

THE
AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

ART. XV.—*The Geology of North Greenland**; by LAUGE KOCH.

Mapping.

During the Second Thule Expedition of 1916-1918, I was engaged as topographer, surveying Melville Bay and part of the northern coast of Greenland (see Report on Greenland, 64, 1922). On my next journey, beginning in 1920, I continued this work and succeeded in mapping the remaining portion of West and North Greenland. In the areas previously mapped, I re-surveyed some areas, and also made various corrections, which now enable me to publish a complete map on a scale of 1 : 300,000. The area thus surveyed extends from the northern boundary of the Upernivik District to Danmark Fiord in the far northeast, and comprises one fourth of the coast of Greenland. See fig. 1.

The numerous expeditions which have penetrated to North Greenland have observed how the inland ice cap descends to lower levels as the ship advances to the north, and in many cases a small local ice-covered area has been mistaken for a part of the vast inland ice. But my journeys in the north of Greenland have shown that some of the greatest ice-free areas of the country occur here.

Another circumstance which has caused wrong conclusions in mapping consists in the distribution of the fiords and glaciers. In no other place does one see so many long, narrow, and straight fiords, and into these the inland ice pours its glaciers. On account of the permanent sea-ice, the fiord-glaciers can not get rid of their

* Translated, condensed, and somewhat altered from a Danish article entitled "De Videnskabelige Resultater af Jubilæumsekspeditionen Nord om Grønland" (Geografisk Tideskrift, 27, part VII, 1924). An earlier report of progress appeared in this Journal for March, 1923, pp. 189-199.

This lowest part of the glacier rises imperceptibly, and hence the horizon line of the inland ice is so distant as not to be visible to the eye; it is, therefore, quite natural

FIG. 2.



Fig. 2.—The areas of the four structural elements: (1) the Archeozoic Gneiss Plain, (2) the plain of undeformed Paleozoic sediments, (3) the area of the Caledonide Mountains, and (4) the down-faulted area of Cape York, composed of Archeozoic gneiss and Algonkian sediments.

that the traveller should think he has a very deep fiord or a sound before him. Such erroneous interpretations occur on the map of Petermann Fiord, drawn up by the Hall Expedition, Beaumont's map of Sherard Osborne Fiord, and Lockwood's map of Nordenskiöld Fiord.

Structural Elements.

During my earlier journeys along the north coast of Greenland, I was enabled to define three structural divisions (see *Journal of Geology*, 26, No. 1, 1923). These are, in North Greenland, beginning in the south: (1) the Gneiss Plain of Archeozoic rocks, (2) the Plain of Sediments, and (3) the area of the Caledonide Mountains. On the expedition of 1920-1923, these elements were further investigated, their exact limits defined, and still another structural element discovered, namely, a down-faulted block comprising the Cape York district, the time of the faulting being apparently Mesozoic. See fig. 2.

(1) *The Gneiss Plain of Archeozoic Rocks.*—In the paper mentioned above, I pointed out that the surface of the inland ice in North Greenland is an extraordinarily low-lying area, due to the fact that the gneiss plain farther south gradually descends to the north. This is distinctly seen when travelling along the west coast of Greenland.

The western boundary of the gneiss area is formed by the coast itself up to Cape York; from north of Cape York to about Etah, however, the plain is bounded by a great fault, the average drop of the western block being about 800 meters.

The northern boundary of the Gneiss Plain is of a purely topographic nature. It can be traced northward to sea-level, but the sediments which cover it here show by their composition that the plain is undoubtedly continued to the north beneath younger formations. The entire eastern portion of the shallow Kane Basin consists of gneiss, which here goes beneath sea-level, and the north coast of Inglefield Land, which strikes east-west, consequently forms the northern boundary of the Gneiss Plain.

In East Greenland, the bottom of Danmark Fiord is known to be floored by gneiss, but its northern limit of exposure has not yet been determined.

(2) *The Great Plain of Sediments* is bounded on the south by the Gneiss Plain, on the west by the Cape York Fault Zone, on the north by the Caledonide Mountains, and on the east by the Atlantic. This limitation is purely geographical, since the original geological boundaries were surely of far greater extent. How far to the south

the sediments formerly extended over the Gneiss Plain, it is now impossible to ascertain.

The fault zone in the western part of the Cape York district is a geologically much younger limitation of the plain, while to the north are the Caledonides, which consist chiefly of the metamorphosed continuation of the strata of the Plain of Sediments.

The maximum thickness of the strata of the Plain of Sediments is not yet definitely ascertained. The oldest strata, of Algonkian age, vary from 200 to 1,000 meters, the Cambrian has a maximum thickness of 500 meters, the Ordovician appears to be 800 meters, and the Silurian averages about 600 meters. This makes a total of from 2,100 to 2,900 meters.

Throughout the vast area of the Plain of Sediments not the slightest indication of flexures, faults, or foldings has been observed.

(3) *The area of the Caledonides* extends over the remaining northern portion of Greenland and forms the north coast of the country. The western part of these mountains was investigated during the last expedition, and on this journey we succeeded in determining their limitation. On the other hand, I was disappointed when it turned out to be impossible to survey the greater part of them eastward into Peary Land, because here the mountains are of an Alpine nature, partly inaccessible, partly covered by glaciers and rock débris. However, the mountains in Peary Land seem partly to be composed of gneiss and granite (mica-schist is found everywhere west of the northern point of Greenland), and, on the whole, this, the eastern portion of the mountain range, appears to be far more folded and metamorphosed than the western part.

In contrast to the greatly metamorphosed strata of Peary Land, it is still possible in the western area of the Caledonide Mountains to distinguish the fossiliferous Pentamerus limestone and the graptolite shales (see page 281).

(4) *The Fault Zone of the Cape York District.*—During my numerous journeys and prolonged stays in this region from 1920 to 1923 I had abundant opportunity to study the many faults, and I was gradually enabled to measure their throw during the topographical mapping of the district in 1923.

Sequence of the Formations.

One of the main objects of my last journey was to ascertain the exact succession of the highly fossiliferous strata which I had discovered on the Second Thule Expedition. These I will now briefly describe so far as this is possible at the present time, when the fossils have not yet been studied. The collections obtained are large, comprising upward of 4,000 pieces of rock with fossils, which together weigh several tons. See fig. 3.

Gneiss Plain of Archeozoic Age.—The most ancient crystalline rocks are believed to be of Archeozoic time, since upon their peneplained surface rest the Algonkian and all later sediments. This gneiss plain about Upernivik stands about 1,000 meters above the sea, but from here it gradually descends, and in Inglefield Land disappears beneath the sea. This is why Inglefield Land lies at low levels, and the corresponding part in East Greenland is to be seen at the head of Danmark Fiord.

Algonkian Rocks.—The oldest sediments rest either on gneiss or on batholiths of syenite and diorite, of Archeozoic age, and it is plain that the Algonkian strata transgressed widely over the Archeozoic peneplain. These formations occur in three different areas:

a. The fault zone of Cape York. The greater part of this district is made up of Algonkian sediments. The basal basalt conglomerate is very thin everywhere, and the *Cryptozoön* reefs are but sparsely developed, whereas white sandstone is of common occurrence and in many places shades into a highly micaceous greywacke. Dolomite occurs locally, sometimes in thick strata, but in many places it is replaced by a peculiar black shale which bears a superficial resemblance to the graptolite shales.

b. Inglefield Land. Here the Algonkian sediments have been eroded to a very great extent and what remains of them does not exceed 200 meters in thickness. In the western part, *Cryptozoön* reefs are particularly well developed, but otherwise white sandstone with a diagonal structure prevails. Dolomite strata are highly developed, but black shale is not seen at all.

c. Mylius Erichsen Land of northeastern Greenland. South and west of Independence Fiord occurs a great

plain of Algonkian sediments that from an altitude of 1,200 meters gradually slopes northeast to sea-level. Profiles of up to 1,000 meters in height and dominantly of red sandstones occur here. However, it is to be borne in mind that the sandstones of this area are penetrated by eruptives, and hence their original thickness must surely have been considerably smaller. Basal conglomerates and purple sandstones must also occur, since they are often seen in boulders, but nothing of dolomites or shale was met with here in the northeast. These strata commonly have diagonal structure, and aside from their color, greatly resemble the white sandstone of Inglefield Land.

All of the Algonkian sediments appear to be of a dry climate. This is indicated, not so much by their red color, as by the unweathered felspar grains, which occur principally in the lower strata. The complete series of strata has, at any rate, been deposited in shallow waters, and some of them may even be desert formations. Ripple-marks and sun-cracks are found throughout the whole series, including the dolomites.

Algonkian Eruptives.—Throughout East and West Greenland there is evidence of eruptive action after the deposition of the Algonkian strata. In the Cape York district and in Inglefield Land, the eruptives are mainly restricted to the western and southern regions, whereas they are seen but seldom in the interior of Inglefield Gulf. These eruptives are principally basic, and almost exclusively diabases, appearing as dikes, or as extended sheets.

In Northeast Greenland there are likewise considerable quantities of Algonkian diabases, but in the main the eruptives here are acidic. Along the east coast of Independence Fiord, there is a fine profile nearly 50 kilometers in length, which exposes no fewer than four great laccolites; and throughout the whole area eruptive rocks may be seen.

Sedimentation then ceased, and for a long time North Greenland was subject to erosion, with the consequent development of an Algonkian peneplain.

Cambrian Strata.—The existence of Cambrian formations was unknown previous to 1922, when I found them widely distributed in the southern and northern areas of

Humboldt Glacier. This discovery makes it certain that Cambrian is also present in East Greenland, although fossils of that age have not yet been found there.

After the Algonkian eruptions had ceased, the surface of the old land was again peneplained, since the Cambrian sea transgressed over a rather level plain. On the northern coast of Inglefield Land, the deposition of this sea commenced with conglomerates which alternate with sandstone, the combined thickness reaching 30 meters. The conglomerates contain, among other things, blocks of diabase, averaging the size of a hand. In the finer-grained strata, which suggest fragmental limestone, there are numerous pieces of brachiopods and trilobites, and also well preserved specimens; among them is *Olenellus*. Above these lower strata occur oolitic limestones, with a thickness of 20 meters, some of which have an abundance of *Hyolithes* and several species of *Olenellus*. An especially fine profile of Cambrian strata is found at Cape Kent at 79° N. Lat. Here the Lower Cambrian is overlain either by Middle Cambrian or more probably by Upper Cambrian greyish yellow limestone, of about 40 meters thickness. Fossils are rare here, but in the lower portion occur two beds, each about 1 meter in thickness, that abound in several species of *Dolichometopus*, *Olenoides*, and other fossils.

The previously described formations of Inglefield Land are overlain by higher Upper Cambrian strata, which north of the Humboldt Glacier extend throughout Daugaard Jensen Land. At this place these strata are not less than 400 meters thick. They consist of limestones and intraformational limestone conglomerates, and are generally unfossiliferous. At the top, however, occur strata with trilobites (*Ptychoparia*) and brachiopods of Upper Cambrian kinds. These strata have a thickness of about 400 meters.

From the fossils collected, it appears that the Cambrian faunas perhaps link with those of the American Cordillera and China. In other words, they seem to be of the Pacific realm.

Ordovician Formations.—During my last journey I found that the Ordovician rocks are far more extended in North Greenland than I originally thought. In fact, strata of Ordovician age extend in a wide belt from

Kennedy Chammel to Independence Fiord. Their thickness is about 800 meters. Along the coast these formations tend to form great vertical cliffs, in some places even beetling, and in their talus slopes it is quite easy to obtain fossils. Only the southern part of Washington Land has been explored in detail, and the majority of my collections were made here.

At the bottom these strata are sandy, but they change very soon into thick-bedded limestones that have *Symphysurus* and brachiopods. This horizon is followed by very compact limestones with *Phyllograptus*, *Didymograptus*, and *Isotelus*. The layers with *Phyllograptus* also have intraformational limestone conglomerates. Clearly they are of Lower Ordovician time.

Higher still occur thin limestones with ostracods, and these are overlain by a series of yellow limestones with darker shales, 290 meters thick. Fossils occur but seldom in these strata, but poorly preserved *Orthoceras* and crinoid stems have been found. Finally, there are very compact brownish limestones, with a maximum thickness of 100 meters, which have below almost nothing except large *Orthoceras*; in the higher strata *Receptaculites*, *Tetradium*, and other forms link these faunas with those of the Upper Mohawkian and seemingly directly with the Galena formation of the upper Mississippi Valley.

The formation with *Receptaculites* is overlain by limestones that abound in *Halysites*, and in the highest beds *Leptæna* is especially common. This formation appears to correlate best with the Richmond series of the United States.

Silurian Formations.—Following the deposition of the Ordovician strata, there was a land interval with erosion. Then the sea again transgressed North Greenland and laid down the oldest Silurian beds, the *Arethusina* formation, apparently of Alexandrian time. At several places in Washington Land as far north as Petermann Fiord I found a series of strata that does not exceed 100 meters in thickness. It commences with conglomerates, the boulders of which consist almost exclusively of corals from the underlying strata. Gradually the conglomerates are replaced by sandstone with brachiopods. These in turn are overlain by bituminous shales and limestones having a thickness of from 10 to 15 meters and contain-

ing great quantities of trilobites (*Arethusina* and other genera). The final beds are sandstones which become coarser toward the top and contain some brachiopods.

In most places the *Arethusina* strata were deeply eroded, and when the sea returned it laid down over them principally conglomerates and coarse sandstone, with here and there zones of limestone (*Pentamerus limestone*). In other words, these strata are nearly all shallow-water deposits. The coarse conglomerates at the bottom of the series are in places more than 200 meters thick. Some of the boulders are of Archeozoic granite and Algonkian sandstone, indicating that considerable portions of North Greenland had been highly elevated above sea-level. In most places fossils abound, but they are restricted to a few rather thin zones. Corals are seldom seen, whereas brachiopods, especially *Pentamerus*, are very common. In addition, there are great quantities of trilobites, *Bronteus*, *Lichas*, and, in the uppermost strata, *Bumastus*. Evidently this series is of Niagaran and middle Gothlandian time, but until the fossils are determined, no closer correlations or faunal affinities can be indicated.

The upper-portion of the *Pentamerus* limestone is very sandy, indicating that emergence had again taken place, finally elevating the region several hundred meters. A long time of erosion followed, since in many places occur deep valleys with nearly perpendicular walls. Later on, all these eroded depressions in the surface of the land were filled by graptolite shales (*Monograptus shales*). The subsidence and re-entrance of the sea must have taken place quickly, since the basal conglomerates of the graptolite shales are very thin and scarcely increase in thickness in the old erosion valleys. In other words, the graptolite shales appear to have been deposited very quickly and to have gradually completely effaced the relief of the former land surface. Now these shales are again deeply eroded in many places, exposing the previous land surface.

The graptolite shales contain subordinate zones of limestone, but otherwise the series is composed uniformly of shales, with a total thickness of 500 meters. Fossils are of common occurrence and very well preserved. At the bottom of the shale occurs *Monograptus*

(like *M. lobiferus*), while the upper strata contain *Cyrtograptus* and *Monograptus priodon*. Their faunal affinities are those of the North Atlantic.

The map shows these strata extending from Kennedy Channel across North Greenland to the eastern part of Peary Land, where *M. priodon* is especially common.

Upward, the graptolite shales become more sandy and gradually pass into coarse sandstones, which in places along the north coast of Greenland attain a thickness of several hundred meters. These terminal Silurian strata bear witness to the beginning of the Caledonian folding.

Carboniferous Strata.—Long after the Caledonides were made and eroded to a low level, the sea of Upper Carboniferous time invaded a small plain in the eastern part of Peary Land. Its deposits consist of shales, limestone, and, at the top, sandstone, and have a total thickness of about 700 meters. The shales and limestones are very fossiliferous (corals, *Fenestella*, and brachiopods), and their fossils appear to be closely related to the faunas from East Greenland (Holms Land and Amdrups Land).

Post-Carboniferous History.—After the deposition of the Upper Carboniferous strata we know very little about the geological history of North Greenland, as later strata are completely wanting. However, one is tempted to conjecture what may have been some of the main features in the subsequent history of the country. As already stated, not the slightest trace of faulting is found in the great Plain of Sediments, and hence we must conclude that the majority of the great fiords on the north coast have resulted from erosion. The drainage west of Peary Land shows that the Caledonides are cut through in many places, and from this we can infer that the river erosion has kept pace with the elevation of the mountains. Of particular importance is the region of Robeson Channel. In Figure 4 this drainage area is shaded, and its extent in Grant Land shown as well; the figure furthermore shows that a land barrier must have existed across the present site of Humboldt Glacier, since a part of this area drains into Robeson Channel.

Kennedy Channel itself forms a direct continuation of the plain south of the Caledonides, and this is why I consider the former not as a sunken area, but as the result of river-erosion.

In my opinion, a rise of land took place after Upper Carboniferous time, so that North Greenland at the end of the Paleozoic, and perhaps ever since, has stood above sea-level. During this long time, erosion in a probably dry climate has formed the numerous canyons which now abound in the region.

FIG. 4.

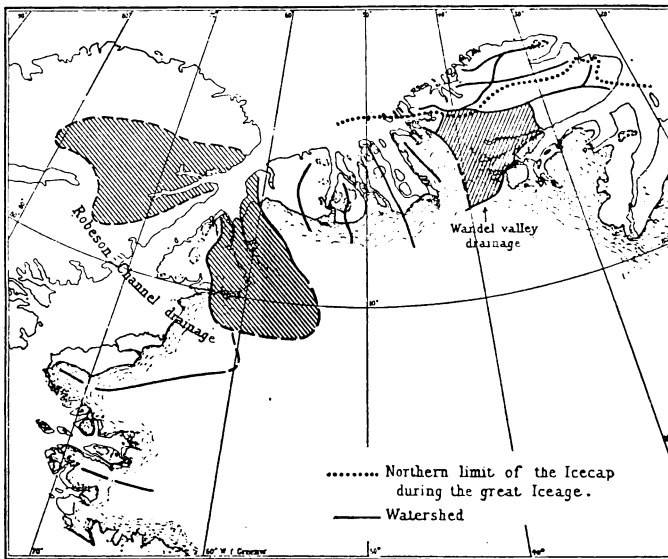


Fig. 4.—The drainage of Robeson Channel and Wandel Valley, also the most important watersheds. The dotted line through Peary Land shows the maximum spread of inland ice during the Glacial Epoch.

The last important event in the geological history of North Greenland was the Glacial Epoch (see fig. 4). In another paper ("Natürens Verden," 1923), I pointed out that the inland ice during the maximum of glaciation did not cover the northern part of Peary Land, but was checked by the Caledonides. In many places in the present ice-free regions there are found traces of great moraines. One of the most interesting regions with such moraines is found in the vicinity of Halls Grave, where a glacier that has filled all of Robeson Channel, and

another that has filled Newman Bay, have penned up a great lake, and formed most interesting drainage conditions.

Morphology.

In Figure 5, I have tried to give an idea of the altitudes in Greenland. At first, the different elevations appear to be irregularly scattered, but a comparison of the relief map with that of the geology shows that the present topography is mainly due to the geological conditions.

The Algonkian sediments of the Cape York district are traversed by numerous faults, which characterize the morphology throughout. In Northeast Greenland, however, these sediments form a vast plain, which from an elevation of 1,200-1,400 meters gradually slopes toward the Arctic Ocean. This plain extends over Mylius Erichsen Land, Wild Land, and Adam Biëring Land.

The Cambrian rocks, and particularly the Upper Cambrian intraformational conglomerates, are but slightly resistant. Formerly these strata extended across the area of the Humboldt Glacier, and a fiord like Cass Fiord has been eroded through them. The present low plains of Daugaard Jensen Land are also due to the removal of these soft Cambrian strata.

The Lower and Middle Ordovician formations and the Pentamerus limestone are made up of very compact and resistant rocks, and where such occur, from Kennedy Channel to Peary Land, the upper plain is as a rule more than 1,000 meters high. This plain is cut through in many places by great fiords. Below the plain there lies to the south a lower area, best seen between St. George Fiord and Victoria Fiord. This lower land is made up of the softer Lower Ordovician strata, which here reach the surface.

The graptolite shales and the overlying coarse sandstone are very soft and can be traced as valleys and plains south of the Caledonides from Hall Basin to Peary Land.

The Caledonides attain their highest elevations in the north of Peary Land, where the strata are very much

FIG. 5.

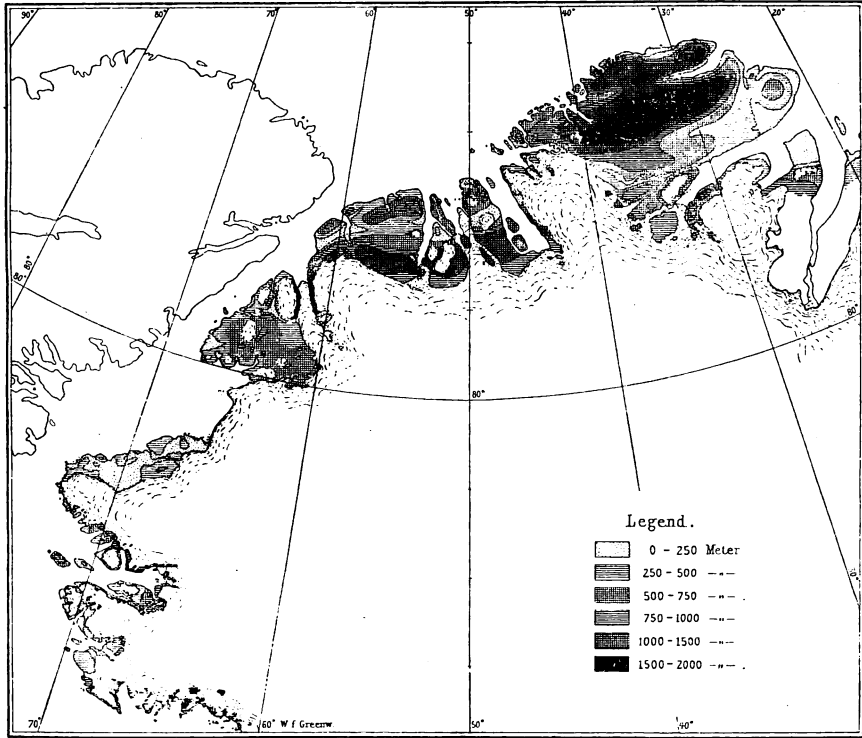


Fig. 5.—Relief map of North Greenland.

folded and the mountain range widest, but in the vicinity of Hall Basin there are peaks up to 1,000 meters above sea-level.

The Carboniferous strata in the eastern part of Peary Land also make an elevated region surrounded by low plains with graptolite shales.