STUDIES ON THE LATEST PRECAMBRIAN AND EOCAMBRIAN ROCKS IN NORWAY

No. 4.

THE EOCAMBRIAN "REUSCH MORAINE" AT BIGGANJARGGA AND THE GEOLOGY AROUND VARANGERFJORD; NORTHERN NORWAY

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Abstract.

The Bigganjargga Tillite (Reusch moraine) of N. Norway rests on a striated surface of the underlying sandstone (Tana Group).

This unconformity can be followed on both sides of the Varangerfjord and can be correlated with a similar slight angular unconformity below the Lower Tillite (Smalfjord Tillite) at Tana (Føyn 1937). The described sections through the latest Precambrian and Eocambrian of N. Norway show many lithological similarities to the corresponding sections in S. Norway and Scotland. The palaeoclimatic implications of the regional distribution of Eocambrian tillites are discussed, and it is concluded that the Eocambrian glaciation probably was more extensive than any other known glaciation.

Introduction.

The Finnmark sandstone series (The Finnmark Group) rests unconformably on the crystalline Precambrian gneisses which form the southern border of the series. These sediments which are relatively little deformed and of low metamorphic grade, are to the northwest overthrust by a nappe of metamorphic rocks. The most complete sequence through the sandstone series is found in the Tana district where the stratigraphy has been worked out by Holtedahl (1918) and Føyn (1937). The succession there can be divided into two subgroups, an upper tillite bearing group (Varanger Subgroup), which rests with angular unconformity on a lower pre-tillitic group (Tana Subgroup). The upper series contains two distinct tillite horizons on either side of a sandstone formation (Nyborg Formation), and the upper tillite is overlain at Digermulen by an apparently continuous succession of sandstone and shale grading up into fossiliferous Cambrian rocks. A detailed description of the sequence from the Nyborg Formation upwards into the fossiliferous Cambrian at Digermulen is given by Reading (1965). Reviews on the Finnmark sandstone series have been published by Rosendahl (1935), Holtedahl (1953, 1960, 1961) and Spjeldnæs (1964). The most recent account of the sedimentation of the tillites and the Nyborg Formation has been published by Reading and Walker (1966).

The stratigraphical succession around the inner part of the Varangerfjord is essentially rather similar to the generalized stratigraphy of the Tana district. Formal stratigraphic names for this formation have so far only partly been introduced and proper stratigraphic names for these formations have been discussed among the Norwegian and foreign geologists concerned. Certain new stratigraphic names are introduced. (K. Bjørlykke, Englund, Kirkhusmo, 1967.)

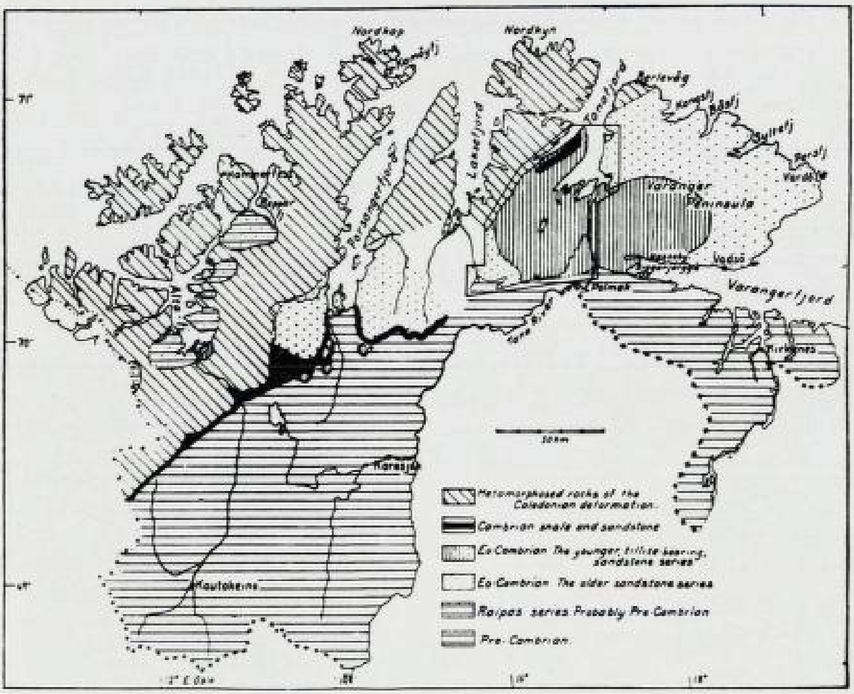


Fig. 1. Geological map of Finnmark after Føyn (1937).

Stratigraphy of the Finnmark Group.

	TANA AREA	VARANGER AREA
Varanger subgroup *	Breivik Formation (Reading 1965)	
	Stappogiedde Formation (Reading 1965)	
	Mortensnes Tillite (Holtedahl 1918)	Mortensnes Tillite
	Nyborg Formation (Holtedahl 1960)	Nyborg Formation
	Smalfjord Tillite * (Lower tillite)	Karlbotn Quartzite †
		Kvalnes Conglomerate *
		(Bigganjargga Tillite)
	angular unconformity 1—2°	
Tana subgroup *	Grasdal Dolomite * (Porsanger Dolomite, Holtedahl 1918)	Tana Subgroup
	Vagge Formation (Føyn 1937)	
	Algasvarre Formation *	
	Stangenes shale (Føyn 1937)	

* Bjørlykke et al. (1967).
† This paper.

The area around the inner part of Varangerfjord and the Bigganjargga Tillite have been visited by a large number of geologists, and accounts of the sedimentary geology of the Finnmark Group in this district are published by: T. Dahll (1868), Reusch (1891, 1892), Tørnebohm (1893), Schiøtz (1896), Strahan (1897), Holtedahl (1918, 1919, 1932), Rosendahl (1931, 1945), von Gaertner (1943), Holtedahl and Føyn (1960), Crowell (1964), Harland (1964). The present paper presents the result of the author's fieldwork in the Varangerfjord area during the summer of 1965.

Geological maps of this area have been prepared by Holtedahl (1918), Holtedahl and Føyn (1960) and Rosendahl (1931) and these maps served as a useful basis for my own fieldwork.

The mapped areas provide good sections through the Tana Sandstone and the overlying tillite bearing group (Varanger Subgroup). The unconformable relation between these two groups is spectacularly displayed in this area, particularly at Bigganjargga where a moraine rests on a striated surface of sandstone of the Tana Subgroup. To the south the crystalline Precambrian crops out, revealing to a large extent the features of the primary topography of the basement.

The Bigganjargga Tillite is now protected by law, and visiting geologists should not hammer at the locality to collect specimens. Loose blocks of Bigganjargga Tillite is usually found around the locality.

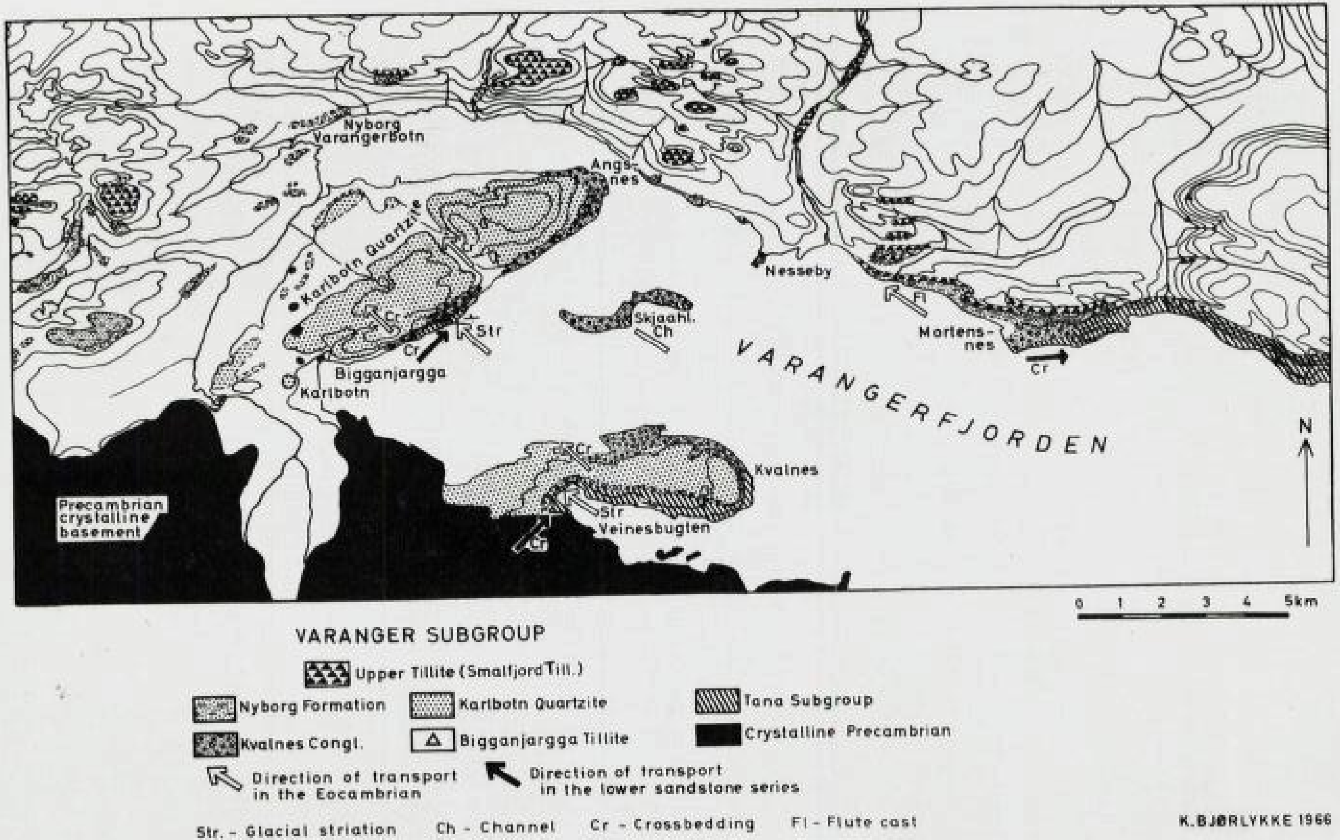


Fig. 2. Geological map around the inner part of Varangerfjord, partly after Holtedahl and Føyn (1960).

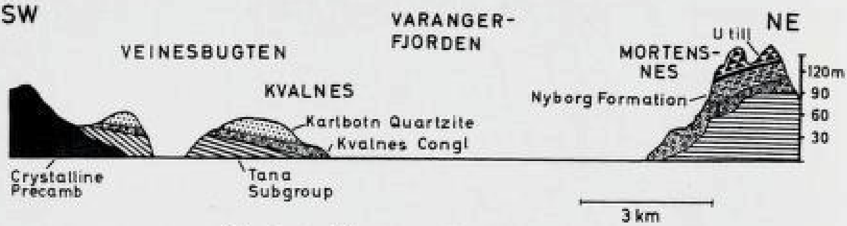


Fig. 3. Profile across the Varangerfjord.

The Tana Subgroup.

The Tana Subgroup can be traced from the Tana area in the west, where a relatively detailed stratigraphy has been established (Holtedahl 1918, Føyn 1937), northwards to the Varanger peninsula, where mostly only reconnaissance work has been done (Holtedahl 1918, Rosendahl 1945) and further to the southwest, to the northern side of the Varangerfjord. The most complete section in the Varangerfjord area is exposed at Klubbfjell (Holtedahl 1918, Rosendahl 1931). In the section at Mortensnes a dark grey sandstone is found below the dolomite conglomerate at the sea level. To the east the conglomerate is overlying green and red shale and sandstone. At the top of the hill, about 100 m above sea level, the conglomerate rests on a pale yellowish sandstone containing red spots of iron oxides. The orientation of foresets in crossbedded units in the sandstones of the Tana Subgroup indicates that transport was from west to east. This sequence bears many resemblances to the Stangenes Shale of the Tana succession described by Føyn (1937), but more detailed investigations must be carried out before reliable correlations with the Tana district can be established.

O. Holtedahl (1918) interpreted all the sandstone on the south side of the Varangerfjord as belonging to the younger tillitic series (Varanger Subgroup), but more detailed mapping supports Rosendahl's view (1931) that the sandstone underlying the Bigganjargga Tillite and the conglomerates at Kvalnes belong to the older Tana Subgroup. To the west at Veines the conglomerate rests on a crossbedded quartzite which overlies the crystalline Precambrian basement. Passing north-east-wards to the point of Kvalnes, the Kvalnes Conglomerate is found to rest on progressively younger beds of sandstone which gradually become more shaly. Ripple marks and mud cracks are common in a dark silty shale at the point of Kvalnes, and a similar lithology is found beneath the unconformity on the island of Skjåholmen. Crossbedding in the Tana Subgroup at Kvalnes and Bigganjargga indicates that the direction of sediment transport was from southwest and west. This is consistent with data recorded from Mortensnes.

An intraformational conglomerate is found, both at Kvalnes and at Bigganjargga, with pebbles up to a few cm in diameter. Some of the pebbles are greenish and may perhaps represent concretions. A similar conglomerate has been described by Holtedahl (1918) from Per-Larsavik on the north side of the Varangerfjord. This conglomerate had been described by Keilhau (1850) as a concretionary rock, but on the basis of polished sections and thin sections Holtedahl (1918, p. 151) was able to demonstrate its conglomeratic nature.

The described lithology of the sandstone around the Varangerfjord corresponds well to that of the lower part of the Tana Group of the Tanafjord section as described by Føyn (1937). The thick quartzites (Vagge Formation) of the upper part of the Tana Subgroup have probably been eroded in the Varanger district.

The unconformity between the Varanger Subgroup and the Tana Subgroup.

Føyn (1937) worked out a detailed stratigraphy of the Tana Subgroup along the Tanafjord and was able to demonstrate that the lower tillite was resting upon progressively younger beds of sandstone of the Tana Subgroup along the eastern side of Tanafjord. This angular unconformity was shown to be rather constant at one to two degrees. A thickness of 600 m of sandstone present at Grasdalen must have been eroded or not deposited at the head of Tanafjord 35 km further south. In the Varanger area the sandstone underlying the tillites most probably corresponds to the lower part of the Tana Subgroup of the Tanafjord section (Rosendahl 1931) suggesting that at least 500 m of the Tana Subgroup were eroded or not deposited before the deposition of the tillites. On the southern side of the Varangerfjord at Kvalnes the author measured a 2—3 degrees' angular unconformity at the base of the tillite, as the tillite to the north is found to rest on progressively younger beds of the Tana Subgroup. Good exposures showing the same unconformity are found at the island of Skjåholmen (Fig. 4). The Kvalnes Conglomerate can often be followed resting on a thick quartzite bed in the Tana Subgroup for some metres and then cutting through the quartzite and underlying shale down onto a lower competent bed.

Fig. 4. Unconformity between the Varanger Subgroup (Kvalnes Congl.) and the Tana Subgroup at Skjåholmen.

On the north side of the Varangerfjord at Mortensnes this unconformity is very clearly shown, and as described by Holtedahl (1918) and Rosendahl (1931) the conglomerate (Kvalnes Conglomerate) can be followed up the hill resting upon progressively younger members of the slightly northwards dipping sandstones of the Tana Subgroup.

The lower tillite (Bigganjargga Tillite).

As a result of its being one of the few examples of a probably terrestrial moraine of Eocambrian age resting on a striated surface, the Bigganjargga Tillite has been visited by many geologists since it was first described by Reusch in 1891 and is a popular excursion locality. Reusch concluded that this tillite is a moraine from an ice age older than the Pleistocene. As mentioned by Reading and Walker (1966) Reusch (1891) used the term boulder-clay in his English summary, whilst Strahan (1897) who confirmed Reusch's conclusions used the term till. In the Norwegian text, however, the conglomerate is referred to as "morene konglomerat" which could be more appropriately translated to moraine or till. However, except for the work on the till-fabric by von Gaertner (1943), little detailed work has been done on this lo-

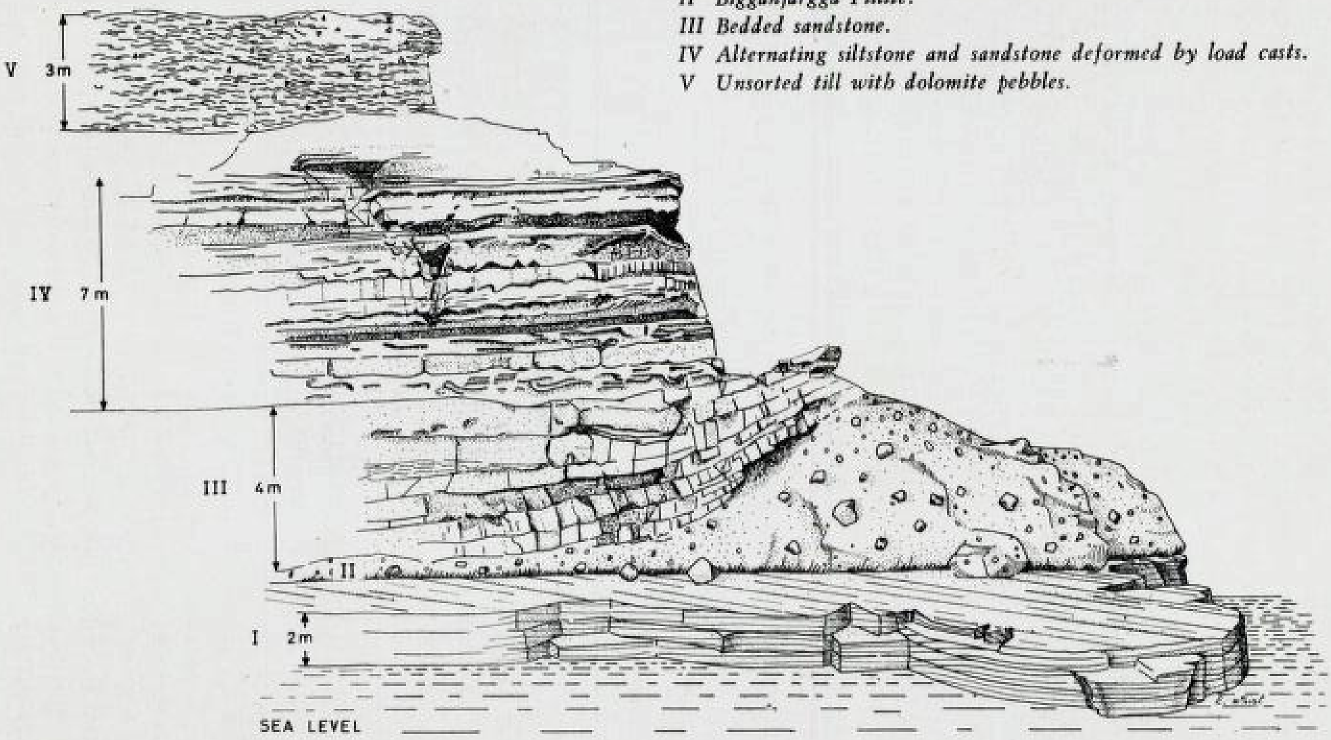


Fig. 5. The Bigganjargga Tillite (Drawing after Photography).
I Crossbedded sandstone of the Tana Subgroup.
II Bigganjargga Tillite.
III Bedded sandstone.
IV Alternating siltstone and sandstone deformed by load casts.
V Unsorted till with dolomite pebbles.

cality. The tillite rests on a flat surface of quartzite, with striations clearly running in beneath the tillite (fig. 5 and 6) and is overlain by a 3 m thick sandstone and silty beds in which loadcasts and slump structures are common. This is followed by the Kvalnes Conglomerate with dolomite pebbles and then the Karlbotn Quartzite continuing up to the top of the peninsula (120 metres above sea level).

The distribution of pebble long axes, based on the author's measurements, shows roughly the same pattern as that obtained by von Gaertner (1943) (Fig. 8). The orientation of most striations is SE–NW (160 g) (Fig. 7) and a probably younger set of striations shows ESE–WNW (120 g) orientations. The boulders and pebbles in the tillite are mainly crystalline Precambrian rocks and sandstone from the sandstone below. The Precambrian blocks are relatively more common than sandstones in the coarser fractions (Fig. 10). The relevant characteristics of the tillite could be summarised as follows:

1. The tillite rests disconformably upon a quartzite which has a striated upper surface.
2. The tillite is homogeneous without any bedding or grading.
3. The tillite shows poor sorting.
4. The pebbles are fresh and show no sign of weathering.
5. Striated and faceted pebbles are found.
6. The long axis distribution of pebbles shows a preferred orientation approximately perpendicular to the direction of the striations of the surface of the quartzite below.
7. The tillite shows a sharp contact with the overlying sandstone and conglomerate.
8. The unconformity between the tillite and the underlying sandstone is to be correlated with a major angular unconformity traceable over a larger part of Finnmark.
9. Pebbles derived from the underlying sandstone are common.

These features show good accordance with the characteristics of Pleistocene moraines. The long axis distribution of the pebbles in Pleistocene moraines are usually parallel to the direction of iceflow, as indicated by the striations, but preferred orientations perpendicular to the direction of ice flow are not uncommon (Holmes 1941). The grain-size distribution curves show that the Bigganjargga tillite has a very sandy matrix. Tills of this lithology frequently give a poor or less re-

Fig. 6 a. Glacial striation at the base of the Bigganjargga Tillite.

liable till fabric than those of a finer grained matrix (B. Andersen personal communication). The apparent lack of correlation between orientation of the pebble long axes and the striations on the basement led von Gaertner (1943) to suggest that the whole outcrop, 70 m long and 3 m high, was one single block of moraine dropped from icebergs onto the already striated surface. In the author's opinion this theory is unlikely and is not necessary to account for the long axis distribution.

It was pointed out by Spjeldnæs (1964, p. 33) that large blocks of frozen moraines transported by floating ice are more likely to be found in a thick sedimentary sequence than on a clean surface of striated quartzites. Spjeldnæs also mentions the possibility that the moraine was deposited when the ice sheet was too thin to produce good striation and reflects a late and local direction of ice movement different from the main one. As mentioned above a probably younger, fainter set of striation has been formed (Fig. 6 b) but this is also oblique to the preferred orientation of pebble long axes.

According to the interpretation of O. Holtedahl (1918 and 1960) the underlying sandstone belongs to the upper sandstone series (Varanger Subgroup), and lies above the main unconformity. Holtedahl

Fig. 6 b. Two sets of striations, the fainter probably being the younger of the two. A probable cresentic gourge related to the younger set of striation (rather faint).

(1918, p. 161) suggested that the sand might have been frozen at the time of deposition of the moraine and therefore able to take the striations. A later deformation of the underlying sandstone should then be expected but the border to the underlying sandstone is sharp and undeformed. The presence of sandstone pebbles in the tillite was considered by H. Rosendahl (1931, 1945) to indicate that the underlying sandstone was at least partly consolidated at the time of the deposition of the moraine. Such an explanation is favoured by the present correlations showing the quartzite to belong to the lower sandstone series (see

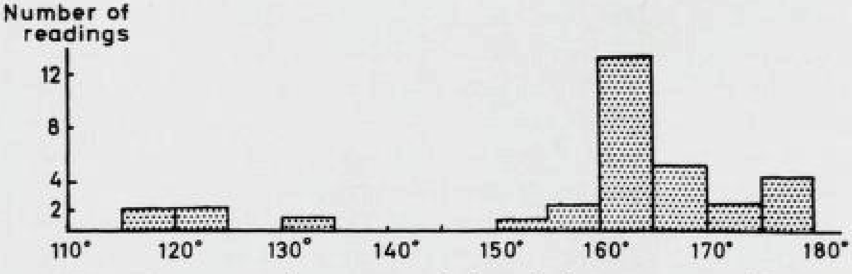


Fig. 7. Orientations of striations at the base of the Bigganjargga Tillite.

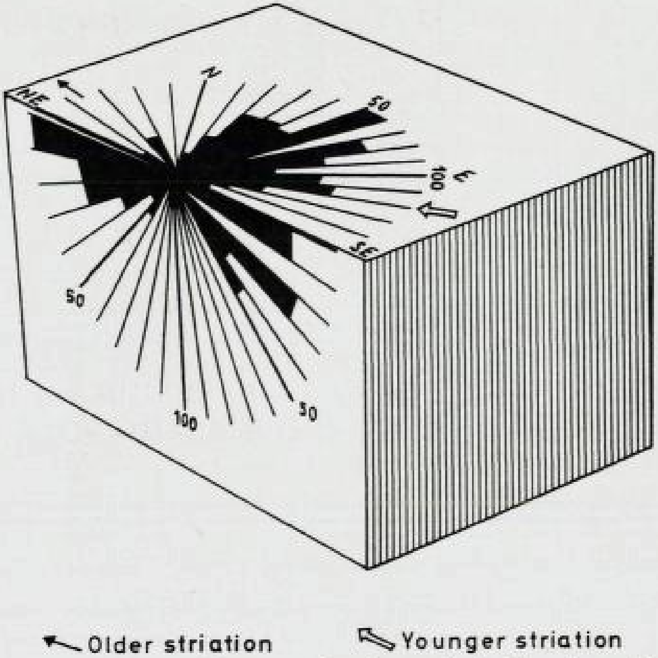


Fig. 8. Vertical and horisontal long axis distribution of the Bigganjargga Tillite based on 200 measurements of pebbles where the apparant long axis is more than 50 % larger than the shorter axis.

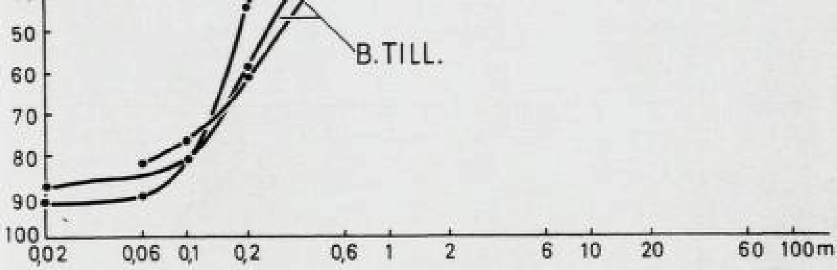
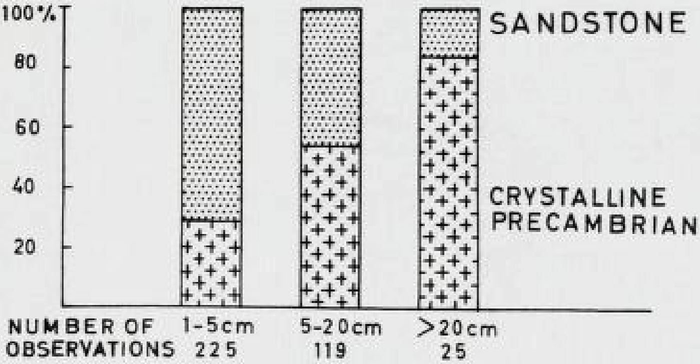


Fig. 9. Grain size distribution in the Bigganjargga Tillite and the underlying sandstone. Each curve is based on 300—600 measurements in thin sections, by use of acetate replicas (K. Bjørlykke, 1966a) and for the larger clasts macroscopic measurements.



COMPOSITION OF PEBBLES AND BOULDERS IN THE THE BIGGANJARGGA TILLITE

Fig. 10.

also Rosendahl 1931). Consequently the Porsanger Dolomite and probably some hundred metres of sandstone of the Tana Subgroup must have been eroded before the deposition of the Bigganjargga Tillite. Crowell (1964) has interpretated the moraine as a mudflow-deposit and the underlying striations as scours due to the erosion caused by the

Fig. 11. Striations at the base of Kvalnes Conglomerate at Veines bay.

mudflow. The stratigraphic correlation with the marine tillites in the Tana district (the glacial origin of which also seems to be accepted by Crowell), the lack of weathering of the pebbles and the occurrence of striated pebbles, according to the author's opinion, favour a glacial origin for the moraine. It is considered that neither the coarser Precambrian gneisses nor the sandstone pebbles were able to take striations and that Precambrian quartzites are rather rare thus explaining the scarcity of striated pebbles. The matrix of the conglomerate is sandy, and the grain size corresponds very closely to the mean diameter of the sand grains in the underlying sandstones (Fig. 9). This suggests that the sandstone was not well consolidated at the time of deposition of the moraine, so that erosion disintegrated the sandstone into whole grains. The author interprets the Bigganjargga Tillite as an erosional remnant of a more extensive moraine, which has been partly reworked and deposited as glaciofluvial and fluvial conglomerates. This is supported by a new find of striations below the Kvalnes Conglomerate at Veines further east (Fig. 11). The Bigganjargga Tillite may therefore be regarded as a part of the Kvalnes Conglomerate.

The Kvalnes Conglomerate.

The Kvalnes Conglomerate is in part well sorted with well rounded pebbles, and is also partly unsorted with scattered angular pebbles in a sandy matrix. The conglomerate rests unconformably upon the Tana Subgroup and represents a lateral continuation of the conglomerate at Bigganjargga. At Mortensnes the Kvalnes Conglomerate is clearly a fluvial conglomerate with large scale crossbedding and well rounded dolomite pebbles. At Kvalnes, however, the conglomerate is often unsorted at the base and better sorted with crossbedding in the upper part. This is illustrated by Holtedahl (1918, p. 165) and it seems probable that the lower part locally includes undisturbed till while reworked glaciofluvial material prevails in the upper part. Along the shore from Bigganjargga to Angsnes the Kvalnes Conglomerate is partly unsorted till, partly sorted glaciofluvial material. Thus above the Bigganjargga Tillite (Fig. 5) a bed of unsorted till with small dolomite pebbles occurs. This latter may be a marine till transgressing over the underlying sandstones and Kvalnes Conglomerates.

On the southern side of the Varangerfjord the conglomerate contains dominantly pebbles of the crystalline Precambrian and of the underlying Tana Sandstone. Dolomite pebbles are relatively scarce at the Kvalnes peninsula and in the Bigganjargga Tillite, but become gradually more common to the N at Angsnes. At the small island of Skjåholmen dolomite makes up about 50 % of the pebbles. The number of crystalline Precambrian pebbles decreases very rapidly to the north and at Mortensnes on the north side of the fiord, dolomite pebbles make up more than 90 % of the assemblage. The same yellow conglomerate crops out at Nesseby (Holtedahl 1918, p. 166) and is sometimes referred to as Nesseby Sandstone. Crossbedding in this conglomerate shows a regular direction of transport from the SE or E. The fact that the direction of transport was nearly parallel to the Precambrian coastline to the S. probably explains why only small amounts of Precambrian pebbles are found farther out from the presumed coast. It is necessary to assume that the Porsanger Dolomite extended to the east of the Varangerfjord before the subsequent erosion. While the Bigganjargga Tillite contains only a very small percentage of dolomite pebbles, the overlying unsorted tillite (Fig. 5) contains mostly dolomite pebbles and some sandstone pebbles of the Tana Subgroup. If this is a marine tillite dropped from floating icebergs it seems natural that it should contain pebbles of a composition different from more locally derived glacial and glaciofluvial conglomerates.

The Nyborg Formation and Karlbotn Quartzite.

The Kvalnes Conglomerate north of the Varangerfjord is overlain by thin-bedded red and grey sandstone and shale, approximately 100 m thick, the Nyborg Formation, in the middle part of which dolomite beds are found. Holtedahl (1918, p. 169) describes a dolomite breccia outcropping in the hills north of the easterly houses at Mortensnes. North of Hammernes a white to grey dolomite occurs, probably at the same horizon. Flute cast structures are found along the shore at Hammernes in the upper part of the Nyborg Formation (Fig. 12). These flute cast structures are mentioned by Crowell (1964, p. 96) who concludes that turbidity currents probably played a role in the local deposition of the Nyborg Formation around Hammernes. Reading and Walker (1966) classify parts of the Nyborg Formation in the Tana District as belonging to turbidite facies. In the Varangerfjord district graded bedding is not typical in the Nyborg Formation and thin-bedded ungraded sandstone prevails. It is felt that the evidence of the sole mark-

Fig. 12. Flutecasts in the Nyborg Formation at Hammernes.

ings at Hammernes is not sufficient to characterise these sediments as turbidites. South of the Varangerfjord the Kvalnes Conglomerate is succeeded by a white to grey quartzite interlayered with numerous conglomerate horizons which wedge out very rapidly. Crossbedding is very

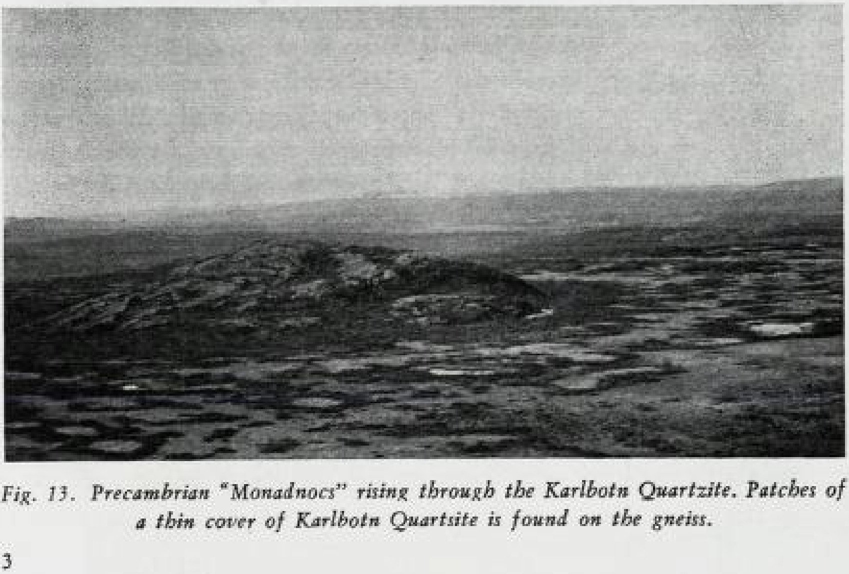


Fig. 13. Precambrian "Monadnocs" rising through the Karlbotn Quartzite. Patches of a thin cover of Karlbotn Quartsite is found on the gneiss.

common in the quartzites. As pointed out by Holtedahl (1918) the similarity to Quarternary glaciofluvial deposits is striking. Due to lack of exposures it is difficult to work out to what extent the Karlbotn Quartzite is contemporaneous with the Nyborg Formation or if it should be regarded as an upper part of the Kvalnes Conglomerate which is thinning out northwards.

Around Karlbotn and northwards to Vesterelven a number "monadnocs" of crystalline Precambrian gneisses are exposed rising up through Karlbotn Quartzite (Fig. 13). On these gneisses a thin 1—2 cm thick layer of quartzite is frequently found. Examination of thin sections across the gneiss-quartzite contact revealed no evidence of weathering of the gneiss. Holtedahl (1918, p. 168) concluded that these monadnocs represent the primary relief during the deposition of the Karlbotn Quartzite.

The Upper Tillite (Mortensnes Tillite).

The Upper Tillite horizon rests conformably upon the Nyborg formation with no signs of erosional contact at the base. This tillite contains scattered pebbles and boulders up to 1.5 m in diameter (Fig. 14). This corresponds to the facies of the Upper Tillite in the Tana

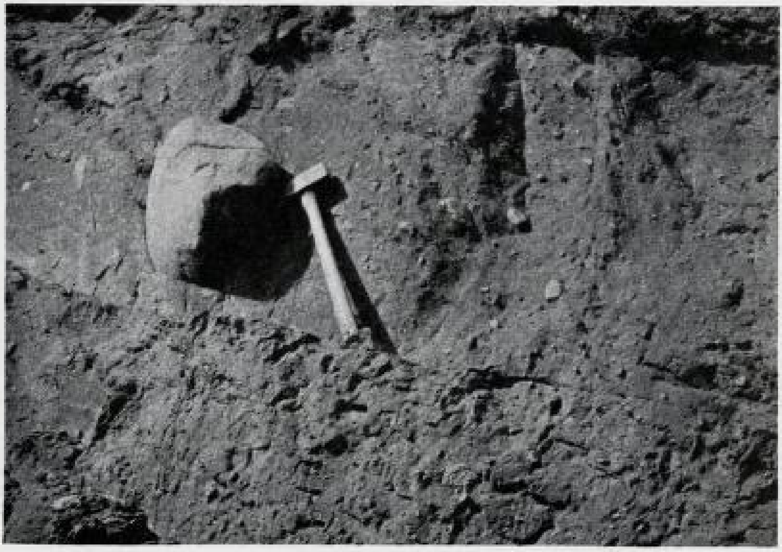


Fig. 14. The upper marine tillite (Mortensnes Tillite) at Mortensnes.

District and is interpreted as an ice-rafted marine tillite (Føyn 1937, Reading and Walker 1966). The Upper Tillite is the stratigraphically highest unit exposed in the area north of Varangerfjord, and the sections up on the hills north of the fjord show alternations of the Nyborg Formation and the Upper Tillite repeated by thrusting or oblique folds of the type described by Føyn (1937, p. 146).

Palaeocurrent and glacial transport.

In the Tana Subgroup at Kvalnes crossbedded sandstones and the shales with mudcracks indicate deltaic shallow water conditions. This agrees with the records from the Tana Sandstone in Tana District which also include mudcracks and ripple marks (Føyn 1937, p. 71). Palaeocurrent measurements from the Tana Sandstone on both sides of the Varangerfjord indicate a direction of transport from the SW or W (See map Fig. 2).

The frequent occurrence of dolomite pebbles in the Kvalnes Conglomerate indicates that the Porsanger Dolomite was also deposited east of the Varangerfjord area, before the elevation and subsequent denudation of the dolomite and the larger part of the sandstone series. This denudation seems to have been accompanied by a period of glaciation. The preserved glacial striations at Bigganjargga and Veines show a transport from SE–NW (160 and 140 g) and at Bigganjargga a younger set of striations is also preserved showing a more easterly direction (120 g). A channel structure at Skjåholmen indicates transport in a SE–NW direction, and the numerous crossbeddings in the Kvalnes Conglomerate and the Karlbotn Quartzite generally show a transport from the SE. The same direction is indicated by flute cast structures at Hammernes. A crescentic gourge below the Bigganjargga Tillite suggests a positive direction of iceflow from SE to NW and this is also supported by the larger percentage of crystalline Precambrian boulders from the south. There is little sign of tectonic deformation in the area south of the Varangerfjord and there is no indication that the mountains of Precambrian gneisses rising above 200 m hight just south of the sandstones are upfaulted relatively to the sediments on the southern side of Varangerfjord. The filling up of the relief in the crystalline basement by the sandstones suggests that this relief is mostly primary. Such a contention is supported by the crystalline monadnocs standing up in the sandstone further north. Faulting along the Varangerfjord before the deposition of the younger tillite bearing series (Varanger Subgroup) was suggested by O. Holtedahl (1918, p. 265). This theory was based on the assumption that the Tana Subgroup was not present on the southern side of the fjord and on an apparent escarpement in the crystalline Precambrian relief along the fjord. This first argument seems to be no longer valid since the sandstones of the Tana Subgroup are also most probably present on the southern side of the fjord. The possibility that faulting along the Varangerfjord took place prior to the deposition of the Tana Subgroup should also be considered. Another possibility is that faulting occurred south of the Varangerfjord.

The cross section across the fjord (Fig. 3) indicates the presence of a trough parallel to the fjord. This trough is parallel to the direction of glacial and fluvial transport suggesting the existence of a glacially eroded trough parallel to the coast which was formed by the crystalline basement. Holtedahl (1918) and Føyn (1937) explained the angular unconformity as being due to tectonic tilting and subsequent erosion (mainly glacial). Reading and Walker (1966), however, suggest that the unconformity is mainly due to glacial scouring at the base of the advancing ice-sheet. The same authors, however, offer no explanation of the northward dipping Porsanger Dolomite in their model (Reading and Walker, 1966, p. 206). The present author considers that if the first glacial period consisted of several glaciations and interstadials the glacial erosion would gradually unload the crust in the south and the isostatic rebound would gradually tilt the sediments to the north. The erosion would be accentuated by the delay between the glaciations and the isostatic depressions. It is also conceivable that the glacier would erode at a deeper level close to the coast than further out, thus forming a depression along the coast which after the melting of the ice could be more or less compensated by the isostatic rebound. As pointed out by Holtedahl troughs are now present along the coast of continents which were covered by Pleistocene glaciers. According to O. Holtedahl (1960, p. 352) such troughs have a tectonic origin and were widened by glacial erosion. The trough along the Varangerfjord formed prior to the deposition of the tillite may well be an Eocambrian equivalent of the Pleistocene troughs, as for example the trough along the Norwegian coast.

Correlations.

Accepting a glacial origin for the tillites of Finnmark, N. Norway, it seems natural to correlate these tillites with probably glacial conglomerates found elsewhere in continuous successions, some hundred and up to a few thousand metres below fossiliferous Cambrian, and to assume that they were deposited during the same climatic period. Thus the Eocambrian tillites become important tools in establishing long distant lithological correlations. The author has been working on the sparagmites of southern Norway (K. Bjørlykke 1966b) and has also had the opportunity to see parts of the Dalradian of Scotland. A tentative correlation with those two areas is presented in fig. 15. A recent find of the Lower Cambrian fossil *Platysolenites* in the Breivik Formation (Føyn, 1967) suggests that this formation corresponds to the Holmia Series in S. Norway and that the quartzite in the upper part of the Stappogiedde Formation is equivalent to the Vangsås Formation (Vemdal Formation) of S. Norway and Sweden. This formation which in Sweden is also known as Ströms Quartzite, is very extensive and clearly transgressive (Skjeseth 1963). In S. Norway there is only one tillite horizon (Moelv Tillite) and a comparison of the stratigraphic sections indicates that it most probably corresponds to the upper tillite in Finnmark.

The correlation of the British and Scandinavian late Precambrian and early Palaeozoic is dealt with by Frödin (1922), O. Holtedahl (1939) and Bailey and O. Holtedahl (1937) and more recently by Harland et al (1966).

As pointed out by Holtedahl (1939), the Port Askaig Conglomerate of the Islay succession and the Schichallion Conglomerate of the Perthshire succession may be correlated with the Eocambrian tillites of S. and N. Norway. While the Port Askaig boulder bed seems to be a till partly deposited on land or in shallow water, partly marine (Kilburn, Pitcher and Shackleton (1965) and A. M. Spencer (personal communication) the Norwegian tillites are mostly marine, dropped from floating icebergs. In N. Norway terrestrial tills are also found (Bigganjargga Tillite), yet no good example of a terrestrial till is described from the sparagmite succession of S. Norway. A succession very similar to that of Islay has recently been described by Howarth et al. (1966) from Glencolumbkille, County Donegal, Ireland. The Islay Limestone underlying the Port Askaig Conglomerate, contains thick limestones with

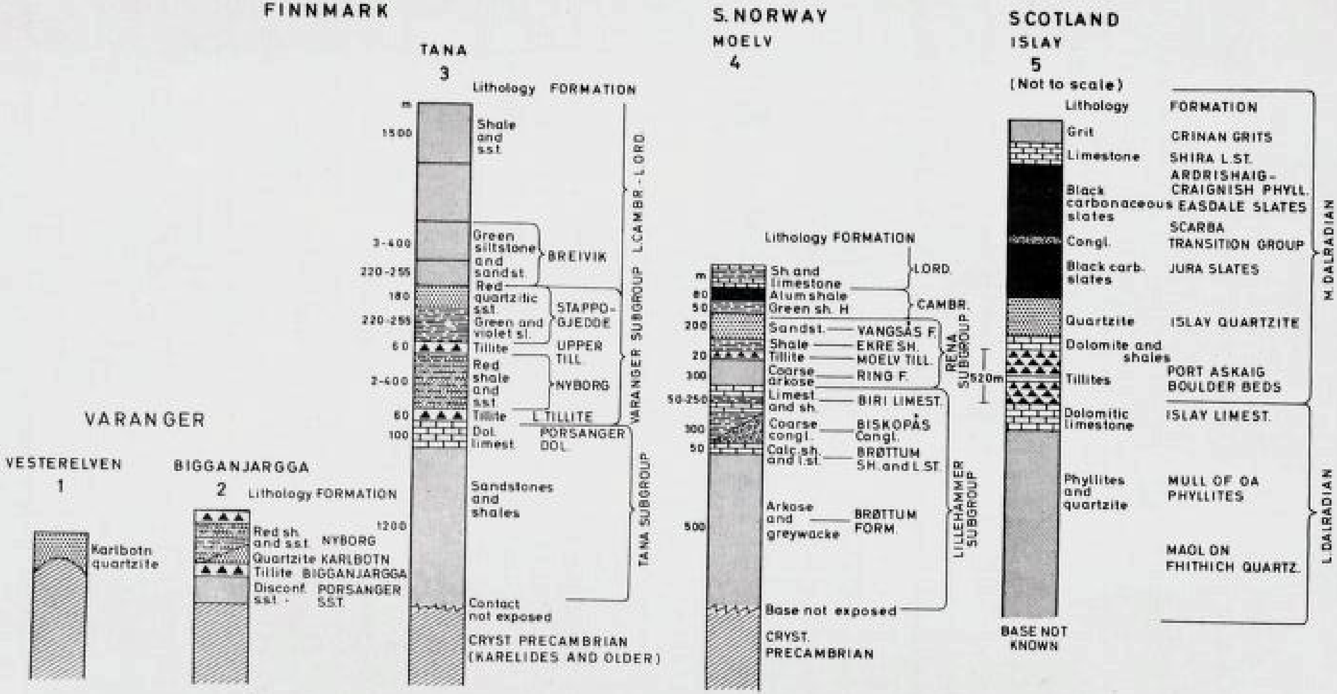


Fig. 15. Late Precambrian and early Palaeozoic successions in Norway and Scotland.
1.—2. O. Holtedahl (1918) and the present paper.
3. Holtedahl (1918) and Føyn (1937).
4. Vogt (1924). Skjeseth (1963) and K. Bjørlykke (1966).
5. Bailey (1917).

oolites and stromatolites as well as some dolomites and is strikingly similar to the Porsanger Dolomite of N. Norway, where stromatolites and oolites are also common. In S. Norway oolites are found in the Biri Limestone (Skjeseth 1963, p. 29). In both Scotland and Norway the dolomites rest on a series of sandstones, mostly deltaic shallow water deposits.

Above the Port Askaig Conglomerate occurs the Islay Quartzite which is thicker, but otherwise very similar to the Vangsåsen Formation of S. Norway and Sweden and similar to the upper part of the Stappogiedde Formation (Reading 1965) in Finnmark. Both in S. Norway and in Scotland this sandstone is overlain by a series of black carbonaceous shales, which in the Oslo Region yield a rich Cambrian fauna. At a late stage in the preparation of the present paper an unpublished draft by the late J. Pringle was shown to the author by O. Holtedahl. This draft included many of the same correlations as made by the present author and is more detailed as far as the Cambrian stratigraphy is concerned.

The Late Precambrian and Eocambrian successions in Spitsbergen (Kulling (1934), Winsnes (1966), Harland et al. (1966)) and in E. Greenland (A. Berthelsen and A. Noe-Nygaard 1965) also have many similarities to the British-Scandinavian succession, though is representative of a more eugeosynclinal facies. In Spitsbergen and E. Greenland there also occur tillite horizons, overlying a dolomite formation. When examining the association of Eocambrian tillites or tilloids one finds that dolomites with stromatolites are very commonly found below and, in many cases, also above the assumed glacial beds. As we have seen, this is the case in N. Europe, but the same relation pertains in the extensively developed late Precambrian and Eocambrian limestones and tillites in Africa from Algeria in the north to Rhodesia in south (Furon 1960). Also in the Congo, two tillite or tilloid horizons are found resting on oolitic dolomites as described by Stanton and Schermerhorn (1963), although the glacial origin of these tilloids was questioned by these authors. In S. Australia in the Adelaide system the same relation is found (Mawson 1949, Howchin 1908), where two tillite horizons occur separated by sediments which were probably deposited in a prolonged interglacial period. Late Precambrian or Eocambrian tillites are also found in China, U.S.S.R. and U.S.A. Reviews of the distribution of Eocambrian tillites have been published by Kulling (1934) and Harland (1964). If these tillites are contemporaneous it would indicate a widespread glacial period in many parts of the world in Eocambrian times, accompanied by carbonate sedimentation before and partly also after the glaciations. These periods of carbonate precipitation are most easily explained by assuming a general increase in temperatures of the oceans, but they could also have been caused by other processes. World maps showing the distribution of alleged late Precambrian/ Eocambrian tillites show that these are present on all continents and in a wide range of latitudes. Harland (1963) points out that the glacial origin of many of these conglomerates should be questioned, but many appear to be well established and it is thus difficult to work out a pattern showing the distribution of glaciated and non-glaciated areas. When reorientating the pole positions according to the palaeomagnetic data, it is seen that some tillite deposits occupy an equatorial position and the Bigganjargga Tillite was according to Harland and Bidgood (1959) deposited, close to the equator. The associated limestones seem also to have been deposited in the polar regions as well as in equatorial areas.

The occurrence of presumably contemporaneous glacial deposits over a wide range of palaeolatitudes down to equatorial positions suggests that the Eocambrian glaciation was very extensive, with low temperatures over a larger part of the world. The extensive occurrence of associated oolitic limestones at very high latitudes suggests relatively high temperatures over a large part of the world, although oolitic limestones are admitably less reliable temperature indicators than glacial deposits.

If the palaeomagnetic data from Eocambrian time are correct, the available evidence suggests that the Eocambrian glaciation was more extensive than any other known glaciation and that a period with relatively warm weather most probably occurred before this glaciation. Even if the palaeomagnetic data should prove unreliable, it is difficult to find a pole position, for which most of the well established tillites are placed at relatively high palaeolatitudes.

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Sammendrag.

Forfatteren foretok sommeren 1965 geologiske undersøkelser i området rundt den indre del av Varangerfjord. Særlig vekt ble lagt på studiet av den klassiske Bigganjargga-tillitten som nå er fredet ved lov. Tillitten hviler på en isskurt flate av sandsten. Det var mulig å følge denne erosjonsdiskordansen både på syd- og nordsiden av Varangerfjorden, og det er sannsynlig at den underliggende sandsten svarer til Tana-gruppen i Tana-området. Den egentlige Bigganjargga-tilliten har en svært begrenset utstrekning, et tverrsnitt på 70 x 3 m og er trolig en erosjonsrest av et større morenedekke. Bigganjargga-tillitten kan oppfattes som en del av en sammenhengende konglomerat-horisont som delvis er usortert konglomerat (tillitt), delvis mer sortert, glasiofluvialt konglomerat med krysskiktning. En ny lokalitet med isskuring ble funnet under Kvalnes-konglomeratet ved Veinesbukten. Over Kvalnes-konglomeratet følger på nordsiden av Varangerfjorden en rødlig sandsten og skifer (Nyborg-formasjonen). På sydsiden av fjorden over Kvalnes-konglomeratet, finner vi Karlbotn-kvartsitt med konglomerater som også trolig er glasiofluviale.

I syd hever det krystalline underlag seg 200 m over Karlbotn-kvartsitten uten at det er noen direkte tegn til forkastninger. Mellom Karlbotn og Vesterelven finner man oppragende koller (monadnoks) som stikker opp gjennom kvartsitten, og ofte kan man på disse finne et tynt dekke av sandsten på frisk uforvitret gneis. Dette viser at man under avsetningen av Karlbotn-kvartsitten må ha hatt et kupert landskap som i mange trekk liknet på det man finner nå. Dette skyldes at den nuværende erosjon i stor utstrekning følger grensen mellom de underliggende krystalline bergarter og den overliggende kvartsitt. Den friske kontakten mellom gneiss og overliggende kvartsitt viser dessuten at man ikke hadde noen dypforvitring under avsetningen av Karlbotn-kvartsitten, noe som passer meget bra med antagelsen om glasiale forhold.

Den geologiske historie i dette området i sen prekambrium-eokambrium kan enklest fortolkes slik:

1. Avsetning av en flere hundre meter tykk sandstens-lagrekke, (Tana-gruppen) trolig som en del av et stort delta med tilførsel fra SV.
2. Tilførselen av klastisk materiale fra deltaet tok slutt, og vi fikk kalksedimentasjon (Grasdalen-Porsangerdolomitt) i et grunthavsområde.
3. Hevning av landet i SV og erosjon av deler av Tana-gruppens dolomitter og sandstener. Erosjonen var trolig for en vesentlig del glasial, og i den siste fase beveget breen seg fra SØ mot NV. Av profilet tvers over fjorden kan man slutte at erosjonen dannet en trauformet renne omtrent parallelt med den nåværende Varangerfjorden dvs. parallelt med kysten i eokambrisk tid. Dette erosjonstrauet har mange likhetspunkter med Den norske renne fra kvartærtiden, selv om det er en del mindre.
4. Morenedekket som Bigganjargga-tillitten er en rest av, ble delvis erodert og overleiret av glasiofluviale sedimenter.
5. På ny fikk vi deltaliknende forhold med avsetning av sandsten og skifer sedimenter. (Nyborg Formasjonen.)
6. Under den siste av de to istidene var området under så dypt vann at vi fikk avsatt glasialt materiale fra flytende isfjell, men ingen egentlig morene. Den øvre tillitt (Mortensnes-tillitten) er den yngste formasjonen i området.

En sammenlikning med tilsvarende avsetninger i Syd-Norge og Skottland viser stor likhet i lagfølgen, og også der finner man glasialsedimenter. En oversikt over utbredelsen av eokambriske glasialsedimenter i Afrika, Asia, Australia, N. Amerika, Grønland og Spitsbergen tyder på at den eokambriske istiden har hatt en stor utbredelse, trolig større enn den kvartære.

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