Stratigraphy of Northwest Greenland

by

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With one map and one plate.

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Introduction.

During the years 1916—18 the Second Thule Expedition travelled over Northwest Greenland from Upernivik to Cape Washington, near the North Point of Greenland. This stretch of country, which includes one-fourth of the entire coast of Greenland, has been visited by more expeditions than any other Arctic region. The Smith Sound—Robeson Channel has throughout a century been the way towards the North Pole, along which explorers like Ross, Inglefield, Kane, Hall, Nares, Greely, Sverdrup and Peary — only to name the most important — have travelled. As a result of all these expeditions, we have a great many descriptions, most of which are purely topographical, and also a few records of a more scientific nature. There has not however been any fixed plan in the work of these expeditions. For the majority of them the object was the North Pole, and therefore, alongside fairly well-known areas, there were extensive stretches of country, which were either only slightly investigated or even quite unknown.

When I joined the Second Thule Expedition as cartographer and geologist, it became my principal task to construct a geological map of the whole area investigated by the expedition. The scale of this map is fixed at 1 : 2,000,000.

Cartography.

It soon became clear to me that, simultaneously with the geological survey, considerable topographical measurements ought to be undertaken, as a great part of the area of investigation was entirely unknown or partly so.

For the topographical measurements the methods indicated by J. P. KOCH [21]* for Arctic survey were used. On the journeys (which were undertaken almost exclusively with dog-sledges) the separate stations were determined by latitude and azimuth on the basis of solar observations with the theodolite. A great number of longitudinal observations were also made, but, as a rule, my stations lay so close together and were connected by so many reciprocal crossings that the position of the stations was more accurately determined by this than by the solar observations in conjunction with the chronometer. During the journeys, which often lasted for months in low temperatures, it was very difficult to get the chronometer to go regularly, therefore in all cases wherever it was at all possible the work was carried out on the basis of latitude, azimuth and crossings.

The topographical survey includes the following areas:

I. Melville Bay from Wilcox Head to Cape York, in all a distance of 500 km.: surveyed from 26 stations. The first survey was made by Ross [26] in 1818, later on several additions were inserted by ASTRUP and MYLIUS-ERICHSEN. The map has been constructed as 1:100,000, and will be published as 1:500,000.

II. The north coast of Greenland between Newman Bay and Lockwood Island: surveyed from 52 cartographical stations. The capes, but not the interior of the land, were surveyed by BEAUMONT in 1875 and by LOCKWOOD in 1882. The map has been constructed as 1:100,000, and will be published as 1:500,000.

III. Various corrections in older maps, as for instance the head of Wolstenholme Fjord on the scale of 1:250,000, moreover the eastern part of Inglefield Land and the northern part of Washington Land, on a somewhat smaller scale, as the measurements here are rather superficial.

It is beyond the scope of this paper to enter more particularly into the purely geographical discoveries, for which the reader is referred to the accompanying map.

* See Bibliography.

Archæan.

History.

Gneiss and granite are mentioned in various places in the literature of Northwest Greenland. Geographically, the information gained is divided in the following manner. DAWSON[5a] and afterwards WILLIS[29] refer the whole of Melville Bay and the coast to the north of Cape Atholl to the Archæan. MYLIUS-ERICHSEN[9a, c, b, d] mentions gneiss from Cape Holm (Wilcox Head), Amdrup Island and several islands thereabouts, moreover, granite is recorded from Welhaven Island, near Cape Walker. ROSS[26] brought home gneiss and granite from Cape Melville, Bushnan Island and the coast between Cape York and Dudley Digges. INGLEFIELD[19] mentions granite from Conical Rock. PEARY[25e] writes that the whole coast between Cape Atholl and Cape York consists of contorted gneiss. LOW'S[22a, b] map shows gneiss from Bushnan Island to the head of Wolstenholme Fjord. In the text gneiss is recorded from Parker Snow Bay. HAUGHTON[13a, b] delineates »granitoid rocks« right up to the north of Saunders Island. In the text, fine-grained granite is mentioned from Cape York, as also that the granite rocks towards the north are covered with red sandstone. Also from Carey Islands granitoid rocks are mentioned. From here NARES[23a] records red gneiss. BESSELS[1n] mentions syenite and gneiss from Dalrymple Rock to the south of Saunders Island. In Inglefield Gulf, PEARY[25b, f] found gneiss at the head of the fjord, and on the coast to the south of Herbert Island.

At Etah (Foulke Fjord) coarse gneisses and mica schists are mentioned from Littleton Island (KANE[20b]); moreover, reddish gneiss and brown syenite (BESSELS[1m]); gneiss (NARES[23b], FEILDEN[10b] and SCHEI[27b]); gneiss, crystalline schists and granite (EMERSON[6, 7a]); hypersthene-quartz-diorites and gabbro (BUGGE[26c]); HOLTEDAHL[17b] writes: »the Foulke Fjord region of Greenland contains basic, intermediate and more acid representatives of a series very characteristic by its

contents of orthorhombic pyroxene (broncite or hypersthene)«. Low [22c] mentions granite (see particulars below).

The stretch of coast between Etah and the Humboldt Glacier has been described by KANE [20b]: »This northern face of Greenland is broken by two large bays, at the base of which are numerous granitoid islands, which, as you approach longitude 65° W, assume the form of an archipelago«. With regard to the country inland, towards the Humboldt Glacier, BONSALL and MC. GARY [20c] write: »From this point (Cape Scott) the land changes, from the high cliffs of limestone and greenstone to rolling hills of red granite«. Nevertheless, both LOW [22a] and WILLIS [29a] mention that sediments occur inland, towards the Humboldt Glacier. On the other hand, quite correctly, on the maps of both, gneiss is indicated in the eastern part of Inglefield Land (compare NARES [23c] and KANE [20d]). DAWSON [5a] also records that gneiss is present in this part.

North of the Humboldt Glacier archæan formations are recorded as not occurring *in situ*, whereas BESSELS [1i, d] mentions erratic boulders from Washington Land and Hall Land. There are no direct observations to hand with regard to the north coast of Greenland. DAWSON [5e] remarks that the deep fjords and the many islands give the country a certain resemblance to the coast between Upernivik and Disco, but is of opinion that if gneiss had been present there, LOCKWOOD and BRAINARD would certainly have mentioned it.

In spite of all these observations it was, however, impossible beforehand to form a reliable conception of the distribution of the archæan formations in Northwest Greenland.

Although all the localities are a direct continuation of the great gneiss-area which outcrops almost everywhere in southern Greenland, I however prefer, with regard to the morphology, to divide the gneiss localities of Northwest Greenland into four areas, viz. (1) the skerries in Melville Bay, (2) the gneiss-area in the district of Cape York — almost hidden by sediments, (3) the gneiss plains on Inglefield Land, and (4) the gneiss fields almost hidden under the inland-ice in the northwest of Greenland.

The Melville Bay.

During my four journeys over the Melville Bay, which were all carried out with dog-sledges, I had an opportunity of investigating most of the islands and the districts free from the inland-ice. They all consisted of gneiss, granite and other acid eruptives (the last-mentioned will be discussed more fully below). Folded, light-coloured gneiss with fine pegmatite veins is the most common kind of rock, thus, the coast between Wilcox Head and Cape Seddon (figs. 1 and 2) consists of low skerries decidedly of gneiss. The outermost islands are low, almost all under 100 metres. The country, bordering on the inland-ice, rises to about 300 metres. The Cape Seddon-Land itself forms a ridge within the inland-ice, where it attains a height of about 1000 metres, before it becomes hidden under the ice. This land is, as far as I can see, formed entirely of gneiss, with only very insignificant portions of granite. This is the only place north of Wilcox Head, where gneiss attains a height of 1000 metres. In the northern part of Melville Bay, the gneiss areas are all quite low. Near Cape York they again become higher, and rise there to 300 metres, a height which is again found along the coast up to Cape Atholl.

Melville Bay must be regarded as a direct continuation of the skerries near Upernivik. If we assume that the inland-ice in the district of Upernivik advances for about 30—40 kilometres farther, we shall get here exactly the same landscape as in Melville Bay.

The District of Cape York (Cape York—Etah).

In this territory gneiss outcrops only in a few places, the land which is not covered by inland-ice consisting almost exclusively of sediments. We can however, as is already evident from the literature on the subject, demonstrate a gneiss plateau under the recent formations in many places.

Between Cape York and Thule gneiss is still dominant. The whole stretch of country between Cape Atholl and Cape

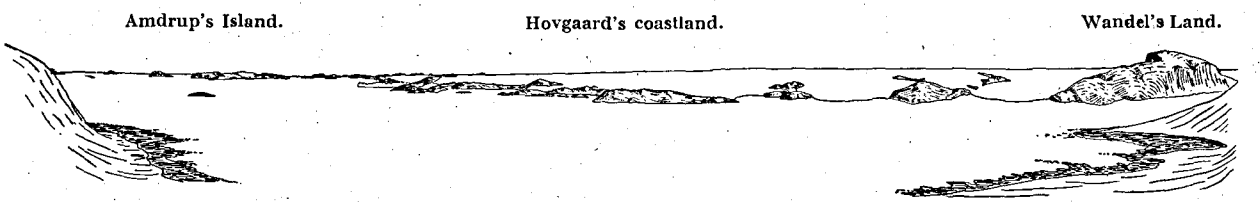

Fig. 1. View towards the belt of rocks and islands girding the coast in the southern part of Melville Bay, seen from the Devil's Thumb.

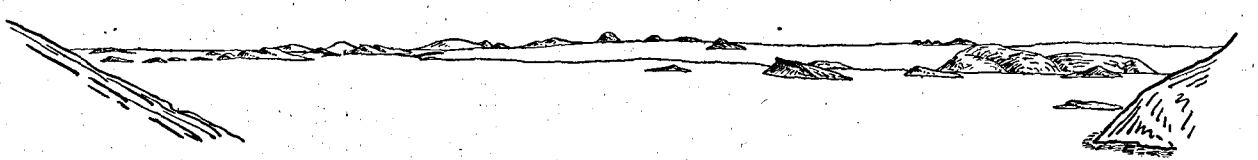

Fig. 2. View towards Steenstrup's Glacier seen from Bloch's Island, Melville Bay. Gneiss mountains.

York forms a level gneiss plain 300—400 metres in height, which in spite of considerable erosion has, to a great extent, still preserved its plateau-like character. The northern boundary of this gneiss plain is formed by a broad valley which, from the coast east of Cape Atholl, leads towards the inland-ice.

Wolstenholme Island, which for the most part consists of gneiss, is naturally connected with the gneiss plain. Between the last-mentioned island and Saunders Island there is a small group of gneiss islets, all of which are quite low with the exception of the conically-formed Dalrymple Rock. Another small group of skerries are the Carry Islands of which I have only investigated more particularly the one which lies most to the southwest; they all consist of gneiss, and their height is only slight.

At the head of the two great indentations, Wolstenholme Fjord and Inglefield Gulf, the strong erosion of the glacier has exposed the gneiss plain. In Wolstenholme Fjord a tiny gneiss-area occurs near the settlement of Ugdle. The layers form, with a very steep face, the innermost southern shore, and here partly hornblende schists, partly gneiss are found. In Inglefield Gulf one finds, exposed, several areas of gneiss which are here fairly dark in colour and highly folded. Besides near the entrance to the last-mentioned fjord to the south of Herbert Island a small area of gneiss and granite running parallel with the coast is to be found. The above-mentioned gneiss-areas are quite low.

Hayes [14] speaks of primitive rocks from Herbert Island, and Peary [25a, g] mentions granite and gneiss from Northumberland Island. I have not been able to find either of these localities again; if gneiss should appear there it will certainly be over small areas.

Inglefield Land.

Immediately to the south of Foulke Fjord the gneiss is again denuded of sediments, and can from there, with a few single interruptions, be traced right up to the Humboldt Glacier.

Near Anoritoq gneiss-granite occurs, otherwise there is everywhere the light-coloured, highly folded gneiss, so well-known from more southerly regions, in several places with a quantity of small fragments of garnet. The whole of Inglefield Land is one extensive, level gneiss-plain (the country is called by the Eskimos Qaqaitsut, i. e. the country without mountains), which in a southern direction, inwards towards the inland-ice, rises to a height of about 300 metres, and from there slopes gradually down towards the Kane Basin. On taking soundings I found that the whole of the eastern part of the Kane Basin is very shallow, only about 40 metres deep, and there can certainly be no doubt that the Archæan plain, which forms Inglefield Land, is continued further under the Kane Basin. Even a slight upheaval will there lay bare great tracts of land. The nature of the whole of the Humboldt Glacier is not properly understood until one regards it as a direct continuation of the slow-moving and fissure-free edge of the inland-ice in Inglefield Land: The »Humboldt Glacier« is no glacier, but is only a level ice-margin which the sea has reached.

Northernmost Greenland.

North of the Humboldt Glacier gneiss is no longer found exposed (as regards two gneiss-areas which belong to the Devonian Folded Mountain Chain, see below). Not until the east coast of Greenland, at the head of Danmark Fjord*, and near Nordostrundingen is gneiss again found. Erratic blocks are however met with everywhere along the north coast, which proves that the whole of North Greenland, also the most northerly Peary Land, was ice-covered during the maximum of the Glacial Period. The moraines of the inland-ice, in the northernmost part of Greenland, mostly contain boulders of sedimentary rocks, and gneiss boulders, as a rule, without being rare, are yet decidedly in the minority. An exception to this rule is formed by the moraine near Porsild's

* Information kindly given by Captain EINAR MIKKELSEN.

Nunatak; there gneiss boulders are predominant, and it seems as if the gneiss is *in situ* under the inland-ice for a short distance; the height of the moraines is 650 metres above sea-level.

Altitudinal conditions of the Gneiss Plain in North Greenland.

If one regards the geological map of Northwest Greenland, it immediately becomes evident that the gneiss plain inwards towards the inland-ice is almost entirely covered with sediments, a condition, which is not known in any other place in Greenland where the gneiss plain otherwise, almost without exception, forms high sea-cliffs. In reality the Greenland gneiss-plain sinks towards the northwest as a gradually sloping plain. The Archæan formations disappear under the sea at the head of Danmark Fjord, and near Nordostrundingen towards the east, and along the west coast the surface of the gneiss plain is almost identical with that of the sea in the western part of Cape York district, in order, ultimately, to disappear in the Kane Basin. The low-lying gneiss plain is also distinctly evident from the height of the inland-ice, of which we have an exceptionally good knowledge through the travels of PEARY, EINAR MIKKELSEN and KNUD RASMUSSEN. If one compares the measured altitudes one sees that the inland-ice, in the whole of North Greenland, is unusually low. The section between Inglefield Gulf and the interior of Danmark Fjord attains a height of above 2000 metres only for a short distance, and north of this, considerable parts of the surface of the inland-ice lie below 1000 metres. The land under the inland-ice must therefore be very low in Northwest Greenland in comparison with the southern regions of Greenland.

Pre-Cambrian Eruptive Rocks.

A thorough petrographical investigation is naturally impossible during the forced sledge-journeys, which are in some part undertaken before the country has yet become free from snow; it is therefore only exceptionally that one discovers areas of non-metamorphosed eruptives which do not assert themselves morphologically in relation to the gneiss plain. Although I have the impression that the latter is exceedingly homogeneous throughout the whole district, yet I have found in a few places by no means inconsiderable areas with eruptives which are certainly more recent than the Archæan, without this being evident from the landscape.

Such a locality is found north of Conical Rock in Parker Snow Bay. One meets here with coarse-grained granite, synite, coarsely laminated mica-schist and diorite. How the single species of rock stand in relation to each other will be shown by future investigations. It is possibly a Batholite with its centre to the north of Parker Snow Bay. Here one finds red sandstone the arrangement of which shows that it has been deposited after the formation of the acid eruptives. In one single place one sees a diabase vein, which has broken through the mica-schist and the sediments.

Another still more interesting area is met with immediately north of Etah. It is undoubtedly a Batholite we have to do with here. The gneiss plain is seen both to the south and north of Foulke Fjord, but a little to the north of Etah one again finds granite, syenite, gabbro and porphyrite, and in one single spot quartzite with areas of strongly compressed granite. EMERSON,[6,7] and afterwards BUGGE[2], examined detached specimens which they had accidentally collected from this place, but a thorough investigation would certainly give interesting results. LOW[22c], who in 1904 paid a short visit to Etah, was aware of the fact that there probably was a large granitic *massif* here. After having mentioned SUTHERLAND'S supposition that the

sediments overlying the granite are of tertiary age he writes: »On n'a pas pu voir le raccordement méridional de ces roches stratifiées avec les granites et les gneiss formant la côte du Groenland au sud, mais au fjord de Foulke, et au cap Isabelle le contact septentrional et bien visible. En ces deux endroits, la formation stratifiée a été redressée et fracturée, tandis que prés du contact, les gris et les calcaires paraissant avoir été changés en quartzite et en calcaires par l'injection de grands massifs de granite.«

As far as I could see, the granitic *massif* has however no connection with the red sandstone, which according to my opinion was deposited after the formation of the eruptives.

Syenite is found to the south of Cape Agassiz, granite forms the coast to the south of Herbert Island, and at the head of Wolstenholme Fjord I found hornblende-schist, but these are all small occurrences, which can best be likened to large pegmatite veins.

On the other hand, there are to be found in Melville Bay a great number of post-archæan formations, which even at a long distance are easily to be recognized. There are only a few localities which I have examined personally: they have always consisted of greyish-brown or grey granite, with portions of hornblende-schist. Morphologically they rise like pointed cones or broad columns with steep, often perpendicular faces. As the height is often above 1000 metres, they are seen from afar and, since the time of the whale-fishers, they have served as sea-marks for those who were crossing Melville Bay. Upon the geological map only a few of them are marked, since the majority of them, with regard to size, are quite unimportant. To the north of Cape Melville there is a black rock-face and behind this a number of high, steep Nunataks; also Mount Haffner and several Nunataks situated south of this I reckon to the post-archæan formations with regard to the morphology, moreover, great parts of Cape Walker with the »Melville Monument« situated to the south, the Nunataks to the north-east of Red Head

and the southern part of Wandel Land and finally the famous »Devil's Thumb« (fig. 3).

Also to the south of Melville Bay, in the district of Upernivik, quite similar formations are found, as for instance Holm's Island, Umanaq in Sugar Loaf Bay, Cape Shackleton and Qaersorssuaq (Sanderson Hope), in fact right down to Umanaqs Bay; a closer petrographical investigation will certainly prove that the Umanaq-cliff, Agpat Island, Storøen and Umanatsiaq are referable to the same group as the above-mentioned localities. I shall here only emphasize the great similarity that exists between the »Devil's Thumb« and the Umanaq-cliff both in petrographical and morphological respects.

A closer petrographical investigation will certainly result in the uniting of the above-mentioned areas into a group by itself — a series of eruptives — of more recent date than the gneiss forming the low skerries which otherwise constitute the general type of landscape on the northwest coast.

Cambro-Ordovician.

History.

SUTHERLAND was the first to describe the sediments in the Cape York district. The description of the distribution of the strata and the stratification is very thorough, and later expeditions have not given a clearer account of the tectonic conditions than has SUTHERLAND. All the later travellers mention the horizontal red sandstone, and several of them occupy themselves with the age of these sediments.

SUTHERLAND[28a] writes: »At Cape York, lat. 76° and on to Cape Atholl, thirty to forty miles further north although differing in outline, owing to the glacial accumulation from Disco Island and other well-known parts of the coast to

Fig. 3. »The Devil's Thumb«. Melville Bay.

the southward the rocks can be referred with certainty to the same trappean formation«.

HAUGHTON [13b, c] does not delineate the sandstone formations on his map, but mentions them in the text, comparing the red sandstone with a similar kind of rock which was found at Cape Bunny and Cape Warrender in Lancaster Sound where Silurian beds occur; it therefore looks as if HAUGHTON considers the series of strata in Wolstenholme Fjord as Silurian. KANE [20b] records from Inglefield Land »the older red sandstones and Silurian limestones«, without, however, mentioning fossils or giving other reasons for this determination. BESSELS [1a] mentions the formation, but does not venture to express anything with regard to age. FEILDEN [10c, b] had no opportunity of investigating the sandstone in Wolstenholme Fjord, but writes, essentially according to HAUGHTON, that Silurian is present there; this area, however, is not included in FEILDEN's map. Not until a little south of Cape Alexander and up as far as Foulke Fjord had FEILDEN an opportunity of studying the sandstone which he referred to the Miocene Period, because the expedition during its stay in Foulke Fjord found a piece of coal (see NARES [23d]). CHAMBERLIN [25d] says very cautiously with regard to the sediments: »The whole group has usually been referred, with doubt, to Tertiary Age, because of the presence of rocks of that age, with a similar constitution, in the Disco region«. SCHEI [27a] delineates upon his map pre-Cambrian where FEILDEN has Miocene, and Cambro-Silurian to the north of this. The locality is not mentioned in the text. LOW [22c], after having mentioned the granite *massif* at Etah, writes about the sandstone: »On n'a pas encore rencontré de fossiles dans ces roches et tant qu'on n'en aura pas encore trouvé, il vaut mieux enlever cette formation du Tertiaire et la compter dans l'Huronien«. On the map the whole coast in the Cape York district is referred to the Huronian. WILLIS follows Low inasmuch as he, on his map, states: »Earlier Precambrian« from the south side of Wolstenholme Fjord up

as far as Cape Alexander. This cape he however regards as Later Tertiary, probably according to FEILDEN and DE RANGE.

HOLTEDAHL [15], who has investigated SCHEI's material from the Bache Peninsula, does not make any special mention of the sediments from Foulke Fjord, but from a small map [17d] it is evident that he refers them to the Cambrian.

The Sandstone Formation between Cape York and the Humboldt Glacier.

Along this stretch of land the Archæan plain is for the most part covered with sediments. The most southern locality is found to the north of Conical Rock, at the Parker Snow Bay, where at a height of about 150 metres on the granite plain a not very considerable sandstone formation is found — with a slight dip northwards. The sandstone is eroded to the south of Cape Atholl, but in the environs of Thule a considerable area with sediments occurs. The southern boundary is formed by a trough-shaped glacial valley, which from the settlement of Narssaq to the east of Cape Atholl extends in a southerly direction inwards towards the inland-ice. The northern boundary is partly formed by Wolstenholme Fjord and partly by the gneiss area at the head of the fjord. Towards the east the sediments pass under the inland-ice, but since the moraines here consist for the most part of archæan materials, there is reason to suppose that at a short distance from the ice-margin the primitive rock is laid bare. To the south of Thule the dip of the strata is 3^0—5^0 northwards. At Thule the dip is 2^0—3^0 south, and across above the gneiss the dip is as much as 12^0 in a southern direction. The whole series of strata thus forms a flat basin, where the strata from the southern and northern gneiss-areas sink down towards the deepest point to the south of Thule. In connection with this the sandstone is rather rare to the south of the fjord. It overlies the gneiss on both sides forming the sou-

thern wall of the valley, to the east of Cape Atholl, and is found just at the sea-margin to the south of the gneiss at the head of the fjord, but otherwise the whole of the country surrounding Thule consists of grey, calcareous rock which is hard, fine-grained and only foliated to a slight degree. To the east of Thule, this calcareous rock is overlain by a very thinly foliated, black slate, which does not occur in other parts of the district. On Wolstenholme Island a small area with curving strata of sandstone overlies the gneiss, on the north side of the Island. The whole of Saunders Island consists of sediments which lie in a perfectly horizontal position.

The peninsula between Wolstensholme Island and Inglefield Gulf consists exclusively of sediments which only along the Gulf of Inglefield lie so high that the archæan plain rises above sea-level. SUTHERLAND mentions several places in Wolstenholme Fjord where the strata have a considerable dip, as much as 45°, the angle of dip may, however, have been somewhat exaggerated, and where the strata are contorted, it is a purely local phenomenon. On the whole it may be said that the sediments between the two fjords are deposited almost horizontally, possibly with a slight southerly dip. This harmonizes with the fact that the gneiss lies above sea-level in Inglefield Gulf where the sandstone also predominates over the limestone, whereas in Wolstenholme Fjord limestone is mostly found.

Between Inglefield Gulf and the Kane Basin the conditions are exceedingly simple. From the head of Inglefield Gulf right up to Etah one meets exclusively with sediments which are to a great extent covered with inland ice. To the east of Etah the inland ice retreats and lays bare the gneiss plain. The latter is only partly covered with sediments. A decidedly glacial erosion has cut itself down in an originally continuous sediment-plateau, so that now only some fragments remain. This, in connection with strong coastal erosion, has exposed particularly beautiful sections through the strata. Both along the coast of Inglefield Gulf

— of which Herbert Island is a continuation — and on Inglefield Land the strata lie practically in a horizontal position, possibly upon Inglefield Land with a slightly northward dip. To the south of Etah sandstone is almost exclusively found. Out towards the Kane Basin the sandstone is however always overlain by limestone. In the vicinity of Etah this limestone is only about 100 metres thick, and attains its maximum thickness to the west of Marshall Bay, where the sandstone has disappeared under the surface of the sea, and the coast consists of limestone cliffs, about 200 metres in height, which cliffs exactly resemble the fine-grained limestone at Thule. Near Cape Russell sandstone is again found and extends from here to Cape Scott. The whole coast of Inglefield Land thus forms a very flat basin with the deepest point somewhat to the west of Marshall Bay.

The Thickness and the Tectonics of the Series of Strata.

The thickness, where it can be decided, does not exceed 400 metres; one can follow the same stratum for long distances, and on the basis of comparisons it can with some degree of certainty be said that the thickness of any stratum varies between 200 metres (the eastern part of Inglefield Land) and 400 metres (Herbert Island and Saunders Island).

The tectonic conditions may be said to be exceedingly simple inasmuch as the whole series of strata with a few exceptions, lie almost horizontally. That sediments overlie the gneiss plain can be very distinctly observed on Inglefield Land. One can here, for instance at Cape Russell, in the lowermost sandstones, find garnets which, as is distinctly to be seen, comes from gneiss rich in garnets, which lies immediately to the south. The gneiss islands, at the head of Inglefield Gulf certainly also belong to the original gneiss plain. On the other hand, the granite localities to the south of Herbert Island and the gneiss areas in Wolsten-

holme Fjord project as islands through the sediments. There have certainly not been any real islands at any of the places when the sediments were deposited, for one finds that the latter curve upwards over the gneiss with layers of conglomerate, sandstone and limestone which do not alter their thickness or nature. One cannot quite dismiss the thought of Batholites which have been so much cooled on the surface that no metamorphosis can be demonstrated in the sediments; but it will be far more natural to assume that, in a few spots, slight dislocations have taken place which here and there have somewhat raised the gneiss plain. Near the gneiss localities at the head of Wolstenholme Fjord, which protrudes just like an island from among the sediments, the angles of dip and of strike in the gneiss and in the sediments overlying it differ greatly, so that it is certain that the sediments are more recent than the gneiss.

Low's [22c] views with regard to the conditions at Etah have already been discussed. It is perfectly correct that strongly metamorphosed sediments are to be found here, but there is nothing to indicate that the quartzite and crystalline limestone mentioned by Low, have any connection with the series of strata mentioned here. At Etah no transition is found between quartzite and sandstone. On the other hand, round about Etah, there is sandstone, which is not at all affected by the masses of granite and syenite which underlie it. When Low, therefore, on the basis of the metamorphosed sediments from Etah, refers the whole sandstone-series between Wolstenholme Fjord and Etah to the Huronian, this assumption rests, at any rate, upon a very slight foundation.

The Nature of the Strata.

The most complete series of strata is known from the head of Wolstenholme Fjord, where the lowermost stratum is gneiss, overlaid by conglomerate, sandstone, limestone and slate. On regarding the entire district taken as a whole, sandstone proves to be by far the most widely distributed

rock, especially to the north of Inglefield Gulf, where the thickness is also greatest, comprising as much as 300 metres. In many places, however, it is difficult to draw a boundary line between sandstone and limestone, since all transitions are to be found.

Conglomerates are nearly always to be met with immediately overlying the gneiss plain, but for the rest, conglomeratestrata may be found in the entire sandstone-series. In some places they are a few metres thick. The cementing matrix consists partly of loose sand, and is partly of a calcareous nature. The grains which can become several cm. in diameter, nearly always consist of greatly rounded quartz. Granite and gneiss fragments are rare. In Inglefield Land one finds in the conglomerates, non-disintegrated, flesh-coloured felspar-grains, with sharp edges, whereas grains of diabase are entirely wanting. The colour is most frequently grey.

The conglomerates are succeeded upwards by a sandstone, which, as a rule, is strongly coloured and coarse, not unfrequently being so loose that it turns to powder between the fingers. At Cape Russell this coarse sandstone consists, for a great part, of small garnets which have undoubtedly been washed out from the gneiss to the south, which is rich in garnets. Through this transitional form one passes into the sandstone proper, which is most frequently rather fine-grained and splits into thin laminæ. The colour varies from white, yellow and red to purple and violet. Where the sandstone forms long, perpendicular sea-cliffs, for instance on Saunders Island and in Inglefield Land, the various-coloured, horizontal strata present a splendid sight. In the sandstone the diagonal structure and the ripple-marks are very common.

From the slaty sandstone to limestone there is a very even transition, and in most places the limestone has remained slaty and somewhat sandy. The perfectly pure, compact limestone is only slightly distributed; it is found well-developed at Thule and to lhe west of Marshatl Bay,

consequently in the centres of the shallow basins. The colour is grey in both localities. Near Thule we find well-developed sun-cracks, salt-pseudomorphs, and possibly traces of creeping animals and prints of rain-drops. Near Rensselaer Harbour there were well-developed cryptozoon-structures.

In the whole of Inglefield Land intraformational conglomerates are very common, the thickness varies from a few cm. to half a metre. This harmonizes well with an erosion-boundary which is to be found on the south coast of Northumberland Island. There was here, in a section of limestone, an old land-surface with valleys and slopes »*en miniature*«, overlaid in turn with limestone which had filled up all the hollows.

In several places to the east of Thule the limestone is overlaid by about 60 metres of black, extremely fine-slated bands with ripple-marks and sun-cracks. This black slate is not found in any other places in the district.

The Mode of Formation of the Strata.

The entire series of strata, mentioned above, bears the impression of having been formed in shallow water. One might well imagine a sudden transgression across a gneiss plain, which, by arid erosion (cf. the non-disintegrated felspar-grains and the commonly occurring red colour), has been covered with loose products of disintegration. Not only the sandstone, but also the limestone and perhaps the slate were probably formed near the coast, along which there have very likely been lagoons, so that through the sea breaking into these, there was at the same places, sometimes deposition, sometimes erosion.

Eruptive Rocks.

Diabase is found to be of common occurrence from Conical Rock as far as Rensselaer Bay. It is especially common near Thule, around Cape Parry and at Etah. On the other hand, it is absent from the interior of Inglefield

Gulf and from Inglefield Land. As areas poor in diabase Herbert Island and the coast north of this, as well as Saunders Island in Wolstenholme Fjord, may be mentioned.

The district around Thule is very rich in diabase, especially in beds. The top of the beautiful Bopladsfjæld (Mt. Dundas), due west of Thule, is a diabase-bed, about 20 metres thick. In the country between Thule and the inland-ice, there are many thick diabase-beds, which, in a high degree, set a stamp upon the morphology of the country. The thickness of the beds does not exceed 200 metres, but the largest can be traced over areas of about 50 kilometres[2]. It is seen that paraphyses have entered into the sediments in a few places.

South of Cape Parry one finds the thickest sheets, and Cape Parry itself is a sheet of about 100 metres in thickness, and of very considerable extension. North of this area veins are most common. The numerous veins which traverse Northumberland Island are probably a direct continuation of the veins on the continent north of Cape Parry.

In Inglefield Gulf the projecting naze Kanga, Cape Cleveland and Cape Chalon are formed of isolated diabase veins.

Cape Alexander — the most westerly point of Greenland — consists of sediments with two almost horizontal, parallel diabase-sheets. The districts north-east of Etah are rich both in sheets and veins. The northernmost diabase-locality is a small vein, only a few metres high, which occurs at Cape Leiper, to the east of Rensselaer Bay.

In many places contact-metamorphism is seen. Slate is, as a rule, highly affected. Limestone becomes of a somewhat darker colour, especially when it is pure; sandstone remains unaffected. In many places diabase contains considerable amounts of iron. Near Granville Bay arsenopyrite and pyrites are found, and, on Northumberland Island, copper; both of these occurrences are connected with diabase veins; the amount, however, is so inconsiderable, that the localities are of no practical importance whatever.

Nowhere is there anything to indicate that a part of

the diabase is older than the sediments or contemporary with them. The complete absence of grains of diabase in the conglomerates justifies me in regarding all the diabase-occurrences as being younger than the above-mentioned series of sedimentary strata. Diabase veins and sheets are not found in the overlying Silurian, on the other hand pebbles of diabase occur in the Silurian conglomerates. On account of these facts, I have referred the diabase to the Ordovician.

The Sandstone Formation in other regions of Greenland.

Warming Land.

Erratic boulders, especially of light-grey and red sandstone, are generally rare on the north coast, but are not entirely absent. Thus east of Cape May a block of light-coloured sandstone with fragments of a diabase vein was found, and near Dragon Point there were several boulders of yellow limestone of the same type as that found in Inglefield Land. When travelling southwards across Warming Land erratic boulders of grey sandstone become more and more numerous while Silurian boulders decrease in number. The most southerly moraines in Warming Land consist of gneiss and granite boulders, mixed with boulders of red sandstone, on the other hand no Silurian boulders are found there. In front of these moraines I found, in a river-bed, red sandstone *in situ*, overlain with Silurian limestone; the height above sea-level was 600 metres. Diabase did not occur.

The Districts around Mylius-Erichsen Land.

PEARY [25c] figures, from Navy Cliff, a sandstone with ripple-marks, but the First Thule Expedition was the first to bring home somewhat exhaustive information regarding the geology of these regions. The cartographer, P. FREUCHEN, brought home specimens of grey and red sandstone from the western

side of the Danmark Fjord and the northern shore of Independence Fjord. Fossils were not found. Moreover, diabase was collected in 11 different localities. Mr. FREUCHEN informed me, that the strata around the two fjords are of exactly the same nature as the strata within the Wolstenholme Fjord and Inglefield Gulf. The cliffs consist everywhere of horizontally situated red sandstone with diabase sheets and veins. Captain EINAR MIKKELSEN found at the head of the Danmark Fjord gneiss overlain by sandstone. BØGGILD [3b], who has treated FREUCHEN'S collections, is of opinion that on the basis of these collections nothing definite can be stated as regards age, but he is inclined to refer them either to the Cambrian or to the Devonian. At a later date BØGGILD [4e] again mentions these strata, comprising them together with the strata in the district of Cape York, into one morphological element, which he calls »Die Sandsteinplateaus des Nordens«, on account of the similarity in their geological structure. The fact of my having demonstrated the presence of red sandstone *in situ* in Warming Land, makes it highly probable, that a broad belt of the red sandstone-formation which stretches from Mylius-Erichsen Land, across Warming Land to the district of Cape York, and further on to Ellesmere Land is to be found under the inland-ice.

The Igaliko Sandstone in South Greenland.

BØGGILD [4b] mentions this series of strata which is well-known from previous investigations, together with some other areas of an unknown age. The Igaliko Sandstone is a series of strata consisting of conglomerates and red sandstone; it rests upon gneiss, and numerous porphyry and diabase veins occur in it. In appearance it greatly resembles the sandstone formation in North Greenland. It is worthy of notice, that already DAWSON [5b] compared the Igaliko Sandstone with the red sandstone, which in very many localities in the Arctic Archipelago forms the base of the Silurian strata. There is undoubtedly much to be said in favour of this comparison.

The Age of the Series.

It is very easy to understand the opinion of SUTHERLAND [12], FEILDEN [10] and CHAMBERLIN [25], that the strata in the district of Cape York should be compared with the Tertiary sandstone-formation, which is found on Disco and in the districts to the north of it. Most of the ship-expeditions have called at Disco on their way up to Cape York, and all the above-mentioned authors have had an opportunity of seeing, that on Disco the gneiss is directly overlain by sandstone with basalt beds and veins. From a purely morphological point of view the resemblance between Disco and the Cape York district is very great. DAWSON [5] adopts, though with some doubt, the view maintained by the above-mentioned three authors, and lastly, WILLIS [29] has, on his map, indicated Later Tertiary south of Etah.

A somewhat different view, however, has also been maintained. HAUGHTON [13] (who from MC CLINTOCK's notes and collections from the islands north of Canada, knew gneiss overlain by red sandstone and above that Silurian limestone) records this succession of strata from several localities in Lancaster Sound. He also mentions the red sandstone in the Wolstenholme Fjord and refers it to the Silurian, although he does not know the fossils from east of Smith Sound. DAWSON [5] is aware of this, and does not reject the theory. SCHEI [27], whose investigations at Etah were of very short duration, found on the Bache Peninsula, situated opposite to Etah, Cambrian fossils in quite similar strata, and therefore refers the Greenland sandstone to the Cambro-Silurian, an assumption which was finally verified when on Warming Land I found richly fossiliferous limestone from the upper Silurian overlying the red sandstone. Thereby a reliable upper limit for the North Greenland sandstone-formation has been attained. LOW's [22] interpretation of the strata has already been mentioned above (p 19), and I shall not enter fully into it here, but shall only point out how improbable it is that an Algonkian

series of strata of such considerable extent should remain, practically speaking, undisturbed.

Quite recently HOLTEDAHL [15, 17c] has dealt with SCHEI's material from the Bache Peninsula. He does not make any special mention of the sediments from Foulke Fjord but from a small map it is evident that he refers them to the Cambrian. In 1918 HOLTEDAHL [18] published a paper, which throws new light upon the sandstone strata in Ellesmere Land and at the Foulke Fjord. He compares the sandstone formation on both sides of Smith Sound with similar formations in Scotland, Finmark, Spitzbergen, East Greenland and several places in North America. In all these areas the strata contain intraformational conglomerates, oolites and chert, and HOLTEDAHL is of opinion that the age must be Ozarkian-Canadian.

This series of strata of red sandstone which covers large areas in North Greenland, both on the west and east coast, and which is found on Ellesmere Land, North Devon, and North Sommerset, and perhaps also in South Greenland, can now with some certainty be referred to the Cambrian or Ordovician. Whether the age can everywhere be limited so narrowly as to the Ozarkian-Canadian I am not prepared to state.

Real fossils have not yet been found anywhere in Greenland*. And in all the other localities outside Greenland the fossils appear to be absent or are at any rate very rare. It is therefore much to be wished, that the strata containing the Cambrian fossils on the Backe Peninsula might be carefully

* EMERSON [6b, a] mentions grey limestones with traces of brachiopods from the Foulke Fjord. The fragments found are stated to have been collected near Port Foulke by the HAYES Expediton. As regards the collection, however, EMERSON writes: »I have not been able to explain how these rocks, labeled by some member of Dr. HAYES party in North Greenland, came into the possession of HALL in Rescue Harbour — — —.« Unfortunately therefore, this statement may possibly be due to a mistake.

investigated, as there is here a possibility of determining the age with certainty.

Ordovician.

On both sides of Steensby Glacier are found the oldest fossiliferous strata I have seen in North Greenland. These layers form the whole of the southern part of Warming Land and can, on the opposite side, on Nyeboe Land, be traced on the floor of some great valleys, between plateaux of recent formation. The surface of these formations is a plain which is only about 600 metres above sea-level. The plain forms a peculiar depression between the surface of the inland-ice, towards the south, which is situated on a much higher level, and the plateaux 600 metres higher towards the north.

The rock in question is a dark, coarsely banded, hard limestone with a few *Orthoceratites* and *Maclurea.* Inwards, towards the inland-ice, it is seen, at a single spot, to rest upon a coarse, red sandstone, towards the north it is overlain by enormous strata of Pentamerus Limestone. The layers are at least 100 metres thick.

Due north of the Humboldt Glacier, within Benton Bay one finds, under richly fossiliferous limestone in the coast-cliffs, a darker-coloured limestone which is generally poor in fossils. At a single spot I found fragments of a large trilobite, which was possibly a *Megalaspis*-like form, but owing to the shortness of the time, it could not be extracted. Here also an orthoceratite was found, and in addition to this some gastropods.

As we know SCHEI has found Ordovician on the opposite coast. From the Bache Peninsula there has been recorded (SCHEI [27c]; HOLTEDAHL [15a, b]) »an orthoceratite-limestone« overlain by a brown limestone with gastropods. Chiefly on account of the similarity in appearance between SCHEI's material which I had an opportunity of investigating in Christiania, and the Greenland rocks mentioned

above, for the present, I refer the latter, though with a reservation, to the Ordovician.

Silurian.

History.

In North Greenland fossiliferous Silurian is met with north of the Humboldt Glacier. Only few ships have passed through the Kennedy Channel, nearly all of them following the west coast, as this is more easy of access, than is the Greenland side. Therefore, exceedingly few observations are to hand regarding the geological conditions prevailing there.

HALL [12a, b, d] was the first who, on the whole, mentioned fossils from the Smith Sound districts. In October 1871, at Cape Brevoort, he »found a rock full of fossils, coral being one of them«. HALL undoubtedly had a clear understanding of the fact that the block in question was an erratic one. In the following spring, fossils were brought to the ship from Offley Island. BESSELS [1b, e, g, h, f, l] gives somewhat fuller information regarding the fossils found by the Expedition, which he has correctly determined as belonging to the Upper Silurian. In September 1871, BESSELS took a journey to the districts east of Cape Tyson, and records from there an orthoceratite, almost a foot in length, in a rock *in situ*. From Offley Island he records corals and brachiopods. He further draws attention to the fact that the rocks near Cape Tyson are different from the strata found to the north, and lastly, he states, that Crozier Island, Franklin Island and the whole of John Browne coast consist of the same kind of rocks as the mountains near the Petermann Fjord. None of the fossils collected by the Polaris Expedition came home.

Considered from a scientific point of view, the so important English expedition under NARES furnished the first-

geological map of the Smith Sound districts, and also brought home accurate observations and good collections from Greenland.

FEILDEN and DE RANGE [10a, d] who have worked out the geological observations, indicate, on the geological map, Silurian only at the entrance to Petermann Fjord, but in the text mention is made of a northern limit for the Silurian strata, from Polaris Bay across to Newman Bay, and the southern limit is set at the Humboldt Glacier. ETHERIDGE [8c], who determined the collections brought home, mentions fossils from Petermann Bay (one species), Bessels Bay (14 species), Offley Island (11 species), Cape Tyson (one species), Polaris Bay (one species), Thank God Harbour (one species), making a total of 25 species all of which are referred to the Silurian. Neither GREELY [11]* nor PEARY [25] deal with these strata; they are naturally indicated as Silurian on DAWSON'S [5a] map, WILLIS [29], on the other hand, has, without mentioning them more closely referred them to the Devonian. The geologist of the CROCKERLAND Expedition, Mr. EKBLAW, has informed me that at Cape Constitution he made a small collection, chiefly of corals.

The Collections brought home.

I visited the fossiliferous Silurian localities only on sledges, and as the distance from there to the base of the expedition was several hundred kilometres, the collections naturally had to be considerably restricted. We brought, however, some extra sledges with us right up to Polaris Bay, and by means of these a comparatively considerable number of collections were sent home from Washington and Hall Land. Unfortunately the expedition had to force the journey

*) BRAINARD records fossils from Gap Valley in the northwestern part of Nyeboe Land. These are however probably erratic blocks, such being found in great numbers there-about. The ice has conveyed them thither from the more southerly Silurian layers, and they contain an abundance of corals and brachiopods.

here considerably, so that in some of the localities only about half an hour was allowed for making collections, but as fossils, in most of the places, occurred in enormous quantities, a great many species could be collected even during so short a time.

On the north coast of Greenland, during a prolonged period of stormy weather, we had ample time for arranging the material and extracting the fossils which had been collected. But, of course, the collections made there had to be considerably restricted, before the difficult return-journey, which cost the lives of two members of the expedition, could be undertaken.

It is not without a certain hesitation that I make an attempt towards a classification of the strata already before the collections have been finally investigated. It is probable, that a palaeontological investigation may result in some alterations in my classification, but for morphological reasons, and in consideration of possible future investigations, I think that I am justified in pointing out the differences within the series of strata.

Middle Silurian.

Pentamerus Limestone.

Above the dark-coloured Orthoceratite Limestone a sandstone is deposited which is of a reddish colour especially when seen from a distance, and which plays a very important part in Greenland. It is extremely uniformly developed; towards the west it is perhaps slightly darker and more compact than farther eastwards, but otherwise it is everywhere grey, very heavy and hard.

In many localities near the heads of the fjords of North Greenland, the thickness exceeds 1000 metres, without the bottom and the top strata differing in any perceptible degree. Fossils are wanting throughout thick layers of the limestone, and taken as a whole, the limestone must be said to be poor in fossils, but locally, layers are found enormously rich in fossils, almost exclusively *Pentamerus*.

The most westerly locality is found on Washington Land near Cape Calhoun. The nature of the country here is very peculiar. Along the coast there is a plain, one kilometre in breadth, which rises only a few metres above sea-level, and not until it has extended for some distance into the country, does it attain to a height of above 100 metres. The coast itself consists of numerous skerries, which do not rise one metre above high-water mark. The whole plain consists of hard, dark-coloured limestone with scanty fragments of *Pentamerus*.

The characteristic development of the Pentamerus Limestone is however not found until near the Petermann Fjord, where both the narrow borders of land, which limit the glacier, consist of this kind of rock. West of Cape Morton, near Cape Lucie Marie, the Pentamerus Limestone reaches almost down to the sea. Here also the colour is dark, but the species of the stone is immediately discernable by the fact of the rock forming high, perpendicular walls with only a few clefts. Facing the inland-ice the rocks attain a height of above 1000 metres, while at the entrance to the fjord the Pentamerus Limestone rises only to about 500 metres above sea-level.

Offley Island, where both HALL's and NARES' expeditions found fossils, belongs for the most part to the overlying stratum, typical Pentamerus Limestone only occurring at sea-level. On the other hand, the latter forms the lower 300 metres of Cape Tyson, and is continued from here across to Newman Bay. In a broad valley south of Cape Tyson I found a stratum with numerous *Pentameri* at a height of about 100 metres; with this exception fossils were rare. ETHERIDGE[8] states that COPPINGER collected several *Pentameri* on Offley Island, and numerous specimens were also found in Petermann Fjord. A new species, *Pentamerus Coppingeri* is described from Offley Island. Erratic boulders with *Pentamerus* are very common on Polaris Promontory.

On Nyeboe Land I did not find fossils, but from a purely morphological point of view it is easy to mark the

Fig. 4. View of Nyeboe Land seen westward from Daniel Bruuns Ice-cap (1290 m). The plateau consists of Pentamerus Limestone traversed by numerous cañons; in the background, to the left, the inland-ice can be seen. The ice-sheet in the foreground is the surface of Daniel Bruuns Ice-cap.

boundary of the Pentamerus Limestone. It forms here enormous plateaux, 1000—1500 metres high (fig. 4), bounded towards the north by the lower Coral Limestone (see below), towards the south partly by the Orthoceratite Limestone, which is only 600 metres high, and partly by the inland-ice, the edge of which lies at a height of only 600—800 metres.

On Warming Land the Pentamerus Limestone is particularly well-developed, stretching right across the country, as a broad plateau, reaching a height of up to 1300 metres. Towards the south it rests on Orthoceratite Limestone, towards the north it is overlain by Coral Limestone and Graptolite Slate. Both within the St. George Fjord and in »Djævlekløften« splendid sections are found across it. In »Djævlekløften« I had to search for a long time before I succeeded in finding other fossils than badly-preserved corals, but suddenly I came across one of the strata rich in fossils. In a wide circumference every single stone-slab was crowded with *Pentameri*, or the latter had, through the action of weathering, been released from the rock and were lying exposed on the surface, partly with shells, partly as stony casts. I did not observe any other brachiopods than *Pentamerus*, of which there appeared to be two or three species; on the other hand, there were a few corals. As the expedition at this time was in a very critical position, it was unfortunately very little that I could bring home from this interesting locality.

»Djævlekløften« itself (fig. 5) is a 700 metres deep canon, down into which numerous glaciers descend, the bottom, however, being free from ice. This is by no means a rare phenomenon in these regions. On Nyeboe Land and Wulff Land numerous cañons of a similar kind are found, being characteristic of Pentamerus Limestone. Their mode of formation is not quite clear. Their orientation is not north—south, as might be presumed, if one imagined that they were formed by the inland-ice. Nor are they grouped as valleys which arise from particularly high plateaux, as

might have been expected if they had been formed by a local ice-covering of the Pentamerus Limestone, the elevation of which is very high, when compared with its surroundings. It must rather be presumed, that we here have to do with fragments of pre-glacial erosion.

The lofty cliffs of Pentamerus Limestone are continued along both sides of the Ryder Glacier, partly at Cape Buttress, partly on the southern part of Wulff Land. The numerous cañons divide the plateau, which is more than 1000 metres high, into remarkable, box-shaped hills, and this, in connection with the intensely red and yellow colours which the limestone exhibits almost everywhere in the fjord-districts of North Greenland, makes the Pentamerus Limestone recognizable even at a long distance.

A verification of one's determination is obtained by the numerous erratic boulders with *Pentamerus* which the ice has strewn all over the country west of the Victoria Fjord.

Nares Land is so completely hidden under the inland-ice, that Pentamerus Limestone does not appear there, whereas it must undoubtedly be found on both sides of the Jungersen Glacier.

Morphologically, the Pentamerus Limestone forms a connected whole from Washington Land across to Peary Land. It presents itself as the fragments of a once continuous plateau, which still in many places reaches a height of almost 1500 metres, that is to say, it is considerably higher than the strata situated to the south and north of it. At the present time the plateau forms the northern boundary of the inland-ice, since the latter must open for itself an outlet through the long, narrow fjord-glaciers, the valleys of which doubtless existed before the Glacial Period. During the maximum intensity of the Glacial Period the Pentamerus Limestone was, however, entirely covered by the inland-ice. This is proved by the numerous erratic boulders occurring everywhere along the north coast and across to the Victoria Fjord; even at the top of a steep alpine peak, due south of Dragon Point, between the St. George

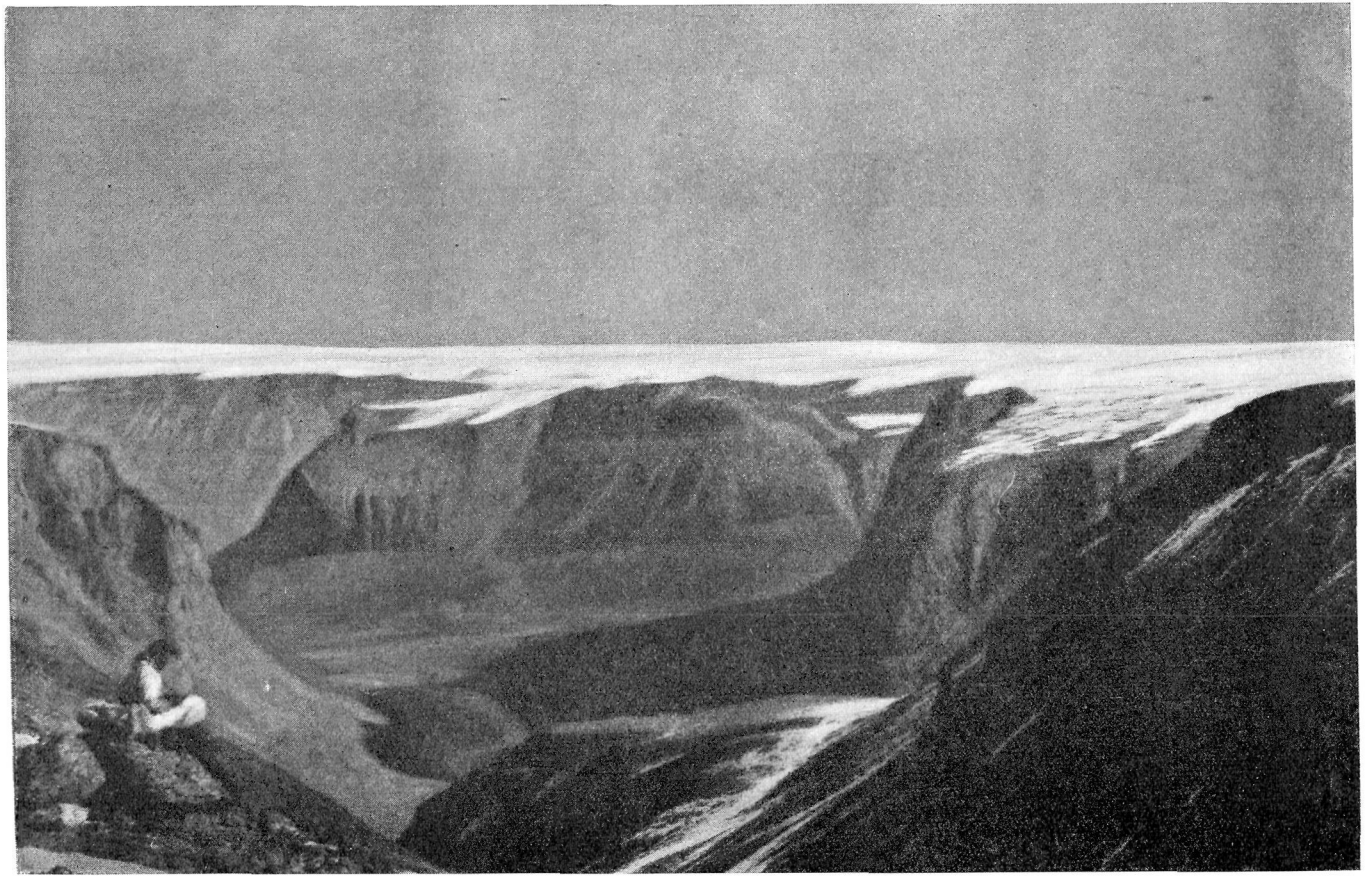

Fig. 5. »Djævlekløften«. Pentamerus Limestone.

Fjord and the Sherard-Osborn Fjord, I found, at a height of 970 metres, a large boulder which was densely crowded with *Pentameri.*

A priori, it seemed probable, that SCHEI had found corresponding formations on Ellesmere Land, and on reading through what SCHEI and HOLTEDAHL have published, points of resemblance will be found between the upper part of SCHEI's Series A and the Pentamerus Limestone. Series A is found along the south coast of Ellesmere Land and the north coast of North Devon.

HOLTEDAHL [16a] has gathered what is known about Series A. The following section is known from the Harbour Fjord: lowermost gneissic granite, above this quartz sandstone, overlain by limestone conglomerates with marly shales and pure limestones, and above this follows »close-grained, hard, impure limestone of a brown or greyish-yellow colour, and very often surprisingly heavy« In this latter limestone, there occur lowermost (at South Cape) *Halysites catenularia Lin., Strophomena spp.* and *Maclurea spp.* HOLTEDAHL is of opinion that it is a Trenton-Fauna. In the upper part of the limestone (at »Baadkap«) *Strophonella cf. euglypha His.* is found, and »in a massive coarse dolomitic rock a great number of internal casts of a pentameroid brachiopod occur«. They are described by HOLTEDAHL as *Conchidium arcticum.* The age of the strata is believed to be Niagaran.

Although so few data exist regarding Series A, yet it cannot be denied that there is a resemblance to the series of strata on Warming Land; in both localities the sandstone is covered by a hard, heavy limestone with *Orthoceras* and *Maclurea,* and above that lies limestone with *Pentamerus.*

Upper Silurian.

The Arethusina-Zone.

Near Cape Constitution (fig. 6) the Silurian strata are developed in a manner different from those of any other locality

I have seen in Greenland. There occur here both folds and faults as well as unconformity, all of which states are otherwise always absent in Silurian strata. During our forced journey I was unfortunately obliged to content myself with a very superficial investigation of this highly interesting area, which, within a very limited territory, offers so many problems.

Cape Constitution and the southerly-situated Cape Independence, form together a lofty mass of rocks, about 400 metres high, which exhibits vertical faces towards the south, west and north, and therefore makes an imposing effect in the otherwise rather low surroundings. Towards the east there is a less decidedly steep face, the whole conveys the impression of being a horst. The neighbouring Crocier and Franklin Islands and two isolated rock-masses north of Cape Constitution belong to this, both as regards form of landscape and kind of rock.

Cape Constitution — Cape Independence form an 8-shaped peninsula which is separated from the continent by a valley. The succession of strata is, where it is best developed: lowermost layers of black, very finely foliated slate with *Arethusina* and *Orthis*, above that conglomerates which gradually pass into a light-coloured, hard limestone, forming the greater part of the mountains.

The most perfect section through the black slate is met with south of Cape Independence, within the so-called Lafayette Bay. On the cape in question, at some distance from the coast, there is seen, at the water-level, black slate which, with a westerly dip of a few degrees, gradually rises to 25 metres above sea-level. The slate can be traced some hundred metres in the section, towards the east it is hidden by down-sliding masses. There is a fault of about one metre in height in the black slate, but it cannot be demonstrated in the overlying strata. In some of the lowermost layers some quite thin zones with well-preserved fossils were found. There were many fragments of a small *Arethusina*, nor were *Orthis* rare, and a few other brachiopods were found.

Fig. 6. Cape Constitution. The Arethusina-Zone lowermost overlain by conglomerates and limestone.

Only a few kilometres to the north, due south of Cape Constitution, the black slates have quite a different appearance. They are exposed up to a height of 40 metres above sea-level and are much folded. The trend of the foldings appear to be N—S. The section with the folds is seen along a distance of 150 metres only. No faults and no thrust-planes occur. In some places brachiopods were found. Only in this section folds occur, otherwise the black slates lie almost horizontal, a few metres above sea-level, under almost the whole peninsula.

In all places where the conditions could be studied, the black slates were overlain by conglomerates, which form the coast between both capes and the greater part of the localities in the small bay between the capes. In Lafayette Bay there is a even transition. The slate, which is very fine at the base, becomes coarser upwards, and limestone beds occur in it. These limestone beds steadily increase in number upwards, and at the same time more and more boulders occur in the limestone, until the whole becomes a homogeneous mass of grey conglomerate, the colour gradually becoming lighter as the slates disappear. Coral-branches, and large rolled balls of *Favosites*-colonies are common, besides which, blocks of granite and diabase occur.

The above-mentioned folded slates have after plication been exposed to erosion, since a flat surface has been formed, upon which horizontal, light-coloured conglomerates have been deposited unconformably. However, also at Cape Constitution itself, disturbances in the conglomerate-strata occur, the lowermost of which being greatly folded and bent; in another place, north of Cape Independence, in the dark slates there is seen a cavity, which is filled up with tumbled-down conglomerates. The greatest thickness of normally deposited conglomerates can be fixed at 150 metres.

The conglomerates are not closely limited towards the upper strata. At Lafayette Bay they are overlain by a light-

coloured, greyish-yellow limestone with some limestone-boulders of about the same quality, above which there is a pure, unstratified limestone. At Cape Constitution the upper conglomerate-strata are distinctly stratified, above this comes light-coloured, unstratified limestone. The thickness of the light-coloured limestone, for instance on Franklin Island, reaches up to 400 metres. It is very hard and capable of resistance, and through the action of frost is disintegrated, large crusts being loosened from the almost vertical rock-faces. North of Cape Lafayette there occur, at the transition between the conglomerates and the light-coloured limestone, some fossils, especially fragments of Crinoid-branches, Brachiopods, Trilobites and Orthoceratites. The light-coloured limestone itself is very poor in fossils, the most common are Cephalopods, Trilobites *(Bronteus)* being more rare.

The highly-varied stratification requires to be investigated in detail, in order that one may be able to pronounce, with any certainty, an opinion as regards the significance of the discordances between the strata. Perhaps the whole is a purely local phenomenon. The local folds and the moraine-like appearance of the conglomerates suggests glacial action, but this harmonizes badly with the fact that in some localities, where the conglomerates are finer in texture, Trilobites and Brachiopods occur.

Coral Limestone.

On travelling along the coast of Washington Land and making collections of fossils at certain intervals the immediate impression is exceedingly variegated. In one locality corals are present in overwhelming abundance, in another gastropods or brachiopods are the group that dominate. The whole is however doubtless dependent upon differences in the facies. Where the conditions are particularly obvious one finds, above the Pentamerus Limestone and beneath the graptolite slates (see below), a series of strata, which in many localities contains a great abundance of

Fig: 7. Coral Limestone from the southern part of Washington Land.

corals, I have therefore united the localities mentioned below into one group, which I name Coral Limestone, even if, in certain strata, other groups of animals are those that predominate.

On the southern part of Washington Land (fig. 7) there is, above the Ordovician and the Pentamerus Limestone, a series of strata, from which rather large collections were brought home from Cape Clay and Cape Webster. The strata dip slightly from Cape Webster down towards Cape Clay. The height of the cliffs is 200—250 metres. In both localities there are steep coast-cliffs. At Cape Webster grey limestone with many fossils occurs at the base, above which follows a reddish limestone, poor in fossils. Almost all the fossils from Cape Webster are fragmentary, which is, however, in some degree due to the fact that the rock in question is unusually difficult to work. Most common are the brachiopods: *Spirifer*, *Strophomena*, *Orthis* and *Atrypa*. Fragments of cystideans occur here, they have not been found in other localities. Corals are fairly common, and the whole series of strata most resembles the Coral Limestone.

At Cape Clay a homogeneous, greyish-blue limestone is met with. The conditions prevailing in this locality are not clear. It is possible, that some of the strata found here belong to the Ordovician. Fossils are very common; tribolites occur abundantly; ostracods are extremely common, gastropods and brachiopods also occur. Strata were found which were almost exclusively formed of fragmentary fossils.

In a somewhat limited area, comparatively easy of access, there seemed to be a good opportunity for investigating the mutual relations between Ordovician, Pentamerus Limestone and Coral Limestone.

Typically developed Coral Limestone is found along the coast between Cape Calhoun and Cape Jefferson. Where steep walls of limestone face the sea, one sees, even at a distance, ball-like colonies of *Favosites* and *Halysites*, which have appeared on the surface through the action of

weathering. At Cape Jefferson itself the Pentamerus Limestone forms along the coast a plain, two kilometres broad, rising only about four metres above sea-level. Above this there is a cliff, 30 metres high, consisting of dark Coral Limestone, overlain by a light-coloured, non-fossiliferous limestone, about 20 metres thick. The Coral Limestone forms a regular coral-reef here with numerous well-preserved fossils, almost exclusively *Favosites*, *Halysites*, *Heliolites*, *Omphyma*, etc. Crinoids and Bryozoa also occur.

As far as I could perceive from the sea-ice, the above-mentioned light-coloured limestone of Cape Constitution sinks below the sea-level somewhat south of Cape Morton. It is overlain by a dark, heavy limestone, bearing a certain resemblance to the darker variations of the Pentamerus Limestone, as it is seen at Cape Calhoun and Cape Tyson. Around Cape Morton the darker limestone is overlain by a light-coloured limestone, which in some localities, is rather sandy and contains a great abundance of fossils. In a single locality I saw a stratum, several metres thick, which consisted exclusively of crinoid-branches. From Cape Morton and the southerly-situated Cape Bryan considerable collections were brought home. The fossils occur in a stratum of light-coloured friable limestone, 30—40 metres thick, the surface of which weathers into small fragments. The collections from Cape Bryan are remarkable on account of the fact that they contain an unusually great number of mussels. Nor are corals, brachiopods and crinoids rare, of trilobites *Bronteus*, *Dalmanites* and *Encrinurus* are found. At Cape Morton a quantity of crinoids and gastropods have been brought to the surface by the action of weathering. Corals also occur. The fossils are fairly well-preserved, mostly as stone casts. The fauna brought home from this locality is rich in individuals, but poor in species.

While practically the whole of Washington Land is formed by Coral Limestone, this plays a far less important part on the north coast. On Hall Land it is, however, still well-developed. Almost the whole of Offley Island consists

of Coral Limestone, which, however, also contains brachiopods and trilobites. The same strata are again found at Cape Tyson, where the Coral Limestone is more than 200 metres thick.

The rather few observations concerning Coral Limestone on the north coast of Greenland, are discussed below, together with the exclusively northern series of strata with graptolites.

Graptolite Slates.

Along the northern shore of the St. George Fjord there is a good opportunity of observing fine sections through the Silurian strata. Where the fjord is still narrow, Pentamerus Limestone on both sides can be seen, occurring in several places as perpendicular cliffs, 1000 metres high. On Warming Land the ice-cap rests, west of Djævlekløften, essentially on Pentamerus Limestone. Close to the northern limit of the ice-cap, other kinds of rock are however met with. Between the ice-cap and Hartz Sound the country sinks, forming a plain, the surface of which is only about 15 metres above sea-level. In several places on the plain, plateaux are however found, which reach a height of 300—400 metres or more. The plain sinks down as a flat strand outwards towards the St. George Fjord, the strata are covered with moraine material and marine clay, and only in four river-beds is there an opportunity of studying the strata *in situ*.

The southernmost of the rivers is 7 kilometres from the edge of the ice-cap, which occurs here to a height af 550 metres, somewhat north of the northern limit of the Pentamerus Limestone. The river is fed by numerous streams from the edge of the ice-cap, and near its outlet it has excavated a very narrow, 20 metres deep, cañon down into the greyish-brown, un-fossiliferous limestone, which probable belongs to the Pentamerus Limestone. The next river is about one kilometre north of this. Here occurs a dark brown, somewhat sandy limestone with corals and many brachiopods. The section of the strata *in situ* is only

a few metres thick, therefore it is impossible to form a conception of the thickness and distribution of these strata, but the numerous detached blocks of Coral Limestone (with *Favosites, Halysites,* etc.) north of this area, make it probable that this is a locality in a fairly thick series of Coral Limestone overlying the Pentamerus Limestone. The strata dip slightly northwards.

A few kilometres north of this river, another is found, which, near its mouth, reveals a small section of the strata *in situ*. The rock here is a greyish-blue limestone with a few crinoids, some brachiopods, as also *Monograptus priodon*. There was a good opportunity of investigating this rock while ascending the ice-cap, since the cliffs here consisted almost exclusively of this kind of rock right up to their summit. On the whole, it appears as if the plateau-like hills, which in several places rise above the plain, consist almost entirely of *Monograptus*-limestone. The strata vary greatly, sometimes consisting of a pure, coarsely banded limestone, sometimes of a slaty limestone finer in texture. In several places sandy areas occur, and the strata become more and more sandy upwards. In several places, especially in the limestone, pyrites are found. I have been able, through actual measurement, to ascertain that the thickness was at least 500 metres; this limestone also dips slightly towards the north or northwest. Throughout the whole series of strata, one finds strata with *Monograptus priodon*, especially in the more slaty parts. In other respects the fauna varies greatly according to the nature of the rock. In the coarsely-banded sandstone there are great quantities of cephalopods and large trilobites (*Bronteus* and *Illaenus*); the more slaty limestone contains other trilobites, mostly small forms of *Phacops* and *Encrinurus*. The brachiopods occur very commonly, and in many species. A form like *Lissatrypa Scheii* is found especially in sandy limestone, but seems also to occur through the whole series of strata.

The northernmost of the rivers which flow through the

plain falls into a small creek; it has cut itself two metres down into the soil, but on account of this more easterly situation there is reason to believe that these strata lie under the series of strata known from the foregoing river. The section goes through black slate of a fine texture, which only contains graptolites. Most common is a *Rastrites*, which resembles *R. Linnæa*, moreover, a *Monograptus* was found, which comes near to the *M. convolutus (His.) var. Coppingerii* established by ETHERIDGE [8a] and recorded from the drift at Polaris Bay, and a *Cyrtograptus* and several species of *Monograptus*.

Almost all the above-mentioned strata contain enormous quantities of fossils, and I succeeded in bringing home across the inland-ice, some choice specimens, 92 in all, including an abundance of well-preserved species. Continuous fogs and snow-storms, hunger and the depression which always follows after the death of a fellow traveller, had created conditions very unfavourable for an investigation of these — geologically — unusually interesting regions and there are still, taken purely from the point of view of a survey, several matters which I did not succeed in investigating owing to the difficult conditions of travelling. Thus I have a very incomplete knowledge of the transition between the Silurian strata and the overlying coarse sandstone. I have the impression that, at any rate in several localities, there is an even transition from the limestone rich in fossils to the un-fossiliferous sandstone, but numerous detached blocks of hard, dark limestone with large cephalopods near the coasts of Hartz Sound might rather suggest the occurrence of such a stratum under the sandstone. Dr. WULFF was of opinion that, in a river-bed on Hendrik Island, he had observed this Cephalopod-limestone overlain by sandstone, but I dare not pronounce any definite opinion as regards the upper limit of the Silurian strata.

I obtained proof that the series of strata — Pentamerus Limestone, Coral Limestone and Graptolite Limestone — is the normal series in the most northerly Greenland, by

ascending to the well-known fossil habitat, Cape Tyson, in the Hall Basin. The Pentamerus Limestone and the Coral Limestone here form the lowermost 380 metres, above which there are limestone and slate with *Monograptus priodon* and an abundance of other fossils, especially brachiopods. Unfortunately, a snow-storm prevented me from investigating these strata more closely. I collected, however, several species, chiefly from detached blocks of rock, several of which are identical with forms from Warming Land.

Summary of Upper Silurian.

The localities mentioned above are here grouped under the name Upper Silurian. I have tried, more particularly on the basis of the rock-species and the fossil-contents, to make a distinction between several groups of fossil-habitats. It is a question whether the palaeontological revision of the material will accept this distinction, but for the sake of the future collecting of fossils I am of opinion that it ought not to be omitted here.

Whether the whole series of strata near Cape Constitution is of a later period than the Pentamerus Limestone, is not quite certain. It is however my opinion that for the present it may be referred to the Upper Silurian. On the other hand, it can be stated with certainty that all the other localities are younger than the Pentamerus Limestone, since the direct overlying has been observed at Cape Jefferson, Cape Morton, Cape Tyson and in many localities within the fjords of the north coast.

Upper Silurian is distributed from the Kane Basin right across towards Peary Land, so that it forms a broad belt above and north of the Pentamerus Limestone. The tectonic conditions are, with the exception of the faults near Cape Constitution, exceedingly simple. As is the case with the Pentamerus Limestone, so here no folds occur and the strata lie everywhere with a slight dip towards the northwest, the degree of dip being 2°—7°. Faults and traces of volcanic activity appear to be totally absent. The rock is of a dark

leaden colour in contradistinction to the red and yellow Pentamerus Limestone, hence it comes that, even at a distance, it is fairly easy to distinguish the two kinds of rock.

Also the forms produced by disintegration differ entirely. While the Pentamerus Limestone forms plateaux intersected by deep ravines with steep, often perpendicular sides, steep faces in the Upper Silurian limestone occur only in a few localities near the coast. Cañons do not occur. The valleys are broad and level, and extensive plains are common. The height is far less than that of the Pentamerus Limestone; on Washington Land the height does not exceed 400 metres while along the north coast it is generally about 500—600 metres. The greatest thickness of stratum I found in the St. George Fjord, where the combined thickness of the Coral Limestone and the Graptolite Slates exceeded 600 metres.

Until the collections brought home have been more closely investigated I dare not state anything beyond the opinion that the series of strata must be referred to Upper Silurian. HOLTEDAHL [17c], on the basis of SCHEI's collections from the neighbouring Ellesmere Land, places SCHEI's Series B »in the very transition zones between Silurian and Devonian«. A closer investigation of my collections will undoubtedly prove their great similarity to the collections from SCHEI's Series B.

Upper Silurian, as is well known, has a wide distribution in the Arctic Archipelago. From the regions around the magnetic North Pole, a broad belt of Silurian extends across North Somerset, Cockburn Land, North Devon, Ellesmere Land and Grinnell Land. From a purely geographical point of view the North-Greenland Silurian localities form a direct continuation of the areas mentioned above.

Devonian.

History.

HALL [12c, d] gives a citation from MAUCH'S* Journal: »A narrow gorge leads into it, on each side of which the slaty overhanging layers of Devonic limestone«. Further on it is recorded that: »All the fossils found near Thank-God-Harbour had been taken from erratic boulders, the slaty limestone of the mountains containing no fossils whatever. Offley Island is, however, formed of entirely different rock, and it was in the native stone that these fossils were embedded«. It has already been mentioned that BESSELS had determined the strata near Offley Island as Upper Silurian; it is therefore an obvious conclusion that the members of the expedition have regarded the overlying slates near Polaris Bay as Devonian. BESSELS [1c, k] himself, however, does not say anything about the age of these slates. On the other hand, he states that the stratification is very irregular.

FEILDEN [10b, d], on account of the similarity to »the gold-bearing series of Nova Scotia«, which was at that time reckoned to be pre-Cambrian, refers the so-called Cape Rawson Series to the Huronian, for he remarks that the strata are older than the fossiliferous Silurian. He afterwards admits, however, that he does not know the conditions at the boundary line between the Silurian and the Cape Rawson Beds. He is aware that the boundary line between the two layers goes from Scoresby Bay across Kennedy Channel to Polaris Bay. North of this line one finds the Cape Rawson Beds, and south of it, Silurian on both sides of the channel. DAWSON [5b] draws attention to the fact that »the gold-bearing Series of Nova Scotia« is now referred to the Lower Cambrian, hence the reason why DAWSON, on his map, delineates Cambrian over large areas of Grinnell Land, and along the whole coast between Polaris Bay and St. George Fjord.

* Member of the »Polaris«-Expedition.

SCHEI [27d] found, along the east coast of Heureka Sound, slightly folded strata containing Trias-fossils, and he makes the suggestion that the Cape Rawson Series might possibly be regarded as the equivalent of the mesozoic slates and sandstone. On SCHEI's map nothing is found regarding the Cape Rawson Series. LOW [22a], and with him WILLIS [29], adopts SCHEI's supposition and refers the whole Cape Rawson Series to the Trias.

That a great part of the Cape Rawson Series is folded, was observed by BESSELS [1c, k], COPPINGER [23g], and FEILDEN [10b, d]. From quite a different locality in North Greenland, viz. the east coast of Peary Land, the Danmark Expedition brought home, in 1908, metamorphosed sedimentary rocks, collected by I. P. KOCH [21].

BØGGILD [4c, d] writes, after having mentioned the Cape Rawson Series »Zusammen mit diesen gehören wohl auch die von der Danmark-Expedition untersuchten Gegenden im westlichen und nördlichen Teile von Peary Land, wo auch stark umgewandelte Sedimente gesammelt worden sind«. As regards the age, BØGGILD writes that the folds must be of Post-silurian date.

As may be seen from the literature on the subject, the informations to hand regarding the conditions in the most northerly part of Greenland, were very confused. It was known that folded strata existed, but great differences of opinion prevailed as to their age and distribution.

The Unfolded Post-silurian Sandstone Formation.

As mentioned above, the stratification at the boundary line between the Silurian and the Cape Rawson Series, has not hitherto been known. In North Greenland there are, however, in many places good opportunities for observing, that the Cape Rawson Series overlie the Graptolite-slates.

To give the name »Cape Rawson Series« to the strata overlying the Silurian limestone, cannot be done as far as Greenland is concerned. The name was created by FEILDEN

to indicate some highly folded strata on Grinnell Land and on both sides of the Robeson Channel. The conception »Cape Rawson Series« appears consequently, according to FEILDEN, to include only the fold itself, within which fold exposed strata from earlier periods are certainly to be found. South of the fold one finds in Greenland an undisturbed Post-silurian series of strata of rather considerable thickness.

This series of strata, consisting almost exclusively of sandstone, forms a belt from Robeson Channel right over to Nares Land. I observed its maximum thickness in the Victoria Fjord, where the sandstone is almost 500 metres thick. The whole series of strata is exceedingly uniform. One meets partly with coarse unbanded sandstone, partly with somewhat slaty bands with numerous mica-laminæ. The colour is grey, sometimes of a greenish or brownish shade. The rock is rather loose in texture, and erosion, especially destruction by frost, has an easy task with these strata. On a contour map the whole sandstone area would therefore appear as a decided depression between the Silurian strata, situated to the south, and the folded areas further to the north. This is seen very distinctly on Hall Land where south of Polaris Promontory, between the Hall Basin and Newman Bay, a plain is found about 600 km^2 in extent. The average height is about 50 metres above sea-level, and the greater part of the plain is covered with layers of marine clay. The boundary towards the folded region coinsides with the southern slope of the Polaris Promontory.

On Nyeboe Land, also, a decided depression from Newman Bay to the St. George Fjord occurs, which is also expressed in the coast-line. In the interior of the country the maximum height lies between 400 and 500 metres. The whole drainage of the central and southern part of Nyeboe Land to the two fjords in question is effected through this depression. The depression is continued also north of Hartz Sound. The thickness of the sandstone is here 350—400 metres. On Wulff Land the conditions are

Fig. 8. Unfolded Post-silurian Sandstone. Sherard-Osborne Fjord.

extremely clear. From a study in particular of the form of the country on the geological map, a direct impression is obtained of the power of resistance of the various series of strata which go to build up North Greenland. Farthest to the south one finds the broad plateau which is partly covered with inland-ice, and which is above 1000 metres in height. North of this there are Coral Limestone and Graptolite-strata which are somewhat thinner and reach a height of 600—700 metres only. Then follows the narrow plain of unfolded sandstone with an average height of only 200 — 300 metres, and north of this the folded region, which is somewhat broader and has alpine peaks of more than 1000 metres in height.

These morphological elements re-appear more or less pronounced, straight from the Hall Basin to the Nordenskjöld Fjord.

In the unfolded sandstone there is nowhere found the least trace of fossils.

As mentioned above, FEILDEN did not know the development of the strata between the Silurian and the Cape Rawson Series; on the other hand, SCHEI records above highly fossiliferous Silurian strata a series of coarse, unfossiliferous sandstone, which are overlain by Devonian. They constitute SCHEI's Series C, which was found within the fjord on the south coast of Ellesmere Land. It is pre-eminently probable that SCHEI's Series C is the same series of strata which is found again in North Greenland as the Post-silurian unfolded sandstone-formation.

On comparing FEILDEN's observations from Grinnell Land and Grant Land and SCHEI's investigations, — as for instance, the Goose Fjord with the series of strata from Warming Land and the St. George Fjord, — one can, with tolerable probability, draw up the following table.

Feilden 1878	Schei 1904	Holtedahl 1917	L. Koch 1920	Geological Periods
Grant Land and Grinnell Land	GooseFjord, Southern Ellesmere Land			
Feilden Peninsula	Great Bear Cape			Carboniferous
Dana Bay Beds	Series D			Devonian
Cape Rawson Beds	Series C		Postsilurian, unfossiliferous Sandstone	
Dobbin Bay and several other places. Offley Isl.; Cape Tyson	Series B	Keyser Member of Helderberg	Graptolite Slates Coral Limestone	Upper Silurian
Cape Hilyard	Series A: Upper Part	Niagaran	Pentamerus Limestone	Middle Silurian
	Series A: Lower Part	Trenton	Orthoceratite Limestone	Ordovician
	Sandstone	Ozarkian	Red Sandstone	

The Folded Mountain Chain of North Greenland.

On a forced sledge-journey under unfavourable circumstances it is of course very difficult to obtain a general view of so intricate a process as the intense folding of a mountain chain. During the journey, however, it became evident to me that such a folding extends along the whole coast

of North Greenland, and I therefore endeavoured, as far as possible, to note down as many tectonic details as I could during the journey. This task was greatly facilitated by the fact that the folded rocks are intersected by a great number of sounds, fjords and valleys whereby many crossing sections are exposed. These, owing no doubt to a rather recent glacial erosion, are still very distinct, and especially in early summer, when a thin layer of snow falls upon the mountains, the tectonic features stand out very distinctly, as there is no plant-covering. Later in summer, when the mountains are snowless, it is only in certain lights as a rule, that the tectonics of the strata can be seen at a distance.

As simultaneously with these investigations, I surveyed and mapped out these regions hitherto almost unknown, and as more than 30 of my cartographical stations occurred within the folded area, I had a good opportunity not only of fixing, by an extensive triangulation, the position of the anticlinals and synclinals directly observed, but also of surveying such mountain-summits and valleys as might be expected to form a continuation of these anticlinals and synclinals. When the whole of this material has been calculated, the conception of the folded region of North Greenland will certainly gain in clearness to a high degree; but yet there are some conditions in these regions which are so obvious that I shall not omit to mention them here.

Polaris Promontory on Hall Land.

The section along the Robeson Channel begins in the south with a series of very highly compressed strata. Along the shore anticlinals and synclinals are seen in close succession. Further to the north there is a huge anticlinal consisting of gneiss and crystalline slates. The districts north of this apparently dip only slightly towards the Robeson Channel, but in reality they dip considerably westwards. The section along Newman Bay begins towards the north with a very shallow synclinal. South of this there are crystalline slates in a very steep dip with two nuclei of

gneiss. The southernmost part of this section I did not see. A series of mountain-peaks across the promontory indicates the underlying gneiss. To the south of this the landscape is characterized by pointed peaks, produced by erosion of the highly compressed slates. The northern part is a level plain, in the surface-form of which the shallow synclinal can be traced far inland.

Nyeboe Land.

Within this area one longitudinal and four transverse sections have been exposed. Here the mountain-chain has been highly eroded and has partially lost its plateau-form. The mountain-peaks produced by erosion contribute towards the comprehension of the tectonic conditions in the interior of the country, but the advanced stage of erosion partially obliterates the continuity of the strata in the sections.

The section facing Newman Bay is very indistinct. A mountain-range, opposite to the gneiss-ridge on Polaris Promontory, extends for some distance eastwards, but no gneiss occurs. The longitudinal section (near Cape Brevoort) gives a clear idea of the extremely complicated tectonic conditions existing here. Numerous faults occur in this place; otherwise they are very rare in the mountain chain. Towards St. George Fjord the peaks discovered by BEAUMONT [23h] are arranged in two rows, both of which indicate synclines. Mt. Stanton, Mt. Love, Mt. Wyatt and Cape Fulford are peaks in the northern row. Rock Hill, Degree Hill and Mt. Punch are those in the southern row. Along the western side of St. George Fjord there is an exceedingly beautiful section through the two synclines.

The Conditions prevailing in Sherard-Osborne Fjord.

The northernmost syncline on Nyboe Land cannot be traced with any certainty across the fjord. On the other hand, two mountain peaks (972 and 1150 metres) south of Dragon Point form a direct continuation of the southern synclinal on Nyeboe Land. South of this synclinal there

is, on both sides, as well of St. George Fjord as of Sherard-Osborne Fjord, an area of highly compressed strata. Of the islands in the fjord the whole of Castle Island belongs to this area. The three small rocky islets east of this area possibly form a bridge between the southern syncline on Nyeboe Land and a large synclinal, south of Cape May, to which BEAUMONT's Mt. Coppinger belongs.

The Mountain Chain between Sherard-Osborne Fjord and I. P. Koch Fjord.

Owing to its numerous glaciers it is difficult to obtain a full view of the tectonics of this region. The north coast of Wulff Land comprises a series of elevations ranging from 300 to 500 metres, all of which consist of strata dipping considerably northwards and striking E.—W. The famous Mt. Hooker belongs to this series. A large valley separates these mountain peaks from the southern chain of somewhat higher mountains, indicating two rather small synclinals. To the south of this there are fragments of a large anticlinal, in the centre of which, facing Victoria Fjord, there is a small area with gneiss. Further southwards, there is probably a large synclinal and, in addition to this, a broad belt of highly compressed strata across the country*.

Stevenson Island in Victoria Fjord shows a large synclinal towards the north; the southern part is a continuation of the area with the highly compressed strata.

Nares Land and Freuchen Land are covered with glaciers to such an extent that continuous sections cannot be seen over great distances, and where the coast-cliffs are not ice-covered, the strata are hidden by loose material to such an extent that one can only establish the existence of the folds, but can state nothing as regards their mutual connection.

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* Only what I directly observed is included in the accompanying sections (see Plate 1). When the strata were highly compressed I chose to draw some of the most distinct folds, rather than give a diagrammatic representation of intense folding

The Northeastern Part.

These regions, which comprise the northernmost mountains of the world, are practically free from ice. Glaciers are found locally only, and they are few in number and small. The strata consist of the same kinds of rocks as in the southwestern area, but from a morphological point of view there is a great difference. As erosive action is far advanced, it is very difficult to obtain a comprehensive survey of the mutual position of the strata in this area. In many localities a fold or a series of steeply placed strata is seen exposed, and, on the whole, it seems as if this region is at least as highly folded as that to the southeast, but correlation of the individual foldings, as already mentioned, can only be made in broad outline.

In only two places large, continuous sections are found, viz., on both sides of the sound between John Murray Island and Elison Island. John Murray Island (northeast of Nordenskjöld Fjord) shows along its east coast a distinct section through a part of the northern folding. This section is about 30 km in length, and no less than three synclinals and five anticlinals are exposed along this stretch of coast. Although it is only a short distance to the section opposite on Elison Island a comparison of the tectonic features is difficult. The island consists of a series of alpine peaks with deep intervening valleys. The southernmost peak, which is visible far and wide, consists of crumpled strata. Another lofty peak, situated further to the north, is formed by a syncline. Between these peaks there is a valley marking a synclinal.

On the land situated to the east, north of I. P. Koch Fjord, mountain peaks, formed by synclinal folds, are seen in several places; these peaks appear to form a row towards De Long Fjord.

Still further to the north folding is seen in many localities.

Fig. 9. View from Lows Point towards Cape Ramsay.

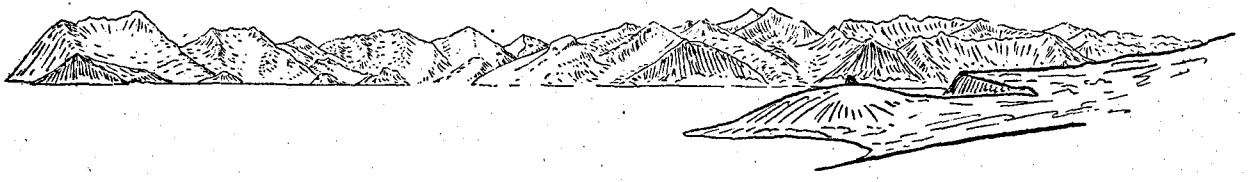

Fig. 10. View from the interior of I. P. Kochs Fjord towards Elison Island.

Fig. 9 and 10. Views of the northern, alpine part of the folded mountain chain.

The Morphology of the Mountain Chain.

On the accompanying plate I have arranged the majority of the sections which I succeeded in drawing. It will be immediately seen that only fragments remain of the original folding. Numerous fjords and valleys intersect the folded strata and the presence of some islands prove, that large parts of the mountain chain have now disappeared.

Regarded purely as a landscape, the folding is however yet very conspicuous. From the low-lying sandstone plain, situated to the south, the folded strata rise rather steeply upwards. The lowest height is towards the west, on Polaris Promontory being about 700 metres, but even on Nyeboe Land there are several peaks above 1000 metres in height. But not until we reach the regions around De Long Fjord do peaks of that height become common, and in the interior of Peary Land I saw several peaks which were undoubtedly almost 2000 metres in height. From the regions south of Fr. Hyde Fjord I. P. KOCH records Alps of a height of 2000 metres. There can be no doubt that the mountain chain attains its maximum height in northern Peary Land.

Even from a long distance it is seen that the landscape of the mountain chain is eroded quite differently from that of the horizontal sediments situated to the south of it. It seems as if an abrasion-plain existed here before the Glacial Period, which from Peary Land sank rather evenly down towards the Robeson Channel. The original plateau-like character has remained most unaltered on Freuchen Land and Wulff Land, but local glaciers and destruction due to frost are now in full activity, moulding the country. The synclinals stand forth more and more distinctly as peaks, while simultaneously the anticlinals are transformed into valleys and fjords (see sections). Under these agencies, the folds, which can be directly observed in the coast-sections, stand out prominently and thereby greatly help us to an understanding of them, but at the same time the beautiful sections produced by the fjord-glaciers are obliterated, so that progressive development will ultimately make

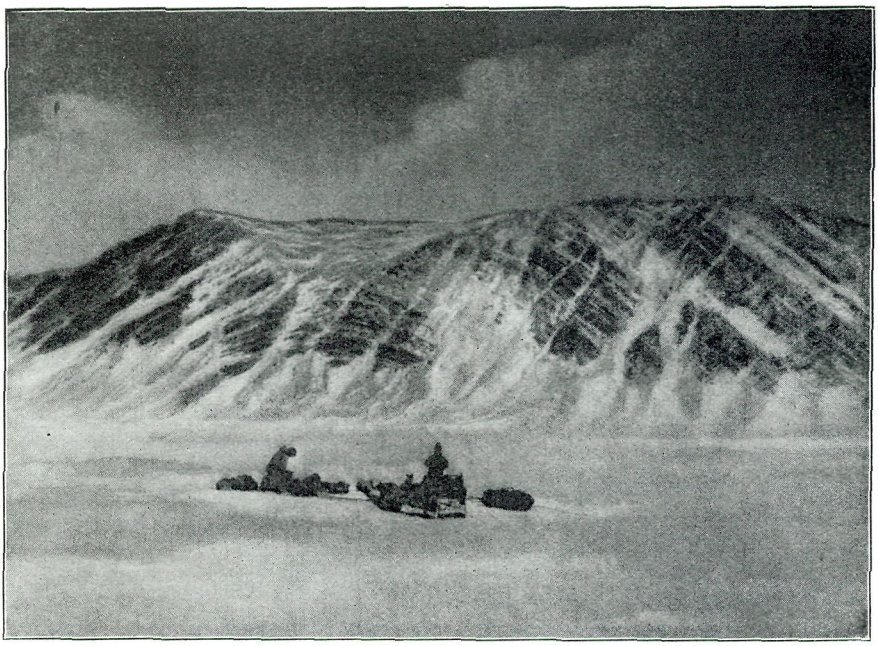

Fig. 11. An anticlinal (Cape Neumayer) in the folded mountain chain.

tectonic survey impossible. The conditions west of Victoria Fjord are most evident, there the coast-sections are yet distinct, and there erosion gives many suggestions as regards the course of the folding of the more or less pronounced plateaux.

The regions north of I. P. Koch Fjord are truly alpine. The extensive sections are covered with loose material, and as a rule it is impossible to arrange the isolated peaks into rows forming synclinals. Anticlinal valleys are somewhat easier to demonstrate. They occur in great numbers west of De Long Fjord. Mascart Fjord, the sounds south of Cape Mohn and the great valley east of De Long Fjord, are all undoubtedly anticlinal valleys.

If the erratic blocks had not proved that northernmost Greenland also has been covered by inland-ice, one might be tempted to believe, that the regions north of I. P. Koch

Fjord had only been eroded by local glaciers. The effects of the inland-ice can no longer be traced, and the valley sinks on all sides from a ridge which approximately follows 83° N. lat. Several observations indicate that this ridge is a synclinal.

The Tectonics of the Folding.

The tectonic conditions may, on the whole, be said to be fairly simple. Nowhere did I observe thrust-planes. On regarding the sections from the Hall Basin across to Victoria Fjord one again finds, as a common characteristic, a southern area with highly folded, sometimes even crumpled strata, and north of this one or several larger and broader foldings. Also in places where I was unable to make drawings of the sections, I found this feature.

Faults are rare. Hence, those found at the northwestern corner are exceptions from the rule. Several areas limited by faults have been only slightly metamorphosed, and here I succeeded in finding a fossil mussel, but unfortunately it was in too bad a state of preservation to allow of closer determination.

There is undoubtedly a considerable difference between the construction af North Greenland and Grant and Ellesmere Lands. None of the North Greenland fjords owe their origin to dislocation, they have undoubtedly all been formed by erosion. On the other hand, it appears that there are numerous fractures between Lake Hazen and Archer Fjord, and SCHEI [27a] records numerous horsts from Ellesmere Land. Anything of this kind (with the exception of Cape Constitution which is situated outside the folded area) is not found in Northwest Greenland.

Petrography.

Unfortunately, it was only possible to obtain very few data as to the elucidation of the petrography. When

travelling along a section of a fold, out on the sea-ice, the tectonic details can be noted down, and then afterwards, when a survey of the whole section is obtained from a distance, the single folds can be arranged in relation to one another. To obtain an impression of the petrographical conditions is, on the other hand, far more difficult. Only in places where one lands, can the rock be determined, and as the journey turned out it was quite impossible to bring home specimens of the strata. By far the greater part of the folded strata appeared to consist of more or less metamorphosed sandstone. The amount of marble is negligible. In two localities, viz., Victoria Fjord and Polaris Promontory decided gneiss was found. On Polaris Promontory, especially, a beautiful transition between gneiss and almost unmetamorphosed sediments can undoubtedly be demonstrated. Quartz-veins are fairly common almost everywhere.

The Age and Extent of the Folded Region.

We owe our knowledge of the folded strata west of the Hall Basin exclusively to FEILDEN[10]. The folding extends from Scoresby Bay to Cape Cresswell in lat 82° 40' N. The strata are recorded to consist of slates, limestone and veins of quartz and chert, and north of 82° 33' quartzites and grits are found.

As already mentioned, FEILDEN had no opportunity of observing the relation of the folded strata to the Silurian strata, and in reality nothing is known as regards the distribution of the folds in the interior of Grinnell Land. SCHEI [27d] mentions slight folding of the Trias-sandstone from the east side of Heureka Sound. However, the American geologist, Mr. EKBLAW, who in 1915 made investigations in Heureka Sound, informed me verbally that a part of SCHEI's Trias stratum is probably palæozoic. It is however certain that the folding does not extend beyond Heureka Sound.

The southern limit of the folding is easy to trace from the Hall Basin across to Jungersen Glacier. To the east of

this the country is almost hidden under the inland-ice, and it was not possible for me to determine the southern limit of the folding on Peary Land. The northern limit is known only in the northern part of Grant Land, viz., from Feilden Peninsula, where, according to FEILDEN, horizontal Devonian and carboniferous strata overlie the folding. The northern limit of the folding in Greenland is represented by two lines, the one running from Archer Fjord on Grinnell Land to I. P. Koch Fjord in the western part of Peary Land, the other along the north coast of Peary Land across to Cape Creswell. Beaumont Island is the western-most Greenland-fragment of this northern part of the folding, and in the course of time large portions of the folded rocks, north of the Robeson Channel, have undoubtedly disappeared.

The Age of the folding can be determined in some measure. It is seen in many places that it is the coarse sandstones, overlying the slates with *Monograptus priodon*, that are folded. Consequently, the disturbances must have occurred at the end of the Silurian period at earliest. The determination of the age upwards is based exclusively on FEILDEN's investigations at Feilden Peninsula. In a section through Feilden Peninsula to Cape Joseph Henry it is seen in two localities that the folded Cape Rawson Beds are overlain by unfolded Dana Bay Beds (Devonian), and over that, unfolded carboniferous limestone occurs. The folding therefore must, at any rate be older than the latest Devonian and Carboniferous.

The Age of the folding is therefore determined as Devonian, presumably the first half of this period, perhaps beginning in the uppermost Silurian.

From the preceding it is evident that the folding disappears towards the southwest and does not extend beyond Heureka Sound. Towards the east it can be traced to the entrance of the Fr. Hyde Fjord where it is abruptly interrupted by the Atlantic Ocean.

Only 550 km from Fr. Hyde Fjord we have Spitzbergen with a huge palæozoic fold, the so-called Hecla-Hook-For-

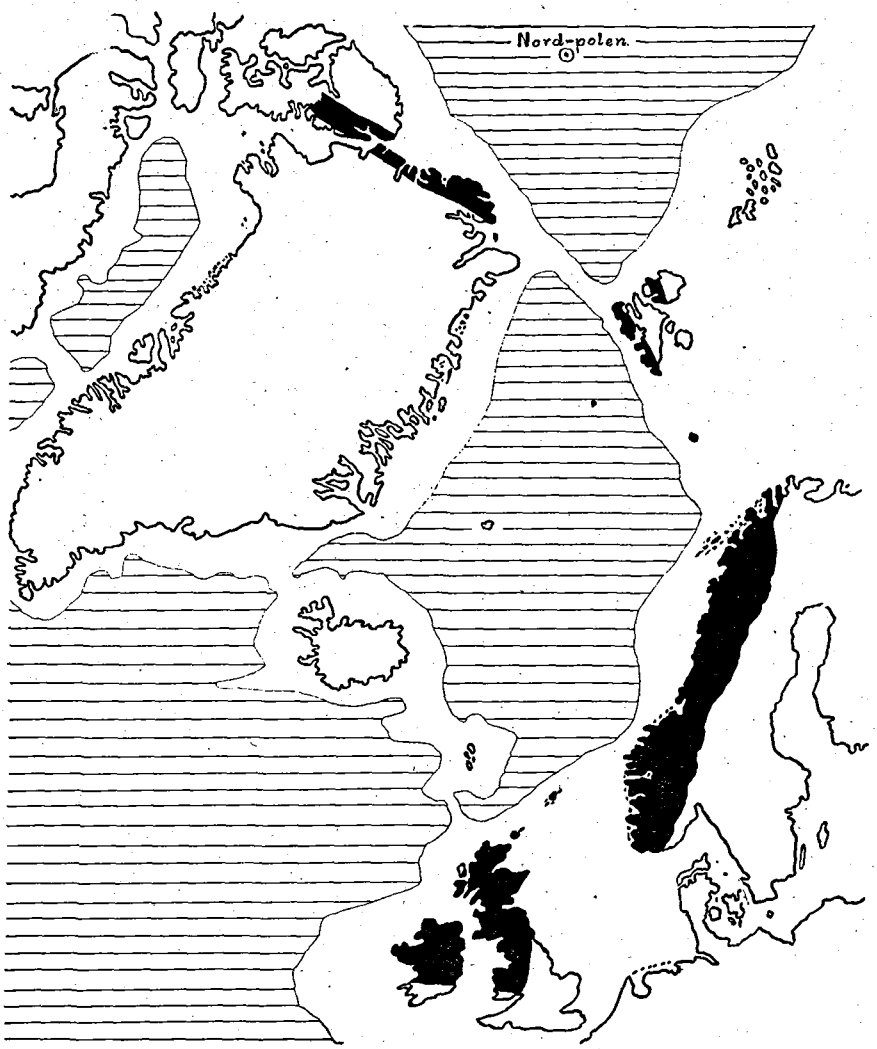

Fig. 12. Map showing the Caledonian Folding. Folded areas black; depths of the sea more than 1000 m horizontally shaded.

mation. NATHORST [24] has determined this as Pre-Devonian, and he regards the Hecla-Hook-Formation as a continuation of the Caledonian-Scandinavian folded region. As regards this he writes: »Möglicherweise deutet der unterseeische Rücken, der sich von Nordwestspitzbergen zwischen dem eigentlichen Polarbecken und der Grönland-See erstreckt, auf eine Fortsetzung des westlichen Zweiges der Hecla Hook-Kette Spitsbergens nach Grönland hin.«

NATHORST's supposition of 1910, has been verified in an exquisite manner; for just in the continuation of this submarine ridge, extending from Spitzbergen towards Greenland, is found the 1000 km long fold which forms the whole north coast of Greenland and the western side of Grinnell Land (see fig. 12).

If the Greenland fold is regarded as the northern tapering part of the Caledonian fold, then it is natural that the thrust-planes should be connected with the central parts of the mountain chain, viz., Northern Scotland and Scandinavia, whereas in North Greenland, as in England and Ireland, is found highly folded, but relatively slightly metamorphosed sediments.

Eruptives more recent than the Folding.

East of Sherard-Osborne Fjord no eruptive veins are found in connection with the folding. On the other hand, these veins become the more numerous, the farther one travels northwards, along the north coast of Peary Land. The veins are partly of diabase, and partly of porphyry: Their size varies from narrow veins up to a thickness of 30 metres or more.

The most southerly locality for these veins is at the north-east corner of Wulff Land. It is some two hundred metres in height and about 20 metres in thickness. Around I. P. Koch Fjord several veins are found, and within De Long Fjord they are very common. A more careful investigation will undoubtedly prove the existence of many more than those

indicated on the map. Near Cape Mohn it can be distinctly seen that the porphyry-mass has penetrated vertically upwards through the folded strata. No beds are found, it is almost exclusively veins that occur; and these frequently form the peaks of mountains.

As regards the age of these eruptives, it can only be said that they are younger than the folding. Diabase is recorded from Heiberg Land (carboniferous), Grinnell Land (mesozoic), and Spitzbergen (mesozoic).

This investigation has proved, that in the first half of the palaeozoic Period, a sea-transgression took place into North Greenland, where the gneiss surface lies unusually low. This transgression is only one part of the coastal displacement, which simultaneously befell the Arctic Arcipelago; but it is particularly interesting on account of the fact, that the North-Greenland geosyncline was involved in the Caledonian folding, which has previously been traced only east of the Atlantic Ocean in Spitzbergen, Scandinavia and Scotland.

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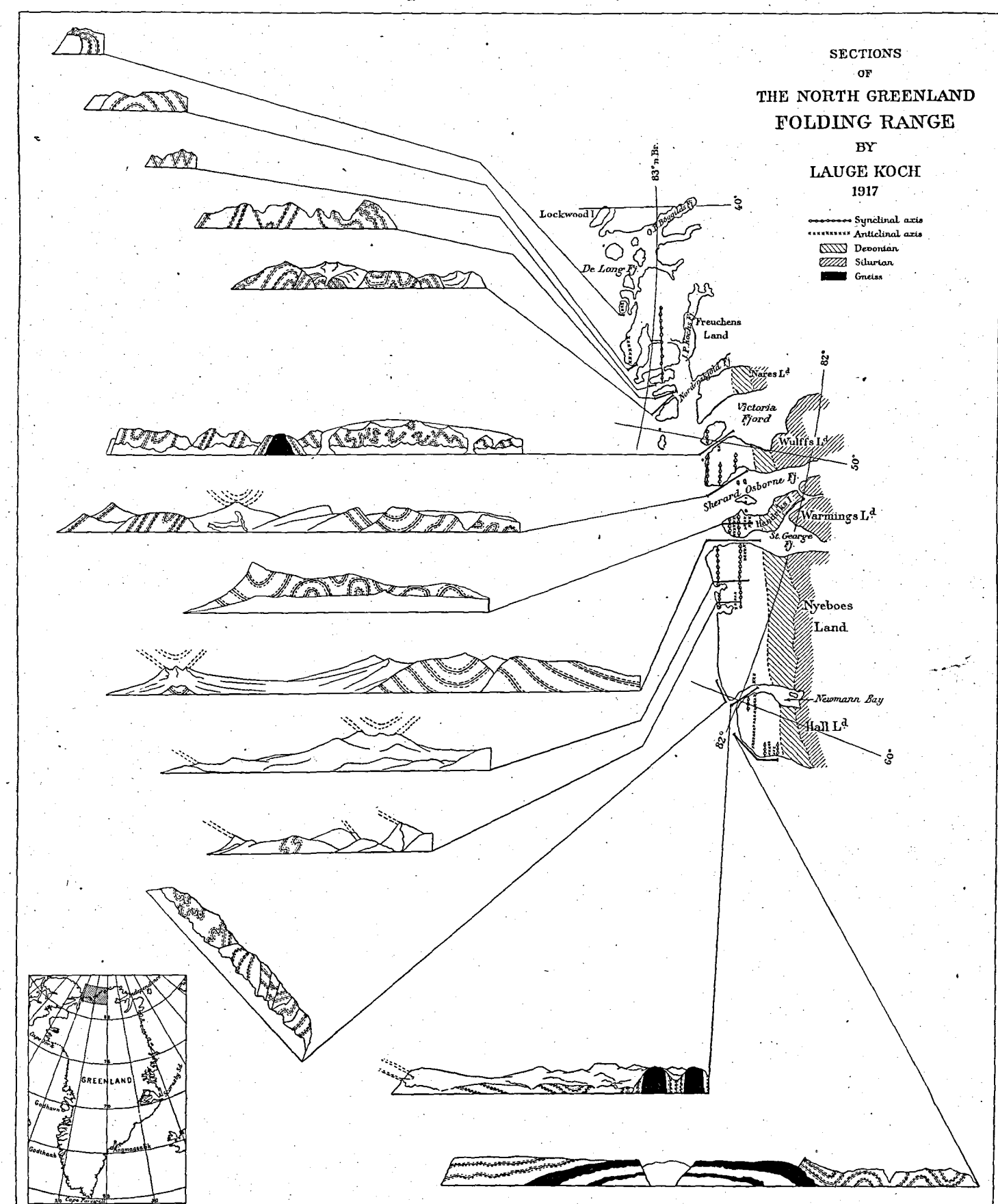
SECTIONS
OF
THE NORTH GREENLAND
FOLDING RANGE
BY
LAUGE KOCH
1917
Synclinal axis
Anticlinal axis
Devonian
Silurian
Gneiss
83° n. Br.
40°
Lockwood I.
De Long Fj.
Freuchens Land
Nares L.d
82°
Victoria Fjord
Wulff's L.d
50°
Sherard Osborne Fj.
Warmings L.d
St. George Fj.
Nyeboes Land
Newmann Bay
Hall L.d
60°
GREENLAND
Cape York
Upernivik
Godhavn
Godthaab
Angmagssalik
Cape Farewell