SEDIMENTATION, REGIONAL STRATIGRAPHY AND CORRELATION

LATE PRECAMBRIAN AND CAMBRO-ORDOVICIAN SEDIMENTATION IN EAST FINNMARK

by

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Contents

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Abstract

The presence of two closely spaced tillite formations within the Precambrian and Cambro-Ordovician sediments of eastern Finnmark permits subdivision into pre-glacial and post-glacial regimes. On the northern side of Varangerfjord the preglacial "Older Sandstone Series" of Precambrian age consists of six lithological members, which collectively represent transgressive-regressive cycles. Within each cycle shallow marine siltstones are overlain by coarser sediments of intertidal, estuarine and fluvial origin. Two distinct sedimentary sources are suggested by palaeocurrent and petrographic evidence. Influx from a westerly direction tended to dominate over a volumetrically less significant source of immature detritus from the east or southeast.

The "Older Sandstone Series" is overlain with slight angular unconformity by the glacially dominated sediments of the lower part of the Vestertana Group. The two tillite formations consist of both continental and marine glacial deposits, with marine influence increasing northward. The interglacial Nyborg Formation consists largely of turbidite sandstones, with a transgressive sequence at the base and a regressive sequence at the top. All of the sediments of the glacially dominated regime appear to have been derived from the south.

Postglacial sediments of late Precambrian to Tremadocian age comprise all but the lowermost part of the Vestertana Group, together with the overlying Digermul Group. The succession is most fully developed in the Tanafjord area, and thins westward. The sediments reflect a predominance of shallow water deposition, with occasional deepening of the basin to permit the influx of turbidite sands which are interbedded with quiet water mudstones. The major source of the postglacial sediments appears to have been to the northeast, but the precise nature of this source remains problematical.

Introduction

In eastern Finnmark a belt of late Precambrian and Cambro-Ordovician sediments extends 200 km from east to west, with a maximum north — south width of approximately 50 km. The succession lies unconformably upon Precambrian crystalline basement, which crops out to the south. The maximum thickness is between 4,000 and 5,000 m., with shallow water sandstones and shales predominating. Dolomites are extremely rare, conglomerates are restricted to certain thin horizons, and there are no volcanics. Two distinct tillite formations occur, beneath each of which there is an unconformity shown only by local downcutting and slight regional discordance. Otherwise the succession is conformable, deposition having occurred in a gently subsiding basin.

Structural deformation is very slight where the sediments closely overlie the basement, but over much of the area the rocks are strongly folded and thrust. In the western part two distinct units are present, the Gaissa Nappe consisting of Precambrian sandstones and, underlying this, the autochthonous Dividal Group (previously the "Hyolithus Zone") of late Precambrian and Lower Cambrian age. A few small basic igneous dykes cut the sediments on the Digermul Peninsula and in the south-eastern part of the Varanger Peninsula.

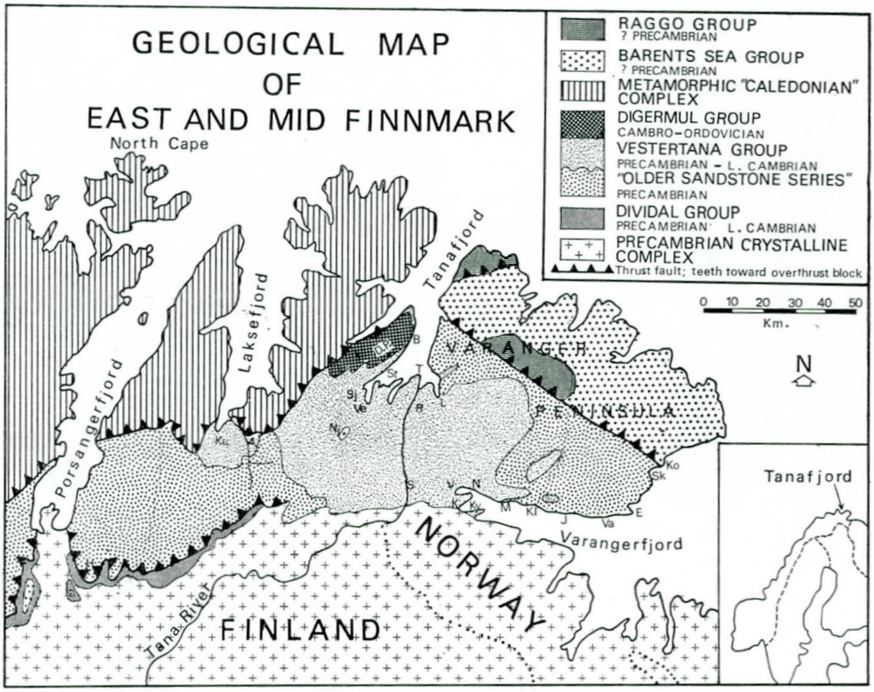


Fig. 1. Geological Map of East and Mid Finnmark. (Largely after Holtedahl, 1918, Holtedahl and Dons, 1960, Føyn, 1937, 1967, Siedlecka and Siedlecki, 1967). Localities: A — Adamsfoss, B — Breivik, D.P. — Digermul Peninsula, E — Ekkerøy, H — Halkkavarre, J — Jakobselv, — Karlbotn, Kl — Klubnes, Ko — Komagelv, Ku — Kunes, Kv — Kvalnes, L — Leirpollen, M — Mortensnes, N — Nyborg, Nj — Njuckagaissa, R — Rustefjelbma, S — Skipagurra, Sj — Sjursjok, Sk — Skallneset, St — Stappogiedde, T — Tananes, V — Varangerbotn, Va — Vadsø, Ve — Vestertana.

The sedimentary succession is bounded to the northwest by the overthrust "Caledonian" metamorphic belt. This metamorphic belt is made up of a number of thrust sheets, the lowermost and least metamorphosed of which is the Laksefjord Nappe (Føyn, 1969), which extends from Laksefjord to the northwest side of Tanafjord. Above this nappe is the Kalak Nappe (Føyn, 1960), or Kolvik Nappe (Gayer *et al.*, 1970), a more highly metamorphosed succession, which comes into thrust contact with the sedimentary succession west of Laksefjord.

The northeastern margin of the sedimentary belt is a fault line, the Trollfjord — Komagelv Fault, beyond which are lightly metamorphosed sediments of probable Precambrian age. These rocks have been divided into two groups (Siedlecka and Siedlecki, 1967), the Barents Sea Group and the Raggo Group, the latter apparently having been thrust upon the former.

The sedimentary succession can be divided into three parts:

3. Digermul Group, c. 1,500 m. — sandstones and shales containing Cambrian and Ordovician fossils.
2. Vestertana Group, c. 1,550 m. — sandstones and shales containing two tillite formations near the base, with Cambrian fossils in the uppermost part.
1. "Older Sandstone Series", c. 1,300 m. — sandstones and shales with dolomites in the upper part.

The "Older Sandstone Series" (Føyn, 1937), previously termed "Older Dolomite-bearing Sandstone Division" (Holtedahl, 1918), has recently had the name Tana Subgroup proposed for it by Bjørlykke, Englund and Kirkhusmo (1967). There is little indication of the geological age of these sediments except that they are younger than the metamorphism of the underlying basement and earlier than deposition of the first tillite. The youngest radiometrically determined age for the basement rocks is 1650 m.y. (Kratz *et al.* 1968).

Above the "Older Sandstone Series" the "Younger Tillite-bearing Sandstone Division" of Holtedahl (1918) is now known to continue upward into the Cambro-Ordovician (Føyn, 1937, Reading, 1965), and has been divided into two groups by Reading (1965). The lower one, the Vestertana Group, includes the Smalfjord Tillite, Nyborg, Upper Tillite, Stappogiedde and Brevik Formations. The recent finds of *Platysolenites antiquissimus* Eichwald at Kunes (Føyn, 1967, Hamar, 1967) and on the Digermul Peninsula (Banks, 1970) have lowered the position of the base of the Cambrian so that it is now taken to be near the base of the Breivik Formation.

The upper group of Reading, the Digermul Group, is exposed only on the Digermul Peninsula. The age is well defined by fossils, especially trilobites and brachiopods (Reading, 1965), as ranging from the Lower Cambrian through the Middle and Upper Cambrian into the Tremadocian (Table 1).

Table 1. Generalized Stratigraphical section for the Tanafjord area.

GROUP	FORMATION	MEMBER	THICKNESS (average)	AGE
Digermul	Berlogaissa		300 m	Tremadocian
	Kistedal		720 m	M. Cambrian—Tremadocian
	Duolbasgaissa	Upper	300 m	L. Cambrian
		Lower	210 m	
Vestertana	Breivik	Upper	350 m	L. Cambrian
		Lower	250 m	
	Stappogiedde	Manndraperelv	190 m	Precambrian
		Innerelv	275 m	
		Lillevatn	80 m	
	Upper Tillite		10—60 m	
	.....	unconformity	.....	
	Nyborg		200—400 m	
	Smalfjord Tillite		2—50 m	
..... regional unconformity of 1—2 degrees				
"Older Sandstone Series"			1300 m	
Precambrian Crystalline Basement				

The Dividal Group (Hyolithus Zone) which crops out in the far western part of the area is laterally equivalent to the upper part of the Vestertana Group.

The use of chronostratigraphical terms such as Eocambrian and Varangian has been avoided in this paper because of the general misunderstanding which has developed since their introduction.

Hobday, Geddes and Reading have worked on the "Older Sandstone Series", Edwards studied the glacial and associated sediments and Banks has been concerned with the post-tillite succession. Reading has directed and co-ordinated the research programme.

Preglacial Regime: "Older Sandstone Series"

1. Regional Aspects

The "Older Sandstone Series" crops out in four main areas, around the head of Porsangerfjord, south of the head of Laksefjord, on the south and east sides of Tanafjord and on the north side of Varangerfjord. In the three eastern areas the stratigraphical position of the "Older Sandstone Series" below the tillites proves a Precambrian age. However in the Porsangerfjord district there is no stratigraphical evidence for age and a Precambrian age is inferred from the lack of fossils. As yet, no firm correlation can be established between the four areas, although it should be possible shortly to correlate lithostratigraphical units in Tanafjord with those on Varangerfjord and ultimately mapping of a large and at present unknown area may link up Porsangerfjord with Laksefjord. However, owing to a gap of some 50 kms. in exposure it is doubtful whether it will be possible to join up the Laksefjord area with Tanafjord.

The "Older Sandstone Series" of Porsangerfjord (Holtedahl, 1918, 1931, White, 1968 a, b, 1969, Roberts, 1970 a, b) is made up of two units. The Gaissa Sandstone Formation (= Porsanger Sandstone of White, 1968 a) is 500-600 m. thick and consists of sandstones and siltstones. The Børselv Sub-Group is 500-520 m. thick and contains a lower sandstone and shale division, the Stabbursnes Formation, overlain by the Porsanger Dolomite Formation. It is probable that the Børselv Sub-Group overlies the Gaissa Sandstone Formation but there is no direct contact between the two units. The stratigraphy and sedimentology of the Porsangerfjord "Older Sandstone Series" are discussed by Roberts (1970 a, b) who showed that the sandstones were deposited in shallow water, either in rivers or in shallow seas, with the dolomite suggesting the establishment of an inter-tidal and supratidal area (White, 1969).

South of the head of Laksefjord little is known about the "Older Sandstone Series" succession except (Føyn, 1967) that a shale and dolomite unit immediately underlies the Lower Tillite Formation and itself overlies undivided quartzites and shales.

The Tanafjord "Older Sandstone Series" is the thickest and most completely exposed. Føyn (1937) divided a 1,200 m. succession of quartzitic sandstones and shales, capped by a dolomite, into several informal units. Siedlecka and Siedlecki (1970) have traced Føyn's units inland into the Varanger Peninsula and formally divided the succession into a number of lithostratigraphical units.

In the Varangerfjord area the "Older Sandstone Series" crops out along the northern shore in low, easily accessible cliffs. The strata are structurally undisturbed and on account of a strike section exposure, lithostratigraphical units can be traced for tens of kilometres. The area was partly mapped and the rocks described by Holtedahl (1918), and Bjørlykke (1967) has made some sedimentological observations on the rocks of this area.

2. The "Older Sandstone Series" of Varangerfjord

Recent work has shown that the succession is about 500 m. thick and can be divided into six informal mapping units.

(i) *Lower Siltstone member*

Exposures of the Lower Siltstone member are restricted to two localities, Mortensnes and Klubnes, where 20 m. of grey siltstone with intercalated micaceous sandstones are visible above the level of Varangerfjord. In the lower half of the member laminated siltstones are dominant, but occasional deep scours and sandstones suggest temporary disturbance by waves. "Ball and pillow" structures are also present. The upper half of the member becomes coarser upward both by an increase in grain size and by the progressive intercalation of lenticular sandstones. Rippled sandstones are followed upward by cross-bedded sandstones, suggesting increasing current activity concomitant with shallowing. Thus the member shows a transition from what was probably an offshore or distal marine environment to one much nearer the coastline.

(ii) *Lower Sandstone member*

The Lower Sandstone member attains a maximum thickness of 125 m. at Mortensnes and thins eastwards to about 100 m. at Klubnes, beyond which it crops out discontinuously as far as Vadsø, where the exposed thickness is 35 m.

The boundary with the underlying Lower Siltstone is transitional. The lower part consists predominantly of fine to medium grained, well sorted quartzose sandstone, which is cross-bedded to a scale of 20 - 50 cms. The foresets are concave upward, asymptotically based, and inclined at a low angle seldom exceeding 15 degrees. Interlayered with the cross-bedded sandstones are sets of subhorizontally laminated sandstones which are even more quartzose than the cross-bedded variety. These laminated beds are well exposed in the lowermost 30 m. of the Lower Sandstone member at

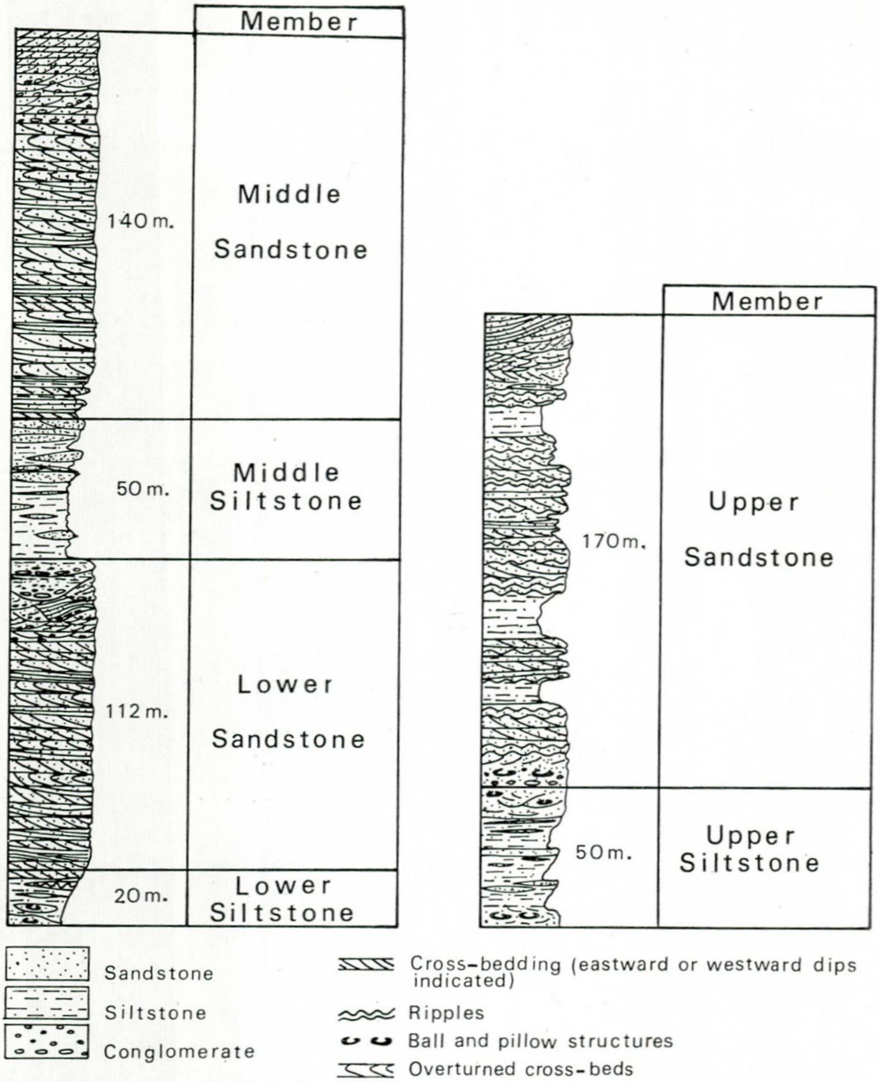


Fig. 2. Stratigraphical section of the "Older Sandstone Series" of Varangerfjord.

Mortensnes and Klubnes, and on Vadsø Island. The base of each set tends to be disconformable at a low angle. Primary current lineation is ubiquitous on the upper surfaces, with an east-west trend predominating. The geometric attributes of these sandstones, the rarity of unstable mineral constituents and the nature of the underlying siltstones together suggest an environment of deposition close to the shoreline. The cross-bedded sandstones are thought to have accumulated in a lower foreshore environment. The laminated sandstones were probably formed by swash-backwash action on the upper part of a beach or as emerging sand bodies within an estuarine, tidal environment.

Overlying the small scale cross-bedded and subhorizontally laminated sandstones are larger scale cross-bedded medium to coarse sandstones. These are present through a thickness of 65 m. at Mortensnes, 45 m. at Klubnes, and about 20 m. on Vadsø Island. The sandstones are fairly quartzose in the lower portions, becoming progressively more feldspathic upward. The individual cross-bedded sets attain a maximum thickness of over a metre, and are lenticular in cross-section. The dips of the foresets are steep, sometimes exceeding 20 degrees. Deformation of the foresets is common and ranges from slight displacement, to recumbent overturning. These overturned crossbeds probably indicate high current velocities, with the drag of a mass of sand being pushed along the sediment-water interface causing the deformation (Rust, 1968). The direction of foreset dip is predominantly toward the east.

Interlayered with the cross-bedded sandstones are horizontally bedded micaceous and feldspathic sandstones. Less frequently encountered are concave-convex cross-beds with foresets which are convex upward. These may have been formed by the rounding of the slip faces of large ripples by tidal changes in flow pattern (Klein, in press), or they may reflect the modification of a bed form during a period of rapidly falling water level (Collinson, personal communication).

The increasing abundance of unstable constituents in the upper parts of these large scale cross-bedded sandstones, their relatively poor sorting, the nature of the sedimentary structures and the position of these beds relative to the underlying shoreline facies and overlying fluviatile facies, suggest the possibility of an estuarine environment of deposition.

Above the large scale cross-bedded sandstones are interlocking lenticular sandstone units with channelled bases. Both mica and feldspar are abundant. Cross-bedding directions are consistent with those in the underlying sandstones, reflecting eastwards moving currents. The environment of deposition appears to have been one of small fluvial channels.

About 35 m. from the top of the Lower Sandstone member are broad shallow channels filled with conglomeratic sandstone of distinctive lithology. Spherical and tubular clasts with a concentric structure are set in a matrix of poorly sorted feldspathic and micaceous sandstones. The size of the pebbles is highly variable, attaining a maximum length of over 20 cms. At the base of each channel there is a poorly sorted conglomerate containing large angular blocks of red siltstones. Above this comes a massive conglomeratic sandstone, with pebbles decreasing upward in size and abundance, and passing into medium-grained sandstone. Infrequently preserved at the top of these sequences is red siltstone, identical in appearance to the large blocks in the basal conglomerate.

These fining-upward units are attributed to deposition by somewhat larger migrating channels than accounted for the underlying smaller scale units. Undercutting of the channel walls possibly caused bank collapse, with the incorporation of large siltstone blocks into the basal portions of the channel fill. The conglomeratic sandstone and massive feldspathic sandstone with a capping of red siltstone reflects progressively less active channel flow with ultimate abandonment and a switch to overbank deposition. Imbrication in the basal conglomerates, cross-lamination in the siltstones and occasional sole marks indicate that currents flowed towards the west.

(iii) *Middle Siltstone member*

The best exposures of the Middle Siltstone member are at Mortensnes and west of Vadsø, with discontinuous exposures between these two localities. The average thickness is 50 m., but the lower contact is everywhere concealed, and there is an upward transition into the Middle Sandstone member.

The bulk of the sequence consists of laminated siltstones which are grey in the lower half and red or green towards the top where thin interbedded sandstones become more abundant. Occasional lenticular bodies up to four m. thick of low rank graywacke sandstone are present throughout the sequence at Per Larsavik and near the top of the member at Klubnes. These sandstones are sharp based and incorporate deformed siltstone clasts in their lower parts. Sole markings include groove casts and poorly developed flutes, indicating an east to west current direction.

The thinner beds are frequently graded, with fine-grained sandstone at the base and laminated siltstone at the top, suggesting the occasional influx of poorly sorted sediment in suspension. The thicker lenticular bodies are suggestive of rapid sedimentation, with insufficient time for the processes of sedimentary differentiation to take effect.

The occurrence, within a background of siltstone, of spasmodically deposited sandstones, together with the vertical position of the member within fluvial sandstones, indicates that the Middle Siltstone member may have been deposited in an interfluvial or interdistributary lake or bay environment. This is supported by the possibility that part of the member may be the lateral equivalent to the channel fill sandstones of the Lower Sandstone member. Progressive filling by overbank deposition, possibly augmented by reverse drift from the distributary mouths, was accelerated by occasional crevasse breaks through the levee, depositing the thicker sandstone units.

(iv) *Middle Sandstone member*

The Middle Sandstone member is exposed almost continuously between Mortensnes and Ekkerøy, but to the west of Jakobselv the unconformity at the base of the Smalfjord Tillite Formation cuts out progressively the higher parts of the succession.

Interbedded green siltstones and cross-bedded red sandstones at the base are overlain by medium-grained feldspathic sandstones. These beds are remarkably similar to the large scale cross-bedded sandstones of the Lower Sandstone member, even to the extent of the eastward dip and the abundant overturning of the foresets. There are also concentrically banded ferruginous concretions. Furthermore, interlayered with the cross-bedded sandstone are lenticular bodies of massive sandstone and fine-grained horizontally laminated sandstone.

In the uppermost 20-30 m. are cross-bedded sets up to 20 cms. thick of coarse feldspathic sandstone containing subangular quartz pebbles up to 3 cms. in diameter. Occasionally sandstones containing a high proportion of mafic constituents are encountered at this stratigraphical level. Cross-bedding inclinations in these upper units are predominantly westward.

The Middle Sandstone member shows a return to fluvial conditions and repeats the sequence of events in the Lower Sandstone member by displaying a change, towards the top, in compositional petrography and reversal of current direction.

(v) *Upper Siltstone member*

Good exposure of the Upper Siltstones are limited to an area around Ekkerøy and the upper Jakobselv valley. Coarse micaceous siltstones and thin lenticular sandstones tend to be grouped in coarsening upward sequences of variable thickness. The sandstone beds become thicker towards the top and have rippled upper surfaces with internal cross-lamination. Penecontemporaneous deformation structures in the lower parts of these units seem to indicate deposition on a relatively steeply sloping surface, whereas towards the top the presence of channels suggests that these may have contributed to the instability. Occasionally, lateral flowage of greater magnitude is indicated by sharp based, sole marked, graded sandstone beds which were possibly turbiditic in origin.

(vi) *Upper Sandstone member*

The Upper Sandstone member consist of alternations of sandstone and siltstone with some shale, and displays greater complexity than any of the lower members. Exposed at Ekkerøy and between Krampenes and Skalneset the basal portions of the Upper Sandstone consist of cross-bedded sandstones, sometimes conglomeratic, with thin siltstone partings. At a higher level there is a tendency for the sandstones between the major siltstone beds to be rippled in their lower parts with a predominance of cross-beds in the upper parts. This pattern possibly reflects shallowing conditions. Preserved bedforms of large scale linguoid ripples with heights of up to 60 cms. have superimposed upon them small asymmetrical ripples trending in a variety of directions, frequently at a marked angle to the larger scale features. This arrangement is strongly indicative of tidal influence (Klein, in press). Small delta shaped fans built in a reverse direction into the troughs in advance of the larger ripples, and the presence of mudcrack horizons further support this contention.

At the top of the sequence small lenticular sandstone beds cut by broad channels filled with quartzose sandstone and overlain by low angle laminated orthoquartzite are interpreted as being representative of a beach and nearshore environment, which appears to have prograded southwestward. An overlying sequence of quartzose sandstone fills broad channels which were conceivably tidal in origin. Thus, apart from the basal beds which may be fluvial, the sedimentary structures suggest a shallow marine environment for this member.

3. Palaeoenvironmental and Palaeogeographical Reconstruction — A Resumé

Two distinct sources of detrital influx are represented in the "Older Sandstone Series" of Varanger Peninsula. Sediments derived from the western or northwestern source are submature to mature in composition. Although coastal processes appear to have reduced the proportion of unstable constituents within the shoreline facies, the presence of moderately mature sediments in the fluvial facies suggests a fairly distant provenance, with selective destruction of the relatively unstable mineral species during transport.

In marked contrast, the sediments reflecting an easterly source are invariably immature in composition. Abundant mica, angular feldspar and labile mafic grains in sandstones containing pebbles which exhibit minimal evidence of abrasion all indicate both a nearby source and an absence of prolonged exposure to high energy processes.

Shallow water marine facies of the Lower Siltstone Member were progressively overridden eastward and southeastward by beach, estuarine (?) and fluviatile sediments of the Lower Sandstone member, filling the basin to a level which permitted the extension of fluvial facies from the east or southeast. A braided pattern was characteristic of the rivers in the east, but farther west as around Mortensnes they were in part of a meandering variety.

The lower portions of the Middle Siltstone appear to be interfluvial equivalents of these channel fill sandstones, reflecting progressive shallowing. A rise in base level which might have been caused by eustatic rise in sea level, tectonic downwarping of the basement, or subsidence due to compaction of the finer grained sediments, permitted the re-establishment of marginal estuarine conditions represented by the basal portions of the Middle Sandstone member. These are once more overlain by a regressive fluviatile sequence, with a sudden reversal of current direction near the top.

This succession is therefore remarkably similar to the Lower Sandstone, and suggest that a delicate balance existed between a greater but more distant source of sedimentation which dominated until the basin was filled, or almost filled, and a nearer but volumetrically less significant source to the east or southeast.

The Upper Siltstone was deposited in response to a renewed rise in sea level relative to the land, and is overlain by the Upper Sandstone member which was in part tidally influenced. The uppermost southwestward building shoreline facies suggests a further change in the size and configuration of the basin of deposition.

The Glacially Dominated Regime

1. Regional Considerations

This part of the succession crops out extensively south of Laksefjord, at the head and to the south of Tanafjord, and around the head of Varangerfjord. South of Porsangerfjord loose boulders of tillite may indicate its presence hidden beneath superficial deposits (Føyn, 1967). The upper part of the succession is exposed further west at Alta (Føyn, 1964).

Over most of eastern Finnmark the stratigraphy is relatively straightforward because the two tillites are easily identified by their stratigraphical position and their sedimentary features. However, along the southern margin of the sedimentary outcrop area and on the Varanger Peninsula, the stratigraphy becomes complicated as some formations thin, or die out altogether. The Nyborg Formation has been shown to rest directly on crystalline basement several km. east of Skipagurra (Holtedahl, 1918, p. 167), and a similar relationship was interpreted west of the Tana River (Føyn, 1937, p. 119). On the Varanger Peninsula, east of Leirpollen, all the formations of the glacially dominated regime thin and possibly disappear to the east (Beynon *et al.*, 1967, p. 11), and, on the north side of Varangerfjord, the Smalfjord Tillite and the Nyborg Formation thin and apparently are absent to the east.

The Lower Tillite has been renamed the Smalfjord Tillite (Bjørlykke, *et al.*, 1967, p. 14) because of the excellent exposures at Smalfjord in the Tana district. The Upper Tillite has been termed the Mortensnes Tillite (Bjørlykke *et al.*, 1967). However, this name is not used in this report because at Mortensnes, on the north coast of Varangerfjord, it is the Smalfjord Tillite which crops out prominently. Although present on the hillside, the section of the Upper Tillite is incomplete, with the base and top unexposed. Until a suitable name is decided, the authors have preferred to retain the name Upper Tillite Formation.

In the Stappogiedde Formation the Lillevatn Member is the name here given to the unit previously called the Dark-coloured Shale and Light-coloured Sandstone (Føyn, 1937) and the Quartzitic Sandstone Member (Reading, 1965). Excellent exposures occur around Lillevatn, a lake about 7 km. south of Vestertana.

2. The Smalfjord Tillite

Føyn (1937) described the tillite in the Tanafjord district and along the southern border of the sedimentary succession. His study also showed that the Smalfjord Tillite rests unconfomably on the "Older Sandstone Series" in East Finnmark. Reading and Walker (1966) interpreted selected outcrops on Tanafjord, and observed that at Trollfjord, where the northernmost exposures of glacial sediments occur, the Smalfjord Tillite is conformable with the underlying shales and dolomites, which make up the upper part of the "Older Sandstone Series". Bjørlykke (1967) outlined several aspects of the Smalfjord Tillite at the head of Varangerfjord.

In the Tanafjord district the Smalfjord Tillite is highly variable in thickness and in lithofacies. Føyn (1937) recorded thicknesses between 10 and 50 m, but mapping around Vestertana has shown it to decrease locally to about 2 m. In the Smalfjord area there are two tillite facies in vertical section, a lower yellow-brown one with a dolomitic matrix and a high proportion of dolomite clasts, and an upper greyish-green one with mostly crystalline clasts. Similar facies were also observed west of Njukcagaissa. Føyn (1937, p. 79) and Reading and Walker (1966) reported stratification of the scour-and-fill type in the dolomitic part. Locally the Smalfjord Tillite seems almost devoid of clasts, and west of Njukcagaissa a varve-like facies with outsize clasts is exposed. The greyish-green part of the tillite commonly shows parallel lamination with "dropped in" clasts, shown by deformed laminae, or is massive.

The presence of irregular sedimentary structures and the predominance of locally derived clasts such as dolomite in the lower part of the tillite suggests a continental rather than marine glacial origin. The upper, occasionally parallel-stratified facies, with a more homogeneous mixture of clasts is probably marine in origin.

Around Varangerfjord the Smalfjord Tillite succession is quite different from that in the Tanafjord district. At Mortensnes, on the north coast of Varangerfjord, the Smalfjord Tillite is recognized by its stratigraphical position between the "Older Sandstone Series" and the Nyborg Formation. Coarse, poorly-sorted, cross-bedded conglomerates (plates 2B and 3A) pass upwards into conglomeratic sandstones and tillites which are rich in dolomite pebbles. This contrasts sharply with the dominantly tillitic character of the Smalfjord Tillite in the Tanafjord district.

On the south side of Varangerfjord, outcrops characteristic of the Nyborg Formation and higher units have not been located, and therefore the stratigraphical position of the units is not certain. Resting unconformably on "Older Sandstone Series" and Precambrian crystalline basement is the Kvalnes Conglomerate (Bjørlykke, 1967), including lenses of tillite, the Bigganjargga tillite, at the base, Above, and locally resting on basement, is the Karlbotn Quartzite, which includes conglomeratic and tillitic horizons. At Bigganjargga a total of about 200 m. is exposed.

Similarities between the Mortensnes and Bigganjargga sections suggest that a correlation can be made between them (Bjørlykke, 1967), but this has not yet been definitely established. The Kvalnes Conglomerate exposed

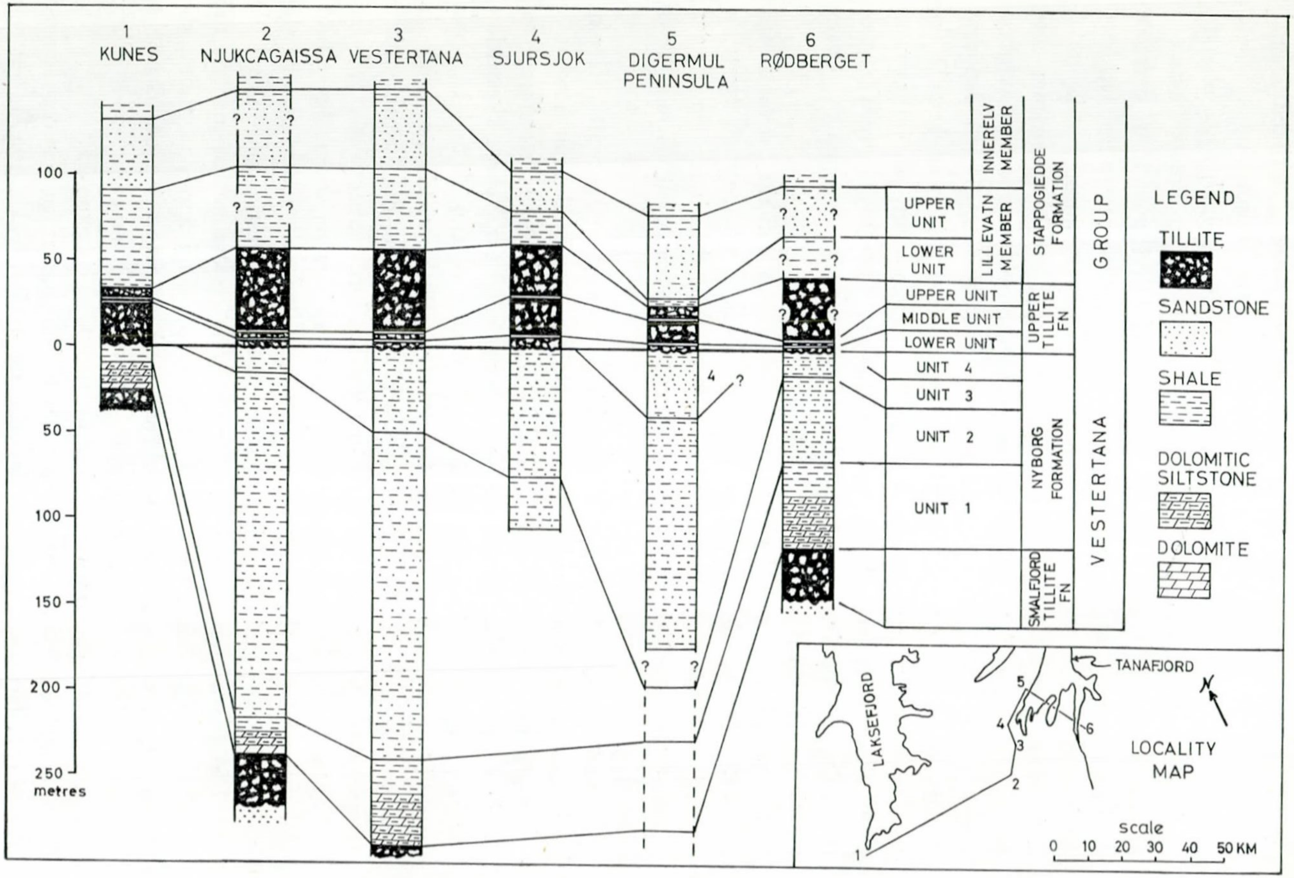


Fig. 3. Stratigraphy of the Glacially Dominated Regime in the Tanafjord and Kunes Areas.

south of Varangerfjord, or indeed the whole section, including the: Karlbotn Quartzite, may be a relic from a pre-Smalfjord Tillite glaciation, in which case the sub-Smalfjord Tillite unconformity may pass through the section at Bigganjargga or above the Karlbotn Quartzite. However, the continuous record of sedimentation present at Trollfjord, far to the north, suggests that only one glaciation took place between the "Older Sandstone Series" and the Nyborg Formation. It is therefore likely, though by no means proven, that the Bigganjargga tillite rests on the same unconformity as the Smalfjord Tillite elsewhere, and is the result of the same glacial episode.

The overlying Karlbotn Quartzite has not been observed in contact with the Nyborg Formation. It may be entirely the equivalent of the Smalfjord Tillite and hence represent an unusually thick section around the south of Varangerfjord, or it may be, at least partly, the lateral equivalent of the lower horizons of the Nyborg Formation which outcrops to the north and west.

3. The Nyborg Formation

The Nyborg Formation was named by Holtedahl (1960) to refer to those strata between the Smalfjord Tillite and the Upper Tillite. Føyn (1937) first described the lithology, and a detailed sedimentological investigation was carried out by Reading and Walker (1966). Bjørlykke (1967) briefly described the formation in the Varangerfjord region.

The lithology is varied and includes dolomite, interbedded sandstones and siltstones, and cross-bedded purple sandstones. The thickness is difficult to measure because the rocks are frequently deformed into tight, asymmetrical folds. A maximum thickness of 300 ± 100 m was estimated by Føyn (1937) in the Njukcagaissa area.

Reading and Walker (1966) showed that the upper junction is unconformable, with the uppermost beds being progressively eroded to the south. Beynon *et al.* (1967) suggested that the thinning of the Nyborg Formation to the east of the Tana River may be due to a sub-Upper Tillite unconformity.

Unit 1. Over most of East Finnmark there is a basal unit up to 30 m. thick, which consists of buff dolomite, or interlaminated buff dolomite and red siltstone. The dolomite content gradually decreases upward. This is the only dolomite unit present in the Vestertana Group and would seem to indicate a period of minimum supply of terrigenous sediment. It may have been due to a transgression caused by a eustatic rise in sea level as the ice sheets melted at the end of the Smalfjord Tillite glaciation.

Unit 2. This unit consists of up to about 200 m. of interbedded red and brown sandstones and siltstones. Many of the sandstones are sharp based and graded, and some have sole marks. These beds are interpreted as turbidites (Plate 3B). As pointed out by Føyn (1937) the maximum grain size in these sandstones decreases to the north. The presence of zones of gradationally based rippled sandstones suggests wave and current activity, implying that deposition did not occur in very deep water. Garnet is a notable constituent of some sandstones and this suggests a source in the garnet granulites in the crystalline basement to the south. Perthite and magnetite are present in small quantities.

Unit 3. This unit is similar to unit 2 except that the colour is grey-green, and no coarse sandstones are present. The more abundant sole marks imply consistent current directions to the north (Fig. 4). Towards the top ripple-marks and non-graded sandstones become abundant, indicating the increasing importance of wave and current agitation.

Unit 4. Lenticular and flaser bedded sandstones predominate at the base of this unit. Turbidites gradually disappear upwards. Ripples show bimodal current directions, the northern mode predominating over the southern one (Fig. 4). Abruptly overlying the rippled sandstones are 10 m. of herringbone cross-bedded purple sandstones, frequently deformed into

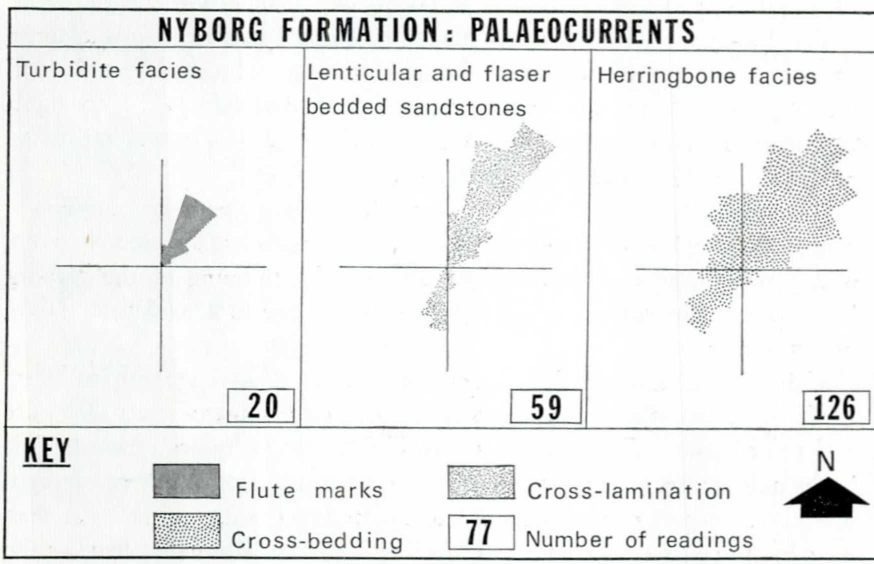


Fig. 4. Palaeocurrents in three facies of the Nyborg Formation.

"ball and pillow" structures. Mud flakes are occasionally found at the base of some cosets. The cross-bedding passes upwards into parallel lamination. These cross-bedded sandstones show a current distribution somewhat similar to the ripples in the sandstones below (Fig. 4).

The lenticular and flaserbedded sandstones at the base of this unit are interpreted as sub-tidal, and the herringbone cross-bedded sandstones are interpreted as deposits of laterally migrating tidal channels such as those described by Oomkens and Terwindt (1960). The overall change to a shallow water environment may have been associated with the eustatic fall in sea level which occurred with the onset of glacial conditions, associated with the Upper Tillite.

4. The Upper Tillite

This formation was first described in detail by Føyn (1937), and a more elaborate interpretation was given by Reading and Walker (1966). As Føyn (1937) pointed out the Upper Tillite is more uniform laterally than the Smalfjord Tillite. As a lithofacies, tillite makes up a much larger part of the Upper Tillite Formation. In the Tanafjord district three types of tillite are recognized in vertical section. The lower facies has been traced to the Varangerfjor area, and all three facies have tentatively been traced to Kunes in the west.

Lower Unit

The distinguishing characteristics of the lower unit are the abundance, compared to the other facies, of shale clasts, and the almost complete absence of sedimentary structures, except for rare, isolated lenticular bodies of sandstone. The colour of the lower unit is similar to that of the underlying sediments. In the Varangerfjord area several striated pebbles were found (Plate 4B). Crystalline boulders up to 1.5 m. long are observed on the north coast of Varangerfjord, while sedimentary clasts up to 40 m. long are present in the exposures on the Digermul Peninsula. In outcrops which are practically untectonized, the sedimentary clasts are frequently folded and broken.

Its sedimentary characteristics, and the fact that the lower unit rests directly upon a regional unconformity, suggest that it was deposited as a ground moraine beneath a continental ice sheet.

Middle Unit

Noteworthy characteristics of this unit are its abundant sedimentary structures and its high proportion of sand and dolomite. South of Sjursjok (Fig. 3), this unit is thin, generally from 2 to 6 m. thick. North of Sjursjok it thickens rapidly to about 25 m. The sedimentary structures include parallel laminations deformed by outsize clasts, cross-stratification, contemporaneously folded and faulted lamination (Plate 4A), and sandstone filled channels. The change from shale fragments in the lower unit to dolomite fragments and sand in the middle unit seems to reflect a change in the source rock of the ice sheet. This could have been accomplished by exposing the Porsanger Dolomite and Sandstone to glacial erosion, after removal of the overlying sediments. The sedimentary structures indicate the presence of current activity, probably as sub-glacial meltwater.

Upper Unit

The upper unit is massive in the Tanafjord district, but at Kunes in the west it is laminated. Above the lowermost few metres the clasts become progressively less abundant and the rock becomes a parallel-laminated siltstone. The continuity with normal marine sediments suggests that the upper unit is marine in origin and probably formed largely by rafting from floating ice.

5. The Lillevatn Member

The Lillevatn Member is readily divisible into two units, the lower unit consisting largely of laminated siltstones and fine-grained sandstones, the upper of interbedded sandstones and siltstones, and occasional conglomerates.

The lower unit of laminated siltstones and fine-grained sandstones varies in thickness from about 55 m. at Kunes to about 3 m. on the Digermul Peninsula. Where it is thick the unit displays a general increase in grain size upwards. The lower, laminated siltstones indicate deposition in relatively quiet water. The upper fine-grained sandstones are frequently rippled, suggesting an increase in current activity probably associated with shallowing.

The upper unit of the Lillevatn Member is about 40 m. thick over most of the Tanafjord district. The lower 20 to 30 m. consist mainly of three sandstone facies. At the base, several metres of medium-grained feldspathic sandstones are erosive into the lower unit of the Lillevatn Member. These are occasionally cross-bedded, but are most commonly weakly parallel-stratified. Several metres of siltstone tend to occur above the feldspathic sandstones. Eroded into these siltstones is the second major sandstone facies, several metres of coarse, poorly sorted sandstones. Towards the southern part of the area these sandstones become coarser and outcrops around Njukcagaissa contain fine-grained conglomerates. Polycrystalline grains containing quartz and feldspar are common. Internal scour and fill structures are the only sedimentary structures observed. Above the coarse sandstones are 10 to 20 m. of fine-grained, thin to medium-bedded sandstones and intercalated siltstone, which are frequently rippled and cross-bedded. These fine-grained sandstones pass gradually upwards into flaser and parallel-bedded sandy siltstones. These, in turn, are transitional into the red mudstones forming the base of the Innerelv Member of the Stappogiedde Formation. Cross-bedding directions in the sandstones of the upper unit of the Lillevatn Member indicate a slight predominance of north and northwestward flowing currents.

The upper unit of the Lillevatn Member is interpreted as having been deposited in various sub-environments of a fluviatile regime. Consequently, the lower unit probably represents a change from offshore to nearshore sedimentation. The coarser sandstones of the upper unit are essentially channel-fill deposits, and the interbedded siltstones are overbank or interfluvial deposits. The siltstones above the unit of fine sandstones are nearshore marine in origin. The northward decrease in grain size suggests a southerly source for the sediment, a was pointed out by Føyn (1937), and this is supported by palaeocurrent directions which show a slight preferred orientation to the north.

6. Summary

The Smalfjord Tillite appears to have been derived from the south where erosion was greatest, and where continental as opposed to marine glacial sediments were deposited.

The interglacial Nyborg Formation begins with a dolomite that suggests a hiatus in terrigenous sediment supply, probably due to a eustatic rise in sea level as glacial ice melted. It quickly gave way to turbidite sedimentation in occasionally agitated water. This great influx of mineralogically immature sediment was probably caused by the isostatic rebound following the retreat of the ice. The upper part suggests a rapid shallowing into a tidal environment, perhaps due to the withdrawal of water into the ice sheets of the second glaciation.

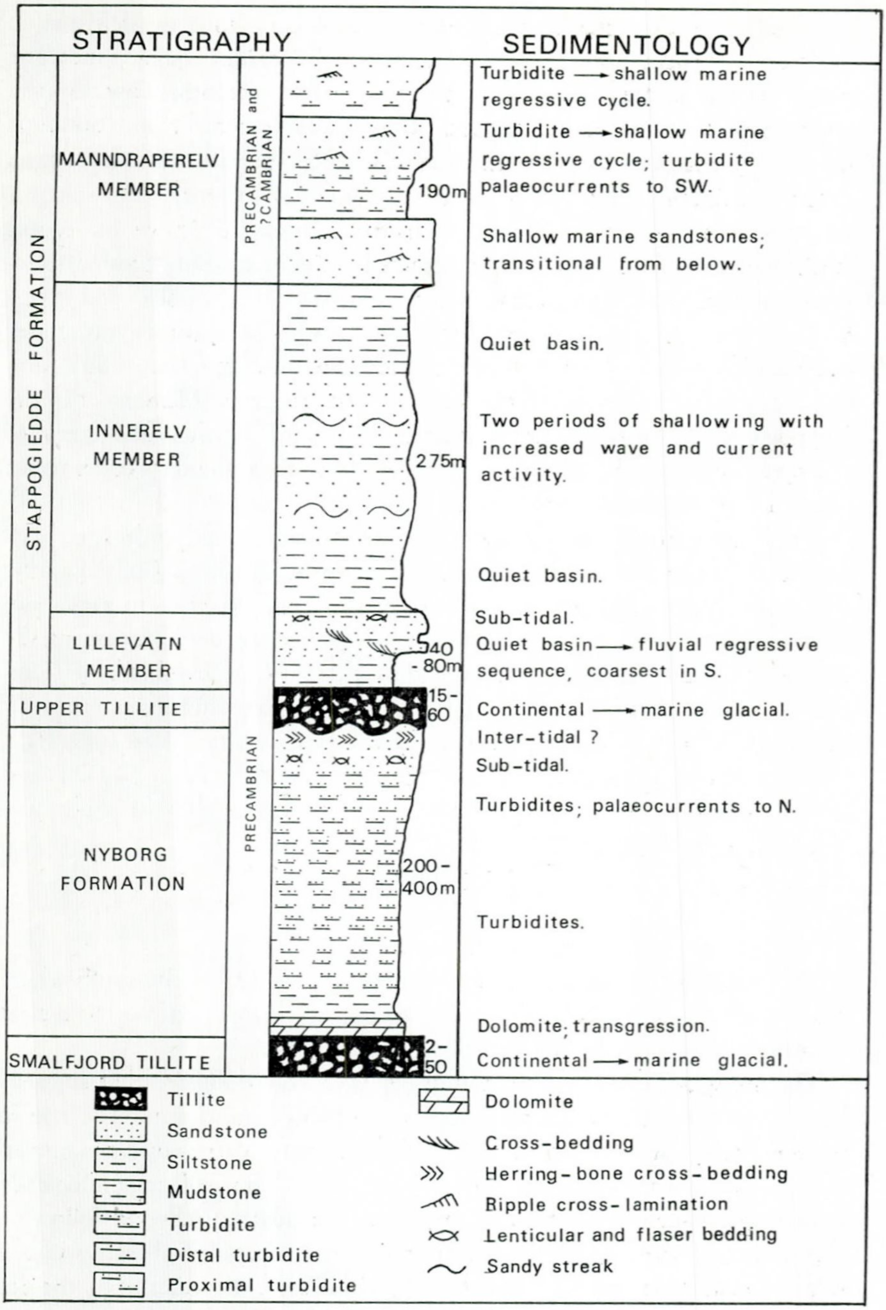
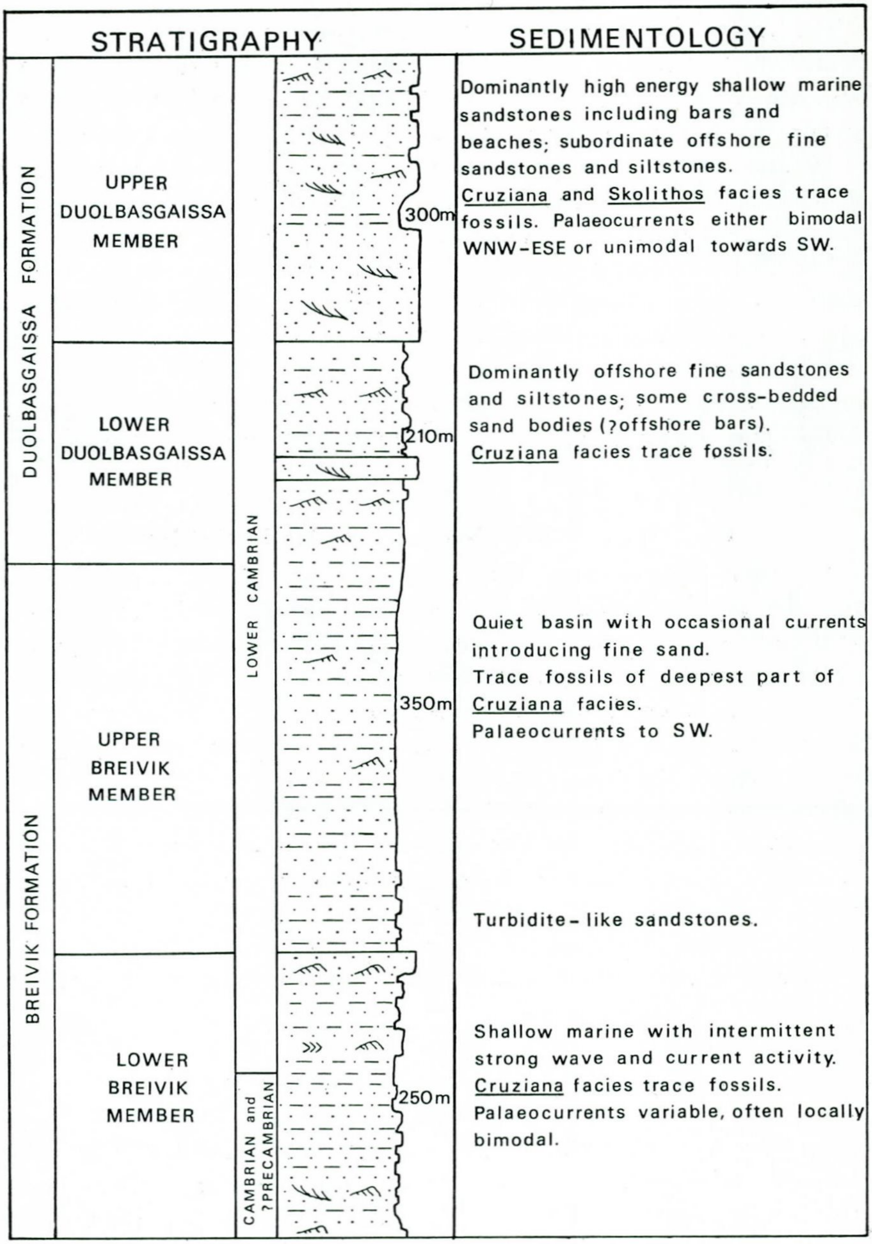


Fig. 5. Generalized Sedimentological Interpretation of the Vestertana Group and part of the Digermul Group in the Tanafjord Area.



Second part of Fig. 5. Generalized Sedimentological interpretation etc.

The Upper Tillite Formation lies with an erosional base on the Nyborg Formation. A lower unit with many locally derived shale clasts may have been deposited as a ground moraine. A middle unit is well stratified and contains much dolomite, presumably derived from the south or southwest as the ice sheet cut through the Nyborg Formation into the underlying dolomites of the "Older Sandstone Series". An upper unit is massive and was probably formed from floating ice.

The Lillevatn Member consists of a lower unit of siltstones probably laid down during a eustatic rise in sea level following the Upper Tillite glaciation. A subsequent post-glacial isostatic rebound once again brought into the basin immature sediment which was deposited, in this case, as fluviatile sandstones. At the top of the member the fluviatile facies gives way to quiet marine mudstones of the Innerelv Member.

THE POST-GLACIAL SHALLOW MARINE REGIME

This part of the succession, which is up to 2600 m. thick, ranges in age from the late Precambrian to Tremadocian. The full succession is only developed on the Digermul Peninsula and in most other areas the highest exposed horizon is the Lower Breivik Member of Lower Cambrian age. Thus the description of this part of the succession will be divided into two halves; 1) Innerelv Member — Lower Breivik Member, and 2) Upper Breivik Member and Digermul Group.

The formal names Innerelv Member and Manndraperelv Member are herein proposed for the Blue-green and Red-violet Slate member and Red Quartzitic Sandstone member of the Stappogiedde Formation which were defined by Reading (1965). The Innerelv is a stream which flows into Tanafjord 500 m. southwest of Stappogiedde on the east coast of the Digermul Peninsula. The Manndraperelv flows into Tanafjord 5.2 km. northeast of Stappogiedde.

1. Innerelv, Manndraperelv and Lower Breivik Members

The thickest development of this part of the succession is found on the Digermul Peninsula and in the Leirpollen area (Reading, 1965, Beynon *et al.* 1967) (Fig. 5, 6). Føyn (1960, 1967) noted that the sequence is considerably thinner to the west at Kunes. He also showed (Føyn, 1967) that the Kunes section can almost certainly be correlated with the Dividal Group ("Hyolithus Zone") at Halkkavarre, south of Porsangerfjord.

Members I, II, III and IV at Halkkavarre are homotaxial with the Lille vatn, Innerelv, Manndraperelv and Lower Breivik Members respectively. The correlation is further confirmed by the fact that the Innerelv Member at Kunes in now thought to be at least 70m . thick and not 25 m. as suggested by Føyn (1967). This makes the thicknesses of the Innerelv Member and Member II approximately equal.

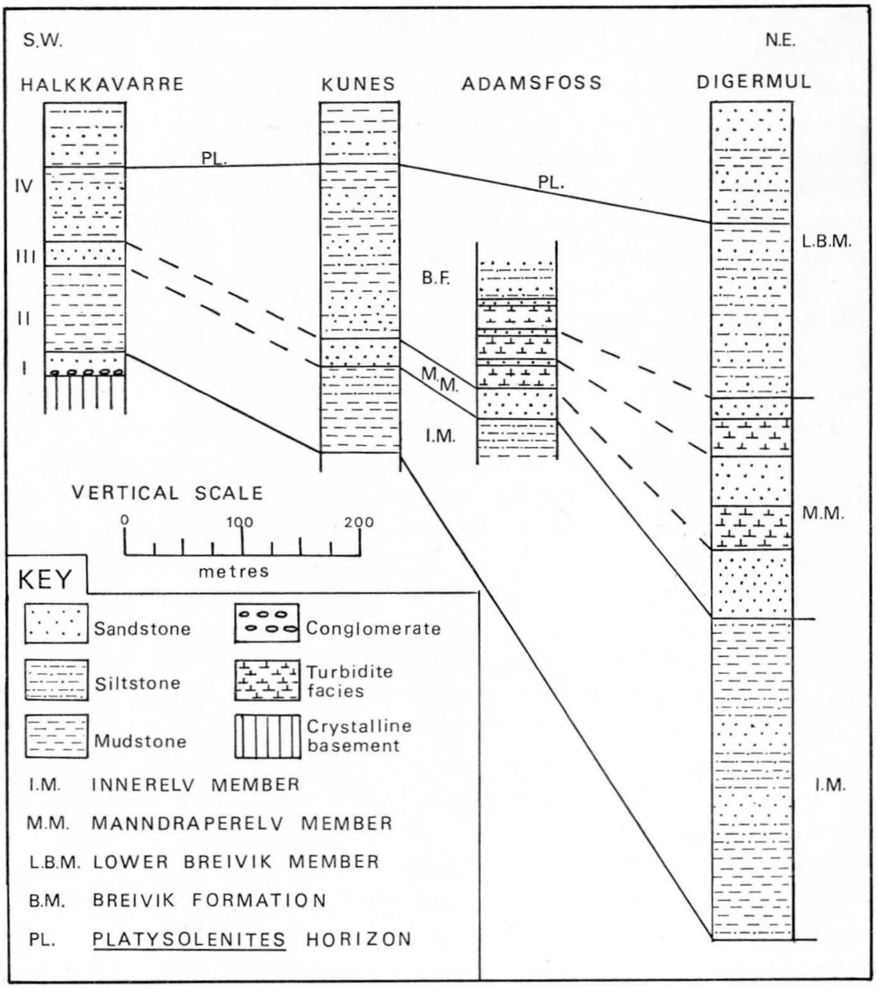


Fig. 6. Stratigraphical correlation-chart for the upper part of the Vestertana Group and the Dividal Group in East and Central Finnmark.

(i) *Innerelv Member*

After the fining upward, transgressive sequence at the top of the Lillevatn Member and the base of the Innerelv Member, deposition of finely laminated mudstones was ubiquitous for a time. On the Digermul Peninsula two coarsening upward sequences are found in this member. They consist of transitions from mudstones through thin-bedded siltstones and fine-grained sandstones into medium to thick-bedded lenticular channel sandstones. The lenticular sandstones often sit within large shallow scours which also contain irregularly bedded rippled siltstones and fine-grained sandstones resembling the silty and sandy streak facies of de Raaf *et al.* (1965) (plate 5A). The predominance of sharp-crested symmetrical ripples over asymmetrical ripples and the general irregularity of the bedding suggest that wave activity was an important factor in the deposition of the sandstone of this member. These coarsening upward sequences are interpreted as representing periods of shallowing of the sea. Quiet basinal mudstones occur at the top of the member.

At Kunes, faintly laminated mudstones become gradually coarser upward and pass into thin bedded siltstones with occasional ripples. In the top 5 m. there is a return to red and green mudstones similar to those found near the base. The general sequence seems to represent a gradual shallowing.

At Halkkavarre most of Member II consists of structureless green mudstone with very occasional thin siltstones. However in the uppermost 15 m. the sediments become silty and in the top 5 m. the bedding becomes highly irregular with sandstones, siltstones and, mudstones infilling large scoops or channels. Thus there is a single shallowing sequence at Halkkavarre which is similar to that at Kunes.

(ii) *Manndraperelv Member*

In the Digermul—Leirpollen area the Manndraperelv Member consists of a lower unit of red sandstones (60-100 m.) overlain by two regressive cycles (40-90 m.). The lower sandstone unit passes gradationally up from the mudstones of the Innerelv Member below. The lowest part of each of the cycles consists of green mudstones with interbedded, sharp based, graded, poorly sorted siltstones and sandstones. These siltstones and sandstones are interpreted as turbidites deposited in a distal environment relatively far from source. Higher up the cycles the turbidite sandstones increase in thickness and grain size and become highly lenticular, indicating deposition in a proximal environment. On the Digermul Peninsula palaeocurrent measurements from channel axes, flutes, grooves and cross-lamination show a consistent transport direction towards the southwest quadrant in both the proximal and distal turbidites (Fig. 7). However in the distal facies a few beds undoubtedly show northeasterly flowing currents. In the Leirpollen area Beynon *et al.* (1967) report northerly transport in the turbidite facies.

The proximal turbidite facies passes up into red and white, well sorted, fine-grained sandstones. These are thin-bedded with many silty partings near the base and become thicker bedded upward. Compositionally they are sub-arkoses and orthoquartzites (Pettijohn, 1957) with iron oxide and/or silica cement. Symmetrical and asymmetrical ripples are common but the bedding often has an irregular hummocky appearance. These sandstones and those of the lower red sandstone unit are interpreted as having been deposited in a sub-tidal shallow marine environment.

To the southwest, at a locality 3.5 km. southeast of Adamsfoss, the Manndraperelv Member as mapped by Føyn (1967) is only 25 m. thick. It consists of red, medium-bedded (10-50 cm.), well sorted, fine-grained sandstones which rest sharply upon mudstones and siltstones of the Innerelv Member.

In the Kunes area the Manndraperelv Member is represented by 25 m. of predominantly red sandstones similar to those found near Adamsfoss. Again these beds sit abruptly upon mudstones of the Innerelv Member. Few sedimentary structures are visible apart from ocassional small scale cross-lamination.

At Halkkavarre, 60 km. southwest of Kunes, member III consists of 20 m. of thin to medium-bedded (1-50 cm.) light grey sandstone. It rests with sharp planar contact on the lenticular siltstones and sandstones of member II. Small scale ripple cross-lamination is common and bedding surfaces show abundant asymmetrical and symmetrical ripples. As with the Manndraperelv Member at Kunes and Adamsfoss, Member III is a fairly homogeneous unit with little internal variation in grain size or bed thickness.

(iii) *Lower Breivik Member*

This member is known to be at least in part of Lower Cambrian age because it contains *Platysolenites antiquissimus* Eichwald. Føyn (1967) found specimens of *Platysolenites* in the Leirpollen area, at Kunes and in member IV at Halkkavarre. We have now found specimens of this fossil on the Digermul Peninsula about 150 m. above the base of the member, a horizon which fits with that of Føyn's specimens from Leirpollen.

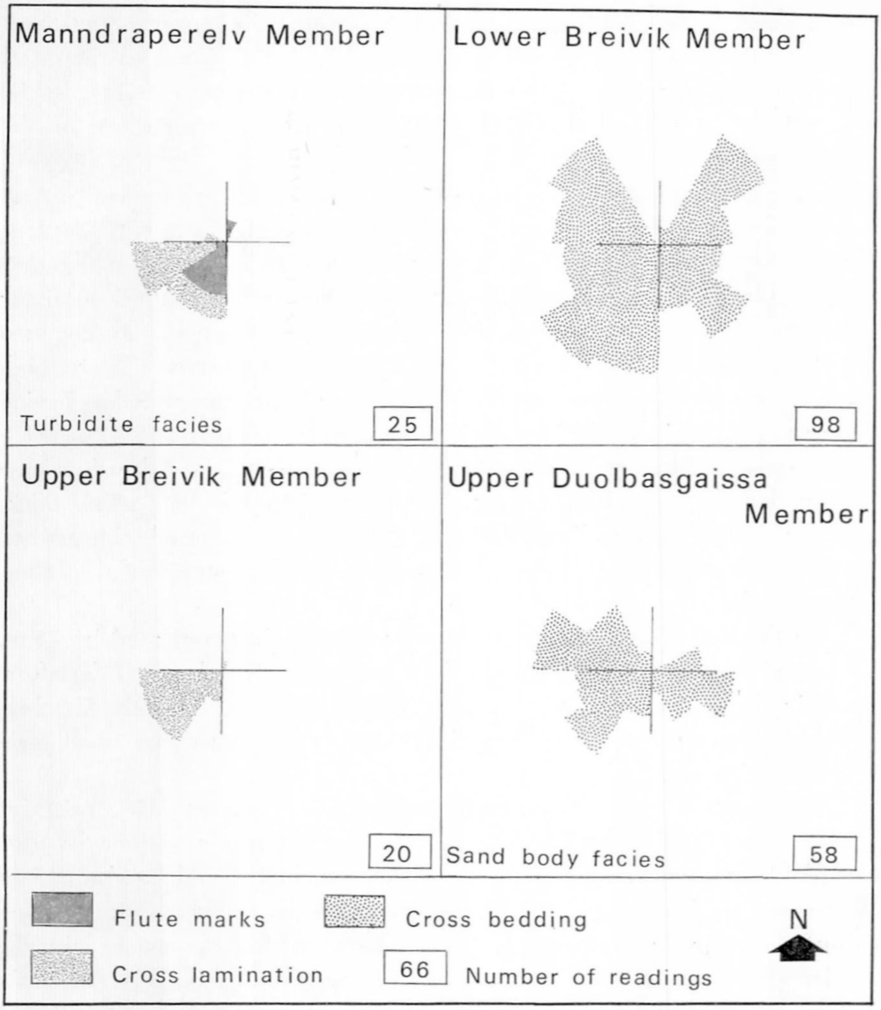


Fig. 7. Selected palaeocurrent measurements from the post-Tillite sediments of the Digermul Peninsula.

P. antiquissimus is well known in southern Scandinavia and the Baltic regions and its presence is thought to indicate a very low horizon in the Lower Cambrian (Hamar, 1967). Its presence in East Finnmark confirms the other palaeontological evidence (Reading, 1965) that this area was part of the Acado-Baltic faunal province in Cambrian times.

In this member trace fossils become common for the first time and several distinctive forms occur including *Phycodes pedum* Seilacher. The late Precambrian and Lower Cambrian trace fossils have been discussed by Banks (1970).

The greatest development of the Lower Breivik Member is found on the Digermul Peninsula where it is about 250 m. thick. In the Leirpollen area it is 230 m. (Beynon *et al.* 1967) although the top may be missing. At Kunes it is estimated to be about 200 m. At Halkkavarre member IV is 130 m. thick according to Føyn (1967) but our observations suggest that this figure should be reduced to 120 m. and all the beds above should be assigned to the overthrust Gaissa Sandstone Formation of Roberts (1970).

On the Digermul Peninsula the Lower Breivik Member consists of rapid alternations of mudstones, siltstones and sandstones. In general the sandstones are thin to medium-bedded (1-50 cm.) but occasional beds up to 1 m. also occur. Within the member small scale coarsening upward sequences (10-50 m.) can sometimes be recognized, particularly in the upper part. However in many places various sandstone types, siltstones and mudstones seems to be interbedded without any visible pattern to their distribution.

Most of the sandstones are rich in quartz and usually contain less than 10 % feldspar; lithic fragments are virtually absent. The percentage of matrix is highly variable. Some sandstones have a silica and/or siderite cement with very little matrix; others may have up to 30 % of micaceous matrix. Many of the sandstones have sharp bases and show evidence of waning current flow within a bed. This is shown by transitions from parallel lamination with primary current lineation at the base of a bed into trough cross-bedding or ripple cross-lamination above. Alternatively, cross-bedding at the base may pass up into ripple cross-lamination. The sandstones with high matrix content often show ripple-drift cross-lamination. Current directions as a whole are variable (Fig. 7) but at certain horizons cross-bedding directions show a consitent bimodal pattern with modes 180° apart and with 80 % of the readings contained in one mode.

The tops of many sandstone beds often appear to have been reworked and asymmetrical ripples have been modified to give a more symmetrical form. This suggests that deposition took place predominantly above wave base. At some horizons, particularly near the tops of coarsening upward sequences, lenticular and flaser bedding (Reineck, 1967) are found and are often associated with marked bioturbation.

The trace fossil assemblage (Banks, 1970) suggests that deposition took place in the *Cruziana* facies of Seilacher (1967).

The trace fossils and evidence of wave activity suggest that deposition did not take place in particularly deep water. The sedimentary structures in the sandstones suggest that periodically there were incursions of very fast sand laden currents into areas of dominantly fine-grained sedimentation. The relative importance of suspensive and tractional transport of sand appears to have been variable. The localized bimodality of current directions at certain horizons suggests that, at times, tidal currents may possibly have been an important agent in sediment movement.

In the Leirpollen area the sedimentary facies of the Lower Breivik Member seems to be similar to that found on the Digermul Peninsula (Beynon *et al.*, 1967).

At the locality near Adamsfoss the lower part of the Breivik Formation as mapped by Føyn (1967) consists of a series of small regressive cycles contain sharp based, graded sandstones and siltstones interbedded with mudstones. These sandstones and siltstones are interpreted as turbidites and they pass upward into white, well sorted, silica cemented sandstones of probable shallow marine origin. The number of cycles present has not been definitely established but there appear to be at least three. These cycles are similar in type to those of the Manndraperelv Member in the Digermul—Leirpollen area except that they are thinner and have no red beds. Above these cycles come interbedded sandstones, siltstones and mudstones somewhat similar to those of the Lower Breivik Member on the Digermul Peninsula although they have not been studied in detail.

In the Kunes area the Breivik Formation has undergone considerable structural disturbance and it is not possible to measure an accurate stratigraphical section through it. The transition from the Manndraperelv Member is laterally variable in aspect and is, as yet, poorly studied. In general the lower part of the Breivik Formation consists of thin bedded siltstones and sandstones with occasional units of thicker bedded, white, well sorted sandstones up to 5 m. thick. There is little evidence of turbidity current activity in these beds and they were probably mostly deposited by traction currents in an offshore shallow marine environment. These beds persists for perhaps 80 m. before passing up into alternating units of red, fine-grained sandstones (up to 15 m.) and green siltstones and mudstones (up to 50 m.). These lithologies continue for an unknown thickness but it is probably not greater than 120 m. In the green mudstones Føyn (1967) found specimens of *Platysolenites* at one locality. Bioturbation is not marked except in the highest parts of the formation.

At Halkkavarre member IV sharply overlies member III. The lowest

25 m. consists of massive mudstone with occasional interbedded sharp based sandstones. This passes up into alternating units of thin-bedded, rippled, micaceous sandstones, 5-15 m. thick, with green siltstones and mudstones. These persist for about 40 m. and near the top Føyn (1967) found specimens of *Platysolenites*. A short distance above this level comes a series of alternating cross-bedded sandstones, thin-bedded siltstones and sandstones with lenticular and flaser beddding, and red and green mudstones. These beds are extensively bioturbated at certain horizons. Much of the member was probably deposited in moderately shallow water except perhaps for those beds near the base.

(iv) *Discussion of Regional Facies Distribution*

The Innerelv Member represents conditions of rather uniform dominantly fine-grained sedimentation over the whole area. It is probable that the transgressive sequence at the top of the Lillevatn Member and the base of the Innerelv Member is related to the transgressive deposits at the base of the Dividal Group and that these reflect a period of major advance of the sea over the Precambrian shield area to the south. There is no evidence as to the source of sediment supply in the member.

The abrupt base of the Manndraperelv Member in the Kunes and Adamsfoss areas and of member III at Halkkavarre contrasts strongly with the gradual transition seen in the Digermul section. This abrupt facies change suggests that a period of erosion or non-deposition may have occurred prior to the deposition of the overlying sandstone in these areas. However, at present, there is no conclusive evidence to prove this hypothesis.

One problem which must be raised is the question of the lithostratigraphical correlation in the Manndraperelv Member and Lower Breivik Member between the Digermul Peninsula and the Kunes/Adamsfoss area (Fig. 6). At Adamsfoss and Kunes the Manndraperelv Member consists of a compact, 25 m., red sandstone unit. Føyn (1967) mapped the regressive cycles occurring above this sandstone as Breivik Formation because the colour of the sandstones in the upper parts of the cycles is white rather than red, the distinctive colour of the otherwise similar sandstones of the Manndraperelv Member in the Tanafjord area. However, on sedimentological grounds it is reasonable to correlate the lowest two regressive cycles of the Breivik Formation at Adamsfoss with the two cycles of the Manndraperelv Member in the Tanafjord region. Thus the single sandstone of the Manndraperelv Member at Adamsfoss and Kunes would then be equivalent to the lowest sandstone unit in the Tanafjord area. However it seems best to continue with Føyn's usage for mapping purposes and to limit the term Manndraperelv Member in the area south of Laksefjord to the distinct 25 m. unit of red sandstone which crops out there.

Thus, at this time, rapid deepening of the basin occurred in the Digermul—Leirpollen area followed by infilling by turbidity current deposits, probably from a number of different sources. Subsidence, was much less toward the west and at Kunes shallow marine conditions predominated for most of this period. The correlation of Member III at Halkkavarre with the Manndraperelv Member must be considered somewhat tentative because of the considerable distance between their outcrops. However the similarity of the successions at Kunes and Halkkavarre is striking and if the correlation is correct it suggests that a large area of uniform, relatively minor subsidence existed between Kunes and Halkkavarre.

No clear pattern of regional development can be seen in the sediments of the Lower Breivik Member apart from those discussed above. In general deposition in most areas took place in offshore environments, predominantly above wave base.

2. Upper Breivik Member and Digermul Group

(i) *Upper Breivik Member*

The Upper Breivik Member, which is about 350 m. thick, sharply overlies a 10 m. sandstone unit which occurs at the top of the Lower Breivik Member. The junction is extensively burrowed. The lower part of the member consists of medium to thick-bedded (10-150 cm.) fine sandstones interbedded with mudstones. The sandstones have sharp, often erosive, bases and occasionally show ripple-drift cross-lamination in their upper parts. These sandstones are interpreted as turbidites.

After about 80 m. these sandstones die out and remainder of the member consists of cleaved mudstones with interbedded thin (1-5 cm.) fine-grained sandstones and siltstones. These sandstones and siltstones are poorly sorted, sometimes graded, often have well developed sole marks (flutes, grooves) and show parallel and ripple cross-lamination. Palaeocurrent measurements show a very consistent pattern of flow towards the southwest (Fig. 7). Ripple morphology on the tops of beds is often modified to a rather symmetrical form suggesting that wave activity was present. Trace fossils, which include *Teichichnus* and *Phycodes palmatum* (see Banks, 1970), are fairly abundant but there is only minor disruption of the sedimentary structures. The trace fossil assemblage suggests that deposition occurred in the deeper parts of Seilacher's (1967) *Cruziana* facies.

(ii) *Duolbasgaissa Formation*

The Upper Breivik Member passes gradationally up into the Duolbasgaissa Formation, the lowest formation of the Digermul Group. The boundary is taken where large horizontal burrows appear abundantly (plate 3B, Banks, 1970). This horizon coincides with a slight reddening of the sediments and the incoming of thicker sandstones. The Lower Duolbasgaissa Member consists mainly of thin-bedded sandstones and siltstones but contains one major coarse-grained sandstone body up to 20 m. thick. The Upper Duolbasgaissa Member is characterized by the predominance of thick sandstone bodies with subordinate intercalations of the thin-bedded facies (plate 6B).

The thin-bedded facies of the lower member consists of fine-grained sandstones and siltstones (1-50 cm.) with interbedded mudstones (plate 6A). Symmetrical and interference ripples are very common and the trace fossils which include *Rusophycus*, *Cruziana*, *Plagiogmus* and *Diplichnites* clearly place these beds in the *Cruziana* facies. Occasional thicker beds of fine-grained sandstone occur up to 150 cm. These usually have irregular, strongly erosive bases, often with flutes, and are commonly deformed into "ball and pillow" structure. Internally they are predominantly parallel laminated and show well developed primary current lineation suggesting deposition in the upper flow regime. Current indicators suggest that flow was towards the south and southwest. There appears to be every gradation between these thick sandstones through medium-bedded sandstones into the thin, graded sandstones and siltstones of the Upper Breivik Member. The origin of the sandstones is not clear but a possible generating mechanism is the outwashing from tidal channels perhaps associated with violent storm activity. Extensive channels offshore from inlets developed through a barrier island system have been described from the present day Georgia coast by Hoyt and Henry 1965). Other possibilities include river generated turbidity currents (Heezen *et al.*, 1964) or rip currents. The thickest of these sandstones are found a short distance below the major sandstone body which marks the base of the Upper Duolbasgaissa Member.

The sandstone bodies in the Upper Duolbasgaissa Member consist of trough cross-bedded and flat-bedded fine to coarse-grained orthoquartzites or sub-arkoses. In certain cases they can be seen to form the upper parts of coarsening-upward sequences. They are interpreted as having been deposited in an active shallow marine environment, probably as a series of bars and beach/barrier island complexes. This is supported by the trace fossils which are representative of the *Skolithos* facies. The *Skolithos* facies was interpreted by Seilacher (1967) as indicative of high energy, shallow marine conditions. A notable feature of the sand bodies is that they tend to wedge out when traced soutwestwards and pass laterally into the thin to medium-bedded, fine-grained sandstones and siltstones. Unfortunately the beds cannot be traced at right angles to this direction so that their true geometry cannot be ascertained. Cross-bedding directions in the sand bodies are often bipolar towards the northwest and southeast but others have cross-beds dipping predominantly southwestwards (Fig. 7).

(iii) *Summary of Upper Breivik Member and Duolbasgaissa Formation*

The sedimentary history of the Upper Breivik Member and the Duolbasgaissa Formation may be considered as one of overall regression with minor transgressions and regressions superimposed upon it. Most of the Upper Breivik Member represents deposition in a "shelf" environment. The Lower Duolbasgaissa Member represents deposition in an environment which was transitional from the open "shelf" into a marginal, coastal environment and the Upper Duolbasgaissa Member represents a predominance of deposition in a nearshore situation. Current directions and lateral facies changes suggest a regional palaeoslope towards the southwest.

(iv) *Kistedal and Berlogaissa Formations*

The Kistedal and Berlogaissa Formations (Middle Cambrian to Tremadocian) crop out in the central parts of the Digermul Peninsula and are, in general, strongly structurally deformed. No study has been made of these rocks since the first full description of the succession by Reading (1965). The succession consists of alternating units of sandstone and shales and contains a rich fauna of tribolites and brachiopods as well as numerous trace fossils. The sediments are probably mostly of shallow marine origin but nothing is known of current directions or the directions of facies changes.

LATE PRECAMBRIAN AND CAMBRO-ORDOVICIAN PALAEOGEOGRAPHY

The construction of palaeogeographical maps from the deformed sedimentary sequences of East Finnmark is hindered by the lack of knowledge concerning the original site of deposition of the sediments relative to the present day location of sediment outcrop. Whereas the Dividal Group and the sediments cropping out along Varangerfjord are considered to be autochthonous, those which crop out in the Tanafjord—Laksefjord area may perhaps have moved a few tens of kilometres. The direction of movement was probably from the WNW. However, since the palaeogeography of the East Finnmark sediments will only be considered in very general terms such movements can be ignored for the purposes of this discussion.

Although the evidence from palaeocurrent measurements must be treated with caution it seems that fundamentally different sediment dispersal patterns occur in the Varangerfjord "Older Sandstone Series", the glacially dominated regime and the post-tillite sediments (particularly those of the Digermul Peninsula).

In the Varangerfjord "Older Sandstone Series" two mineralogically distinct sources are present, a mature west or northwesterly source and an immature source to the east or southeast. In the glacially dominated regime there is good evidence from several areas that the source was to the south, and proximity to the eastern margin to the basin is suggested by the cutting out of the Nyborg Formation and Smalfjord Tillite beneath the Upper Tillite on the Varanger Peninsula to the east. Above the Lillevatn Member the evidence from the Digermul Peninsula suggests that a land mass to the northeast then provided the major supply of detritus, at least until the end of Lower Cambrian times, after which nothing is known. The picture is complicated however by the occurrence of northward flowing turbidites in the Manndraperelv Member of the Leirpollen area. Little is known of the source area for the Vestertana Group sediments in the Laksefjord region or for the Dividal Group except that the latter may have been derived from the south.

The palaeocurrent data is supported by preliminary studies of the sandstone mineralogy. In particular, perthite, garnet and iron ore, which are common constituents of the sandstones of the Nyborg Formation, are absent in the sediments of the post-tillite regime on the Digermul Peninsula.

The nature of the north-easterly source, present in post-tillite times, is problematical. The derived sediments are quartz-rich, with feldspar (plagioclase $>$ K feldspar) rarely exceeding more than 10 % of the rock, even in the turbidites. Mica, hornblende and zircon all occur in small amounts. This mineralogy suggests a source area composed either of acid to intermediate igneous rocks or of clastic sediments of the appropriate composition.

The sedimentary succession is bounded to the northeast by the overthrust sediments of the Barents Sea Group and Raggo Group (Siedlecka and

Many others have helped in the field with the collection of information and discussion of ideas, especially Drs. M. G. Laird and J. D. Collinson, Messrs R. Gwynne, D. E. Large, C. Marmont, J. P. Platt, J. M. Moss, H. Rollinson, P. N. Taylor, R. M. Weinberg, and Misses M. J. Carpenter, P. V. Green and I. Sanzen-Baker.

Financial help has come from many sources, but the cost has been born mainly by grants from the Natural Environment Research Council and from Norges Geologiske Undersøkelse for which the authors are most grateful. The first author would also like to thank Shell International Petroleum Co. Ltd. for a maintenance grant during the period of this work.

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DISCUSSION

Professor J. G. C. Anderson said that, in his opinion, the rocks described by Dr. Reading formed one of the most important parts of the geological sequence — the boundary between the Precambrian and Cambrian systems. East Finnmark appeared to be an area where the beds spanning this time were best exposed. The base of the Cambrian had for many years been a centre of controversy and some people regard the glacial horizon as an attractive a base as any for the Cambrian.

Could Dr. Reading tell us something about the petrology of the clasts in the glaciogene? As regards the base of the glaciogene, apart from being a bit tougher, it looked to the speaker as being exactly like some of the sands and gravels that one could see in Aberdeenshire as a result of fluvio-glacial action from the recent ice age. Did Dr. Reading think that some of the beds, particularly in the lower horizon, were of fluvio-glacial origin?

Dr. Reading replied that he did not have time to deal with all the interpretations within the tillite but undoubtedly in the lower tillite there was a much stronger aspects of fluvio-glacial sedimentation — particulally at Mortensnes. There were presumably marginal deposits of the true tillite and were mapped as members of the Lower Tillite Formation. There was very little evidence of fluvio-glacial sedimentation in the Upper Tillite. With regard to the petrology of the clasts, there was a general tendency to pass from carbonate material in the lower part of the tillite to more crystalline material in the upper part. The lower tillite in general was more dolomitic than the upper, although in places the upper tillite was dolomitic. The extremely variable petrology indicated a number of sources.

Mr. J. D. Roberts asked if the clasts of dolomite were fewer in number as one moved towards Varangerfjord, as opposed to Laksefjord where there was an abundance of dolomite clasts, and secondly, was the dolomite sedimentation associated with the lower tillite a true dolomite sedimentation or simply a sludge left over after scouring on a dolomite surface.

Dr. Reading noted that there was certainly a vertical change in the proportion of dolomite clasts within the lower tillite. This necessitated a strong stratigraphic control in order to detect any lateral changes, and as yet the authors had no definite evidence of a lateral variation. In answer to the second point, there was a true carbonate sedimentation associated with the tillite.

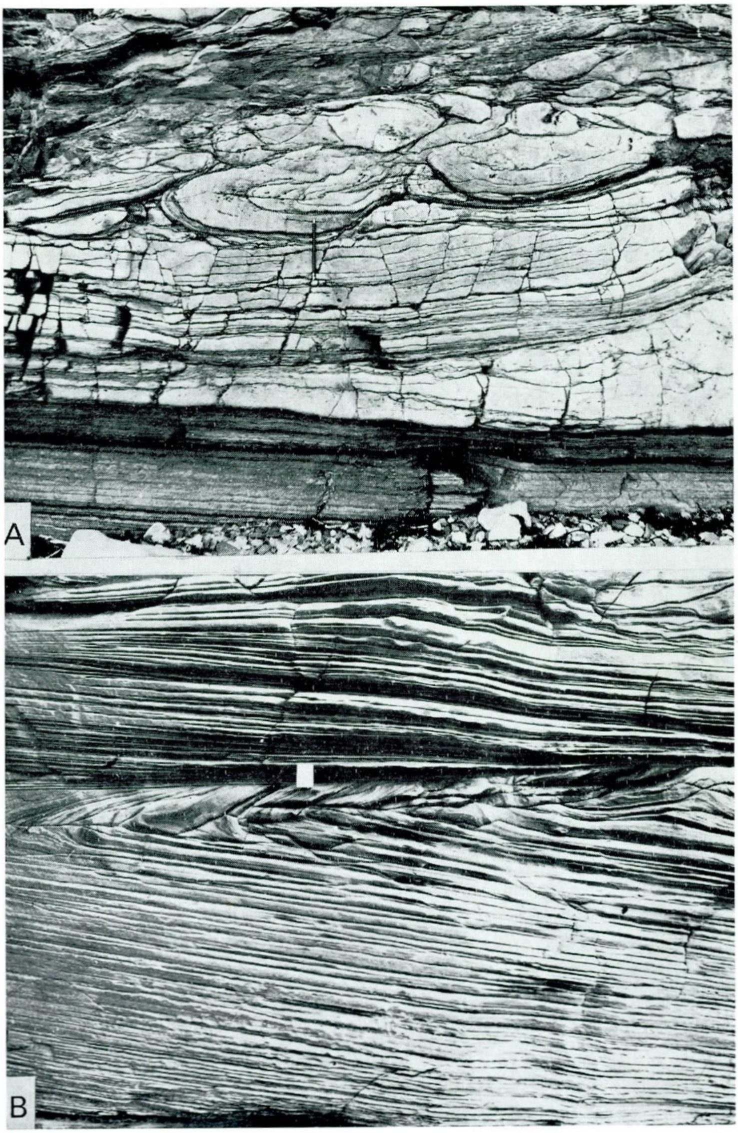

PLATE 1

1 A — A penecontemporaneously deformed bed of micaceous sandstone contained within horizontally laminated siltstones of the Lower Siltstone member, Mortensnes. Pencil is 19 cm. long.

1 B — Overturned foresets within normal cross-bedded sandstones in the central portions of the Lower Sandstone member, Mortensnes. Scale 5.5 cms. long.

PLATE 2

2 A — Multidirectionally orientated asymmetrical ripples in the Upper Sandstone member, SW of Skallneset. Hammer is 30 cm. long.

2 B — Coarse, poorly-sorted conglomerate (Kvalnes Conglomerate) of the Smalfjord Tillite resting unconformably on cross-bedded sandstones of the "Older Sandstone Series" at Mortensnes. Outcrop is about 2 m. high.

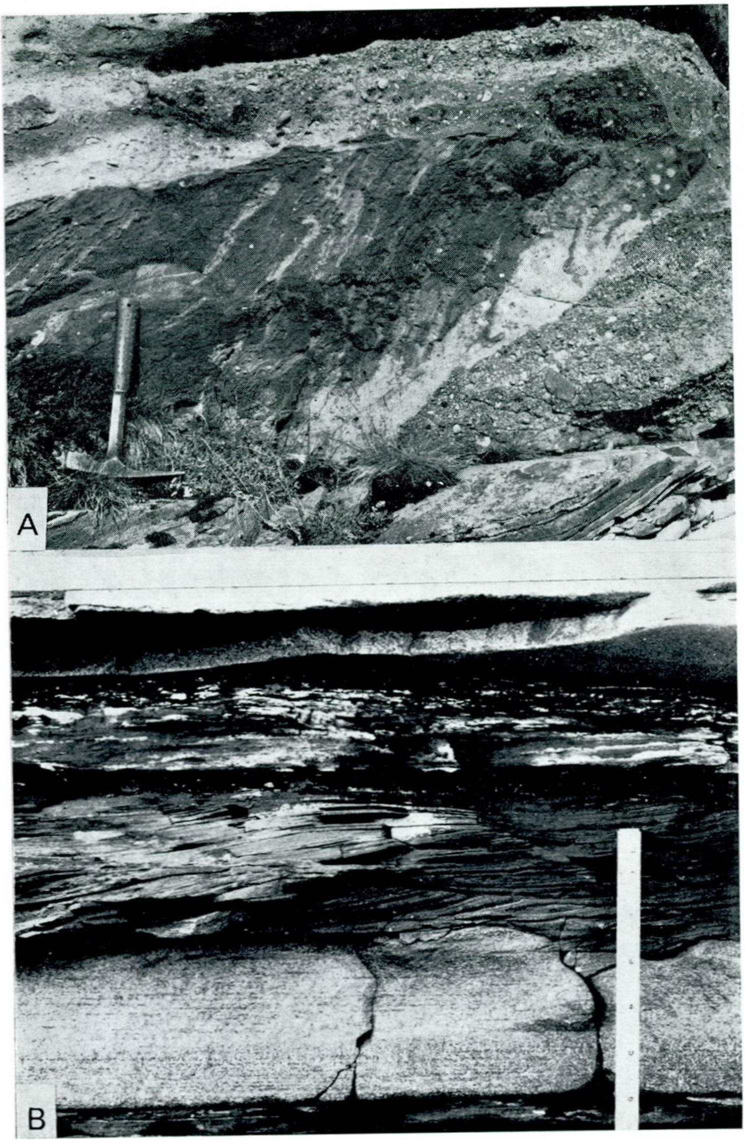

PLATE 3

3 A — Block of deformed sandstone at the base of the poorly sorted conglomerate (Kvalnes Conglomerate) of the Smalfjord Tillite, Mortensnes.

3 B — Graded sandstone turbidite bed in the Nyborg Formation (unit 2). Parallel-laminated sandstone at the base passes up into ripple-drift cross-laminated fine-grained sandstone, which grades up into parallel laminated siltstone. The sharp base of the overlying turbidite is seen at the top, Hammernes. Tape is 17 cm. long.

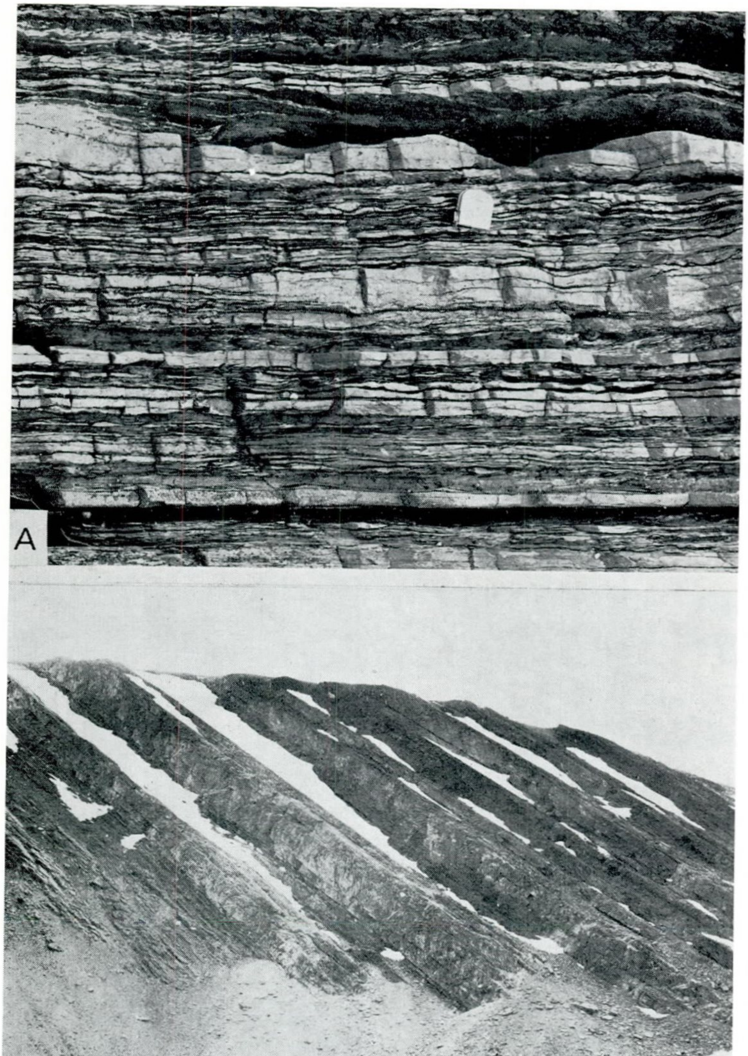

PLATE 6

6 A — Thin-bedded, fine grained sandstones and interbedded siltstone/mudstone. Note the lenticular nature of the bedding and the many laminae which are broken into flat, irregularly rippled lenses. Lower Duolbasgaissa Member, Digermul Peninsula. Tape measure is 5 cm. square.

6 B — General view of the Upper Duolbasgaissa Member showing the alternations of thick-bedded sandstone bodies with thin-bedded fine-grained sandstones and siltstones. The photograph shows the top 150 m. of the member. Breivik, Digermul Peninsula.