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ART. V.—*On the Paleozoic Formations of Finmarken in Northern Norway;* by OLAF HOLTEDAHL.

Far beyond the Arctic Circle, between latitudes 69° and 71° N., lies the Norwegian district of Finmarken. It is the most northern prominence of the Scandinavian peninsula. The present Finmarken is only a part of the old Finmork (the home of the Finns or Lapps) which originally also embraced the land to the east.

Except in the most western part of Finmarken, where there is a continuation of the wild and rocky land of the Norwegian mountain zone farther to the south, most of this district is relatively low, from 300 to 500 meters above sea-level. The most typical landscape is the undulating plain, with here and there deeply incised river valleys. In the valleys birches are common, along with a few pines, but on the high plains grow only dwarf bushes and mosses.

Though a good many geologists have travelled in Finmarken and many geological details have been published, yet very little has been known as to the general geological structure and age of the rocks. Tellef Dahll in 1867 tried to put the different rocks into order and divided the sedimentary series, whose dominating rocks are sandstones, into an older *Raipas* and a younger *Gaisa* system; the former having dolomites as a typical member.

As to the age of these series, which are very unlike anything known from more southern parts of the Scandinavian Peninsula, opinions have been very divergent. The earlier investigators have generally thought them to be of fairly recent date, belonging to the Devonian or

still younger formations, while in more recent time these "sandstone formations of Finmarken" have commonly been regarded as being older, possibly a northern parallel to the arkoses and sandstones of the "Sparagmite division" of southern Norway, a thick series of rock coming, in as far as we yet know, conformably below the Lower Cambrian *Holmia*-shale.

A rock of Finmarken that has gained a wide reputation is the tillite, found in 1890 by Reusch at different places in the Varangerfjord. The age of this tillite, found in Dahll's Gaisa beds, is generally stated in text-books to be Cambrian; this fixing of the age, however, had no real basis since no fossils had been found and the relation of the formations to those of the more southern parts of the Scandinavian Peninsula were not determined.

During four short summer seasons (1914-1917) the writer has worked for the Geological Survey of Norway in this northern land and has obtained results that may also be of interest to American stratigraphers.[1]

Table of Finmarken Formations.[2]

Late Silurian time.

Overthrusted, metamorphosed rocks and intrusive masses of the Caledonian deformation.

Possible late or middle Ordovician time.

Tillite-bearing sandstone series. *Bossekop series* of the Alten district. Thickness 200-500 meters. The *Bossekop and Mortensnes tillite* has a thickness of about 10 meters, the *Bigganjargga tillite* of 2-3 meters.

Unconformable contact.

Lower and basal Ordovician time.

Sandstones and shales with dolomites:

Varanger series. Thickness over 3000 meters. Above are impure and interbedded dolomites, grey and red sandstones. Then a sandstone succession of about 2000 meters in thickness. Below, dark shales and thin-bedded sandstones. The *Raipas series* of the Alten district, containing large masses of lava and tuff, is thought to be the equivalent of the Varanger series.

[1] A complete account in the Norwegian language (with a short summary in English) has appeared in a paper entitled "Bidrag til Finmarkens geologi," Norges Geologiske Undersökelse, No. 84.

[2] As to Dahll's terms *Raipas* and *Gaisa*, the former has been retained for the volcanic sandstone-shale-dolomite series of the Alten district, while the latter could not be maintained as it was found to contain very heterogeneous things.

FIG. 1.

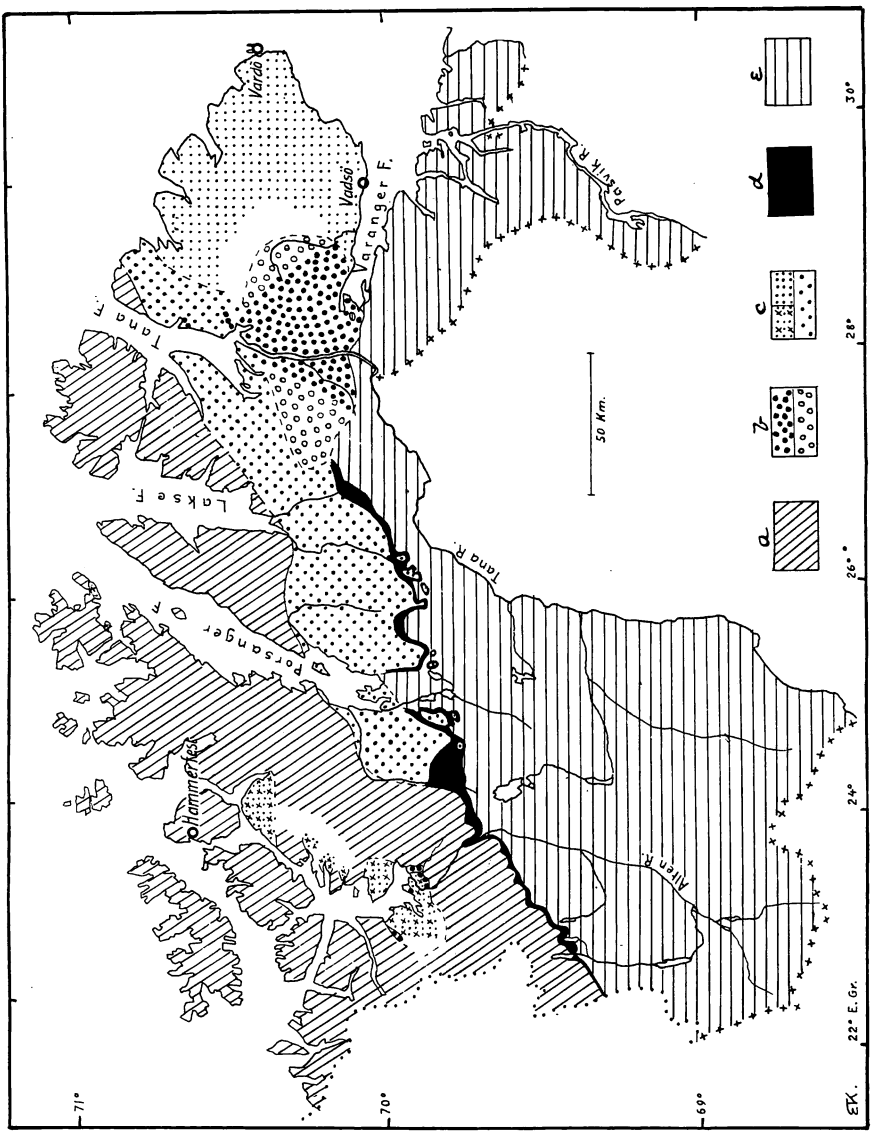

FIG. 1.—Geological map of Finmarken. *a*, metamorphic and intrusive overthrusted rocks of the Caledonian deformation. *b*, above, the tillite-bearing sandstones; below, the probable further distribution. *c*, the older dolomites and sandstones; above, the younger or Varanger series; in the west with volcanic rocks (Raipas); below, the older or Porsanger series. *d*, Lower Cambrian series of shale and sandstone with *Platysolenites*. *e*, pre-Cambrian rocks.

Porsanger series. Thickness between 500 and 1000 meters. Above is the Porsanger dolomite with intraformational conglomerates, about 100 meters thick. Below is the Porsanger sandstone, terminating upwards in shales.

Conformable contact.

Lower Cambrian time.

Dividals series or *Hyolithus zone.* Thickness about 240 meters. A series of shales and sandstones with *Platysolenites* and other fossils.

Great unconformity.

Pre-Cambrian peneplained floor. A complex of ancient rocks.

The distribution of the various formations is given in the map, fig. 1. The object of the present article is to tell about the relatively unaltered sedimentary series, and therefore the pre-Cambrian formations, and the metamorphic rocks of the Caledonian deformation, are not to be considered.

Lower Cambrian Shale and Sandstone Series with Platysolenites.

Lying unconformably upon the generally highly metamorphosed pre-Cambrian, which consists of hornblende schists, quartzites, gneiss, and granite, different in different districts, is found a not very thick series of Lower Cambrian green and reddish shale, alternating with sandstone beds. The thickness of this, the Dividals series, is about 240 meters. That is a very characteristic series, which the writer after having seen it inside the Altenfjord in 1914 announced in a preliminary paper[3] as being a continuation of the "Hyolithus zone" of the Swedish geologists, the "Dividals series" of K. Pettersen, who for many years worked on the geology of the Tromsö district, the Norwegian area to the southwest of Finmarken. In this series are known Lower Cambrian fossils, the bulk of which were found recently in the well known sections of Torneträsk of northern Sweden.[4] Fossils of this time have also since been found at different localities in Finmarken. A species of *Obolus* in badly preserved specimens was found in 1915 by the writer in a section on the Alten River (fig. 2) and in 1917 *Platysolenites antiquissimus* Eichwald was found at two different places farther to the east, south of the Porsanger-

[3] Norges Geologiske Undersökelse, Aarbok, 1915.

[4] See Guide Book No. 6, XI, Internat. Geol. Congress, Stockholm.

fjord, by J. Braastad, mining engineer, and by the writer. This fossil occurs about 120 meters above the pre-Cambrian rocks. The exact zoologic position of *Platysolenites* is, however, not yet determined, as nothing other than the slender crinoid-stem-like cylinders have been found. On the other hand, it seems fairly certain that it represents the stem, or possibly the arms, of a cystid. At any rate, in the whole of the Scandinavian Baltic

FIG. 2.

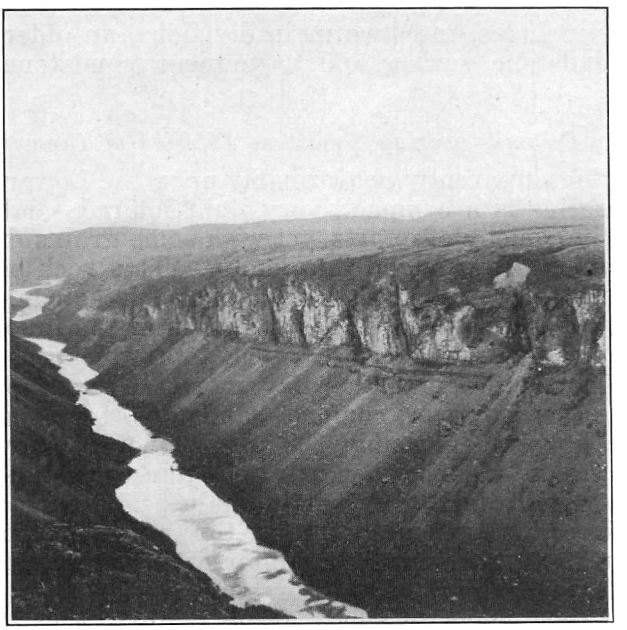

FIG. 2.—Canyon of the Alten River, 30 km. from the sea. Altitude from river to plain, 400 m. Photograph by Kr. Nissen.

region it is an excellent guide fossil to the oldest known fossiliferous zone, or the Lower Cambrian.

To the southwest of Finmarken, in the district of Tromsö Th. Vogt found in 1915 in the "Hyolithus zone," besides *Platysolenites,* other Lower Cambrian fossils, chiefly trilobites.

The Lower Cambrian series, except in its uppermost part, is almost undeformed and rests on the even or peneplained surface of the pre-Cambrian, a surface that now

dips slightly toward the N. N. W., due to the Caledonian deformation. In the western part of Finmarken, the unaltered Cambrian, having here a thickness of 150 meters, is covered by the metamorphic thrust rocks of the West Scandinavian mountain range, just as it is further south along the eastern part of this range, while to the east we find the practically undisturbed stratigraphical sequence; and here one has the opportunity of studying the younger beds, which are of the type not known further south, that is, the *Finmarken facies.* I divide this younger series, consisting chiefly of sandstone or sandy shales, into two main divisions, an older dolomite-sandstone series, and a younger sandstone with tillites.

Older, Dolomite-bearing Sandstone Division of Finmarken.

Resting apparently conformably upon the Lower Cambrian series is a compact, very light-colored sandstone, consisting chiefly of quartz, yet with some grains of feldspar which are changed into kaolin. This rock belongs to a very thick sandstone series, which I have named the *Porsanger sandstone,* as it is well seen at the inner portion of the Porsangerfjord. The total thickness is at least 500 meters and probably more. Not all of this thickness is, however, compact sandstone, for especially in one horizon (probably 300 to 400 meters above the base) occur thinner bedded and darker sandstones, together with dark grey sandy shale. The surfaces of the thin-bedded sandstones have, through a thickness of many meters, exceedingly fine interference ripple-marks.[5]

In the upper part of the Porsanger series occur interbedded thick zones of sandy, often reddish brown shale, and finally the series is terminated by a reddish brown and green shale zone, with only thin beds of sandstone, having a thickness of from 50 to 100 meters. Above this shale comes the *Porsanger dolomite,* a compact, light-colored dolomite that weathers whitish as a rule. The thickness of this dolomite is difficult to fix, due to tectonic deformations which have strongly folded it and in places thinned it considerably. I consider the thickness, however, to have been at least 100 meters.

This dolomite shows many interesting features. Some of the zones are much silicified, with fine-grained quartz

[5] Compare Kindle, Geol. Survey Canada, Mus. Bull. 25, 1917.

in layers or in irregular masses. Nodules of dark colored silica are frequently seen, with the characteristic appearance of chert. Exceedingly common are intraformational dolomite-conglomerates, the larger fragments with their edges generally fairly well-rounded. Of very great interest also is the occurrence of nicely laminated dolomite, restricted to a thickness of several meters.

FIG. 3.

FIG. 3.—Vertical and horizontal section through stromatolite material of the *Gymnosolen* type. Natural size.

The laminæ are concentrically arranged, sometimes only slightly convex, sometimes more so, sometimes with a tubular or cylindrical appearance (fig. 3). This is the *Cryptozoon* structure of American stratigraphers, and will be more fully treated further on. Between such laminated layers occur sometimes innumerable small oolite-like, irregularly built grains.

Over the Porsanger dolomite follow, in the Porsanger district, the metamorphic thrust rocks, and accordingly the originally higher sequence can not be followed further here.

Younger beds, of the Varanger series, are found on the Varanger Peninsula further east, where we have, especially on the north side of the fjord, excellent sections

Fig. 4.

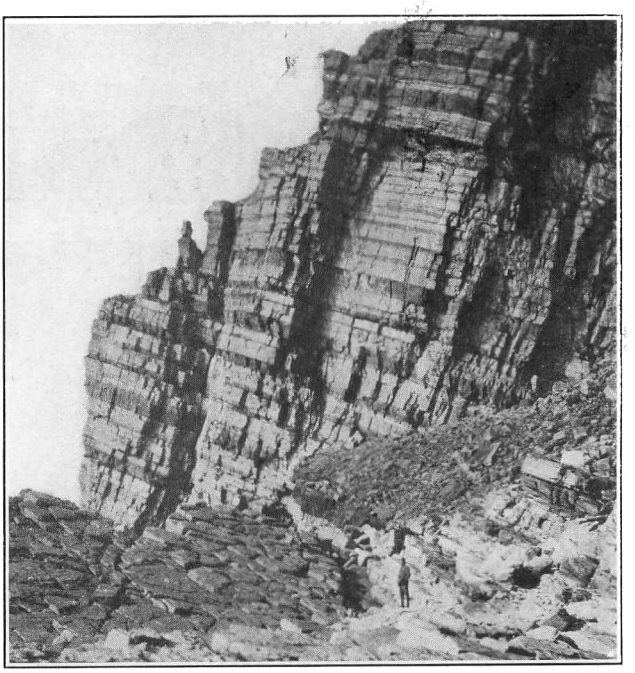

Fig. 4.—Cliff of Varanger series of alternating beds of red and ripple-marked sandstone and yellow-weathering impure dolomite. North coast, between the Tanafjord and Vardö.

through a sedimentary series of quite remarkable thickness. To the west occurs here a series of dark shales or slates with thin layers of quartzitic sandstone. They rest upon a light-colored sandstone which I believe overlies the Porsanger dolomite. Even if this sequence is not yet determined, we know that the dark shale must be younger than the Porsanger series, as the latter is met with in the most western part of the Varanger Peninsula,

at the Tanafjord, where this series does not have such shale deposits. Above the shale follows a sandstone of about 2000 meters thickness, which I have studied very little. Still higher appears a thick series of thin-bedded, impure, light colored, yellow-weathering dolomite or dolomitic limestone alternating with red sandstones with the greatest abundance of ripple-marks (fig. 4). Above the ripple-marked strata comes another sandstone, reddish and grey, with layers of compact shale, and finally another series of yellow-weathering dolomite and red

FIG. 5.

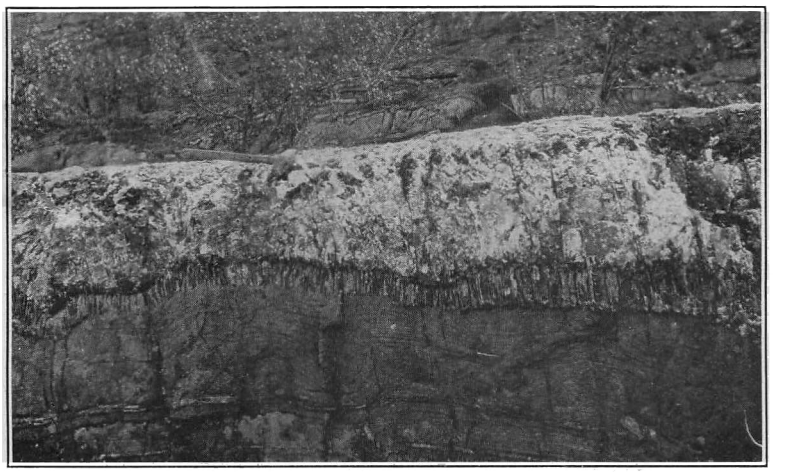

FIG. 5.—Stromatolite dolomite with silicified tubes. Raipas Mountain, at inner end of the Altenfjord.

sandstone, exceedingly like the previous one. At the base of this last mentioned series occurs a thin horizon of dark shale with thin layers and nodules of dark impure limestone. In one of these layers occur concretionary structures. These are made up of concentrically arranged lamellæ of dark limestone of coarser or finer grain, often containing clastic quartz particles and oolites. Oolites, more or less silicified, are also seen in somewhat higher horizons of this dolomitic series.

The total thickness of the different formations exposed on the north side of the Varanger Peninsula and constituting the Varanger series, certainly much exceeds 3000

meters, while the Porsanger series probably has nearly 1000 meters, making together at least 4000 meters of sediments.

In my opinion the Raipas series of the Alten district of western Finmarken, exposed in a "window" through the overlying metamorphic thrust rocks, is an equivalent of the Varanger series. The sedimentary rocks of the Raipas are dark shales, several horizons of dolomite and a sandstone. In the dolomite are found concentric structures of different types, here strongly silicified. Through an incomplete silicification of a layer having tubular laminated structures the curious subcylindrical tubes seen in fig. 5 have originated. The Raipas sandstone has in some layers a peculiar conglomeratic character,

FIG. 6.

FIG. 6.—Conglomeratic sandstone from the older division. North side of the Varangerfjord.

showing a concretionary or ball-like structure, found also in the upper sandstone of the Varanger series (fig. 6). Microscopical examination shows that the conglomeratic sandstone must be of the nature of an intraformational conglomerate. This for the reason that the sandstone of the groundmass and the included pieces (phenoclasts) has been and still is carbonaceous; and where parts of the quartz and feldspar grains have been dissolved or corroded, the dissolution and replacement by dolomite material have gone on concentrically in a regular manner in the round inclusions, when the material was homo-

geneous. In places with distinct bedding, the process of replacement is more complete in some layers than in others.

The Raipas series is marked especially by the presence of thick masses of volcanic material, tuffs and lava beds. The fact that these are not known from the Varanger Peninsula, 200 kilometers to the northeast, does not in my opinion contradict a contemporaneity of the series in the two districts. The volcanic activity seems to have been confined to the western district.

Remarks on the Cryptozoon-like structures.—These concretionary masses are found in Raipasfjeld in Alten, at the Porsangerfjord, and on the north side of the Varanger Peninsula in the Syltefjord. They are especially well developed in the Porsanger dolomite, where a rock several meters thick is made up of them. We find here different types. One (fig. 3) is identical with the *Gymnosolen ramsayi* described by Steinmann from pieces of dolomite brought by W. Ramsay from the western shore of the Kanin Peninsula on the arctic coast of Russia,[6] east of the White Sea. This type seems to be very much like forms of *Cryptozoon minnesotense* of Winchell,[7] which is described as consisting of subcylindrical and upwardly directed cones from 1 to 2 inches in diameter, giving the appearance of a succession of cups, or cones, piled on top of each other. In addition to this type, we have, however, many others, which are more hemispheric in structure, the convexity varying in all sorts of ways, till we meet a type of rock that in vertical section appears as a very slightly curving set of laminæ. In the author's opinion it seems impossible to distinguish between these types of structures, as all sorts of transitional forms occur, and therefore he also thinks that the many "species" of *Cryptozoon* described from North America can not be maintained in a critical revision. I can not regard these structures as real fossils which deserve generic and specific names. In a paper by Kalkowsky, "Oolith and Stromatolith in norddeutschen Buntsandstein,"[8] we have been made acquainted with a designation that serves very well for all of them, viz., *stromatolites,* a term that includes these laminated, concentrically built

[6] Fennia, 31, 1911.
[7] Geol. Nat. Hist. Survey Minnesota, 14th Ann. Rept., 1886, pp. 313-314.
[8] Zs. d. d. geol. Gesellsch., 60, 1908.

structures, occurring in limestones and dolomites. In fact, some of the stromatolites from the Triassic figured by Kalkowsky are extraordinarily similar to the *Gymnosolen* structure and thus probably also to *Cryptozoon minnesotense*. Walcott's *Collenia* from the Algonkian should likewise be considered as a stromatolitic structure.

As to the nature of these structures, I can not agree with Steinmann, who regards *Gymnosolen* as a cœlenterate, probably some sort of a coral; or with Grabau and Shimer, who in their "North American Index Fossils," 1, page 46, place *Cryptozoon* among the Stromatoporoidea; or with Wieland, who thinks *Cryptozoon bassleri* is nearly related to *Lithothamnium*.[9] The laminated structure without any indication of a radial one, and with inclusions of oolite and clastic mineral particles, can, in the writer's opinion, only mean that it is in the main to be regarded as a chemical precipitation, one, however, that probably came into existence through the organic processes of living organisms. I consider this type of rock to belong to what Andrée in "Ueber Sedimentbildung am Meeresboden"[10] calls "physiologischer Fällungskalk." It is natural to think of primitive plants, marine algæ, as the most active organisms in these respects, and we have here a strong hint in the known calcium carbonate-precipitating activity of fresh-water algæ, most conspicuously seen in hot water springs, where the calcareous deposits may be very like the stromatolites. This indirect activity of algæ has recently been emphasized by Walcott,[11] who reports the inclusions of cells of blue-green algæ in the Algonkian *Gamasia*, a form, however, very different from the *Cryptozoon*-like *Collenia*. We may also be reminded of Walcott's announcement of having found bacteria in Algonkian limestone,[12] and the well known statements of Drew that fine calcareous muds are precipitated by denitrifying bacteria in the Gulf of Mexico.

Even if the stromatolites most strongly resemble calcareous sediments that have been precipitated by plants in fresh-water lakes and hot springs, it seems difficult to assume with Walcott that all the limestones and dolo-

[9] Bull. Amer. Mus. Nat. Hist., vol. 33, 1914
[10] Geol. Rundschau, 7, p. 282, 1916.
[11] Algonkian algal flora, Smithson. Misc. Coll., 64, 1914.
[12] Proc. Nat. Acad. Sci., 1, 1915.

mites containing the algal deposits have also been formed in fresh water. Their exceedingly wide distribution in space and time, the huge thickness of the limestones with *Cryptozoon* structures, and above all the fact that marine fossils occur in the Ozarkian-Canadian *Cryptozoon*-bearing rocks of North America can only be explained by the assumption that these basins of deposits have also been a part of the world-wide oceans.

FIG. 7.

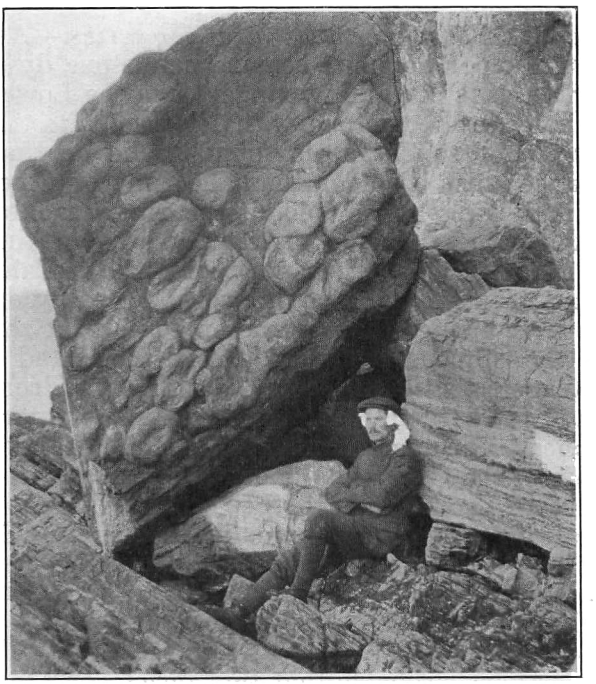

FIG. 7.—Bed of stromatolite in dark limestone. North side of Varanger Peninsula.

The fact that oolites so commonly occur with stromatolites strongly supports the view that we have here to do with chemical precipitations. The irregular small concretions found associated with the stromatolites of the Porsanger dolomite may also be regarded as oolites ("oolitoids") which, probably through not having been able to roll freely on the bottom, have had the precipi-

tated material irregularly distributed on their surface. These bodies in fact seem to represent a structure intermediate between oolite and stromatolite.

Of considerable interest is the fact that while most of the stromatolites of Finmarken are found in dolomite, one zone (see fig. 7) occurs in a rock that according to an analysis made contains 87·6 per cent $CaCO_3$ and only 0·57 per cent $MgCO_3$, thus indicating that the usual high content of magnesia is due to a secondary process, a dolomitization which probably took place very soon after their deposition.

Age of the Porsanger and Varanger series.—As to the age of this older dolomite-bearing sandstone division of Finmarken, it is certainly younger than the Lower Cambrian shale and sandstone with *Platysolenites,* because the Porsanger sandstone is found to lie on that zone. Further, it must be older than the time of Caledonian mountain-making, as the dolomite-bearing sandstones are overlaid by the thrusted mylonitic rocks of the Caledonian deformation. The chief period of the Caledonian deformation in this part of the world probably occurred considerably earlier than the accepted contact zone that bounds the Silurian-Devonian, for in the island of Hitteren off the Norwegian coast,[13] southwest of Trondhjem, and in Spitzbergen,[14] Downtonian unmetamorphosed sandstones occur unconformably above the deeply eroded remnants of the Caledonian mountain range.

It is now known that in the Tromsö district to the southwest of Finmarken (and likewise in the Swedish district farther south) there occurs above the green and red shales of the Lower Cambrian (Hyolithus zone) and below the mylonitic rocks, a series of black shales of considerable thickness. As suggested especially by Th. Vogt, it is very probable that this series corresponds to the Middle, possibly also to the Upper Cambrian black shales of southern Scandinavia. This series of black shales is not present in Finmarken, as here the Porsanger sandstone lies directly upon the Lower Cambrian green and red shales and sandstones. Therefore a break seems to exist here. Now if we consider the stratigraphical sequences in the different Scandinavian-Baltic Cambro-Silurian districts, we meet a striking fact, also found

[13] According to the investigations of Reusch.
[14] According to the investigations of Hoel and the writer.

elsewhere. This is the extremely well-marked *transgression* at the very boundary between the Cambrian and Ordovician. The *Dictyograptus* shale and corresponding sediments overlap in different areas upon various older strata; in Dalarne in central Sweden the transgression is over pre-Cambrian rocks, in Oeland over Middle Cambrian, in Estland over Lower Cambrian. We have in this fact a strong indication of the probable age of the Porsanger series. If we assume it to be basal Ordovician, we have here, in a relatively eastern part of northern Fennoskandia, exactly the same stratigraphical succession as that of the eastern part of south Fennoskandia, in Estland, where the "Unguliten sand" lies upon Lower Cambrian clay and sand which has, among other fossils, *Platysolenites*. The elevation of the northern land which has given rise to the enormous sandstone masses of Finmarken may, in fact, have been one of the causes of the early Ordovician transgression.

It is furthermore of considerable interest in correlation to note that even if the stromatolites can not be considered as actual fossils, they represent a very characteristic type of rock which in various regions seems to be nearly as good as guide fossils; for instance, the widely distributed cryptozoons of North America, which are exceedingly typical for the limestone-dolomite facies of the Cambro-Ordovician transition zone and the basal Ordovician, the Ozarkian and Canadian of American stratigraphers. Another interesting fact is that I have seen the *Cryptozoon* structure in limestone of Ozarkian age, collected by the Second Arctic Norwegian Expedition in the "Fram" on the south coast of Ellesmereland.[15] What without doubt is a stromatolitic structure is further mentioned from a sedimentary series, containing dolomite, limestone, sandstones and shales of Cambro-Silurian age, occurring in northeastern Greenland.[16] In fact, a few fragmentary fossils found here—Nathorst mentions orthocerids, a small *Orthis*, small gastropods—may very well belong to a low Ordovician zone.

Stromatolites also occur in dolomite in the so-called Heclahook system of Spitzbergen, and even though no

[15] Holtedahl, O., Summary of geological results, No. 36 of Rept. Second Norweg. Arctic Exped., "Fram," Kristiania, 1917.

[16] Nathorst, A. G., Bidrag till Nordöstra Grönlands geologi, Geol. Fören Stockholm Förh., 23, 1901.

fossils are found here, the system is known to be unconformably overlaid by the Downtonian sandstone series. I have seen a good deal of the Heclahook limestones and dolomites, and some of them are remarkably like those of Finmarken.

Rocks similar to those of the Heclahook of Spitzbergen are further known in Bear Island, midway between Spitzbergen and Norway, and here in one horizon fragmentary fossils have been found by the Swedish explorers Nathorst and Andersson.[17] Through the kindness of the director of the zoo-paleontological department of the Swedish State Museum, Professor G. Holm, I have had the opportunity of studying these fossils, which have proved to be of a quite decidedly American character, and to belong to Black River time. Besides several bryozoans and cephalopods and a *Rafinesquina,* which could not be specifically determined, there occur species of so decidedly an American character as *Gonioceras occidentale* Hall, *Actinoceras bigsbyi* Hall, and *Tetradium* cf. *syringoporoides* Ulrich. Thus the American Black River faunal element has spread very far into northern European waters.[18]

The dolomite with *Gymnosolen* from the Kanin Peninsula of northern Russia east of the White Sea is so extremely like the corresponding rock from the Porsanger series that their contemporaneity can not be doubted.

Not only the stromatolites, but many other characters of the Finmarken dolomite as well are typical of the calcareous rocks of most of the above mentioned regions. Oolites, intraformational conglomerates, and nodules and layers of chert (or chert-like quartz) are characteristic features of the Ozarkian-Canadian limestones and dolomites of North America, and are also known in those of

[17] Andersson, J. G., Stratigraphie und Tektonik d. Bären Insel, Bull. Geol. Inst. Upsala, 4, 1900.

Lindström, G., A species of *Tetradium* from Beeren Eiland, öfvers. Kgl. Sv. Vet. Akad. Förh., 1899.

[18] After the present article was written, the author spent some time during the summer of 1918 on Bear Island, and succeeded in finding a still lower fossiliferous horizon. It is separated from the Tetradium limestone by several hundred meters of dolomites and dolomitic limestones. This older fauna is also very distinctly American in type; the age may be fixed as Canadian. The fossils are silicified, and the especially common ones are cephalopods (including *Piloceras*), gastropods, and *Calathium.* Yet older dolomites have very distinct stromatolites, besides oolites. The Heclahook system of Bear Island is thus found to comprise basal, lower, and early middle Ordovician zones, and the same is without doubt true for the Heclahook formation of Spitzbergen.

Greenland and Spitzbergen. Oolites and intraformational conglomerates (the latter in great thickness) are likewise found in the basal Ordovician of Ellesmereland.

When we furthermore recall that the dolomite-bearing sandstones of Finmarken are on the confines of the Arctic Ocean and nearest to the American Arctic occurrences, the assumption is very probable that all belong to an *American* or *Arctic-American facies.* Still another important fact pointing toward the same conclusion is that the only place in northwestern Europe where rocks occur showing a likeness to the dolomites of Finmarken is in the extreme northwest of Scotland. Here occurs a sedimentary series of basal Ordovician age, and, according to the contained fossils, decidedly of the American facies. This Durness dolomite is clearly separable from the underlying Lower Cambrian sandstones by a marked faunal break. An unconformity has also been observed by Grabau.[19] Here again we have a stratigraphic sequence identical with that of middle and eastern Finmarken. Not only this, but in the Durness dolomites there also occur chert, oolites, and intraformational conglomerates. Certain concretionary structures mentioned[20] may be of a stromatolitic nature.

A sedimentary series like that of the dolomite-bearing sandstone of Finmarken is not known anywhere in southern Scandinavia. On the other hand, in the highly metamorphic and very thick sedimentary series of the western part of northern Scandinavia, thick dolomites and limestone are very characteristic, and in this occurrence we have a somewhat similar correspondence.

From the statements just presented, it is seen that there are many facts pointing toward the existence of an ancient narrow barrier of land crossing the Scandinavian peninsula. To the north and northwest of this barrier occurs the thick dolomite-bearing series with the Arctic-American facies, and on the other or southeastern side occur shales and nodular limestones only a few meters in thickness, the latter being the *Dictyograptus* and *Ceratopyge* divisions of southern Scandinavia. This postulated barrier (see map, fig. 8) is therefore the continuation of the one generally assumed to exist between

[19] Bull. Geol. Soc. America, 27, p. 563, 1916.

[20] Geological structure of the northwest highlands of Scotland, Mem. Geol. Survey Gt. Britain, p. 424, 1907.

the corresponding different facies of the British Isles and of eastern North America.

There is reason to believe that the upper part of the very thick dolomite-bearing division of Finmarken

FIG. 8.

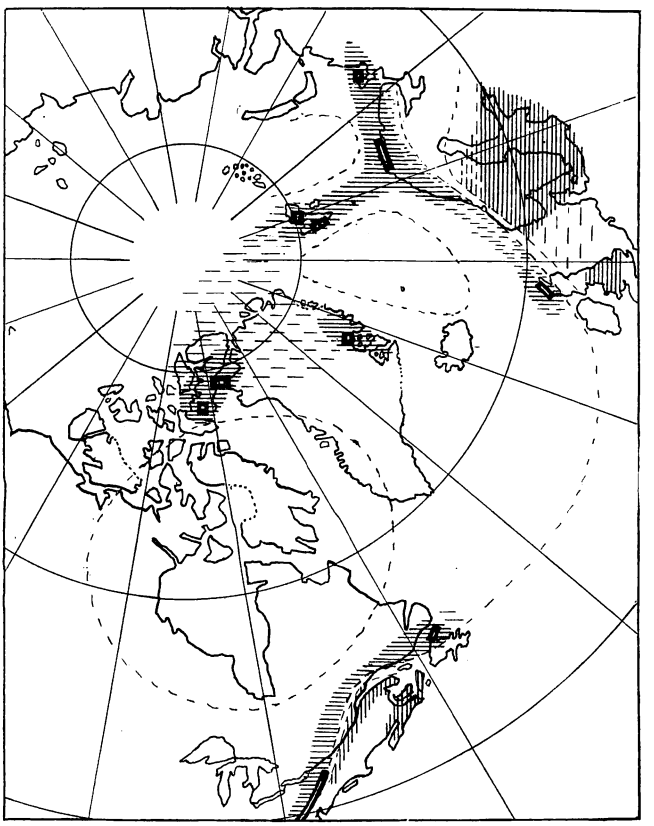

FIG. 8.—Paleogeography of early Ordovician time. Black squares indicate occurrences of dolomite and limestone of Ozarkian-Canadian age, and of American-Arctic facies. Vertical lines, areas of probable further extension. Horizontal lines, areas of Atlantic-European facies with *Dictyograptus*. Between the broken lines occur the assumed land-masses.

reaches as high into the Ordovician as the *Tetragraptus* (*Phyllograptus*) horizon correlated with the British Arenig. It is also of considerable interest to point out that this time in Scotland was one of extreme volcanic activity, which may correspond with the Raipas eruptions. Recently Carstens has shown that eruptions took

place in the Trondhjem district in central Norway in early Cambro-Ordovician time, and these may very well be correlated with those of the Raipas.

The land barrier above pointed out appears to have continued into Black River time, as is indicated by the fossils of Bear Island, but it may have had a somewhat different situation. While the Bear Island fauna is of a decidedly American character, it is a well known fact that the Middle Ordovician faunas of the southern Scandinavian Baltic region (except the graptolites and bryozoans) do not show American relations at all. The same may be said of a northern fauna of about the same or probably of a somewhat younger age than the one from Bear Island, found by Nansen at the south side of Yugor Strait (Nova Zembla) and described by Kiaer.[21] While in my opinion the stromatolite-bearing dolomite of the Kanin Peninsula is indicative of the earliest American Ordovician facies, yet that of Yugor Strait shows that this Arctic Russian district belongs to the Scandinavian Baltic faunal province of Middle Ordovician time.

Younger, Tillite-bearing Sandstone of Finmarken.

Unconformably above the dolomite-bearing division comes a younger series, without dolomites but with tillites. The unconformity between them is not very strongly marked in eastern Finmarken, though in places it is readily seen, e. g., at the inner end of the Varangerfjord. In western Finmarken it is much more marked, indicating that the Raipas series was folded before the tillite-bearing division (the Bossekop series) was deposited. The presence of this folding was one of the reasons why, in my preliminary paper,[22] written when I had seen only this western part of Finmarken, I was led to conclude that the Raipas formation was of young pre-Cambrian age, since such a pre-Caledonian folding was not previously known in the Cambro-Silurian of the Scandinavian peninsula.

Preceding the deposition of the tillite-bearing division, we have in eastern Finmarken the origin of a big fault. This is especially distinct at the inner end of the Varangerfjord, and it is without doubt continued along the north coast of the Kola Peninsula, where Ramsay long ago assumed a fault line, dividing the pre-Cambrian

[21] The Lower Silurian at Khabarova. Norweg. North Polar Exped., 4, Kristiania, 1904.

[22] Norges Geol. Undersökelse, Aarbok, 1915.

gneiss-granite district to the south from the small occurrences of sedimentary beds to the north, in the Fisherman Peninsula and the island of Kildin. Contrary to the opinion of Ramsay, I hold that these sediments are younger than the dislocation, and that they probably are contemporaneous with the tillite-bearing division of Finmarken, since in places they are observed to lie upon the old granite floor. The fault may be seen in connection with the downwarping of the crust in the postulated geosyncline to the north, where the older series was deposited (see fig. 8).

The basal rocks of the tillite-bearing division of Finmarken in the Varanger district are mostly very light colored, whitish grey sandstones, resting upon the very uneven, yet well-rounded hilly surface of the old granite and gneiss. A little above the base comes the local tillite of Bigganjargga, 2 to 3 meters thick, with a grey colored groundmass, and resting on the nicely striated and polished surface of the conformably underlying sandstone. Above the typical tillite, which is found in two places about 8 kilometers apart, are observed coarse, only slightly bedded conglomerates, which may very well be of fluvio-glacial origin. Besides the facts mentioned, the very common erosion-channels also tell of purely continental deposition.

While these basal sandstones and conglomerates have a very restricted distribution, higher up occurs a more widespread zone with mostly reddish brown shales and sandstones, above which follows conformably the reddish brown tillite of Mortensnes. Still higher are grey and greenish shales, which finally contain sandstone beds. About 200 meters above the tillite, red quartzitic sandstones are the dominating rocks. The greatest observed thickness of this younger division is 400 to 500 meters. The reddish brown tillite is widely distributed, and maintains a thickness of about 10 meters. It is also seen at the Tanafjord, but here with less thickness and smaller bowlders. This wide distribution, and the occurrence between conformably lying shaly sediments without any distinct boundary below and above, are seemingly only to be explained by assuming a deposition from drifting icebergs.

Where the continental ice was situated is very easily determined; first, we know that there was a high southern land at this time (see fig. 9), and secondly, the rock

nature of the bowlders of the different conglomerates is to a large degree like that of the pre-Cambrian ones now exposed in this district. We also find in the different conglomerates an abundance of sedimentary rocks, especially quartzitic sandstone, and furthermore, very commonly there are dolomitic rocks with the characters of the older series, and with cherts, oolites, and stroma-

FIG. 9.

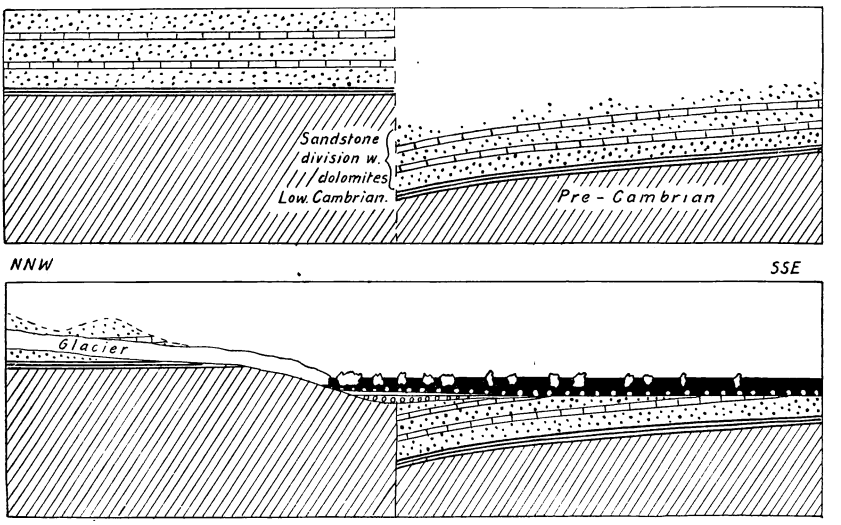

FIG. 9.—Above, hypothetic section through the inner end of the Varangerfjord, showing the geologic structure after the fault had appeared. Below, the assumed conditions at the time of the deposition of the reddish brown tillite.

tolites. These sedimentary rocks had their home above the pre-Cambrian to the south, where they are now totally removed.

In western Finmarken, in the Bossekop series, occurs a reddish brown rock with all the characters of the Mortensnes tillite. It is found as a zone in a sequence of light-colored quartzitic sandstones with minor intercalations of brown shales, nearly 200 meters thick. As in the Mortensnes tillite, here in the west also are found bowlders with distinct glacial striæ (fig. 10). These striæ in some bowlders are seen to have been deformed by later crustal movements, those of the Caledonian mountain-making.

As to the very important question of the age of this younger tillite-bearing sandstone of Finmarken, it is still very difficult to give any exact information, as no fossils are found. If my interpretation of the age of the older division is correct, it must be placed somewhere between the Lower Ordovician and the higher Silurian. It is distinctly older than the Caledonian deformation, because in places the rocks are highly folded, and in western Fin-

FIG. 10.

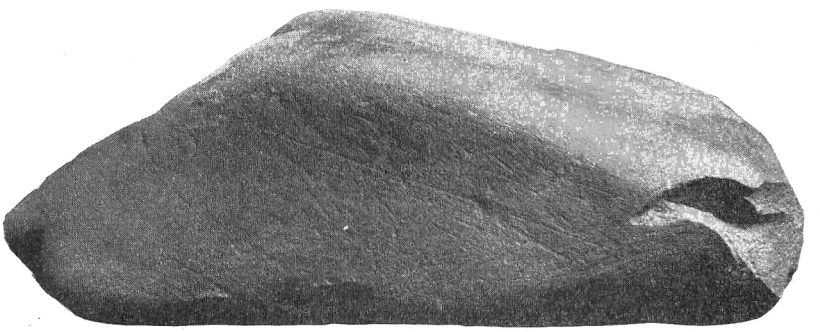

FIG. 10.—Glaciated quartzite bowlder, from the tillite at the inner end of the Altenfjord. Entire surface also with fine slickensided strata due to the Caledonian deformation. One half natural size.

marken they are overlain by thrusted mylonitic rocks. The most probable supposition is, in the writer's opinion, that the time is of Middle or possibly Upper Ordovician age.

The investigations of Wiman in Jemtland, Sweden, have shown that a dislocation there preceded the deposition of the *Orthoceras* limestone, which in places rests on the pre-Cambrian and whose conglomeratic basal layers contain pieces of Cambrian shales. This deformation of the crust might have been contemporaneous with the one preceding the deposition of the tillite-bearing division of Finmarken. In parts of Jemtland we find, furthermore, thick series of quartzites that are in part probably of Middle and Upper Ordovician age, and that may have been derived from a land-mass which then lay to the northwest and which may have continued northward into the southern part of Finmarken and the Kola Peninsula.

In the Trondhjem district of central Norway occurs the so called Hovind group, in which are found fossils of Upper Ordovician age; this is a series characterized to a

large degree by very coarse sediments, sandstones and coarse conglomerates, indicating deformation of the crust in the preceding time. This Hovind group comes above the effusive rocks, which I consider to be contemporaneous with the Raipas of western Finmarken.

I may in this connection also be permitted to point out the occurrence of coarse bowlder conglomerates in the Girvan-Ballantræ region of Scotland, the Kirkland and Benan conglomerates of Llandeilo age. These conglomerates likewise tell of considerable crustal deformations, which have brought about the denudation of the Arenig rocks now found as pieces in the conglomerate.

It seems of course a little remarkable at first to assume for the tillites of Finmarken an Ordovician age. Still, I can not see that it is contradicted by any of the known facts. Our knowledge of the late Paleozoic shows that it is very difficult to trace the existence of continental ice masses in the marine sediments. Furthermore, it must be strongly emphasized that this glaciation of Finmarken was probably a purely *local* one. In my opinion it was brought into existence by the rising of a high land to the south of the Varangerfjord, a land about the size of which we know nothing with certainty, as its age can not yet be fixed. As the Cambro-Ordovician sequence of the Baltic region indicates fairly quiet conditions, it is reasonable to believe that the land had its higher part in the north, i. e., in Finmarken, which is also a probable assumption since the great fault runs here. If we assume a land-mass of the width of the Scandinavian peninsula, high and rugged toward the Arctic Ocean, with a gentle slope toward the south, and a distinctly insular climate with much moisture on the north side, these conditions might very well bring into existence glaciers reaching down to the northern sea. On the other hand, Estland and southern Scandinavia may, under these assumptions, have had a rather warm climate. In fact, even on the north side the conditions might not have been at all severe. In South America at present glaciers creep down to the Pacific Ocean at so low a latitude as 46·5° S., the mean temperature of the year being here 8-10° C., the same as that of southern New York, and yet the inland has mountains not much higher than those of Norway to-day.

University of Kristiania, May, 1918.