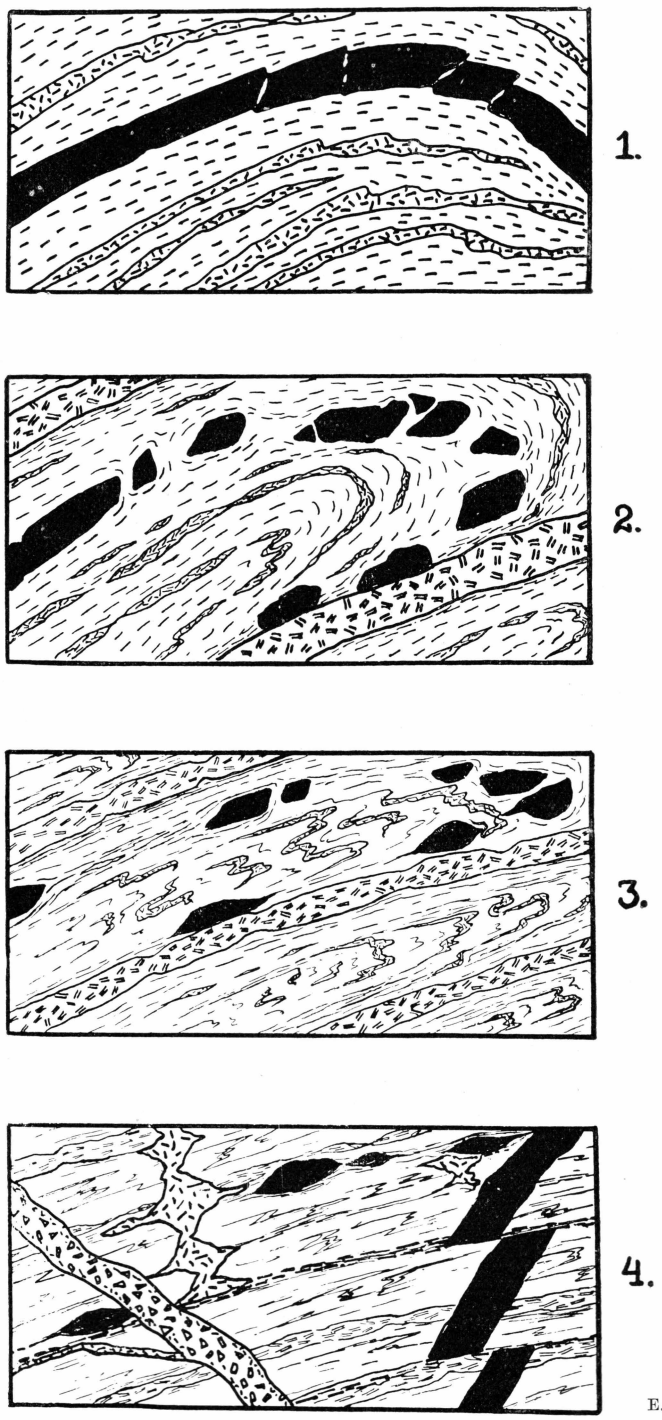

Fig. 21. The kinetic development of the gneisses of Cape Greg referred to on p. 103.

with experiences collected from migmatite-regions in Fennoscandia, especially from the south coast of Finland, where the kinetics of the injection-phenomena have been more conclusively described by WEGMANN than is the case from any other parts of the world. (53.). BACKLUND has investigated phenomena of the same character in the northerly gneiss-regions of Greenland (2.).

READ's descriptions (35., 36.) of the injection-complexes of the northern Highlands of Scotland also give material for various comparisons, although he did not generally pay attention to the kinetics in the same degree.

They are of course of particularly great interest as belonging to a section of the Caledonian folding-range related to that of East Greenland. But, as BACKLUND several times has pointed out, these phenomena can hardly anywhere be studied under more fortunate conditions than in the bare Arctic cliffs of Greenland.

In the foregoing the relative strength of the different stages of the kinetic development has not been taken into account. Evidently there has been at least one great hiatus between the movements, namely between the main-folding and its granitization and the latest granite injection. The present paracrystalline structure of the gneiss has been caused by the last granitization, which on the whole was completely kinematic, and consequently, in comparison to the movements, later than the granitic influence in the gneiss-regions in the south parts of Liverpool Land. As we have seen, there are in the young granite of Hurry Inlet inclusions of para-gneisses which correspond to the gneisses here in question, and it therefore seems natural to combine the last granitization here at Cape Greg with this injection. We consequently have to reckon with two great granitization-phases at the origination of the complex, one of which was contemporaneous with the great folding, while the other was later and has highly obscured the rock structures caused by the first granitization.

The main-folding is probably contemporaneous with the granitization of the gneisses of the south coast.

The Tectonics of the Store Fjord Region.

As already pointed out, the granite of Store Fjord has a decidedly syntectic character and assimilates older rocks, probably on a grand scale. At least the latest intruded parts of this great granite complex are but little affected by tectonic deformations. So far as we know the southern contact with the Cape Greg gneisses is an assimilation contact, the granite penetrating and assimilating the gneissic material. The main part of the included material is, after all, not gneissic, but rather of

dioritic composition, indicating that the first intrusions on this place were dioritic.

It seems natural to connect the granite of Store Fjord also genetically with this diorite, in the same way as we have done with the southern diorite intrusion and its granitic margin, although here the granitic part, probably due to the more deep-seated character (the more advanced denudation) plays a more important rôle.

Also the synkinematic granitization of the Cape Greg gneisses has evidently been mainly caused by the same granite, although at a stage before the pure granite had reached the surface.

In the interior parts of Store Fjord we have the young granite corresponding to the Hurry Inlet granite, giving good support to the theory of the double granitization of the rock-ground of Central Liverpool Land.

The tectonic position of the gneisses of the Frydendal Valley on the southern shore of the Fjord (p. 58) is very difficult to explain on account of its isolated position. The petrological character of the rocks, particularly the type of deformation, shows several features recalling the Hurry Inlet gneisses, but on the other hand the high-temperature structures are lacking here.

The schistosity is horizontal and gives evidences of strong shearing; the pitch is about north-south. Unlike the gneisses of Cape Greg, most layers here are almost mylonitized, in every case showing well developed post-crystalline deformation. Microscopic investigation indicates only a slight recrystallization after this movement.

The gneiss is penetrated by both the granites. The eastern contact with the Store Fjord granite is tectonically interesting because the granite in the neighbourhood of the contact has developed a very coarse porphyric structure, grading into "Augen"-gneiss structure (*cf.* p. 59). It evidently has originated in consequence of movements at the contact in connection with the consolidation of the magma. This orthogneiss structure is sub-parallel with old structure of the gneiss-complex and therefore probably belongs to the same cycle of orogenic movement, and as to time we consequently are justified in putting the intrusion of the Store Fjord granite very near the deformation of the gneisses.

The relation to the younger granite is illustrated by the big inclusion of gneiss opposite the Fjord. Here the gneiss-structure is abruptly cut off by the massive granite.

Of importance for the interpretation of the tectonics of Store Fjord are also the pegmatites cutting the granite in the steep cliff-walls, particularly in the other parts of the Fjord. There are several generations cutting each other and evidently in part belonging to the younger granite. The most prominent of these veins appear in the east-westerly wall as

fairly horizontal bands. They dip 30—40° to the north or north-east. South of Store Fjord, the author got the impression that the dikes generally had a southerly dip, which means that the Fjord is situated in a kind of "culmination", in an arch of fractures injected by the pegmatites. It evidently coincides with the central part of the igneous body and depends on the principal direction of strain during the last stage of its consolidation (*cf.* CLOOS etc.). The observations are still too scanty to allow of any further conclusions according to this method of investigation, used especially by BALK in several investigations (4.5.), but here it would undoubtedly give good results.

The Tectonics of Liverpool Land north of Store Fjord.

The observations from the northern part of Liverpool Land are very incomplete, and are restricted to a few points, particularly in the region south of Cape Topham.

South of Polyp Harbour the tectonics of the Frydendal Valley of Store Fjord seem to be repeated. We here have almost similar highly parallel-laminated, deformed gneisses, which with good reason can be regarded as the continuation of the last-mentioned formation, although they petrologically contain more amphibolitic material and altered limestone than do the former.

The contact with the Store Fjord granite shows also here the coarse porphyric character grading into "Augen"-gneiss-like rocks

On the north side of Polyp Harbour the diorite area of Hildegard Island affords an opportunity to study the mechanics of intrusion of this granite. As a typical feature we have to mention the absence of any direct contact between granodiorite and paraschists. All along the border of the diorite rocks we find a pink, more or less pegmatitic, microcline-granite originating a broad injection-zone, which outwards grades into the gneissic rocks forming typical migmatites. Towards the diorite contact it has a dioritic appearance and composition, but the hornblende and biotite are generally in some degree parallel-orientated. The granitic rocks correspond petrologically to the contact-varieties of the Store Fjord granite and also its stratigraphical position is almost the same. Whether this granite is differentiated from the same magma as the granodiorite or forms a later independent granitic intrusion, is impossible to decide at the present stage of the investigation.

This type of obscured contacts around granodiorites of this kind seems to be almost the rule and has been described from the most different areas, both in older and younger formations. We find it around the Precambrian granodiorite of Fennoscandia, around the Caledonic diorites in Scotland (34. 35. 36.) and in Scandinavia, around the diorites of the American Cordillera and so on. This circumstance points to a relationship

between the microcline-granites and the granodiorite, at least in so far that they might belong to the same cycle of intrusion, or in other words to the same orogenic sequence. There seem, however, to exist some differences as to the mechanics of intrusion of the two magma-components, depending on local circumstances. The relative difference in time of the two intrusions varies, depending on whether the differentiation happened before the magma had begun to move upwards under the influence of the orogenic actions or not until it already had mainly got its definite position. In the latter case it could differentiate and consolidate more or less *in situ*. As a comparison the author here wishes to refer

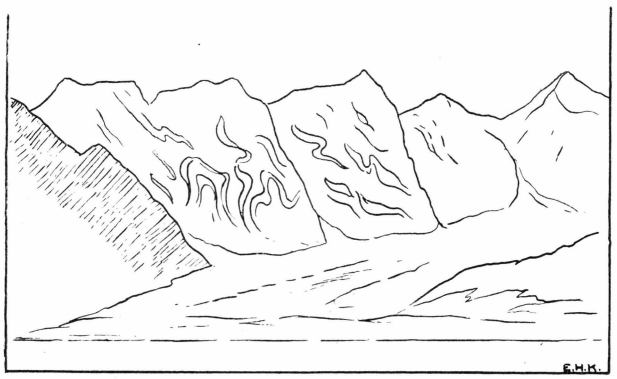

Fig. 22. Folding in the gneisses north of Cap Greg.

particularly to the description by READ of the Strath Oykell granite (35.) and some other similar localities.

Personally, the writer has earlier touched upon this question in connection with the description of the Andean diorites of Tierra del Fuego.

In the case here in question evidently quite a long time elapsed between the intrusion of the diorite magma and the intrusion of the granitic magna. The former was already consolidated when the granitic magma intruded. Due to the granitic intrusion it cannot be proved whether the contact between the granodiorite-body and the gneisses originally was an igneous intrusion contact or a tectonic contact.

On the west coast of Terminal Sound (*cf.* the map) opposite Hildegard Island, the gneisses rest under the diorite. The diorite therefore seems to form a comparatively thin lens- or sheet-like body intruded in the gneisses. At any rate it was intruded after the gneisses got their present parallel-structure.

North of the diorite-complex there is a sudden change in the tectonic style of the gneisses. The layers become far more folded and also the granitization is considerable, particularly in the inner parts of the fjord

area, inside Trekanten Island. Opposite Cape Fennia (*cf.* the map) the layers form a big anticline turned over to the north. The kernel of the anticline is composed of almost white limestone or dolomite. Seen from the sea the tectonics in some degree resemble those of the coast at Glasgow Island.

The granitization of this region is interesting on account of its clearly post-tectonic character, in comparison with the big folding of the area. Opposite the limestone-occurrence named above, there is a series of highly granitized gneisses, situated in the direction of the folding-axes of the limestone, composed of rocks rich in red garnet and sillimannite, with inclusion of almost eclogite-like "Schliers" of garnet-fels. The latter here evidently have the character of skarn-rocks, originated at the assimilation of limestone within the granite (*cf.* p. 61).

The big folding of Inder-Fjord continues also north of Cape Topham. The style here is shown by fig. 16. No landing, however, was made along the northernmost coast section, and we were only able to state that the gneiss-layers here generally have a very steep dip and are strongly folded.

At Cape Topham a system of big light-pinkish schists dipping north-west penetrates the dark gneisses.

At Murray Island the most conspicuous feature of the gneisses is the kataclastic deformation, which gives the rocks a character highly resembling the so-called leptites of the Scandinavian Precambrian. The linear schistosity is strongly developed. The dip is varying, but always steep, the pitch is almost horizontal.

Summary of the Tectonic and Stratigraphic Sequence of the Rock Formations of the Crystalline of Liverpool Land.

The parallelization of the different regions described in the foregoing can as yet only to a limited extent be made with some degree of certainty. On account of the complicated tectonic conditions great care must be taken in the comparison of the rock-types, both of the former sedimentary rocks and of the igneous rocks of the crystalline complex. The metamorphosis and the degree of granitization is generally too strong to allow of any subdivision in detail and we therefore only wish to find out some features of the geologic development of the Crystalline of Liverpool Land.

The parallelization can be made according to 1. the lithological similarity, 2. the sequence of the tectonic movements, 3. the sequence of the igneous intrusions. Both the latter phenomena are closely dependent on each other. On account of the circumstances mentioned above, the

lithological similarity can only to a very limited extent be used in the comparison.

We have found within every gneiss-terrain investigated one strong injection of granitic material in connection with strong orogenic action. This was particularly noticeable in the gneiss-region of the south coast and also in the Cape Greg region and in the southerly sections of Liverpool Land. This phase of granitic intrusions has been compared with the granites of group 2 of SEDERHOLM from southern Finland (p. 87). It evidently can be parallelized with similar phenomena described by BACKLUND and KOCH from Hochstätter Foreland, Clavering Island, Kempe Fjord and other similar gneiss-areas of the northerly parts of East Greenland (2,21). This great syntectonic injection has caused a high degree of plasticity of the sediments intruded, and the deformation and folding therefore is characterized by an abundance of soft, almost flowing forms. On account of the comparable behaviour of these injections there seems to be warrant for regarding them as synchronic.

Also earlier granitic injections have possibly occurred, but here they can hardly be taken into account, on account of the dominating later injections.

In the gneiss-areas mentioned above, we have, in addition to tectonic movements connected with the granitization, as a rule also a later semiplastic deformation with a more pronounced shearing, and, as the last stage, movements *en bloc*. They have been specially pointed out from the south coast and from the Cape Greg gneisses. To the same (second) stage we evidently also may refer the strong tectonization of the garnet-pyroxene-gneisses of Hurry Inlet, and also the mylonitization of the gneisses of Store Fjord and Murray Island. The tectonigation has acted with different strength in different areas.

Both the stages named above, however, obviously belong to the same tectonic phase.

A much later phase of movements was pointed out at Cape Greg (p. 101). These movements, which mainly had the character of faults, were probably of less importance. They happened prior to, and possibly in connection with, the last big granitization at the intrusion of the Hurry Inlet granite and the younger granite of Store Fjord.

Broadly speaking, the intrusion of the granodiorites was earlier than the first great granitization mentioned above. All the regions consisting of these rocks are closely connected from a petrological point of view, and they evidently represent the same or at least analogous magmas. It is not necessary to conjecture an absolute synchronism of their intrusion, but after all they belong to the same phase of the tectonic development, and the lapse of time between their intrusion can hardly have been very great. They probably intruded during the later stages of the main-

folding. The most southerly of the regions could be proved (p. 108) to be injected between the both phases of the main-deformation.

The relation to the newer microcline-granites has been treated several times in the foregoing. The granodiorites are evidently older than the most prominent of these intrusions, the big intrusion of the Store Fjord granite, and evidently also than the later phase of the injection in the migmatite-gneiss areas. They probably belong genetically to the same magmatic activity and represent different phases of the same main orogeny of the crystalline of Liverpool Land.

The last plutonic intrusion of regional character is represented by the Hurry Inlet granite and the granite of the inner parts of Store Fjord, but on account of the geological position there is a strong reason to refer it to a much younger phase of intrusion. The generally even-coarse-grained structure is highly reminiscent of several of the young granites of the Scandinavian Precambrian (Group 3 of SEDERHOM), which are composed of plutonic rocks of decidedly post-orogenic character, consolidated at a comparatively high level within a partly cooled earth crust.

The distinct hiatus between the older microcline-granite and the Hurry Inlet granite is *i. a.* proved by the conditions in the garnet-gneiss area of Hurry Inlet (p. 96). In this region we have to do with a phase of movements which is younger than the main-deformation of the gneisses of Cape Greg and the south coast, and which overlaps the injection of the older granite (the Store Fjord granite). The mode of occurrence of the Hurry Inlet granite is here characterized by cross cutting, undeformed pegmatites and aplites.

The author desires to lay stress on the great care which must be taken in investigating the contact effect, and particularly the recrystallization caused by granites. One might *e. g.* at first think of the contact relation between the younger granite and the gneisses of Frydendal Valley. In spite of the close vicinity of the granite, the gneisses here show a typical postcrystalline character; the structure is remarkably well preserved also within inclusions in the granite. On the other hand, we have the gneisses included in the granite west of Hurry Inlet (Nøkkedal Valley) which are completely recrystallized and in this respect greatly resemble the gneisses of Cape Greg.

We have seen that locally a great number of movement-phases can be separated, but the observations are still too incomplete to connect all these phases with each other. The data repeated above and given in the foregoing pages enable us — with every reservation — to summarize in the following way the events which have given rise to the present character of the crystalline rocks of Liverpool Land:

1. The old basal formation consisting of sandstones, argillaceous sediments and lime-sediments with interbedded volcanic rocks, composing a thick series of geosynclinal character, was affected by tectonization and abbyssic intrusions. On account of later orogenic actions and metamorphosis there are probably very few traces left of the earliest of these movements.

The first event which still can be studied in the rock-structure in all parts of the country is the strong tectonization which has given rise to the kinetic structures on the south coast and on the east coast. Owing to contemporaneous granite injection the rocks were comparatively plastic and the tectonics therefore rather complicated.

2. After the first orogenic action there probably were — locally-more quiet periods during which the granitic intrusion continued. From this time derive a great number of basic dikes cutting the older structures (South Liverpool Land).

3. The first phase of orogenic action was immediately followed by an orogenic activity with a less plastic style of the foldings. We find from this stage overthrusts and overfoldings of considerable extent. This has *i. a.* given the gneisses of Hurry Inlet their present shape. In connection with these movements ophiolitic greenstones intruded (Hurry Inlet, Cape Greg, North Liverpool Land).

In connection with the same movements the great intrusions of granodioritic magmas took place. They were followed by granitic intrusions which in the region of Store Fjord and Polyp Harbour reached the earth crust. This granitization can in the field hardly be separated from the foregoing one and possibly derives from the same magmatic activity. The granites probably in part reached the earth crust before the diorites, partly not till later. During this stage the metamorphosis was strong and led to the origination of the garnetiferous rocks of Hurry Inlet and similar formations.

As the latest synorogenic intrusion we have to annotate the diabase-dikes of Cape Greg.

4. The last event of importance in the development of the rock-ground of Liverpool Land was the intrusion of the younger granites of Hurry Inlet and Store Fjord. They affected the older rocks in a considerable degree, as regards the structure and mineral-composition, and also by originating migmatites. This granitization is obviously much younger than the foregoing one.

This scheme of course only represents a first attempt to interpret the development of the rock-ground of Liverpool Land and it is given with full acknowledgement of the incompleteness of the evidence.

There still remain a few words to add about the possibility of a

stratigraphic subdivision of the gneisses of Liverpool Land. From the tectonic description it ought to be clear that such a division presents very great difficulties, and is at the present stage of the investigation more or less infeasible, as, before the tectonic conditions of the whole area are better known, there are no possibilities of deciding the original sequence of the gneisses on every locality.

On account of tectonical evidence we can with a high degree of feasibility conclude that the gneisses of the southern parts of Liverpool Land generally belong to more superficially tectonized formations than the gneisses of the northern parts, but this of course does not say anything about their primary position.

The schists of South Liverpool Land are, as we have seen, mainly psammitic and pelitic, locally with embedded limestones. At Cape Greg the composition was more complex, with interbedding of quartzitic and altered pelitic layers and probably also some limestone. On the whole, both these regions show several similarities. Also the garnet-pyroxene gneisses of Hurry Inlet can be referred to the same group.

The gneisses of North Liverpool Land, including the gneisses in the region of Store Fjord, have in many respects a different character and the writer wishes to leave the possibility open that they in part might belong to another (older?) gneiss-formation forming the bottom of the foregoing.

E. ON THE POSITION OF THE CRYSTALLINE COMPLEX OF LIVERPOOL LAND WITHIN THE CALEDONIAN FOLDING OF EAST GREENLAND

Liverpool Land forms an isolated crystalline area, without any direct connection with other petrologically related parts of East Greenland, and the determination of its position within the formation of the country is therefore difficult. On account of the absence of determinable sediments, the actual age of the gneisses on Liverpool Land is still more uncertain than in the northern parts of King Christian X Land.

The oldest formations which have been determined with certainty are the Eo-triassic layers, resting immediately on the crystalline basement. Between their deposition and the origination of the Crystalline a long space of time must have elapsed, and they do not give any guidance in estimating the age of the last-mentioned. On account of the close resemblance to all these formations it lies close at hand also to reckon the Liverpool Crystalline to the same group. We have here the same type of granitization and the same generally horizontal position of the schistosity with almost flat-lying pitch pointing to tangential movements (*cf.* Backlund 1, 2.).

If we follow the general strike-directions of Liverpool Land, they partly point towards the crystalline areas of the inner parts of Scoresby Sound, partly northward. The small crystalline occurrence of Canning Land mentioned by Noe-Nygaard (28.) undoubtedly belongs to the same formation as the northernmost parts of Liverpool Land. On the whole, the continuation seems to lie mainly in the northerly direction.

The crystalline areas of the east coast of Greenland have been interpreted in two different ways. According to the earlier opinion they should belong to the Archaean. Investigations by Lauge Koch, however, made it probable that they were first originated in connection with the Caledonian movements stated by him. This theory has been supported by the petrographical investigation of Backlund. According to these authors the tectonic movements and the granitization were Caledonian;

the basal rocks are at least for the most part Precambrian. Other authors (WHITTARD, PARKINSON, 33., ORVIN 32., ODELL 31., TEICHERT 50.) prefer to restrict the Caledonian influence to the unaltered Predevonian sediments and conjecture an Archaean age for the crystalline complex, both along the coast and east of the fjord-region. Particularly TEICHERT lays stress on the superficial character of the Caledonian folding of East Greenland, and he does not believe in any more powerful deep-folding connected with granite-intrusions, of the type suggested by KOCH and BACKLUND (*cf.* FREBOLD 14, 15.).

In other words, the mainproblem concerning the Caledonian folding of East Greenland is the same as we at present meet with in most of the older and in part also in later orogenic zones in the world, *i. a.* the question of the relationship between the crystalline section and the unmetamorphic section of the folding zone. We meet with it in the Hercynic region in Moldanubicum, in the Caledonides of Scotland, in the Precambrian Carelides of Finland, in the eastern sections of the Alps, in the southernmost parts of the Andes of South America and so on. Quite recently several authors have put forward the opinion that the crystalline sections of such folding areas, in contrast to earlier interpretations, must be regarded as belonging to the folding-structures of these cycles and not as old resistant areas.

The existence of old resistance blocks in the same region as later formed crystalline complexes in many cases makes the definite solution of this problem very difficult. On the other hand, the occurrence of such crystalline structures, originated contemporaneously with the folding, can hardly any longer be denied. The boundary between the crystalline and the unmetamorphic parts of the orogene does not necessarily mean the boundary between a folding-zone and an old resistant block. It is of less importance if the crystalline originally was an old complex which was folded within the new folding, or if it originated in connection with plutonic intrusions and strong metamorphosis of the geosynclinal sediments of the folding zone.

When considering the Crystalline of Greenland, including Liverpool Land, the reasons for connecting its origination with the Caledonian folding seem to be fairly well founded. The tectonic conditions clearly point to a folding coincident with the folding of the Algonkian sediments and the position of the folding-axes and partly also the style of folding speaks against the interpretation as Archaean structures. This of course might be the case with the more westerly, less known sections. Until further evidence supporting the opposite opinion has been delivered, the author therefore regards also the Crystalline of Liverpool Land as Caledonian, in agreement with the theory of LAUGE KOCH.

The Liverpool Land section differs from most of the hitherto des-

cribed crystalline complexes of the country through its more complicated structure, which points to the possibility that we here have to do with a more central part of the mountain range. The rocks seem generally to be more altered than in the regions earlier described, but nevertheless they offer many points of comparison. The investigations by KOCH, and BACKLUND in especial, demonstrated that the rock-material composing the base of the gneisses in the latter is originated through granitization of sediments belonging to the Eleonora Bay formation, which by KOCH was determined as youngest Precambrian up to oldest Palaeozoicum. This formation consists of quartzite, phyllitic schists, limestone, with uppermost an interbedding of quartzitic layers with phyllitic and calcareous schists (*cf.* BACKLUND 1.). We have seen that this stratigraphy also could be used in the gneiss-area of the southern parts of Liverpool Land in particular.

Of great interest is the occurrence of big granodioritic areas of Liverpool Land. In the most different parts of the world this rock-type has exposed itself as a normal constituent of every complete orogenic folding-range. The rock-type always forms a very distinct zone within the orogene, and belongs to its geosynclinal part (to use a term for which the warrant still is a matter of discussion. *cf.* F. E. SUESS 48.). In this case the correspondence with the Caledonian Trondhjemitic rocks of Norway is particularly interesting.

The occurrence of this rock-type on Liverpool Land seems to support the opinion expressed by KOCH already 1929 (21.) that this region might belong to the central parts of the Caledonides of East Greenland.

On the other hand, the complicated tectonics of the gneisses, with recumbent folds and overthrusts, do not necessarily mean that they have been formed at a very deep folding. In the section here in question we have to reckon with the influence of the intruding granites, which already in less deep-seated parts of the earth crust gives rise to a considerable degree of plasticity, which makes possible the origin of a folding style normally belonging to the deep-seated parts of great folding ranges.

Before entering on the question as to the possibility of parallelizing the formation described in the foregoing with other parts of the world, the author desires to draw attention to the perfect correspondence between the general style of the gneisses from the Kangerdlugsuak-region, south of Scoresby Sound, shown in WAGER's magnificent pictures in his recent preliminary report of the WATKINS' expedition 1923 (52.). He refrains from taking up a position with regard to the parallelization of these formations and the gneisses of Christian X Land, but this possibility obviously must be taken into account.

Several authors have been dealing with the question of the parallelization of the Caledonian foldings of the Arctic. A summary of the different theories has recently been published by FREBOLD (15.). In a paper about the Hekla Hook formation of Svalbard, KULLING (26.) has treated the parallelization of this formation and Eleonora Bay and other similar Algonkian resp. old Palaeozoic formations in other parts of the world. Of older investigations, those of HOLTEDAHL in particular (18. 19.) have been of great importance.

Here only a few words will be added about the Caledonian around the Northern Atlantic.

BACKLUND has already (2.) drawn parallels between the plutonic rocks of East Greenland and those of the Caledonides of Scandinavia in particular. As he has pointed out, the parallelization of the potash-granites in both regions presents much of interest in showing that the sequence of intrusions on the whole seems to be repeated on both sides. The similarity becomes still more conspicuous if we try to connect the granodiorites of Liverpool Land with the Trondhjemite-Opdalite series of Norway. There exist differences in composition and also in the tectonic position which have already been pointed out (p. 77), but on the whole they, however, have no influence on the general conclusions about the parallelizations, which are based on the whole rhythm of the movements and the mechanics of intrusion.

A comparison with the scheme of tectonics given by GOLDSCHMIDT (17,) for the Stavanger-region shows that we there have only in a slight degree any correspondence with the movements pointed out from Greenland before the dioritic intrusions, but in other respects they offer certain similarities. Movements earlier than the consolidation of the Trondhjemites are known from other parts of Greenland.

The author further wishes to draw attention to the correspondence between a group of plutonic rocks of the Caledonides of northern Scotland and Liverpool Land.

In Scotland we have a group of granodiorite rocks connected with acidic granites described by HORNE, GREENLY, READ a. o. One of the best described of these areas is the Straith Halladale injection-complex described by the last-mentioned author. Under the guidance of Professor READ the author had the opportunity to make acquaintance with this complex and could state its close resemblance, both as regards the rock-type and the injection phenomena, with the granodiorites of Liverpool Land and the granites connected with them. The diorites of Liverpool Land are on the whole slightly older in comparison with the tectonic movements (the Norwegian Trondjemites are still older) and therefore in some degree deformed, but this may easily depend on local differences in the tectonic development. The granodiorites of Central Sutherland and other parts

of the northern Highlands are regarded as Late-Caledonian, a conception which agrees well with the granodiorites of East Greenland.

Still more important is the correspondence between the youngest, postorogenic granites of the Hurry Inlet type, and the youngest so-called newer granites of north-east Scotland. The author had personally the good luck to make acquaintance with the Helmsdale granite and its different varieties, and was struck by the close resemblance, both as regards the macroscopic appearence of the granite itself, and also its mode of occurrence. The Helmsdale granite and a number of other granite-areas belonging to the same group are referred to lower Old red (37) and are overlain by Devonian conglomerate. They consequently are Post-Caledonic or coinciding with the latest Caledonian movements — the term used in its widest sense.

The conditions of Hurry Inlet, where conglomerate of Old red type (*cf.* p. 11) lies immediately on the granite and consists of granitic material, render it very probable that these granite-groups of Scotland and Greenland can be parallelized, and so far as the author can see there is nothing to contradict such an interpretation. The consequence would be that one part of the crystalline complex of Liverpool Land is still younger than KOCH has suggested. If this parallelization is correct, we have to regard the last metamorphosis of the gneisses of Liverpool Land as Devonian (Cape Greg) and we have partly to do with Devonian migmatites.

Another consequence of the parallelization given above — which agrees with the point of view expressed by BACKLUND — is that the basal gneisses of Liverpool Land probably, in part at least, belong to the same series as the Moin-gneisses of Scotland.

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Færdig fra Trykkeriet den 7. Maj 1936.

EXPLANATION TO PLATES AND MAPS

Plate 1.

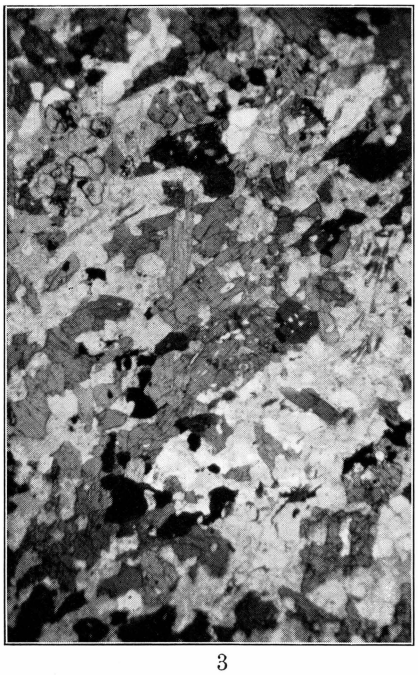
1. *Garnetiferous gneiss*, Hurry Inlet. In the lower right-hand corner antiperthitic felspar is seen; in the upper corner a rotated mica-garnet aggregate. Nic. +, Magnification 37 ×.
2. *Garnet-pyroxene-gneiss* Hurry Inlet. Garnet (black) with reaction rim, antiperthitic felspar and pyroxene in the centre. The colourless mineral is quartz. Nic. +, Magnification 25 ×.
3. *Garnetiferous amphibolite.* Cape Svainson. Nic. ||, Magnification 37 ×.
4. *Pyroxene-granodiorite*, Hodal Valley N. of Hurry Inlet. The hypidiomorphic structure is less pronounced than in the granodiorites of the east coast of Liverpool Land. Nic. +, Magnification 25 ×.



1



2



3



4

Plate 2.

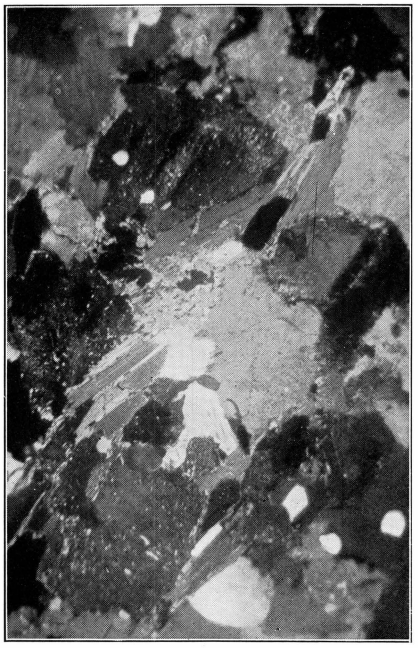
1. Hurry Inlet granite. Nic. +, Magnification 43 ×.
2. Diabase-inclusion in gneiss, Cape Greg. The big grain on the right-hand side is plagioclase which shows a slight turbidity due to heating. In the upper part of the picture turbid plagioclase lests embedded in altered pyroxene are seen; on the contact between both minerals reaction zones consisting of mica and garnet. In the lower left-hand corner aggregates of lawsonite surrounded by mica. Nic. ||, Magnification 43 ×.
3. Cape Greg gneiss. The dark gray mineral is slightly altered microcline. The structure is postcristalline. Nic. ×, Magnification 16 ×.
4. Fine-grained gneiss from Murray Island, showing paracrystalline structure. Nic. +, Magnification 16 ×.



1



2



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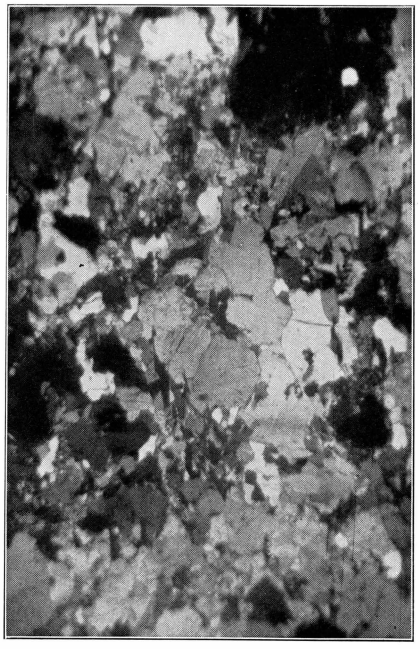

4

Explanation of the Colours of the Maps.

1. Drift-covered area. The rock-ground is nowhere visible.

2. Mesozoic sediments with conglomerates containing pebbles of 3, 4 and 9. (Mainly Eotrias).
3. Arcose-sandstone and conglomerate with pebbles of 3 and 9, in the northernmost localities of 4. (Devonian?).
4. Hurry Inlet Formation (BACKLUND) consisting of quartzite, phyllite and limestone (Cambro-Ordovician?).

5. Migmatite-gneisses of the Hurry Inlet granite.
6. Migmatite-gneisses of the Store Fjord granite.
7. Migmatites with limestone.
8. Strongly tectonized migmatite-gneisses (including the garnet-pyroxene-gneisses of Hurry Inlet).

9. Hurry Inlet granite (Devonian?).
10. Store Fjord granite (Caledonian).
11. Granodiorites and related rocks (Caledonian).
12. Granite with inclusions of older rocks.
13. Basalt (Tertiary).

14. Dikes of granite-porphyry (belonging to 9).
15. Dikes of ouachitite (cut by 16).
16. Dikes of basalt (Tertiary).

17. Thrust or fault.

Correction.

Rhoté I. on Fig. 20, p. 102 is identical with Janus Ö in the map.

1
2
3
4
5
6
7
8
9
10
11
12
13
P 14
O 15
B 16
17

22° V. L.

Cape Jones

Nörrefjord

Store Fjord

Cape Syntektite

Söderfjord

Forposten

Frydendal

71°

Mariager Fjord

Cape Read

Randers Fjord

Nangebugt

Hyttebugt

Cape Greg

Klit Valley

Hodal

Bodal

Kalkdalen

Fame Islands

Isbrosund

Janus Isl.

EMMANUEL GL.

Nakkehoved

Glasgow Isl.

Horsens Fjord

Snippen

Vejle Fjord

45'

Cape Höegh

Kolding Fjord

Snuden

Rathbone Isl.

Gabet

Hagen

Gletscherbugt

Lille Fjord

Raffles Isl.

Cape Hogdson

Hurry Inlet

Södal

590

Nökkedal

Gubbedal

743

204

751

30'

Scoresbysund

438

Rosenvinge Bay

Cape Hope

Cape Svainson

Cape Tobin

22° V. L.

5 4 3 2 1 0 5 10 15 km

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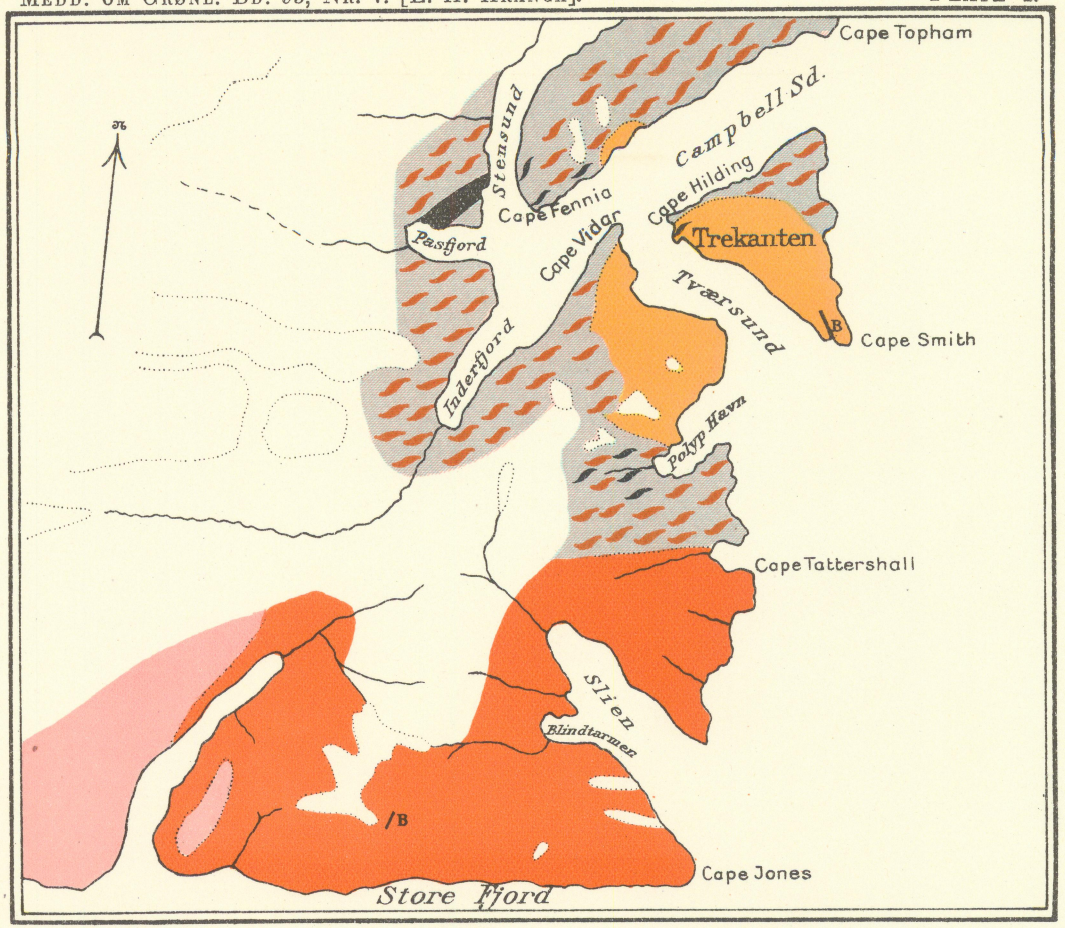

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