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No. 3.

LATEST PRECAMBRIAN AND EOCAMBRIAN STRATIGRAPHY OF NORWAY

By K. Bjørlykke, J. O. Englund** and L. A. Kirkhusmo***

Introduction.

Research on latest Precambrian and Eocambrian rocks of Norway has been intensified in recent years, and the need for a revised lithostratigraphical division of these sediments has grown. Up to present many lithostratigraphical units have been given only informal names or names conflicting with the rules of lithostratigraphical nomenclature (Henningsmoen 1961, Størmer 1966 a, International Subcommission on Stratigraphy and Terminology 1961, American Commission on Stratigraphic Nomenclature 1961, Stratigraphical Code Subcommittee of the Geological Society of London 1967).

The present paper presents the results of discussions among many geologists concerned with latest Precambrian and Eocambrian stratigraphy in Norway, and members of the Norwegian Geological Society, Section for Stratigraphy.

The authors wish to thank all geologists who have contributed to the result. Particularly detailed comments have been received from Rektor S. Føyn on the stratigraphy of latest Precambrian and Eocambrian of N. Norway, and from Professor G. Henningsmoen and Professor N. Spjeldnæs on stratigraphical nomenclature.

Both in southern and northern Norway moderately deformed sediments of latest Precambrian and Eocambrian age are present in depressions in the crystalline Precambrian basement. These sediments which in both areas contain tillites, are overlain by fossiliferous Lower Cambrian (Holmia series), apparently without any major break. In S. Norway the latest Precambrian and Eocambrian sediments form a well defined lithological unit consisting of sandstones, shales and limestones,

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the overlying Cambro-Silurian rocks being more pelitic. In Finnmark a sandy and shaly facies prevails up to the Lower Ordovician (H. Reading 1965). The present paper is concerned with these moderately deformed sediments only.

SOUTH NORWAY

Latest Precambrian and Eocambrian sediments in S. Norway have earlier been referred to as "sparagmites", a name introduced by Esmark (1829) to designate coarse feldspathic sandstones and conglomerates. Since "Sparagmite" is not an internationally recognized petrological term, the authors maintain that this term should be avoided in formal lithostratigraphical nomenclature. New names on formations have been introduced to replace names which conflict with the rules of lithostratigraphical nomenclature. According to the code of stratigraphic nomenclature for Norway (Henningsmoen 1961, p. 231), two formations cannot have the same name and it is advised that the name adheres to the earliest established formation. The name Biri Limestone was introduced by Kjerulf (1857) while the name Biri Conglomerate was subsequently introduced by K. O. Bjørlykke, 1905. Since Biri Limestone is the earliest established unit, the name Biri Conglomerate should consequently be avoided, and the name Biskopås Conglomerate is here suggested as the name for this formation. Similarly the Moelv Tillite (Vogt 1924, Moelv Conglomerate) and Moelv Sparagmite (Vogt 1924) are regarded as two formations, and the term Moelv Sparagmite is suggested altered to the Ring Formation. Ring is located north of Moelv and provides good sections through this formation. The uppermost sandstone formation below fossiliferous Lower Cambrian has previously been referred to as the Quartz Sandstone formation. The name Vemdal Formation was first used in Norway by Kulling and Strand (in press) followed by K. Bjørlykke (1965, 1966) and Englund (1966). It seems here natural to follow the rules of priority and retain the name Vangsås Formation which was introduced by Kjerulf (1857). This name refers to a locality in the district around lake Mjøsa close to type localities of other formations of the group, while Vemdal is referring to a locality in Sweden.

The sequence from the Elstad Sparagmite up to the top of the Vangsås Formation is given the name Hedmark Group after the county (fylke) in which most of the type localities are located. The group is divided into two subgroups, the lower one given the name Lillehammer Subgroup. A good section through parts of the Lillehammer Subgroup is seen along the main road from Lillehammer to Moelv. The base of the Lillehammer Subgroup is not exposed. The upper subgroup, named the Rena Subgroup, is particularly well exposed in road sections between Rena and Åsta (K. Bjørlykke 1966). Spjeldnæs (1959) has claimed the existence of an unconformity between the Rena Subgroup and the Lillehammer Subgroup based on the evidence of crystalline limestone boulders in the Moelv Tillite which should have been metamorphosed prior to the deposition of the Moelv Tillite. This contention has, however, so far not been confirmed by mapping.

Vogt (1924), Holtedahl (1960) and Skjeseth (1963).	This paper
Ringsaker Quartzite } Quartz Sandstone Vardal Sparagmite	Vangsås Formation { Ringsaker Quartzite Vardal Sandstone
Ekre Shale	Ekre Shale
Moelv Conglomerate (= Moelv Tillite)	Moelv Tillite
Moelv Sparagmite	Ring Formation
Biri Shale and Limestone	Biri Shale
Biri Conglomerate	Biskopås Conglomerate and
Brøttum Shale and Limestone	Limestone
Brøttum Sparagmite	Brøttum Formation
Elstad Sparagmite	Elstad Formation

Fig. 1. Nomenclature on latest Precambrian and Eocambrian formations in S. Norway.

The Hedmark Group in the type area.

L i l l e h a m m e r S u b g r o u p .

Elstad Formation. This formation was first described by Kjerulf (1857) as "Elstad Quartzite." Later K. O. Bjørlykke (1905) introduced the name "Elstad Sparagmite."

The formation occurs between Ringebu and Fåvang in Gudbrandsdalen where it is apparently underlying the Brøttum Formation. It is developed as a grey sandstone with a thin calcareous shale at the top, named Elstad Shale by Englund (1966).

Many authors have discussed the stratigraphical position of this formation, and it is still uncertain whether it is younger or older than the Brøttum Formation.

Literature: K. O. Bjørlykke (1905), Werenskiold (1911), Oftedahl (1949, 1954 a, 1954 b), Skjeseth (1963), Englund (1966).

Brøttum Formation. In earlier papers this rock unit was referred to as "Older dark sparagmite." The name "Brøttum Sparagmite" was introduced by Vogt (1924).

In Gudbrandsdalen it consist of an alternation between layers of sandstone and shale, while a sandstone with some few conglomerate layers dominates in Østerdalen.

Literature: Holtedahl (1953, 1960), Oftedahl (1954 a), Skjeseth (1963), K. Bjørlykke (1966), Englund (1966).

Biskopås Conglomerate. The name "Biri Conglomerate" was proposed by K. O. Bjørlykke (1905) for the coarse conglomerate overlying the "Older dark sparagmite."

Literature: Münster (1900), Goldschmidt (1909), Rothpletz (1910), Oftedahl (1945, 1956), Holtedahl (1953, 1960), Skjeseth (1963), K. Bjørlykke (1966), Englund (1966).

Biri Shale and Limestone. The name "Biri Limestone" was introduced by Kjerulf (1857). Because the formation is developed as black shales with limestone it was called "Biri Shale and Limestone" by Vogt (1924) and Skjeseth (1963).

On the eastern side of lake Mjøsa the formation can often be separated in two members (Kirkhusmo, unpubl.). The lower member, below the Biskopås Conglomerate, corresponds to the "Brøttum Limestone and Shale" a name proposed by Vogt (1924). The upper member, the original "Biri Shale and Limestone," has a great areal distribution.

Literature: Münster (1900), Goldschmidt (1909), Rothpletz (1910), Holtedahl (1953, 1960), Skjeseth (1963), K. Bjørlykke (1966), Englund (1966).

Rena Subgroup.

Ring Formation. The name "Moelv Sparagmite" was proposed by Vogt (1924) for the "Younger red sparagmite."

The Ring Formation can generally be separated in two members. The lower member is fine-grained and corresponds to the "Moelv Shale" of Skjeseth (1963). The upper member consists of a coarse-grained sandstone often conglomeratic.

Literature: Münster (1900), Holtedahl (1921, 1953, 1960), Grender (1962), Skjeseth (1963), K. Bjørlykke (1966), Englund (1966).

Moelv Tillite. The name "Moelv Conglomerate" was proposed by Vogt (1924) for this formation. Holtedahl (1922) was the first to assume a glacial origin for this "tillite-like" conglomerate in the type area south of Moelv.

Literature: Holtedahl (1922), Holmsen (1954), Holmsen and Oftedahl (1956), Spjeldnæs (1964), K. Bjørlykke (1966).

Ekre Shale. At the base of the "Quartz Sandstone" formation described by Münster (1900), there occurs a green-red shale that was called Ekre Shale by Vogt (1924).

Literature: Vogt (1924), Holmsen and Oftedahl (1956), Skjeseth (1963).

Vangsås Formation (Vemdal Sandstone). This unit was first described by Kjerulf (1868) as "Vangsåsen-quartzsandstone." But the "Quartz Sandstone" formation as described by Münster (1900), was divided into the following members by Vogt (1924): Ekre Shale, Vardal Sparagmite, and Ringsaker Quartzite. Later the name "Quartz Sandstone" has been used for the upper two members. Skjeseth (1963) introduced the name "Mjøsa Quartz-sandstone."

The formation has a great areal distribution along the eastern margin of the Norwegian and Swedish Caledonides. The name Vemdal Sandstone (Törnebohm, 1873) is proposed by Kulling and Strand (1966, in press) for these deposits in Norway and Sweden. The name "Vangsås Sandstone" is here used in a more restricted sense for the formation in the type area in Southern Norway.

Literature: Schiøtz (1902), Vogt (1924), Holtedahl (1953, 1960), Holmsen and Oftedahl (1956), Grender (1962), Skjeseth (1963), K. Bjørlykke (1966), Englund (1966), Kulling and Strand (1966).

Other lithostratigraphical names in Southern Norway.

Arnestad Limestone. Schiøtz (1902). Corresponds to Biri Shale and Limestone (Tørnebohm, 1896 and K. O. Bjørlykke, 1905).

Biri Conglomerate. K. O. Bjørlykke (1905). Synonym for Biskopås Conglomerate.

Bjørånes Shale. K. Bjørlykke (1965). Dark shales below the Moelv Tillite in the Bjørånes window.

Literature: Oftedahl (1956), K. Bjørlykke (1965).

Brøttum Limestone and Shale. Vogt (1924). Corresponds to the lower member of the Biri Shale and Limestone.

Elstad Shale. Englund (1966). Upper member of the Elstad Formation.

Elstad Sparagmite. K. O. Bjørlykke (1905). Described as "Elstad Quartzite" by Kjerulf (1857). Lower member of the Elstad Formation.

Elta Limestone. Schiøtz (1902). Corresponds to Biri Shale and Limestone (Tørnebohm, 1896 and K. O. Bjørlykke, 1905).

Gausdal Quartzite Formation. K. O. Bjørlykke (1893). Corresponds to the upper part of the Hedmark Group (Rena Subgroup) and it possibly also includes younger beds.

Literature: K. O. Bjørlykke (1905), Oftedahl (1954 a).

Glomstad Limestone. Schiøtz (1902). Corresponds to Biri Shale and Limestone (Tørnebohm, 1896 and K. O. Bjørlykke, 1905).

Helgeberg Limestone. Vogt (1952). Corresponds to a part of the Biri Shale and Limestone.

Mjøsa Quartz-sandstone. Skjeseth (1963). Synonym for Vangsås Formation.

Moelv Conglomerate. Vogt (1924). Equivalent to Moelv Tillite.

Moelv Shale. Skjeseth (1963). Lower member of the Ring Formation.

Moelv Sparagmite. Vogt (1924). Synonym for Ring Formation.

Quartz Sandstone. Vide: Vangsås Formation.

Reistad Limestone. K. O. Bjørlykke (1893). Corresponds probably to the Biri Shale and Limestone (Skjeseth, 1963).
Literature: K. O. Bjørlykke (1905).

Ringsaker Quartzite. Vogt (1924). Upper member of the Vangsås Formation.

Synnfjell Sandstone. Proposed by Strand (1938), who correlates the formation with the Vangsås Formation.

Vardal Sparagmite. Vogt (1924). Corresponds to the lower member of the Vangsås Formation.

NORTH NORWAY

The latest Precambrian and Eocambrian sediments in Finnmark have been referred to as "The Finnmark Sandstone Series" by O. Holtedahl (1918) and it seems natural to introduce the name Finnmark Group as a formal name for this unit. The Finnmark Group is naturally divided into a lower subgroup consisting of sediments below the tillites and an upper subgroup containing two tillite horizons. The lower subgroup has by O. Holtedahl (1918) been referred to as Porsanger Sandstone and Porsanger Dolomite. In the Porsanger area, however, the base of the sequence is disturbed by thrusting and the most complete section is found along the Tanafjord. Therefore, the name Tana Subgroup would be most suitable to designate the sequence below the lower tillite (Smalfjord Tillite) in the Tanafjord section. The base is not exposed according to Føyn's (1937) description of the section along the Tanafjord from Grasdalen to Stangenes. The lowermost part of the Tana Subgroup, exposed at the Varanger Peninsula, will have to await more detailed mapping before it can be subdivided into formations.

The Varanger Subgroup rests with angular unconformity on the Tana Subgroup (Føyn 1937). The name Varanger as a lithostratigraphical unit was introduced by Dahll (1868) for brownish shales and conglomerates from the inner part of the Varangerfjord. The Varanger Subgroup is here defined to include the Smalfjord Tillite at the base and the Stappogiedde Formation at the top (Fig. 2). The Vestertana Group as introduced by Reading (1965), comprises the Breivik Formation in addition to the formations included in The Varanger Subgroup. Many members of the Stratigraphic section of the Norwegian Geological Society (= The stratigraphic commission of Norway) claimed that the Varanger Subgroup had priority to the Vestertana Group and that the Varanger Subgroup and the Finnmark Group should not include the Breivik Formation. Other members held the view that the Varanger Subgroup (or the Vestertana Group) should include the Breivik Formation and possibly also parts of the Digermulen Group (Cambr.—Ord.) since a shaly and a sandy facies prevails also in this part of the sequence.

	HEDMARK GROUP	FINNMARK GROUP	
Rena Subgroup	Vangsås Formation	Stappogiedde Formation	Varanger Subgroup
	Ekre Shale	Mortensnes Tillite	
	Moelv Tillite	Nyborg Formation	
	Ring Formation	Smalfjord Tillite	
Lillehammer Subgroup	Biri Shale and Limestone	Grasdal Dolomite	Tana Subgroup
	Biskopås Conglomerate	Vagge Formation	
	Brøttum Formation	Algasvarre Formation	
	Elstad Formation	Stangenes Shale	

Fig. 2. Stratigraphy of the Hedmark Group and Finnmark Group.

Remarks on chronostratigraphical units and on the correlation between North and South Norway.

Both the Finnmark Group of N. Norway and the Hedmark Group of S. Norway have here been divided into two subgroups. In Finnmark the base of the upper subgroup is placed at the base of the lower tillite (Smalfjord Tillite) above the dolomite formation (Porsanger Dolomite —Grasdal Dolomite). The Varanger Subgroup thus corresponds very closely to the chronostratigraphical units: *Varegium* (Asklund 1956), *Varangian* (Harland 1965) and *Eocambrian* as emended by (Holtedahl 1961). According to Holtedahl (1961) the Eocambrian should be regarded as lowermost Cambrian and the base of the tillites should serve as a lower boundary of the Eocambrian. The "Esmarkian" is by Rosendahl (1945) and Spjeldnæs (1965) used as a chronostratigrapic name for the youngest Precambrian below the tillites. The Esmarkian should according to these authors include the Tana Subgroup and the Lillehammer Subgroup but the lower boundary of the Esmarkian has not been sharply defined.

In S. Norway a significant change in lithology is found at the base of the Ring Formation which mainly consists of coarse sandstones and conglomerates resting on the Biri Shale and Limestone. The base of the Ring Formation therefore forms a natural boundary between the Rena Subgroup and the Lillehammer Subgroup. The Moelv Tillite most probably corresponds to the upper tillite (Mortensnes Tillite) of N. Norway, and the Ring Formation may therefore be contemporaneous with the Nyborg Formation of N. Norway. An equivalent of the Smalfjord Tillite (lower tillite) horizon appears to be absent in S. Norway. A close correlation of the base of the Varanger Subgroup with the base of the Rena Subgroup is therefore not possible at this stage.

The top of the Varanger Subgroup may, however, be correlated with that of the Rena Subgroup. To a large extent due to the work by Føyn (1967) a lithological correlation of the upper part of the Stappogiedde Formation with the Vangsås Formation now seems justified (see also K. Bjørlykke, 1967).

List of formal lithostratigraphic units of the Finnmark Group, N. Norway.

Algasvarre Formation is here introduced as a formal name for the sediments between the Stangenes Formation and the Vagge Formation as described by Føyn (1937) p. 71, Fig. 5 f—p from the Tananes section.

The formation consists mainly of quartzites and with subordinate shales (590 m).

Borras Group (Føyn 1964) rests unconformably on the Bossekop Group and is overthrust by a metamorphic nappe.

Type locality: Alta area.

Corresponds probably to the upper part of the Varanger Group (Føyn 1964).

Bossekop Group (Føyn 1964)—rests unconformably upon the Raipas Suite and is overlain by the Borras Group.

The Bossekop Group corresponds to the upper part of the Tana Subgroup (Føyn 1964).

Grasdal Dolomite is in this paper introduced as a formal name on the sediments overlying the Vagge Formation in the Tanafjord section at Grasdalen (Føyn 1937, p. 75).

The formation consists of dolomite and shales (50 m) and is overlain by the Smalfjord Tillite.

Karlbotn Quartzite (K. Bjørlykke, 1967) is a conglomeratic quartzite overlying the Kvalnes Conglomerate at Karlbotn.

Klubbfjell "series" (Rosendahl, H. 1931, p. 491) is a part of the Tana Subgroup exposed at Klubbfjell below the unconformity at the base of the Varanger Subgroup.

Kvalnes Conglomerate (K. Bjørlykke, 1967) rests unconformably upon the Tana Group.
Type locality: Kvalnes on the south side of the Varangerfjord.

Mortensnes Tillite (O. Holtedahl 1918) is the upper of the two tillite horizons in Finnmark and is often referred to as "the upper tillite."
Type locality: Mortensnes on the north side of the Varangerfjord (O. Holtedahl 1918, H. Reading 1965).

Nyborg Formation (O. Holtedahl 1960)—is a red and grey shale and sandstone found between the two tillite horizons.
Type locality: Nyborg on the north side of Varangerfjord east of Varangerbotten.
Literature: Rosendahl 1931, 1945, O. Holtedahl 1960, H. Reading 1965, H. Reading and Walker 1966.

Porsanger "avdelingen" (division) (O. Holtedahl, 1918) consists of massive sandstone (Porsanger Sandstone) and an upper dolomite (Porsanger Dolomite). Corresponds to the Tana Subgroup of the Tanafjord section.

Smalfjord Tillite—is in this paper introduced as a formal name for the lower of the two tillite horizons in Finnmark. The type locality at Smalfjord is described by Føyn (1937).
Literature: Holtedahl (1918), Føyn (1937), H. Reading (1965), H. Reading and Walker (1966).

Stangenes Shale (Føyn 1937, p. 70) makes up the lower part of the Tananes section and is underlain by conglomeratic beds and shales which is not yet included in any formally established Formation.

Stappogiedde Formation (H. Reading 1965)—is divided into three members: 1. Quartzitic sandstone (at the base) 2. Blue green and violet slate. 3. Red quartzitic sandstone with greywackes, sandstones and mudstones.
Type locality: Stappogiedde at the Digermulen peninsula.

Vagge Formation (Føyn 1937, p. 73) consists of an upper quartzite member (150 m) and a lower shale member (80 m).

Varanger Subgroup (Størmer 1966 b) consists of the Smalfjord Tillite, Nyborg Formation, Mortensnes Tillite and the Stappogiedde Formation.

The Varanger "System" was introduced by Dahll (1868) to designate brown conglomerates and shales at Mortensnes. Holtedahl (1918) used the name Varanger "Avdelingen" about parts of the Tana Group at Kongsfjord.

Vestertana Group (Reading 1965) includes the Breivik Formation in addition to the formations included in the Varanger Subgroup.

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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.)

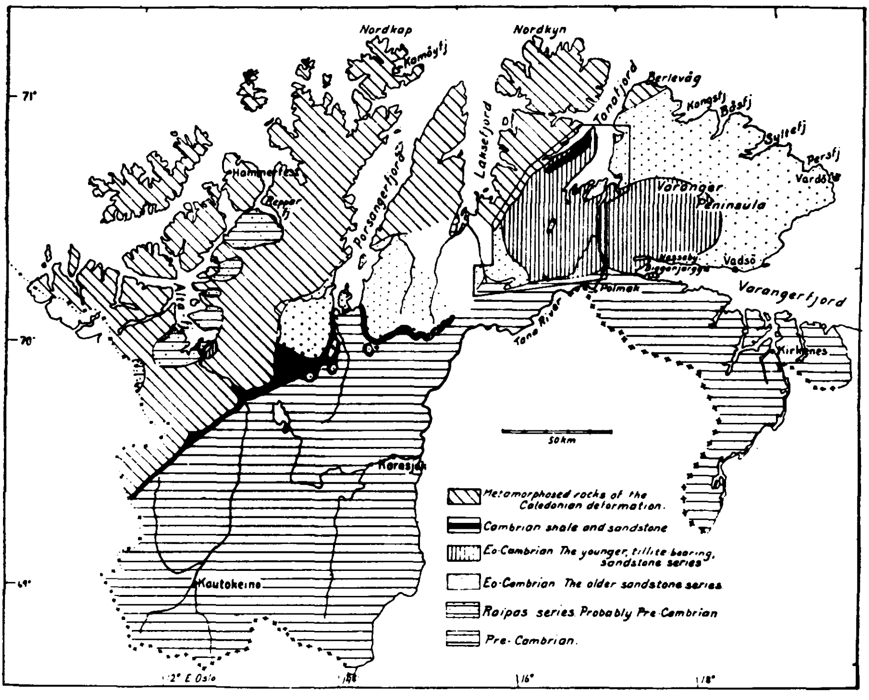

Fig. 1. Geological map of Finnmark after Føyn (1937).

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.

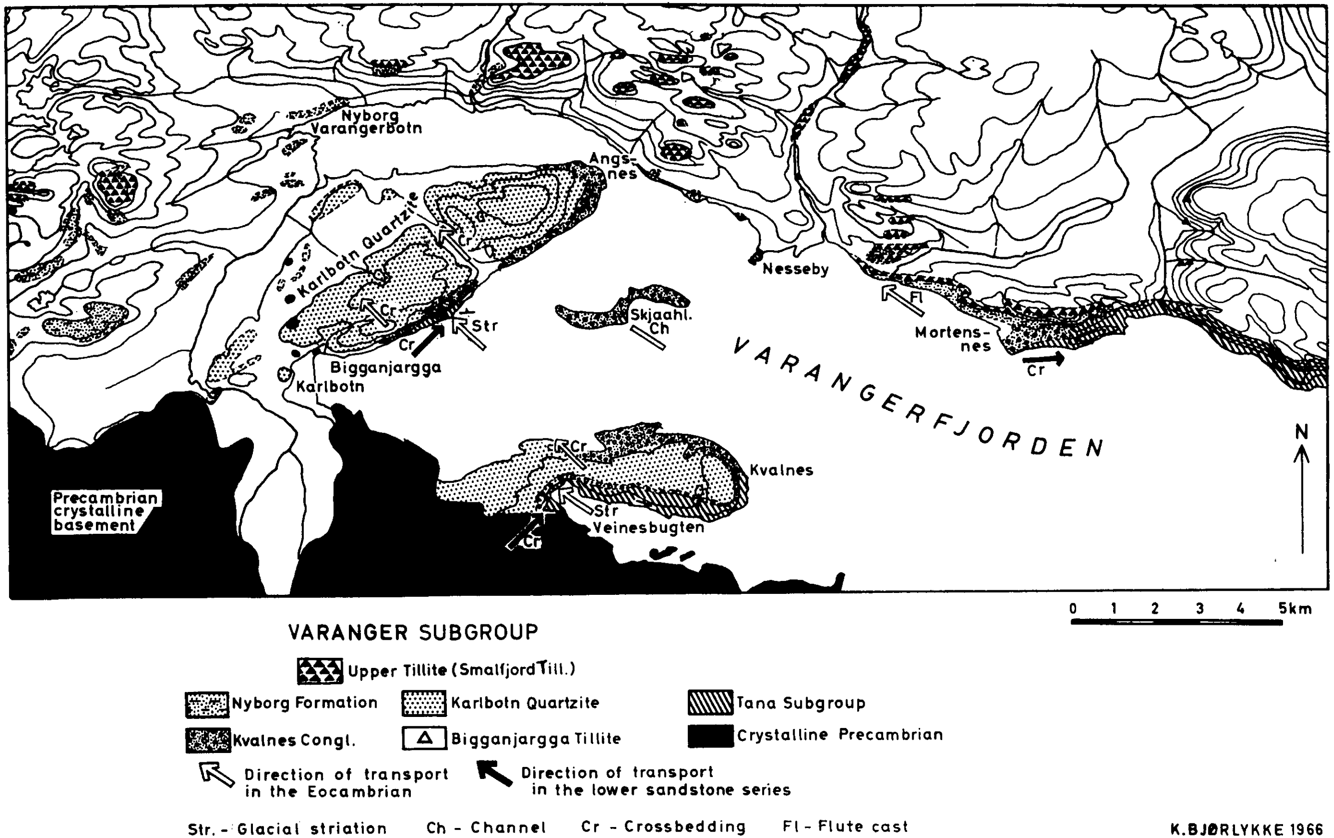

Fig. 2. Geological map around the inner part of Varangerfjord, partly after Holtedahl and Føyn (1960).

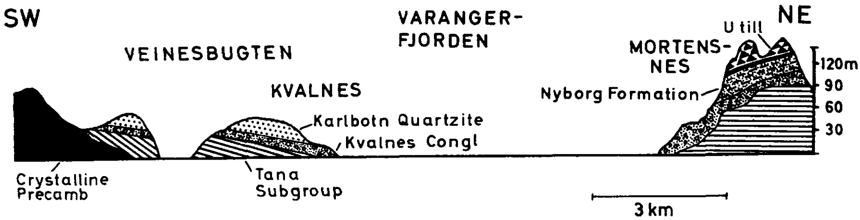

Fig. 3. Profile across the Varangerfjord.

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-

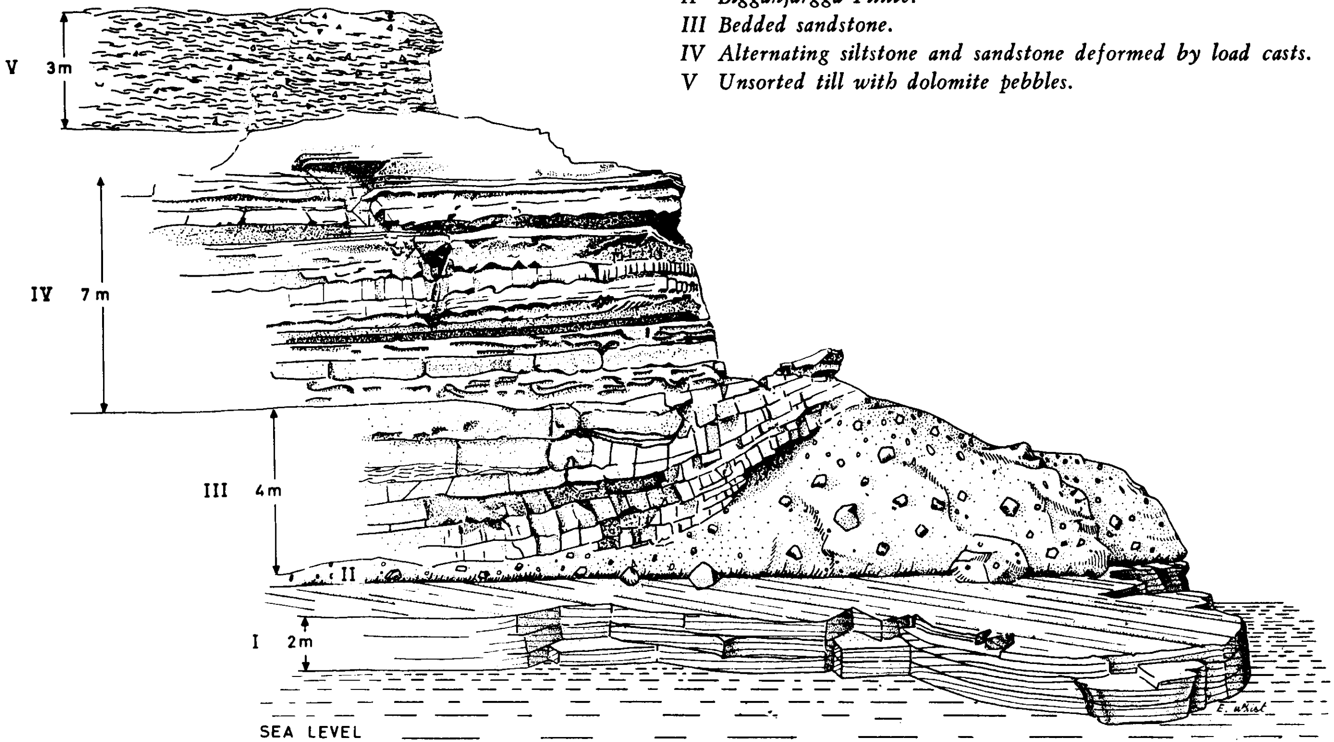

Fig. 5. The Bigganjargga Tillite (Drawing after Photography).
I Crossbedded sandstone of the Tana Subgroup.
II Bigganjargga Tillite.
III Bedded sandstone.
IV Alternating siltstone and sandstone deformed by load casts.
V Unsorted till with dolomite pebbles.

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-

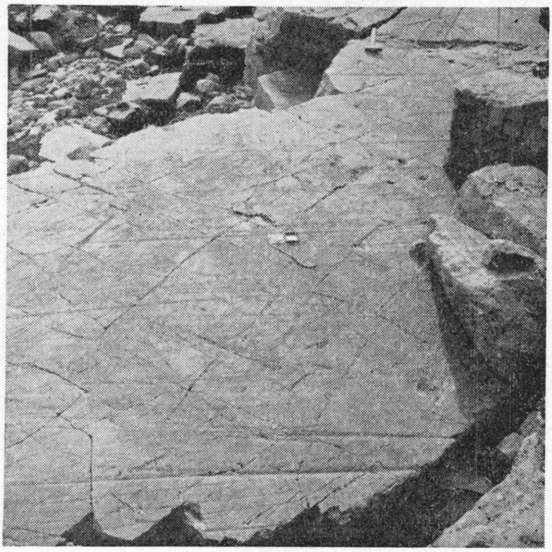

Fig. 6 a. Glacial striation at the base of the Bigganjargga Tillite.

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

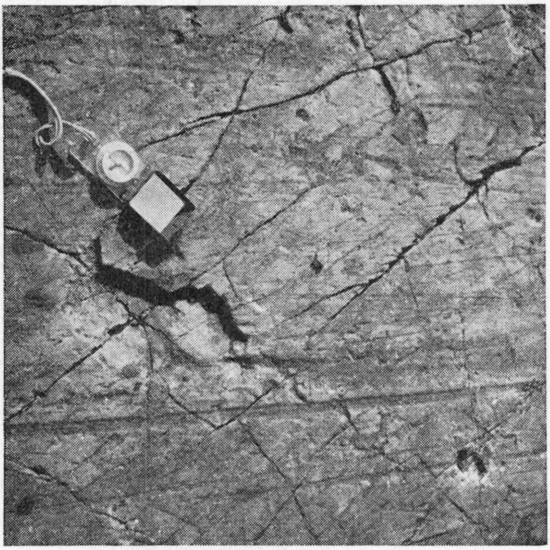

Fig. 6 b. Two sets of striations, the fainter probably being the younger of the two. A probable cresentic gourge related to the younger set of striation (rather faint).

(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

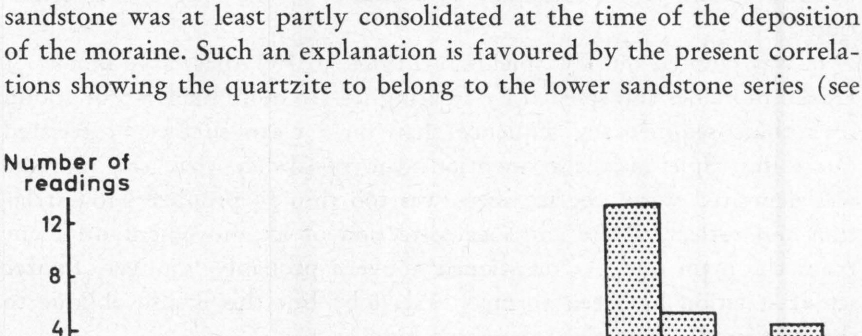

Fig. 7. Orientations of striations at the base of the Bigganjargga Tillite.

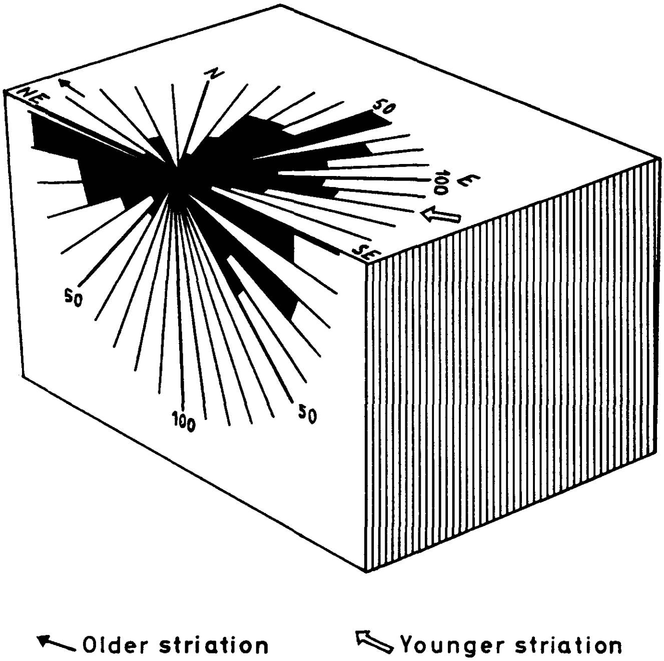

Fig. 8. Vertical and horisontal long axis distribution of the Bigganjargga Tillite based on 200 measurements of pebbles where the apparant long axis is more than 50 % larger than the shorter axis.

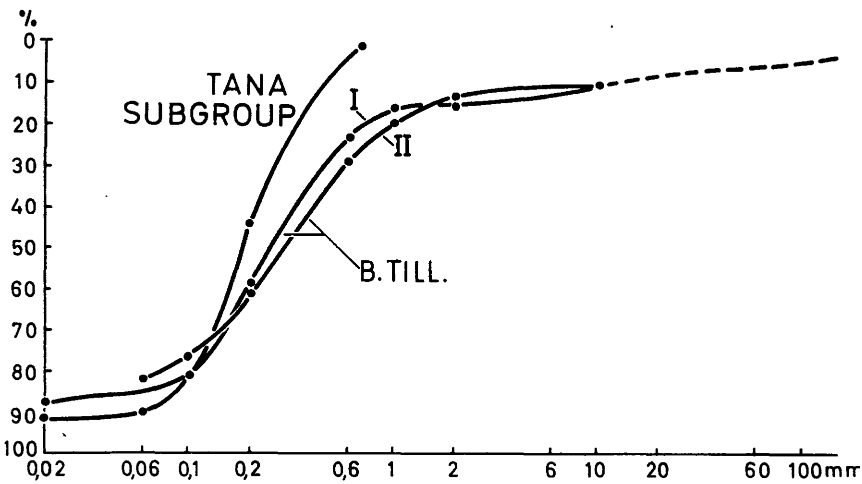

Fig. 9. Grain size distribution in the Bigganjargga Tillite and the underlying sandstone. Each curve is based on 300—600 measurements in thin sections, by use of acetate replicas (K. Bjørlykke, 1966a) and for the larger clasts macroscopic measurements.

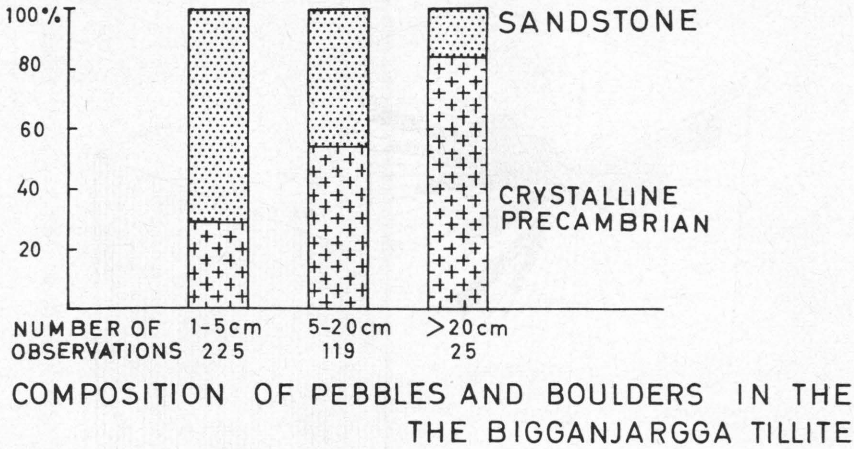

Fig. 10.

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

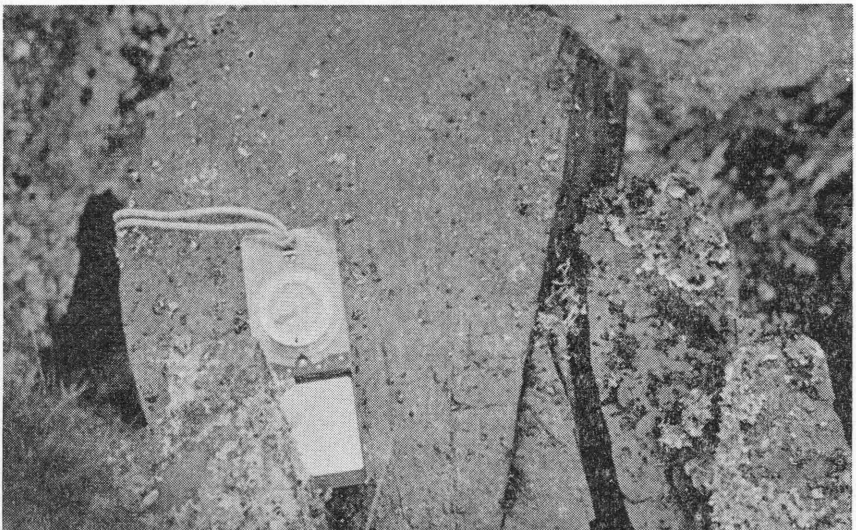

Fig. 11. Striations at the base of Kvalnes Conglomerate at Veines bay.

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

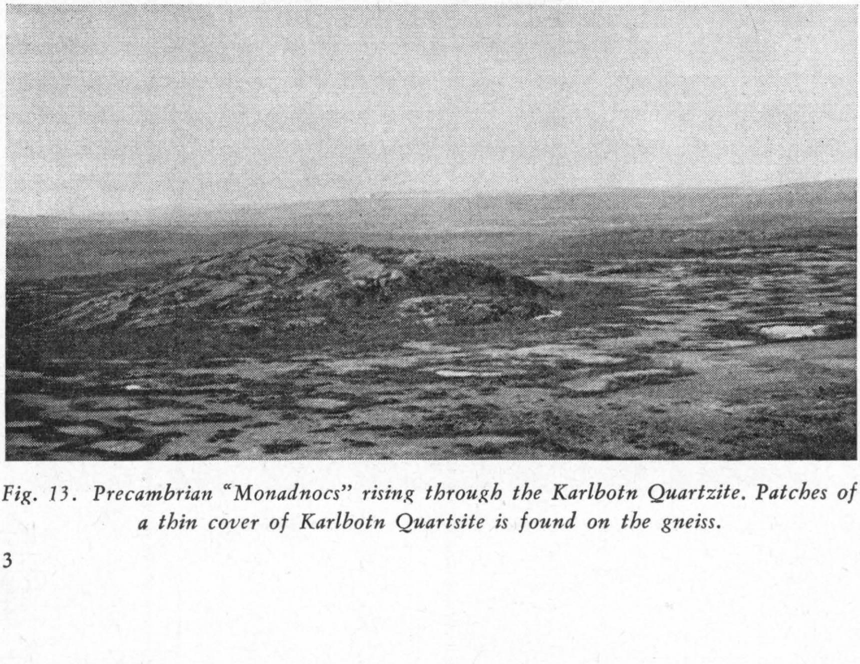

Fig. 13. Precambrian "Monadnocs" rising through the Karlbotn Quartzite. Patches of a thin cover of Karlbotn Quartsite is found on the gneiss.

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

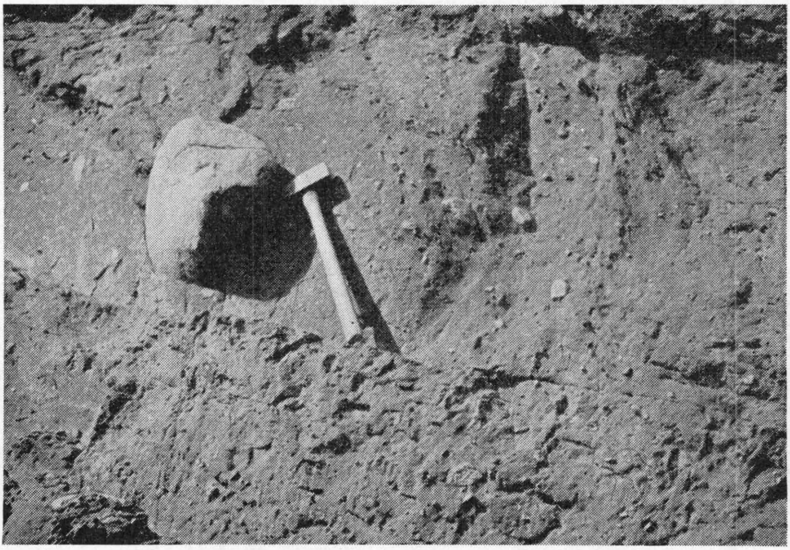

Fig. 14. The upper marine tillite (Mortensnes Tillite) at Mortensnes.

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

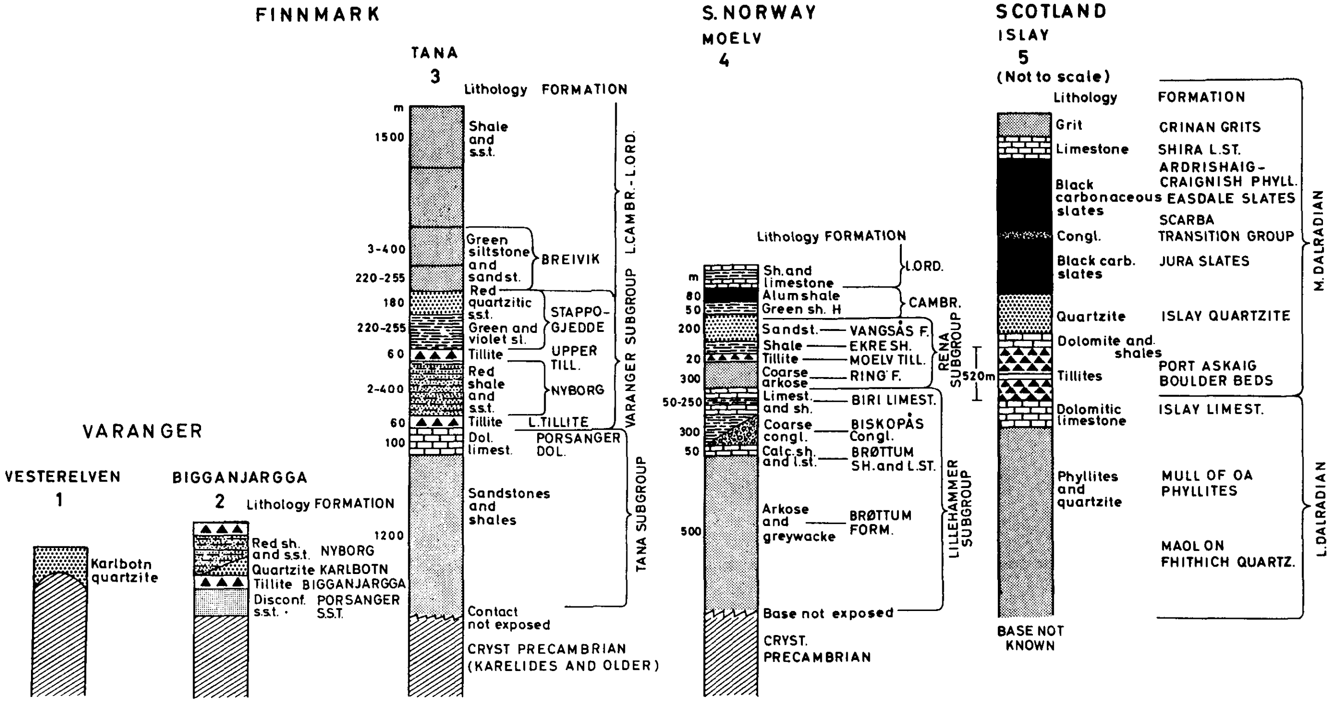

Fig. 15. Late Precambrian and early Palaeozoic successions in Norway and Scotland.
1.—2. O. Holtedahl (1918) and the present paper.
3. Holtedahl (1918) and Føyn (1937).
4. Vogt (1924). Skjeseth (1963) and K. Bjørlykke (1966).
5. Bailey (1917).

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 grunthavs-område.
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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STUDIES ON THE LATEST PRECAMBRIAN AND EOCAMBRIAN ROCKS IN NORWAY

No. 5.

MICROFOSSILS FROM LATE PRECAMBRIAN SEDIMENTS AROUND LAKE MJØSA, SOUTHERN NORWAY

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Abstract.

Microfossils extracted with ordinary palynological methods from the Biskopås conglomerate (Biri-conglomerate) and the Biri-shale of the late Precambrian age in Southern Norway are described. Two principle categories of spherical bodies occur: 1) spherical masses entirely composed of minute "cells" and 2) spherical shells of simple or composite membranes. They are further divided into six provisional forms (designated A—F) by their micro-structures. Certain forms occur united into clusters suggestive of a reproduction by budding. The natural affinities of the fossils remain problematic.

However, there is some evidence from thin-sections of the source material to suggest that bodies of category 1 may be "spores" produced by unicellular organisms roughly half a millimetre in diameter.

Material and treatment.

The investigated material came from two different stratigraphical units in the Hedmark Group of Southern Norway: 1) Phosphoritic pebbles from the "Biri-conglomerate," collected by Dr. N. Spjeldnæs at Moelv (identical with the material from which *Papillomembrana* Spjeldnæs 1963 has been described) and by Mr. D. Huseby at Roterud (Biri); 2) calcareous shale ("Biri-shale") collected by Mr. D. Huseby at Vismundelva (Biri). The stratigraphy of the Hedmark Group (Sparagmite Group) is described by K. Bjørlykke *et al.* 1967.

The samples were treated according to usual palynological methods, i. e. hydrofluoric acid maceration followed by oxidization with Schulze's mixture for about 24 hours. However, the oxidization had only very little if any effect on the result. Before maceration, the samples were thoroughly cleaned and then heated for a short time over a Bunsen burner. The residues were mounted in glycerin-jelly.

Results.

The maceration residues largely consist of black to brownish (yellowish) grey microscopic particles and fragments apparently of organic origin and ranging in size from less than one micron to a few tens of microns. In addition, organized bodies form a striking, although quantitatively small component. They are more or less irregularly circular in outline with diameters ranging from less than 10 μ to nearly 40 μ. The greater part of them is approximately spherical, others are flattened but appear to have had a roughly spherical shape originally.

These bodies, as well as most of the odd objects, disappear after heating the residue for a few minutes to c. 800° Centigrade, or treating it with chromic-sulphuric acid. This is taken to show that the objects are of organic origin.

For a description in this report, I have selected the forms that look most convincingly organized. I have not attached formal names to them, for I feel that a better understanding of these and similar objects and their significance is wanted before they can be treated taxonomically in a proper way. References to previously published names are almost meaningless since they are in general too briefly characterized.

The most useful character for separating the forms appear to be the micro-structures of the bodies or their walls, although I make no claim to fully understand them. Two principle categories may thus be distinguished: 1) Spherical bodies apparently wholly composed of a large number of small "cells," the whole body with or without a distinct enveloping membrane; 2) spherical shells, interior empty, with or without enveloping membrane.

To the first category belong Forms A and C described herein. The spherical masses are more or less opaque so that their interior is not easily observed, but from the more translucent examples as well as a few more or less squashed ones (cp. Pl. I fig. 1 and Pl. II fig. 5) I infer that they are entirely built up of small, approximately spherical "cells." The second category comprises the rest of the forms described and shows a much wider range of variation. Form B faintly resembles the first category in its shell composition (one layer of "cells"). More finely granular (not "cellular") wall structures are seen in Forms E and F. Form D has an irregularly porous wall structure.

One highly interesting feature is a tendency within certain forms to be united in clusters highly suggestive of a reproduction by budding. This is seen in Forms B and C, distinguishable also by their micro-strucvariation in their dimensions and the micro-structures in the smallest members are distinctly finer than in the largest ones, suggesting that the former are juvenile. There seem to be two different modes of attachment represented: In Form B a clear tendency to form irregular chains is seen, while in Form C a centrifugal arrangement around a mother-cell seems to prevail.

The natural affinities of these microfossils remain problematic. Perhaps the biologically most interesting feature is the "budding" seen in certain forms, which in itself is suggestive of vegetative phases of organisms not much beyond the unicellular level of organization. The "cellular" composition of some forms and the resistance of the membranes on the other hand suggest a kind of "spore" function. But there is nothing to suggest that they are derived from higher plants.

Apertures and markings of various kinds which have been reported by some authors on microfossils of corresponding age have not been observed in the present material.

In this connection I would like to draw attention to the sporomorphs Type I and Type VII described by Spjeldnæs (1967) from the same source material. They show within a well defined membrane several spherical bodies resembling to varying degrees my Form A. The incomplete specimen designated by Spjeldnæs as Type VI exhibits a fairly similar morphology. In the Types VI and VII of Spjeldnæs the contained bodies appear to be wholly composed of granules or "cells" (as in my Form A), but in Type I there appears to be only a superficial layer of "cells." It seems possible to visualize the entire bodies as roughly spherical, unicellular organisms, perhaps with outgrowths or appendages in some cases (cp. Spjeldnæs' figs. 1 and 2, Pl. 4), and in the size range of a few tenths to half a millimetre. The presence of granular or "cellular" bodies inside them is in the line with a "spore" function as suggested for these bodies above.

In his thin-sections Spjeldnæs (l. c.) has also noted a form (Type V) which corresponds fairly well with my Form B, but it throws no additional light on their morphology.

Microfossils from Precambrian and early Cambrian sediments have attracted an increasing amount of interest in the last decade, particularly in the USSR, where they are being used for correlation of the otherwise nonfossiliferous sediments (cp. f. i. the papers by Chepikova 1966 and Pychova 1966). To draw any stratigraphical conclusions from the present, very limited investigation, however, is hardly permissible.

A comparison with previously, usually very briefly, described forms can only be too superficial to be of any use. Still, I would like to draw attention to one category in the present material, represented by the "cellular" Forms A and C, which seem to have equivalents in material described by Timofeev (1959, p. 26, "*Symplassosphaeridium*") from the Upper Cambrian *Dictyonema*-shale from Vologda, and by Roblot (1963, figs. 27, 28) from the Middle Brioverian in France. The "budding" seen in the present Form C, however, seems to be something quite distinct.

Timofeev (1963) has previously reported some microfossils from the Eocambrian in Finnmark, Northern Norway, but none of the present forms appear to be similar to them.

None of the microfossils obtained can be seen to have any relationship to *Papillomembrana compta* Spjeldnæs (1963) which was described from thin sections of pebbles from the Biskopås conglomerate ("Biri-conglomerate").

I am not prepared to distinguish between the microfossil assemblages of the pebbles of the "Biri-conglomerate" and the stratigraphically somewhat younger "Biri-shale" as known at present. A somewhat greater variety of forms have been seen in the former, which have yielded the more rare forms described herein, but the most frequent forms (A and B) occur in either sediment.

Descriptions

FORM A
Pl. I, figs. 1–5.

Globular bodies, 15 to 24 μ in diameter, apparently composed of densely packed "cells" ranging in diameter from 1.5 to 2.5 μ but in any individual specimen being rather uniform in size. No separate enveloping membrane visible. The component cells are distinct on the surface, their presence inwards towards the centre is not always easily ascertained. However, it is quite clear that more than a single superficial layer of cells exist, and in a few favourable specimens a continuously changing pattern of cells can be seen as one is focussing through them. Most specimens are too opaque or otherwise too obscure in the middle to permit a statement regarding the interior structure. More or less opaque specimens often appear facetted on the surface.

Occurs in both the conglomerate and the shale.

FORM B
Pl. I, figs. 6–22.

Globular bodies of varying dimensions united in an irregularly chain-like manner. The individual bodies are composed of an approximately spherical capsule enveloped in a thin membrane. The internal capsule appears to be a hollow shell whose wall consists of one layer of densely packed "cells" or granules (opaque "cells") with diameters up to 1.5 μ. However, in the smaller members of a cluster these wall elements are noticeably finer and often indistinct. Quite often the capsule is too opaque for its structural details to be shown; however, its hollow nature has been ascertained in a fair number of specimens.

The enclosing membrane is less than 0.5 μ thick and fairly distinct, particularly in the smaller members of a cluster. In the larger members it is very corrugated, but far less so to nearly smooth in the smaller to smallest members. In some specimens the origin of these corrugations is indicated by their replacement in part by small, somewhat less than hemispherical bulges, whose size and form make it probable that they were cast by the underlying component elements of the capsule wall.

Separate bodies comparable to individual members of this form occur frequently; such specimens resembling the smaller cluster members are quite abundant, while larger ones are fairly rare.

One specimen reminiscent of an enveloping membrane devoid of its capsule is shown in Pl. I figs. 15 and 16; its pattern of hemispherical bulges is somewhat coarser than usual for Form B.

The objects thus referred to in Form B compose an assemblage of rather heterogeneous aspect. A further differentiation attempted at an earlier stage, particularly for the separate bodies, could not be maintained because the characters were found to intergrade too much. A good reason for lumping is provided by the fairly wide range of variation often seen in the members of one single cluster.

Occurs in the conglomerate and the shale.

FORM C
Pl. II, figs. 1–5.

Globular body, diameter c. 30 μ, with smaller bodies, usually 5–10 μ in diameter, attached to it. The individual bodies, whether large or small, are composed of more or less spherical "cells" whose diameter is 2.4—3.0 μ in the larger ones and down to less than 0.5 μ in the smaller ones. An enveloping membrane is fairly distinct in the smaller members, less distinct or possibly missing in the larger ones.

Found in the conglomerate.

FORM D

Pl. II, figs. 6—9.

Spherical shells, the two specimens seen have diameters 25 and 30 μ respectively. The wall appears porous in optical section, with cavities of circular to rather elongate oval outlines and greatly varying dimensions; in surface view they appear as a net-work with greatly varying mesh form and size (from less than 0.5 μ to c. 10 μ). Wall thickness varies between approximately 2 μ and 4 μ.

Found in the conglomerate.

FORM E

Pl. II, fig. 10.

Almost flattened objects of irregularly rounded outline (original shape probably ovoid to spherical), diameter about 20—30 μ. The wall itself is probably very thin, the most conspicuous character being irregularly distributed opaque granules from less than 0.5 to somewhat over 1.0 μ in diameter, sometimes fused, and giving the surface an unevenly spotted appearance.

Found in the conglomerate.

FORM F

Pl. II, fig. 11.

Flattened objects of subcircular outline (original shape probably approximately spherical), diameter of the two specimens observed 33 x 36 μ and 27 x 30 μ respectively. Membrane less than 0.5 μ thick, of a finely granular composition showing in surface view as fine (less than 0.5 μ), evenly distributed dots.

Found in the conglomerate.

Acknowledgements.

I wish to thank Dr. Nils Spjeldnæs, University of Aarhus, and Mr. Dag Huseby, University of Oslo, for the samples used. Much painstaking laboratory and microscopy work was done by Mr. D. Huseby. A grant towards technical assistance from the Norwegian Research Council for Science and the Humanities is gratefully acknowledged.

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Explanation of plates.

All figures are from untouched negatives, photographed through an oil immersion lens with n.a. 1.14. Magnification is x 1000 throughout. The slides are preserved in the Palaeontological Museum of the University of Oslo under the common designation PAP 6. The exact position of the fossils in each slide is indicated by coordinates on the labels. Slides No. 13 and 14 are from the shale, the rest from the conglomerate.

Plate I

Figs. 1—5. Form A. - Fig. 1: sl. 3, the specimen is slightly squashed and some "cells" coming loose are seen in the lower right hand corner of the figure; fig. 2: sl. 1; fig. 3: sl. 5; fig. 4: sl. 14; fig. 5: sl. 6.

Figs. 6—22. Form B. - Fig. 6: sl. 14; figs. 7, 8, 9: sl. 13; fig. 10: sl. 11, the specimen has small "buds" resembling those in fig. 17 but not clearly showing in this focus; fig. 11: sl. 11; fig. 12: sl. 13; fig. 13: sl. 14; fig. 14: sl. 10, a specimen composed of four bodies of almost equal size; figs. 15, 16: sl. 9, two foci of a membrane resembling that in Form B, but lacking the internal capsule; fig. 17: sl. 11; figs. 18, 19: sl. 9; fig. 20: sl. 13; fig. 21: sl. 12; fig. 22: sl. 9.

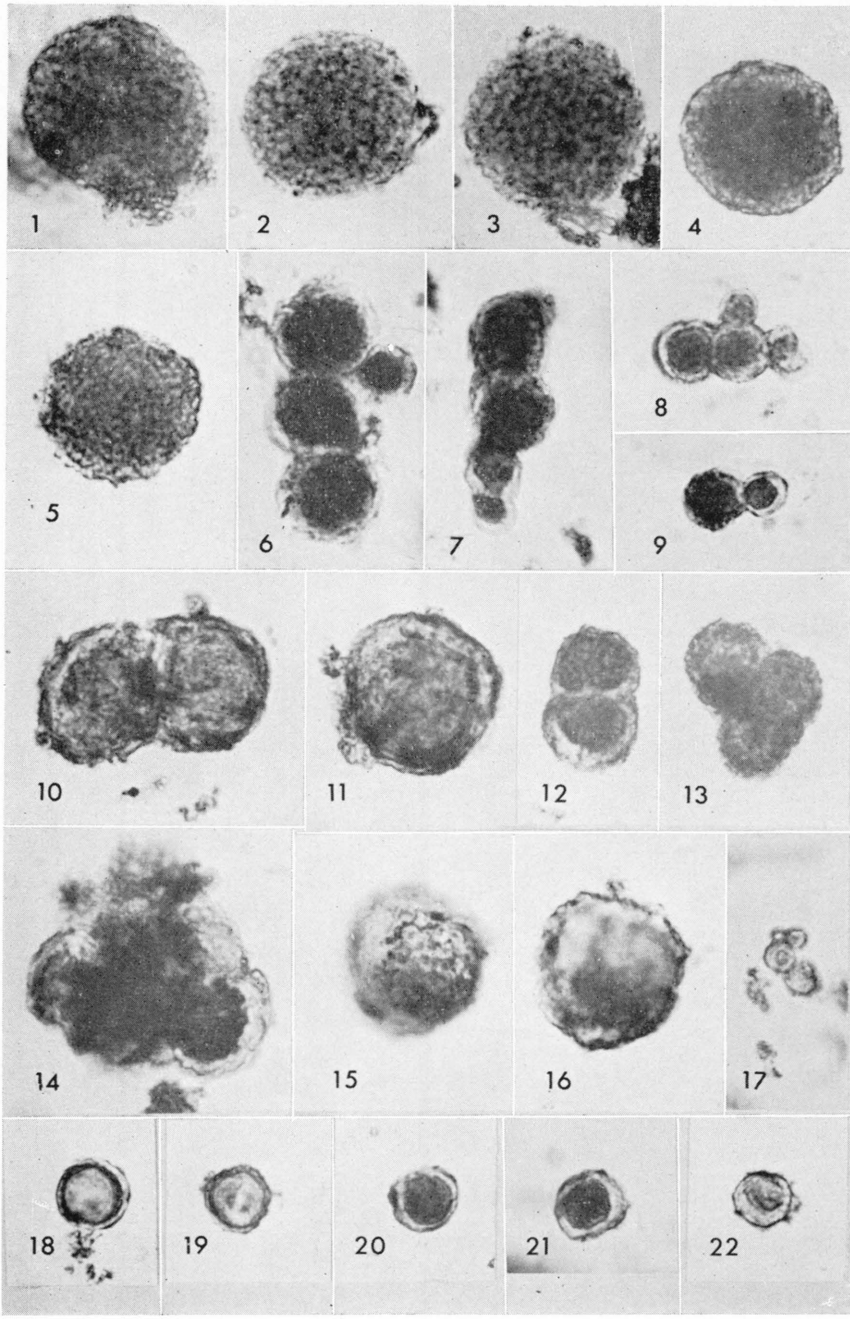
Plate II

Figs. 1—5. Form C.—Figs. 1—3: sl. 5, three successive foci of one specimen; fig. 4: sl. 2; fig. 5: sl. 12, specimen composed of two bodies, one of which is squashed and the "cells" dispersed.

Figs. 6—9. Form D.—Fig. 6, 7: sl. 6, two foci of one specimen; figs. 8, 9: sl. 4, two foci of one specimen.

Fig. 10. Form E, sl. 7.

Fig. 11. Form F, sl. 8.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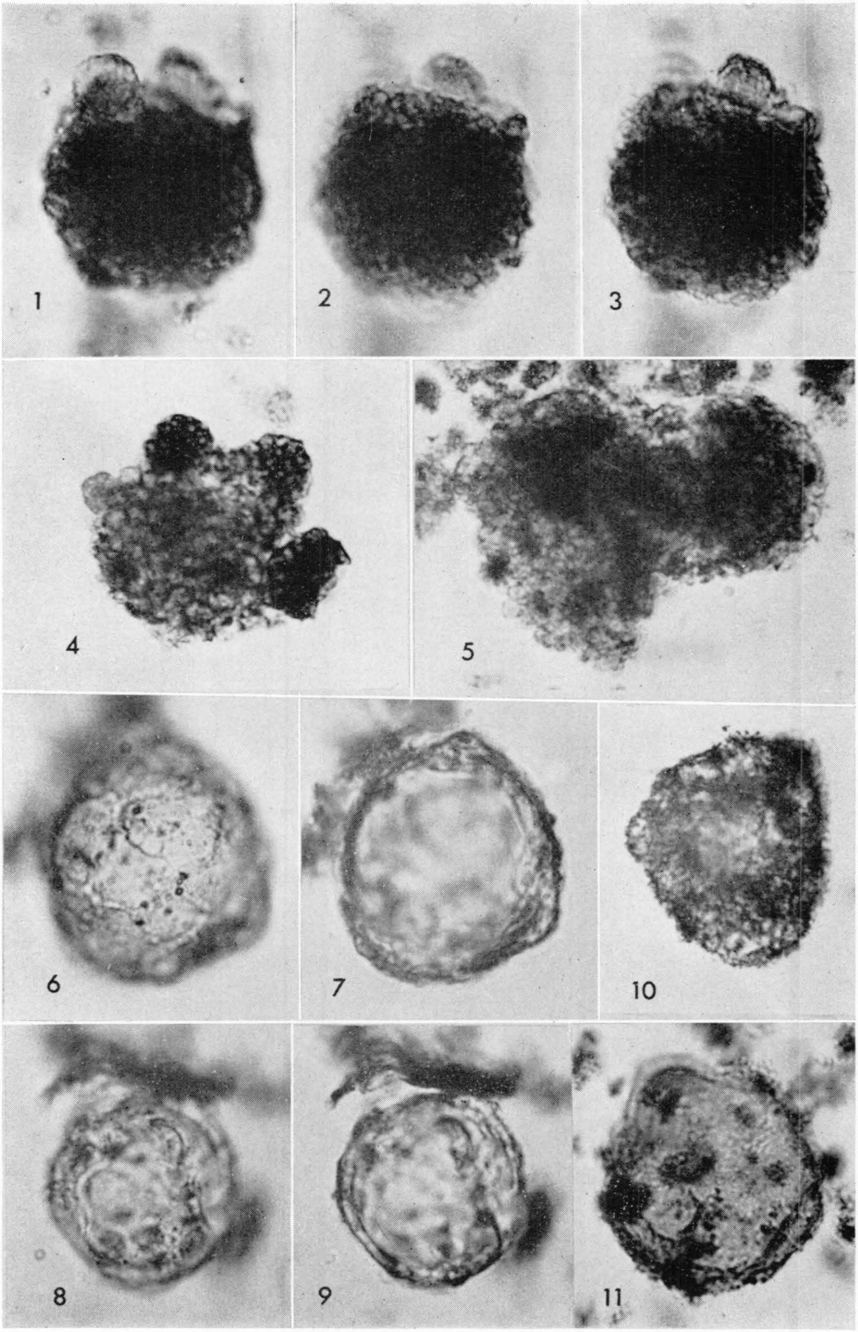
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STUDIES ON THE LATEST PRECAMBRIAN AND EOCAMBRIAN ROCKS IN NORWAY

No. 6.

FOSSILS FROM PEBBLES IN THE BISKOPÅSEN FORMATION IN SOUTHERN NORWAY

By Nils Spjeldnæs, Geologisk Institut, Aarhus Universitet, Denmark.

Abstract.

Fossils are reported from pebbles in the lowest part of the Biskopåsen Conglomerate in the Late Precambrian Lillehammer Subgroup at the northern end of lake Mjøsa in Southern Norway. The most common and widespread fossils are *Papillomembrana compta* Spjeldnæs (1963), calcareous structures (pisolites and others), and cross sections of "Sporomorphs." The present material is not sufficient for biostratigraphical correlations. The geological development of the basin at this time is supposed to be due to epirogenic movements rather than to tectonics. The lithology of the pebbles in the conglomerate is highly variable, and some of them have passed through complicated and severe diagenetic changes.

Introduction.

In 1959 the author found some structures in limestone pebbles in the Biskopåsen Conglomerate (Esmarkian), which were interpreted as organic. Further work revealed a number of organic structures in different types of rock. The most striking one, *Papillomembrana compta* has been described separately (Spjeldnæs 1963).

All the material described here come from the lower part of the Biskopåsen Conglomerate at the base of Biskopåsen (about 125 kms. N. of Oslo). The localities are cuts in the main road, and the railway along the Eastern share of Mjøsa, at the border between the Biskopåsen Conglomerate and the Brøttum Formation. The general geology of the area has been described by Holtedahl (1953, 1960) and by Skjeseth (1963). A detailed study of the region is now made by cand. mag. L. Kirkhusmo. The stratigraphic terminology used in this paper is taken from Henningsmoen 1957.

The present find appear to be the first undoubted records of fossils from the lower part of the Lillehammer Subgroup. Worm burrows of the *Skolitos-*, *Monocraterion-* and *Diplocraterion*-types have been recorded from the upper part of the Eocambrian Vangsås Formation in Furnes by Skjeseth (1963), and similar structures have also been recorded from Ringsaker by Spjeldnæs (written communication, Fossilnytt 1962—3). Rothpletz (1910) recorded a number of supposed microfossils from the Biri Limestone, which he regarded to be of Ordovician age. Timofeef (1963) has also recorded some carbonaceous microfossils from the various horizons of the Sparagmite Group.

None of the fossils were seen in the field, they were all found in thin sections of pebbles from the conglomerate.

The author is indebted to professor O. Holtedahl for inspiring discussions and encouragement in the earlier stages of this study. The author has also benefited from discussions on the sedimentology and stratigraphy of the Biskopåsen Conglomerate with cand. real. K. O. Bjørlykke and cand. mag. L. Kirkhusmo, who has also supplied important informations. Dr. S. Manum has kindly undertaken to study the material, and other samples palynologically, and his results are reported in another paper in this volume. NAVF (The Norwegian Research Council for Science and Humanities) has supported the studies with a grant, for which the author would like to express his gratitude.

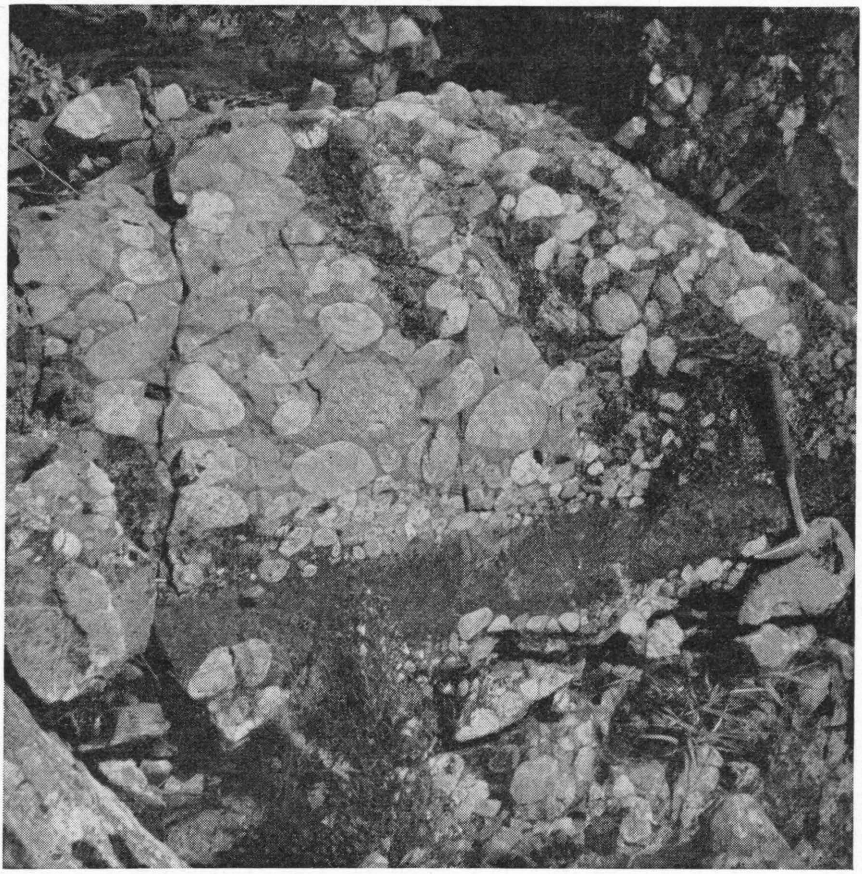
The material containing organic remains, or structures supposed to be of organic origin, is deposited in Paleontologisk Museum, Oslo.

Geological Setting.

The Biskopåsen Conglomerate, in which the fossils are found, is part of the Sparagmite Group. In Southern Norway, the older (Esmarkian) part of the Sparagmite Group, (the Lillehammer Subgroup) is found in the central part of the Sparagmite basin, whereas the younger, Eocambrian part, the Rena Subgroup has a wider geographical distribution (cf. Spjeldnæs 1964, pp. 27—31, textfig. 2).

The Biskopåsen Conglomerate is interpreted as a fluviatile-deltaic formation, because of its structures, such as imbrication of pebbles, and lag-bedding. This is supported by the shape of the pebbles (high sphaericity, but not always well rounded), and geologic distribution.

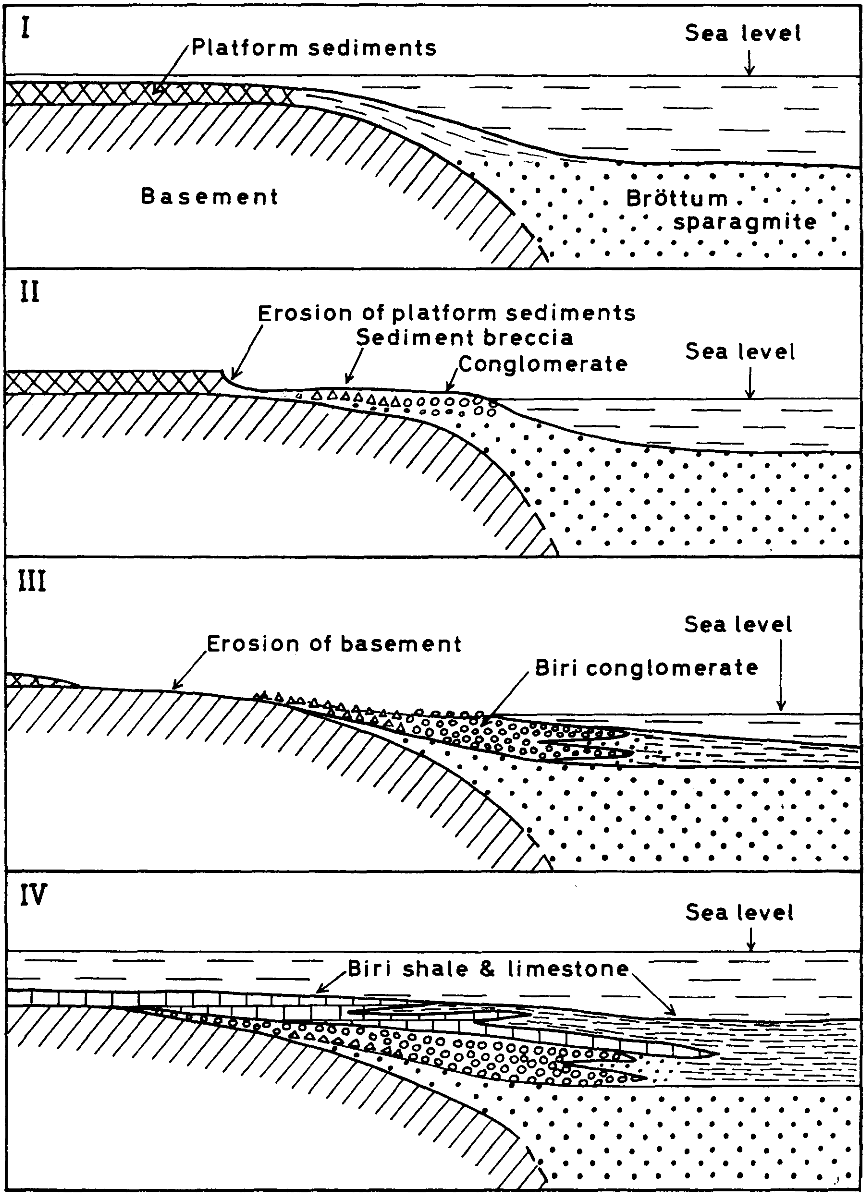
It has been demonstrated by Skjeseth (1963, p. 28—29) and Bjørlykke (1966, pp. 11—12) that the Biskopåsen Conglomerate forms a



Textfig. 1. The typical Biskopåsen Conglomerate, from just S. of the fossil-locality. The pebble frame-work is clearly visible, filled with finer, graywacke or arkose material.

series of fan-like deltas along the southern margin of the basin with transport directions from the South and South-East. In the West and North, the conditions are somewhat more complicated (Englund 1966), but here also the Biri Conglomerate is interpreted as a shallow water deposit.

Traditionally (cf. Skjeseth 1963, p. 29) the formation of the Biskopåsen Conglomerate was explained by a sharpening of the relief and resulting erosion, due to sinking of the basin along faultlines. Since a sinking of a marine basin (the Brøttum Formation is supposed to be


I
Platform sediments
Sea level
Basement
Bröttum sparagmite
II
Erosion of platform sediments
Sediment breccia
Conglomerate
Sea level
III
Erosion of basement
Sea level
Biri conglomerate
IV
Sea level
Biri shale & limestone

marine) would lead to a transgression, and the Biskopåsen Conglomerate must be regarded as regressive, the author has suggested that the Biskopåsen Conglomerate was formed when previously deposited sediments were exposed to erosion during an epirogenic lowering of the sea-level. This is illustrated diagrammatically in textfig. 2.

This hypothesis also explains the presence of large quantities of pebbles of different sediments and other supracrustal rocks in the basal parts of the Biskopåsen Conglomerate. This is best seen in the fossil-locality, where the basal beds almost resemble a sedimentary breccia, with angular fragments of easily rounded rocks, mostly limestones (Textfig. 3). The largest fragments may be up to 2 metres in diameter (Textfig. 4), and the sediment is not well sorted, except for the lack of the finest fractions. The breccia-like conglomerate consists of a peculiar mixture of tolerably well rounded and often highly sphaerical pebbles of hard rocks, such as quartzite, pegmatite quarts and granites, and angular pebbles of highly variable size, mostly consisting of rather soft sediments, most of them calcareous, or with carbonate cement.

This indicates two different sources of the pebbles, one distant, giving hard, presumably older, crystalline rocks, and a very close one, giving sediments which presumably are not very much older than the formation of the conglomerate itself, even if no exact information of their relative age can be found. The source of the "soft" pebbles must have been a very close one. Considering the rapid rounding of limestone pebbles in a fluviatile environment (cf. Pettijohn 1957, pp. 526—27 pls. 37—38) the transport distance can hardly have been more than a few hundreds of metres. This, and the thorough mixing of the diffe-

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Textfig. 2. Diagram, showing the author's hypothesis of the formation of the Biskopåsen Conglomerate (Biri Conglomerate on fig. III). *I.* indicates the time of formation of the Brøttum Formation, with flysch-like sedimentation in the basin, and shallow-water sediments on the submerged platform. *II.* Indicate the beginning of the regression, resulting in erosion of the shallow-water sediments at the platform, and formation of short transported sedimentary breccias at the base of the Biskopåsen Conglomerate. *III.* Further erosion leads to formation of more long-transport fluviatile-deltaic conglomerates in the upper part of the Biskopåsen formation. *IV.* A new transgression results in the deposition of the Biri Formation, with limestones on the platform and marginal parts of the basin, and shales in the central part of it.

Some of the Biri Formation sediments so also occur below the Biskopåsen Conglomerate in some localities, indicating that such sediments were deposited in the initial stages of the regression, and have in some cases been preserved below the conglomerate in the marginal part of the basin.

Textfig. 3. Sedimentary breccia at the base of the Biskopåsen Conglomerate in the fossil-locality. Note the difference between the angular limestone pebbles (i. a. just above the hammer head) and the more rounded, white quartz pebbles. The small black pebbles are either dark limestone or phosphorite, some of which are fossiliferous.

rent types of pebbles suggest an accumulation shortly below a coastal or river cliff. In the upper parts of the conglomerate, the pebble content is more uniform (Textfig. 1), as the "hard" types dominate, and the few "soft" sediments are found as well rounded pebbles. This indicate that the original cliff receded rapidly, probably in a southerly direction.

The sediments found as pebbles may be the lateral equivalent of the Brøttum Formation on the shelf outside the basin (Textfig. 2). Below the Biskopåsen Conglomerate, and the Brøttum Sparagmite there are sometimes found limestones and shales, which have been named the Brøttum Shale and Limestone (cf. Skjeseth 1963, p. 28). According to oral information from cand. real. L. Kirkhusmo, this unit is just a lower part of the Biri Shale and Limestone, and the Biskopåsen Conglomerate must therefore be regarded as a tounge in the Biri Formation.

The latter may indicate that the sediments and therefore also the fossils are derived from the lower part of the Biri Shale and limestone. This will explain the fact that the supposed erosional cliff must have been considerably North of the presumed southern border of the basin, especially if the later tectonic movements are taken into consideration.

The variety of rocks found as pebbles is, however, much wider than that found in the Biri Shale and limestone, and it can not be excluded that other sources are involved also. One of the common rock types among the "soft" ones in the fossil-locality, is a fairly fresh, medium-grained diabase, often developed as a vesicular rocks (cf. Bjørlykke 1905, p. 29). Most of the pebbles, which are up to ½ metre in diameter are fresh, but some of them show a concentric weathering crust, indicating some distance and time of transport. This kind of diabase is not known from the Precambrian area South of the Sparagmite Basin —but being an ordinary diabase type, it may have been confused with the Permian diabase dykes occurring in the Precambrian East of the Oslo Graben (cf. Hjelle 1959). Palaeomagnetic dating of the dykes may show if any of these are of Late Precambrian age. It is difficult to decide if the diabase pebbles come from dykes, sills or thick lava flows, but the absence of very fine-grained types with lava structures points to dykes or sills. The vesicular rocks may indicate lavas, but such rocks are not uncommon in diabase dykes. Anyhow, the presence of a large number of diabase pebbles of uniform petrology may indicate a pene-contemporaneous volcanism.

In the fossil-locality itself, which consists of three parallel sections in the main road, the railway and the shore of lake Mjøsa, there is only a short distance between the base of the Biskopåsen Conglomerate, developed as a sedimentary breccia, and the Brøttum Formation. No intervening limestone or shale is exposed here. In the upper (southern) part of the section, a considerable part of the Biskopåsen Conglomerate, is well known, and especially its tectonics has been described by a number of authors (i.a. Münster 1900, pp. 9—12, Bjørlykke 1905, pp. 28 —30, Holtedahl 1944, p. 29).

Textfig. 4. A large boulder of limestone in the sedimentary breccia at the fossil-locality.

The exact position of the breccia-like conglomerate with fossiliferous pebbles is quite clear, being the lowermost conglomeratic bed above the typical Brøttum Sparagmite. There are, however, arkose/grayvacke beds between the conglomerate horizons higher up, and they are almost indistinguishable from the typical Brøttum Formation lithology. This is also the case higher up in the Biskopåsen Conglomerate, but here the arkose/grayvacke is restricted to thin beds between the conglomerate horizons, and as fill in the pebble-framework in the well sorted, coarse conglomerates.

Bjørlykke (1966, p. 10—12) reports that the border between the

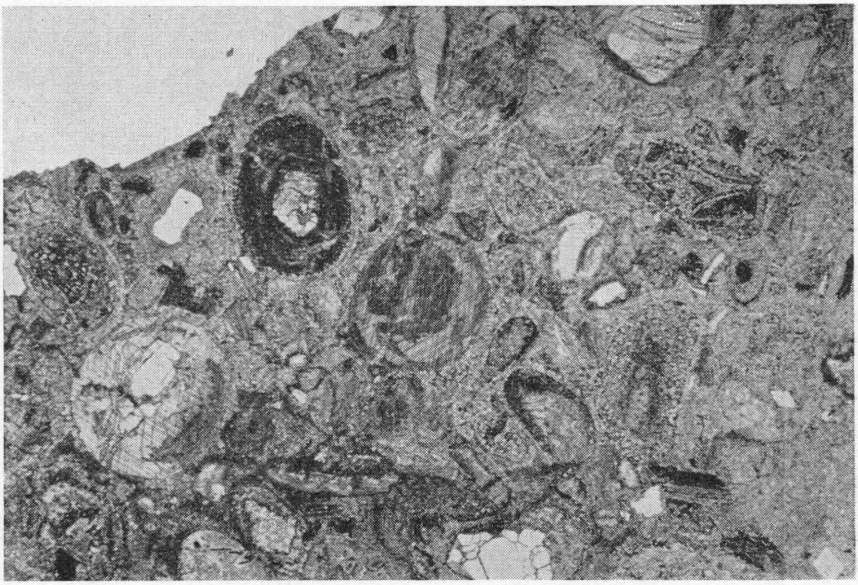
Textfig. 5. Thin section of the sedimentary breccia, showing a phosphatic pebble consisting of an assemblage of different, phosphatecemented rocks, and also a quartz pebble (upper left). Both pebbles are strongly sutured. From the fossil-locality. 5 x

Brøttum Formation and the Biskopåsen Conglomerate is difficult to define, because conglomerate horizons appear with increasing frequency in the upper part of the former formation, and Holtedahl (1944, p. 29) specifically refers to some beds about 20 m. *above* the fossiliferous ones at Biskopåsen as "conglomerate beds in the Brøttum Sparagmite."

Following these authors, the beds discussed here should therefore probably belong in the upper part of the Brøttum Formation. Since the border between these formations is hard to define sharply, and the bed in question—in the opinion of the present autor—belongs to the Biskopåsen Conglomerate both lithologically and by geological genesis, it is referred to the latter formation, at least until a more refined stratigraphical terminology of the border beds has been made.

Structures in carbonate pebbles.

Most of the "soft" pebbles are carbonate rocks, or carbonate cemented ones. The most common type is medium gray, with a yellowish to brown weathering colour. It represents one general type, because all

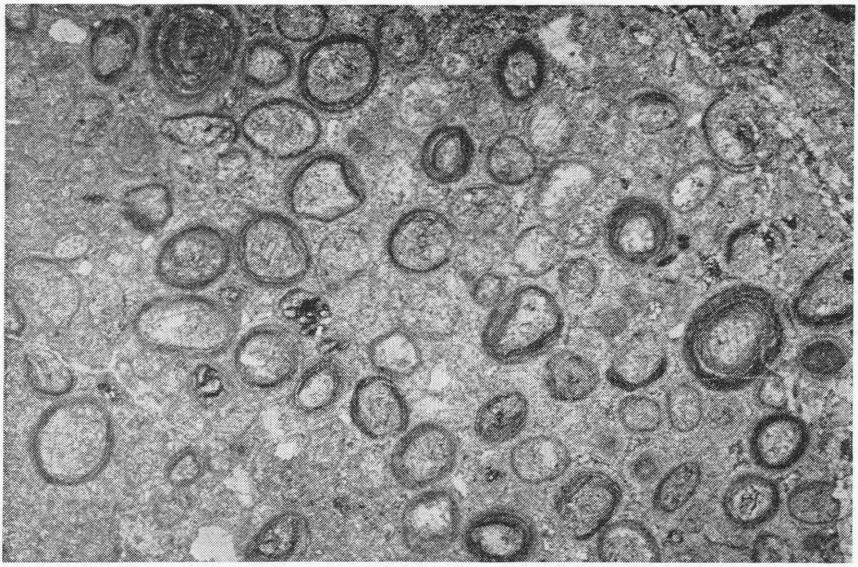


Textfig. 6. Thin section of limestone pebble showing oolites or pisolites completely recrystallized to monocrystalls unless where dark substances still show "ghosts" of the original structure. Note quartz and microcline crystalls of variable size as the core in some of them. From the fossil-locality. 5 x

gradations between the end members are found. It ranges from rather pure carbonate rocks, often oolitic, to carbonate cemented arkoses. The content of terrigenous clastics is highly variable in amount and grain-size, but constant in mineralogy, consisting of quartz and feldspar (normally microcline). The grains—even the larger ones—are often conspicuously angular, and the feldspar content varies from 20 to over 50 %. Clay minerals are generally absent, or difficult to observe. Some of these rocks look like the ordinary Brøttum Sparagmite, where the fine-grained argillaceous matrix has been replaced by carbonate.

The carbonate pebbles have been exposed to severe diagenetic changes, falling into three categories, bulk solution, internal solution, and dolomitization.

The bulk solution shows up as indented pebble surfaces, and as stylolites. The former are certainly due to pressure after deposition of the conglomerate, and these structures are found not only in the carbonate pebbles, but also in the phosphorites and even in the quartz pebbles (textfig. 5). When the pebbles from the Biskopåsen Conglomerate



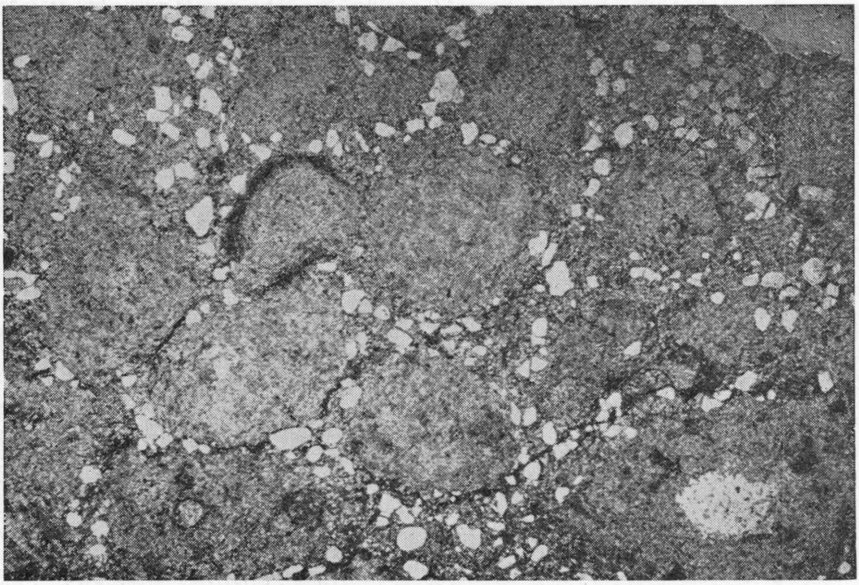
Textfig. 7. Thin section of limestone pebble showing oolites or pisolites most of which do not have a mineral grain as the core. Some appear tolerably well preserved, but others have almost disappeared. From the fossil-locality. 5 x

weather out free, they often show distinct solution marks where the adjoining pebbles have been pressed into oneanother. This is especially the case with the carbonate pebbles, even if they do not appear to have been drastically deformed in shape during this process.

The stylolithes are quite common, as black lines in the limestones. Some of them might be predepositional (in relation to the conglomerate), as they do not show any orientation, neither to bedding nor to directions of tectonic pressure. In some of the pebbles, the stylolithes are exceptionally irregular, and grade into thin shale flakes.

The internal solution is seen as corrosion of quartz grains, and to a lesser degree in feldspars (cf. textfig. 3, 6, 10). In a number of rocks the quartz grains are reduced to mere skeletons, and it is possible that some of the pure carbonate rocks have been formed by carbonatization of an original greyvacke. In some cases a decrease in volume has accompanied this metasomatism, as a reconstruction of the original shape of the quartz grains indicate that they would fill more than the present volume of the rock.

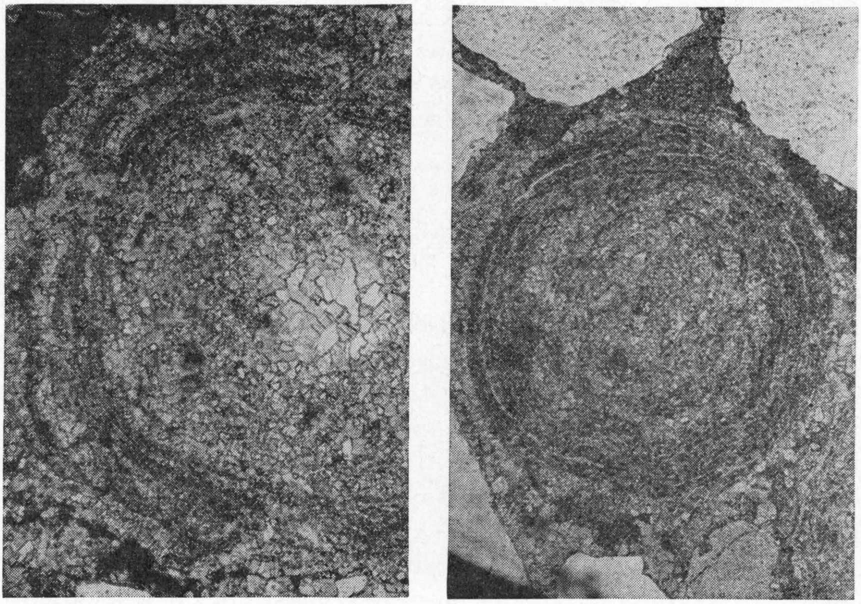
Such a carbonatization of an arkose or graywacke material can be



Textfig. 8. Thin section through a dolomitized pebble, with more quartz in the matrix than most of the others, and completely recrystallized oolites or pisolites. In the centre of some of them new calcedon-like quartz has formed (i.a. lower right). From the fossil-locality. 5 x

expected in a well aerated, warm shallow water sea, and may have occurred just after deposition, or considerably later. Judging from the frequent observations of highly corroded quartz in many of the carbonate cemented rocks of the Sparagmite Group, the author is inclined to regard many of them as the result of carbonatization of normal arkoses and greywackes. The observations made on the present material indicate that this process may lead to almost pure carbonate rocks. As usual in this type of metasomatism, the clay minerals, and other fine grained material disappear first, then the quartz, and last the large feldspars.

A number of the pebbles are more or less dolomitized. This was suspected because of their brownish weathering colour, and it was confirmed by X-ray diffraction studies. (The method used for a semi-quantitative study is the same as that used by Jørgensen & Spjeldnæs 1964.) They range from almost pure limestones with only traces of dolomite to almost pure dolomites. Of the 9 samples studied, 5 are in the interval between 40 and 60 % dolomite. The carbonatization is very strong also in the dolomite rocks, but not significantly stronger than



Textfig. 9. Thin sections of two tolerably well preserved structures, which are interpreted as algal pisolites. From the fossil-locality. 40 x

in the more calcittic ones. This may indicate that even if both dolomitization and carbonatization were dependant on the same environmental factors (temperature, pH and Eh), they were not directly interconnected.

Some of the purer carbonate rocks are oolitic or pisolitic. In most cases the oolites are rather irregular in shape, and in many cases they consist only of a thin crust over a clastic mineral grain, which may be highly decomposed. This grain may either be quartz, feldspar or a carbonate. The layers in the oolites are in some cases accentuated by phosphate, iron-oxides or organic matter. Such oolites remain intact, at least superficially, when a slight recrystallization destroys the normal ones (cf. textfigs. 6–7). By further recrystallization, the whole oolite is transformed into a sphaerical carbonate monocrystal, often with the original clastic mineral as a core (textfig. 6).

In the present material it is difficult to distinguish between real oolites and algal pisolites, because the finer structure have generally been lost by recrystallization. No specimens with the typical radial orientation of oolites are found, but it is assumed that some of the almost sphaerical bodies with regular and continuous concentric lines are genuine oolites. Typical algal pisolites are met with in some cases (textfigs. 9—10) but mostly they are too much recrystallized to be properly identified. This is especially true with the ones having a large core (textfig. 6).

A number of stages in diagenetic changes can be seen. At first, the central part of the oolite or pisolite recrystallize, and the original concentric structure disappears where it is not accentuated by dark substances.

Then the whole body is changed into one single crystal of carbonate (mostly calcite). Because of the cleavage surfaces of the calcite, the oolite rocks at this stage have a striking resemblance to a crinoidal limestones. In other cases the whole sphaere is transformed into a diffuse mass of fine-grained dolomite (textfig. 8). At a last phase in this line of diagenetic change, fine-grained quartz appear in this central part of the sphaeres.

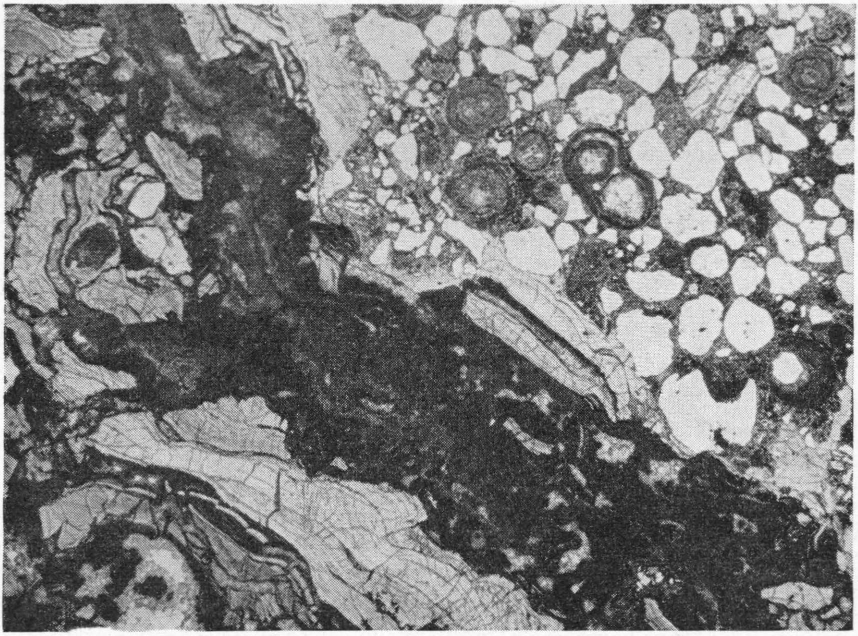
There can hardly be any doubt that the more typical pisolites are formed by organisms (possibly blue-green algae), but it is impossible to define these organisms closer, and also to tell whether the other sphaerical bodies are due to organic activity or are purely inorganically formed oolites. The pisolites are of the general type met with in beds of all ages, ranging from the Precambrian to the Recent, and they lack features which can be utilized stratigraphically.

Other structures of doubtful origin are frequently found in the carbonate pebbles, and some of them may recall cross-sections of fossils. Having in mind all the peculiar pseudo-fossils which may arise during diagenetic changes of carbonate rocks, the author is inclined to regard all these structures as inorganic, or at least too doubtful to warrant a description.

In addition to the ordinary carbonate pebbles referred to above, there are some other ones. Most of them are transitional to the phosphorite pebbles described below. There are also some dark, recrystallized limestones with no fossils or typical structures.

In one of the largest carbonate boulders, there is a complex cavity, filled with stalagmitic calcite (recrystallized), phosphorite and calcedony, in that order (textfig. 10). The preserved part of the cavity is of decimetre size, and the structures in the limestone is otherwise very well preserved, as illustrated by the pisolites in textfig. 9.

Another, unexpected type is an antraconittic limestone of exactly the



Textfig. 10. Thin section of a lime-cemented sandstone with strongly corroded grains of quartz and feldspars, and numerous pisolites. A cavity was formed in the rock, and was later (before erosion of the rock) filled with stalactitic calcite, phosphorite and calcedony. The part of the cavity preserved in the boulder is about 35 cm. long and 15 cm. high. From one of the largest boulders in the fossil-locality. 5 x

same type as found in the Middle and Upper Cambrian of the Oslo Region. Only one boulder, about 30 cm in diameter was found, consisting of several cm. long, columnar crystals of almost black calcite, which smell strongly when hit with a hammer. Even the smell is similar to that of the Cambrian rocks. The antraconites are supposed to have originated in a rather specialized environment (cf. Henningsmoen 1957, p. 61—62), and the presence of this rock-type in the Biskopås Conglomerate indicates that the source area was one with a variety of different sediments.

Structure in phosphorite pebbles.

The phosphorite pebbles are much fewer and smaller than the carbonate ones. The largest is about 10 cm. in diam., and most of them are 1½—3 cm. In contrast to the carbonate pebbles many of them are also well rounded, and it is possible that they have passed through more than one sedimentary cycle.

In composition they range from limestones or sandstones with minor quantities of phosphate cement to almost pure phosphorites, where fossils are more common than identifiable quartz grains, and where X-ray diffraction analysis show only apatite (probably F-apatite) besides very minute traces of quartz and clay-minerals. In many cases the intermediate types show a polymictic assemblage of different rocks, mostly phosphorite cemented, and of different shape and size (text-fig. 5). Even the pure phosphorites often show micro-brecciation and a complex history of recementation (pl. 3 figs. 2—3). Some of the phosphorite pebbles must, judging from their black powder and coal-like appearance have a considerable carbon content.

Organic remains are found only in the rather pure phosphorites, and only in a small fraction of these. Either the pebble is devoid of fossils, or they occur in profusion. The fact that many of the fossils are not well preserved, and that all transitions are found between tolerably well preserved fossils, and those which are almost completely destroyed, may indicate that the fossils were originally much more wide-spread, but were destroyed by diagenetic changes in the sediment.

The organic remains fall into two groups, *Papillomembrana compta,* and "sporomorphs." The latter noncommittal term is used in accordance with Roblot (1963, p. 1559, 1964, pp. 107—108) for small (5—60 μ) single or complex, sphaerical structures with carbonaceous walls.

It is used here in a slightly extended sense, including also larger structures incorporating small ones, even if they have a mineralized shell. Another term which might also have been used, is acritarchs, in the sense of Downie, Evitt & Sarjeant (1963), but as the studies of the present material has not progressed far enough to allow commitments as to biological affinities, they are referred to as sporomorphs and related structures—in short sporomorphs. This does not indicate that the author believes that all of them necessarily are of vegetable origin, even if most of them may be so.

Papillomembrana was described by the author (Spjeldnæs 1963), and there is nothing to add to the description of the well preserved specimen, although the figures of the type specimens are given (pl. 1, figs. 1—3, pl. 2, fig. 1) here because of the bad reproduction in the original paper. Neither is there any new information on the possible biologic relationship of the organism nor any records of it, or similar ones, from other localities.

The holotype is still the only tolerably uncompressed specimen known, all the others are more or less flattened. It is difficult to give an exact number of the specimens found, because there are many badly preserved specimens, and a complete series exist from compressed, but readily identifiable specimens, to "ruins" which can only be suspected to belong to *Papillomembrana* because of their resemblance to the better preserved specimens in size, colour and gross shape. In one thin-section more than 30 such "ruins" are found, but only 3—4 specimens can definitively be referred to *Papillomembrana*.

Several different types of sporomorphs occur, most of them in the same pebbles as *Papillomembrana*.

Type I. 600—700 μ in longest diameter, slightly compressed from one side. The walls are thin, black and irregular, presumably consisting of an organic membrane (pl. 3, figs. 1—2). The irregularities of the walls may be partly original, but has evidently been much modified by diagenetic processes. In some cases the wall has disappeared completely, and in others it is only preserved in small fragments. The interior is filled with clear, isotropic phosphorite, without the structures found in the darker phosphorite outside the sphaere. In most cases there are also small, black granules distributed in the interior, and in one or two cases (pl. 3, figs. 1—2) they are partly aggregated into a large number of small sphaeres, 8—15 μ in diameter, consisting of one layer of granules, which are up to 2—2½ μ in diameter. The larger granules are "cellular," but the smaller and more common ones appear just as black dots.

The number of specimens belonging to this type is difficult to establish, as there are all transitions from the well defined ones to lumps of light phosphorite with the same general size and shape, but entirely without a wall. About 6—8 well defined ones, and approximately 20 diffuse ones have been observed.

Type II. Sphaerical, uncompressed, 250—450 μ in diameter with a wall resembling that of type I in structure, but with a much more irregular outline, mostly as bulges of the wall and thread- or filament-like protuberances of considerable dimensions. These structures may have been modified through diagenesis, but are too common and regular to be all accidental (pl. 3, fig. 3, pl. 4, fig. 1, pl. 5, fig. 1, 5). There might also be apertures in the walls, but it is difficult to discriminate between original apertures and dissolved parts of the walls in this type of material. Like the first type, they are filled with clear phosphorite, often with some granules, but without the filamentous structure common to most of the phosphorite outside the sporomorphs. In one of the specimens of this type, (pl. 5, figs. 1, 6) there is a rather dense mass of rod-like bodies about 5—7 μ in length and 1—1½ μ in width. The interpretation of these structures must be left open at present, even if they resemble features described as fossil bacteria and fungi, as their organic nature is not entirely beyond doubt.

About 10 well preserved specimens, and more than 40 diffuse ones have been observed.

Type III. Almost perfect sphaeres (in a few cases aggregates of sphaeres), without visible ornamentation or outgrowths of the wall (pl. 2, figs. 2—3). Most of them are 70—90 μ in diameter. Smaller cross-sections show thick and diffuse walls, indicating that they are peripheral rather than equatorial sections. There are also a large number of smaller, more or less circular sections, but they are hard to study, because their diameter is too close to the thickness of the thin-sections used (approximately 20 μ). It is therefore impossible to give exact information on the real size-distribution of this type, the figures above refers to the larger, and well preserved specimens, and do only give a definite upper limit for their size.

Like the two other types, the interior is filled with light, isotropic phosphorite, and there are no structures observed inside this type. The walls appear to be thicker, but that might be due to the fact that more specimens are well preserved, and the difficulty in measuring the wall thickness in the other types. In a few specimens the clear phosphorite is also found in a thin band outside the wall. This may indicate either that the clear phosphorite was formed by late diagenetic processes, or that these specimens had an outer wall which has been dissolved. It is difficult to give an exact number for the specimens of this type, but it is the most common one in the present material. More than 80 undoubted specimens have been observed, and a large number of diffuse or small ones do also occur.

Type IV is found only in a few specimen, and all characteristic features are found only in one of them (pl. 3, fig. 2, pl. 5, fig. 4). It is about 125 μ in longest diameter, slightly assymetrically dorsoventrally compressed (bunlike). The wall appears to be granulose, and laterally thickened. The irregularities in the wall may be due to diagenesis, as the material is not large enough to prove its constancy. In the central part there is a sphaerical body, granular and quite similar in appearance to the phosphorite outside the sporomorphs, but without the characteristic filamentous structure. Between the sphaerical body and the wall, there is a thin layer of clear phosphorite, which also continues outside the wall, with a diffuse outer border.

Type V. Only three specimens have been found, and the description is based on the best preserved one (pl. 3, fig. 3, pl. 5, fig. 3). It consists of a cluster, 160—190 μ long of irregular sphaeres with granular walls. The sphaeres are from 30 to 80 μ in diameter. The wall substance is light brown, and entirely different from those in the other types. The thickness of the walls are also highly variable, and there seems to be openings between the sphaeres.

In addition to these rather common, or well defined types, there are some others which are either less well defined, or occur only in one specimen.

Type VI. Only one fragmentary specimen has been observed (pl. 5, fig. 6). It consists of a sphaerical shell, consisting of quartz, about 500 μ in outer diameter, and 60—65 μ in thickness. The fragment, which consists of about 170° of the shell, consists of three single crystals of quartz, but this may be due to later recrystallisation. There is no sculpture to be observed neither on the outside nor on the inside of the shell. The interior is filled with an irregularly globular mass of granulose material. This may be interpreted as diffuse sphaeres, approx. 30 μ in diameter, with granulose walls, but they have suffered too much from diagenetic changes to be properly described.

Type VII. Only one specimen has been observed (pl. 4, figs. 2—3), consisting of an highly irregular membrane or wall surrounding a roughly sphaerical mass consisting of small, granular sphaeres. The shape of the outer wall may easily be due to external and diagenetic changes. The granular sphaeres vary in diameter from 5 μ to 20 μ, and are of brownish colour, different from the ordinary walls. There are also several other irregular membranes resembling the present one in size and structure, but without the granular sphaeres inside.

Type VIII. Three specimens are found, and the description is based on the best preserved one (pl. 5, fig. 2). It is an irregular, angular body, possibly a fragment of a larger one, 350 μ in length, and darker in colour than the surrounding phosphorite. It shows a system of thin, distinct lines or tubes parallel to the margins, and branching at the widest end.

In addition to these, well defined types there are in the phosphorites a number of stylolite-like membranes, often of considerable size. Some of them are similar enough to stylolites in other rocks to be interpreted as inorganic structures, but other are very irregular, curved, and appear to carry long protuberances. Some of these membranes may therefore be of organic nature, even if it is impossible to define them properly on the present material. Some of them are shown in figures illustrating other structures, particularly pl. 1, fig. 1, and pl. 3, figs. 2—3.

There are also some micro-structures in some of the specimens (pl. 5, fig. 5) as referred to above. The whole phosphorite also shows a characteristic, filamentous structure, which under high magnifications appear as tufts of very fine filaments. Such structures are known also from other, younger phosphorites, and may be biological in origin. They recall fungal threads, but since the thin sections used for this study are too thick to observe the details of the filamentous structures, they are only mentioned here. The appearance of the structure in the thin sections without immersion optics is seen in pl. 5, fig. 5 and pl. 2, fig. 3, and some of the details observed in higher magnification, and with the use of immersion optics can be seen in pl. 1, fig. 2 (inside the holotype of *Papillomembrana compta*).

Concluding Remarks.

The fossils found in the pebbles in the Biskopåsen Conglomerate are remarkable in several ways.

They are more numerous, and varied than most Precambrian assemblages described up to now. This may partly be explained by the comparatively young age supposed for these beds, but it is perfectly understandable that some authors (i.a. Rothpletz 1910) have suggested an Ordovician age for the Biri Formation, with similar lithology as the pebbles described here. The observation of some types of fossils where small bodies occur within larger ones in the Biskopåsen pebbles recall similar observations from Ordovician beds (Kozlowski 1963, Henry 1964). The structure and dimensions are, however, different, and the fossils described here are at present not of any stratigraphic value, as similar material from other, contemporaneous beds have not been studied with the same methods.

As mentioned above, no fossil resembling *Papillomembrana* has yet been described from other localities, and the other structures are either too generalised, or also unknown in other localities. A structure (Fossil I) described by Ewers (1933, figs. 2—3) from the Visingsø Formation in Sweden resembles type VI described here in having a quartz shell, but differs in details of structure, and in size. The other structures described by the same author do not recall any of the forms from the Biskopåsen pebbles, even if the material is the same (phosphorite pebbles), and the supposed age (young Precambrian) is roughly the same.

When the present fossils are compared with the assemblage described from essentially the same material by Manum (1967) the differences are immediately apparent. In Manum's material, the organized structures are very few, whereas organic debris is very common. The sizes are also different, as the most important structures described here are much larger than those in the palynological material. This is partly due to the fact that the smaller specimens are difficult to observe in the thin sections, and are easily overlooked. The lack of large specimens in the dissolved material is explained by the fact that the walls of most specimens, as visible in thin sections, are incomplete, and often almost completely destroyed. There are only some very few specimens, which survive both the diagenetic changes and the extraction process. On the other hand, these are much better preserved than the average ones observed in the thin sections.

It is evident that also the larger specimens (including *Papillomembrana)* occurred in the material which has been studied palynologically, since most of the pebble which yielded the type specimen of *Papillomembrana compta* was used for these studies, and the two thin sections made from the same pebble both showed numerous large specimens.

It is also interesting to note that (except for *Papillomembrana)* none of the specimens seem to have been compressed. This, and the filling of most of the specimens with light coloured phosphorite, contrasting strongly against the darker groundmass, indicate that the phosphorite was formed at an early stage of diagenesis.

The smaller bodies found inside type I can with great certainty (because of their size, and wall structure) be referred to Manum's type A, and it is likely that a number of the smaller specimens of type III can be referred to his types E and F. A conclusion about the preservation and distribution of the fossils in the pebbles is that the palynological technique gives a well preserved, but highly selective assemblage whereas the thin section studies gives a much richer, but less well preserved one.

As regards the age of the pebbles, there is lots of coherent geological and lithostratigraphical evidence pointing to young Precambrian age, possibly rather close to the Cambrian/Precambrian border, but there are some uncertainties to this, aside from the young aspect of the assemblage, and the obvious fact that the pebbles are older than the conglomerate in which they are found.

Absolute age determinations of beds in Northern Kola (Polevaya & Kazakov, 1961, p. 110), which have been correlated with the Sparagmite Group in Finnmark gives ages both on clay minerals and glauconite which are just above 1000 m. y. The Porsanger and Lillehammer subgroups are correlated because of their striking lithological similarity, especially in the upper part, but it should be noted that the crystalline basement below them are of different age, being much older in Finnmark than in southern Norway. In fact, if the Lillehammer subgroup could be proved to be about 1000 m. y. old, it would be older than the supposed age of the crystalline basement (8–900 m. y.)! The geochronology of the basement is also somewhat in doubt, as it is possible that the basement of the Lillehammer Group belongs to the older Precambrian, on the Eastern side of the "mylonite" zone, which divides the Precambrian both of Sweden and Norway (cf. Hjelle 1963, fig. 1).

Even if the evidence for a young Precambrian (Vendian or Riphean III) age of the Lillehammer Subgroup seem good, the uncertainties mentioned here make more studies necessary. Both the isotope ages of the immediate basement, and biostratigraphic studies, especially correlations with the Russian platform will be valuable.

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Explanation to plates.

All figures on the plates are from thin sections of phosphorite pebbles from the basal part of the Biskopåsen Conglomerate, at the fossil locality.

The thin sections belong to Paleontologisk Museum, Oslo.

The photographs shown in pl. 1, figs. 2 and 3, and pl. 2, fig. 1 were taken by Dr. S. Manum, the rest by the author.

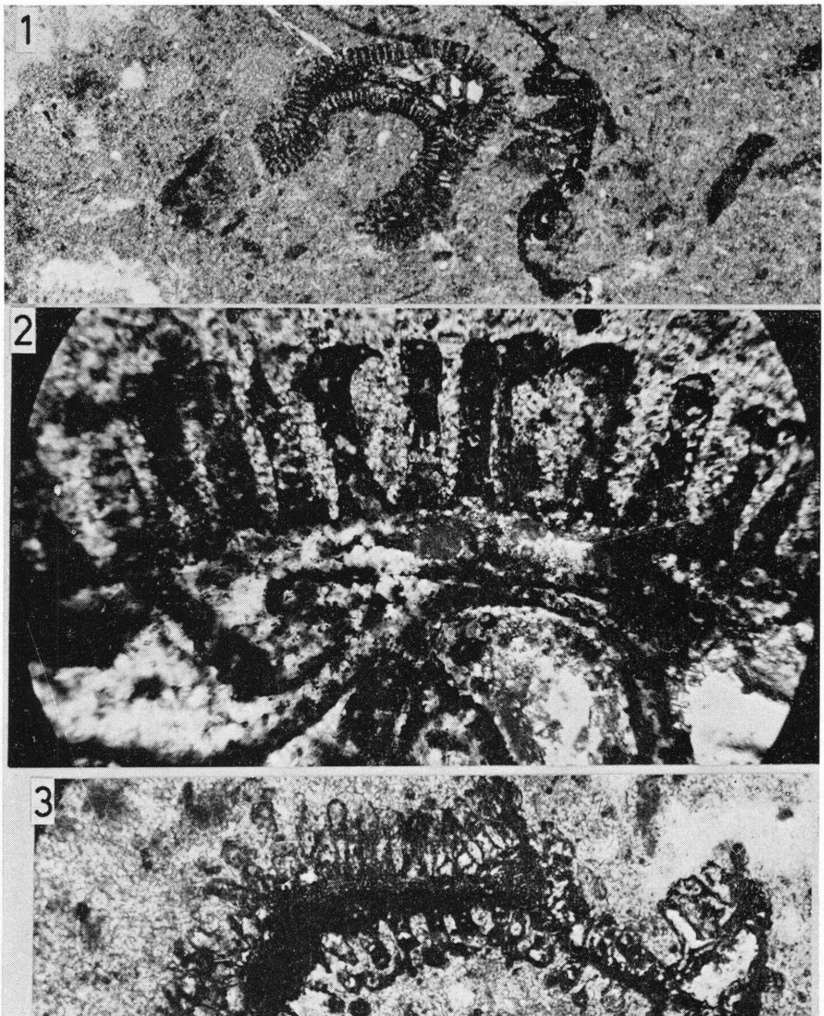
PLATE 1

Papillomembrana compta Spj.

fig. 1. Holotype (PMO 73173) and the surrounding rock, including a stylolite-like black membrane. 60 x.

fig. 2. Detail of holotype, showing structure of protuberances and enigmatic internal features. On the internal walls, there are tufts of very thin threads (fungal or algal?). 740 x.

fig. 3. A compressed specimen, showing the hollow protuberances.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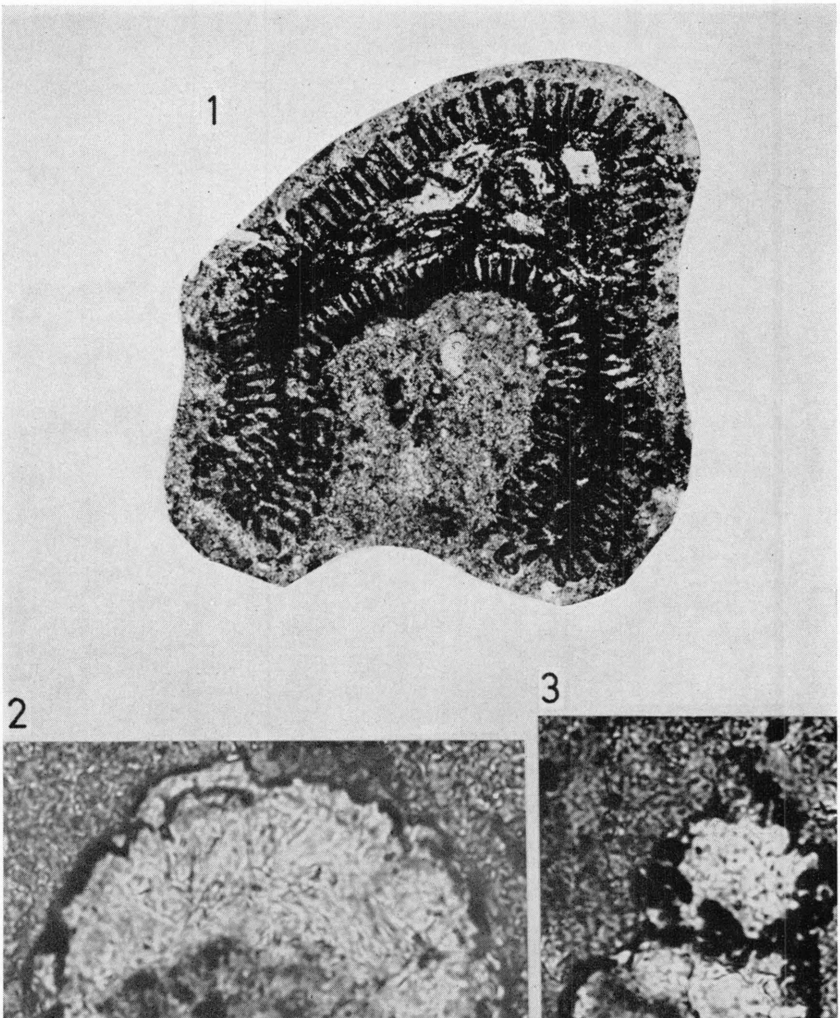
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PLATE 2

fig. 1. *Papillomembrana compta* Spj. The holotype. 135 x.

fig. 2. Sporomorph, type III. The structures seen in the walls may be due to partial destruction of the walls, or be original. 675 x.

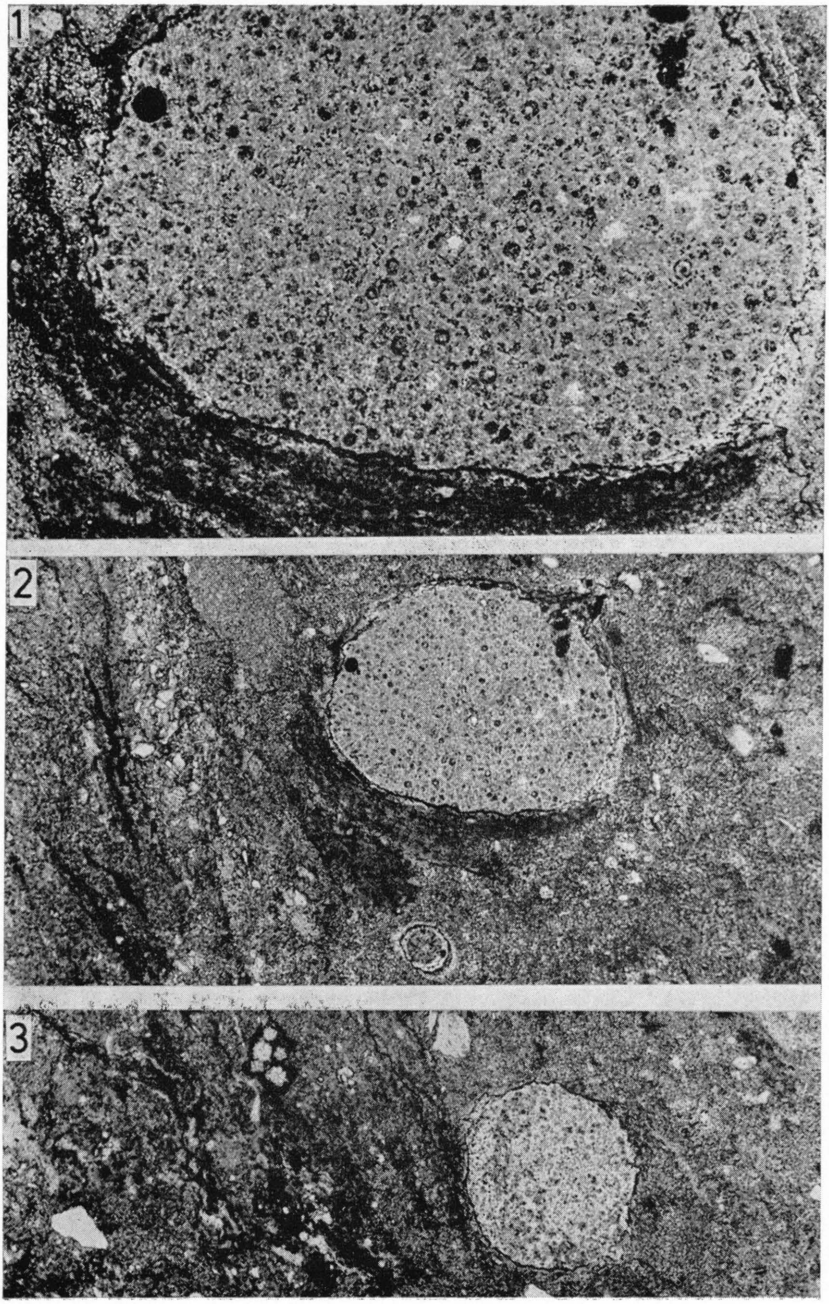
fig. 3. Sporomorph, possibly belonging to type III, consisting of an aggregate of three sphaeres. This is the only specimens of this kind observed. 675 x.

PLATE 3

fig. 1. Sporomorph of type I, with small sphaeres inside, resembling Manum's type A. 150 x.

fig. 2. Sporomorph of type I, the same specimen as above, but also showing one of type IV (cf. pl. 5, fig. 4) 60 x.

fig. 3. Sporomorphs of type II (cf. pl. 4, fig. 1) and type V (pl. 5, fig. 3) 60 x.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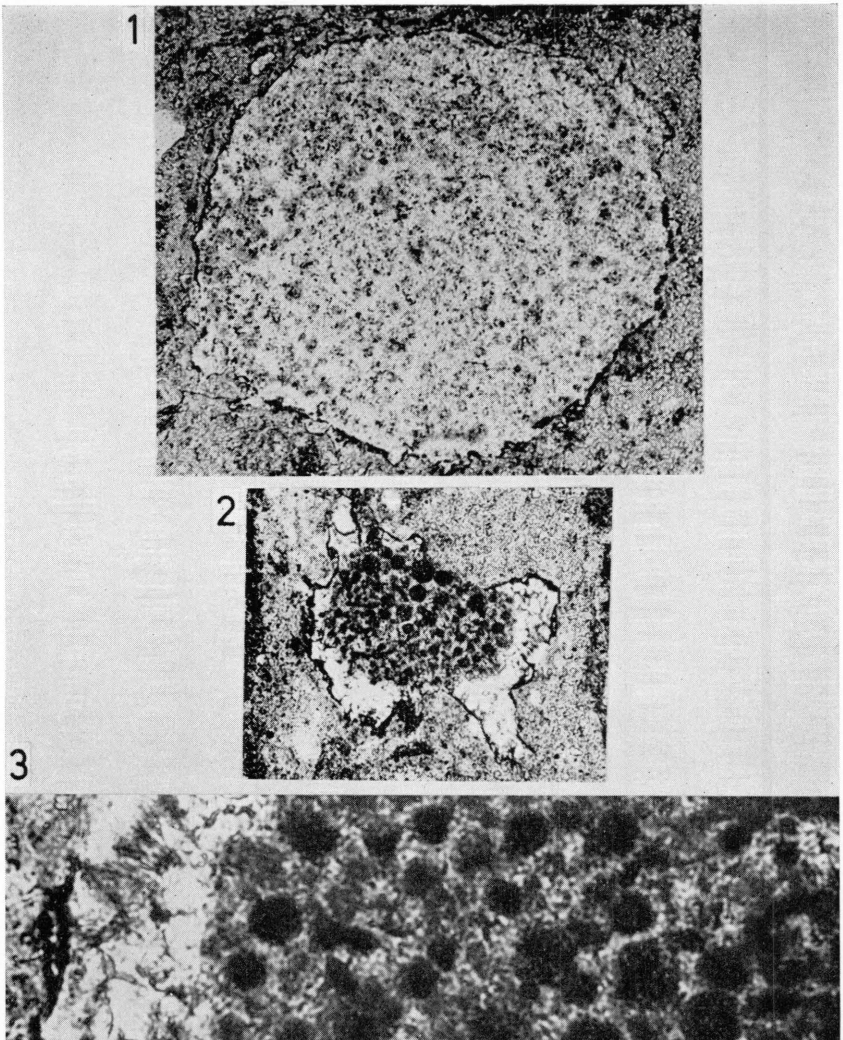
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PLATE 4

fig. 1. Sporomorph of type II, showing protuberances of the wall, and badly defined internal structures. 150 x.

fig. 2. Sporomorph of type VII, showing thin, irregular outer membrane, and cluster of sphaerical bodies inside. 150 x.

fig. 3. The same specimen as in fig. 2, but enlarged to show the sphaerical bodies, and structure in the phosphorite. 675 x.

PLATE 5

fig. 1. Sporomorph of type II, with rod-like bodies inside. cf. also fig. 5. 150 x.

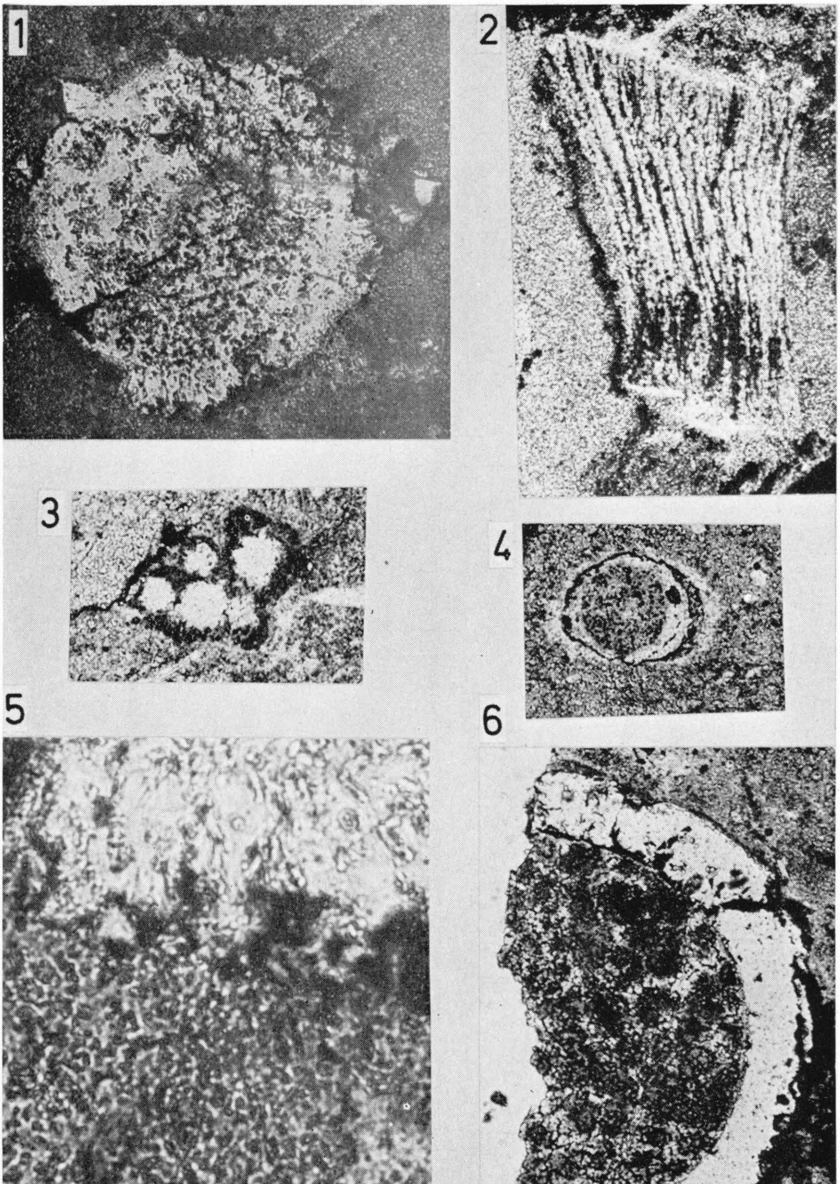
fig. 2. Problematic fossil, type VIII, showing internal structure. 150 x.

fig. 3. Sporomorph of type V, showing thick, somewhat diffuse walls, and possible connections between the agglomerated bodies. 150 x.

fig. 4. Sporomorph of type IV, showing thickened, granulose walls, and clear phosphate also outside the structure itself. 150 x.

fig. 5. Detail of wall of the sporomorph shown in fig. 1. The wall structure is almost completely lost, and the different filamentous structures inside and outside the wall is easily seen. 675 x.

fig. 6. Sporomorph of type VI, showing quartz shell, and globular bodies inside it. It should be noted that the quartz in the shell is the bulk of the quartz found in the whole thin section. 150 x.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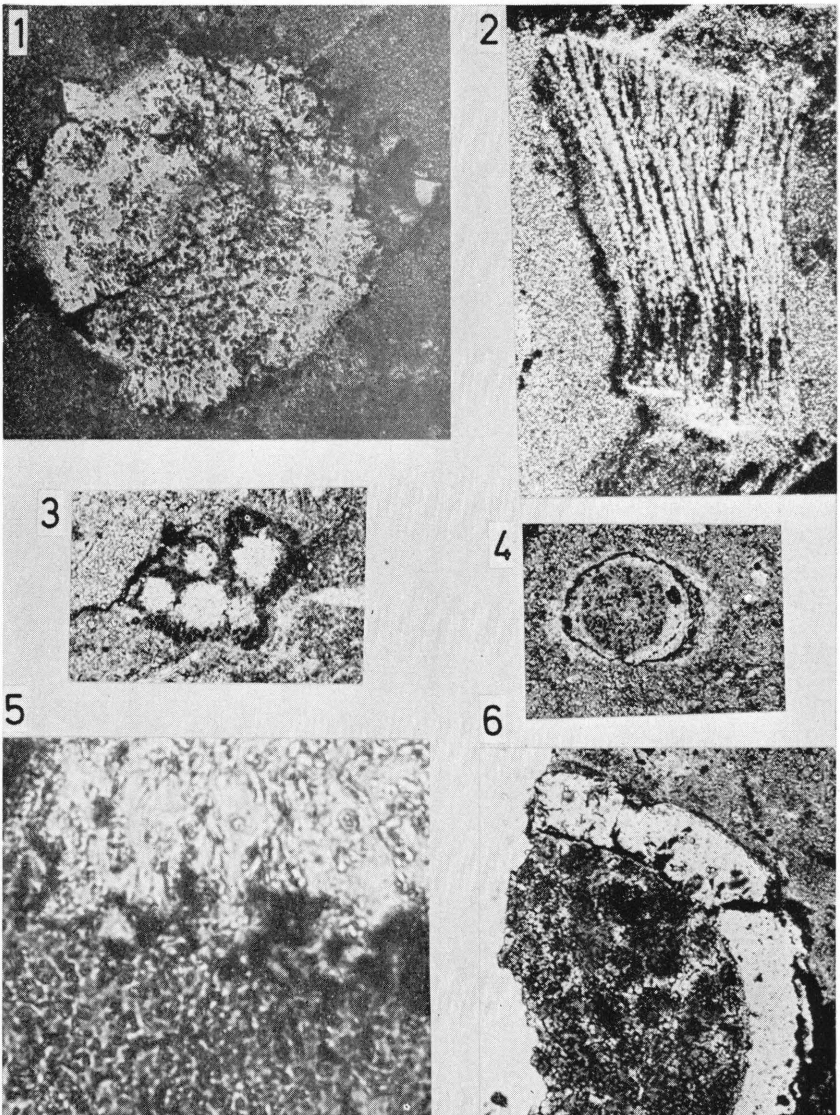
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STUDIES ON THE LATEST PRECAMBRIAN AND EOCAMBRIAN ROCKS IN NORWAY

No. 7.

EOCAMBRIAN ROCKS ON THE NORTH-WEST BORDER OF THE TRONDHEIM BASIN

By J. Springer Peacey
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Abstract.

Three occurrences of Eocambrian rocks on the north and west borders of the Trondheim basin are compared, namely in the Gangåsvann, Opdal and Tømmerås areas. It is shown that the sequence in the Gangåsvann area consists of two parts: a lower, highlyfolded succession which, in geological setting, resembles the Opdal area and an upper, lower-grade unit which closely compares with the succession in the Tømmerås anticline. The two are separated by a major tectonic break which marks the border of the "Trondheim region" proper.

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The apparent absence of Eocambrian rocks on the north-west margin of the Trondheim basin is only one of the intriguing anomalies shown by the current 1 : 1 million geological map of Norway. But since the publication of the revised edition in 1960 new work south-west of Trondheim, in the Gangåsvann area (Peacey, 1963), and around the Tømmerås window (Springer-Peacey, 1964) suggests that the search for these earliest Caledonian sediments is a rewarding study because they can provide a marker horizon by means of which the complex geological history on the edge of the "Gneiss region" may be elucidated.

Descriptions of the two areas mentioned were published in the chronological order that they were mapped but, by chance, the results of the second piece of work throw light on the first. Thus it is now possible to understand the tectonic position and setting of Eocambrian rocks in the Gangåsvann area better than previously and, in turn, this knowledge illuminates the problem of how the rocks of the Trondheim basin relate to the high-grade "Gneiss region" lying to the west.

(a) The Tømmerås area.

Geological relationships in the Tømmerås anticline hold half the solution to the puzzling association of Eocambrian rocks seen farther south. Here, in an area with simple structure and low metamorphic grade, a number of features appear which seem to characterize the Eocambrian in a particular geological setting, and which can again be recognized in the upper part of the rocks of this age in the Gangåsvann area.

At the northern extremity of the Trondheim basin the Precambrian basement is domed up to form a long ridge trending north-east. Upon this lie greenschists and mica-schists which belong to the Cambro-Silurian and beneath them a thick sequence of sandstones and siltstones, presumably Eocambrian in age. Along the south-western flank of the ridge the cover rocks thin towards the substratum and finally the Eocambrian and the lowermost Palaeozoic units wedge out against it (Fig. 1). As the rocks are only weakly metamorphosed, sedimentary features, such as cross-bedding and grading, are well preserved, particularly in the Eocambrian. In the Palaeozoic rocks thin horizons can be traced for long distances as they taper against the basement and there seems no good reason to doubt that the junction between basement and cover represents a primary discontinuity with overstep of the younger horizons over the older. (Springer-Peacey, 1964.)

The Eocambrian rocks, named in this area the Leksdalsvann Group, comprise two characteristic units: a lower one of dark, sandy siltstones with pale calcareous lenses, and an upper unit of pale, microcline-bearing, graded and false-bedded sandstones. Another diagnostic feature of this group is the scarcity of basic igneous material, either volcanic or intrusive. Only rarely do thin amphibolite sheets occur in it and this provides striking contrast to the rocks above and below. In the Pre-Cambrian basement the basic rocks are principally intrusive igneous bodies. They represent a swarm of dolerite and gabbro sheets in which the original ophitic textures, the lensoid shape and primary cross-cutting relationships can sometimes be observed. The Palaeozoic rocks seem, from their composition, to be liberally mixed with volcanic débris; the thick amphibolites present may be flows or water-laid effusive material. But truly igneous textures have never been observed even in the most massive amphibolite horizons. Thus, before the deposition of the Eocambrian in this area, the basement rocks were already fractured

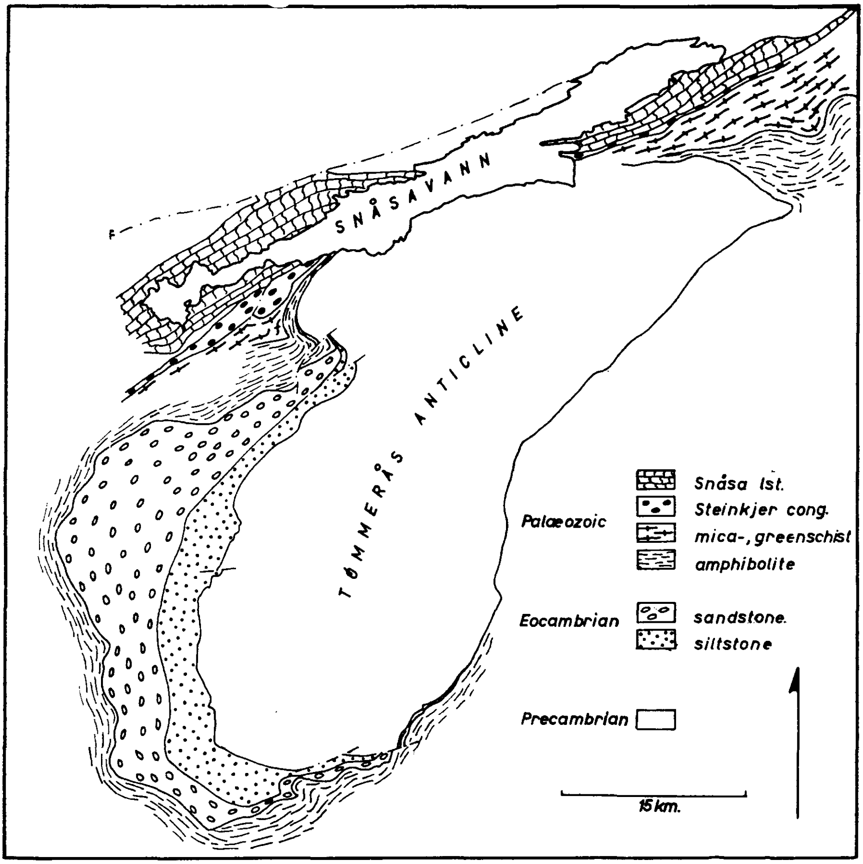

Fig. 1. Geologisk kart over Tømmerås-området.

and intruded by ophitic dolerites; the subsequent igneous activity, virtually absent in Eocambrian times and which became more pronounced later, was mainly volcanic in character.

Another aspect of the geological history which perhaps typifies the Eocambrian in this particular setting is the low metamorphic grade and the simplicity of the tectonic history. For although there are minor structures of various ages and metamorphism sufficient to induce the growth of garnet locally, these do not disguise the sedimentary nature of the rocks or their original disposition.

(b) The Opdal area.

The Eocambrian is seen in another setting in the Opdal area and this provides the second half of the solution to relationships at Gangåsvann. Although an upper series of Eocambrian rocks is missing here many other features of the two areas are remarkably similar.

The stratigraphy is often blurred by the effects of high-grade metamorphism and extreme migmatization but, despite this, in many places distinct lithological units can be recognized. The Eocambrian is represented by feldspathic flagstones with small amounts of mica-schist and above them lie mica-schists and amphibolites which are thought to be of Cambro-Silurian age.

The intense multiple folding which these rocks have suffered is obvious even from the 1 : 1 million map and it is scarcely to be expected that primary features remain. It is often difficult to tell which of the rocks represent the "basement" and the only trace of original unconformity is suggested by the fact that the flagstones rest upon differing rock types at different localities (Holmsen 1960). Both Eocambrian and Palaeozoic are cut by lenses and sills of hornblende schist which have been folded together with the rocks surrounding them. These basic sheets are interpreted as intrusions and lavas of Lower Ordovician age.

This highly-folded and metamorphosed complex of rocks, in which basement, cover and the later intrusions have been deformed together, is separated from the rocks of the Trondheim synclinorium by a thrust plane, dipping eastwards, which carries low-grade Palaeozoic deposits upon it. Not only is there a marked difference of grade across this boundary but it also appears that the tectonic history of the upper rocks has been much simpler (Holmsen 1955).

(c) The Gangåsvann area.

Whereas in Opdal the whole fabric and mineralogy of the rocks has frequently been rebuilt by the effects of the Caledonian orogeny, erasing any traces of former relationships, the process in the Gangåsvann area has not been so penetrative. Although in places metasomatism has swamped the rocks, converting all except the most quartz-rich to unremarkable granite-gneiss, elsewhere it is still possible to detect something of the former stratigraphy, tectonic pattern and even metamorphic grade.

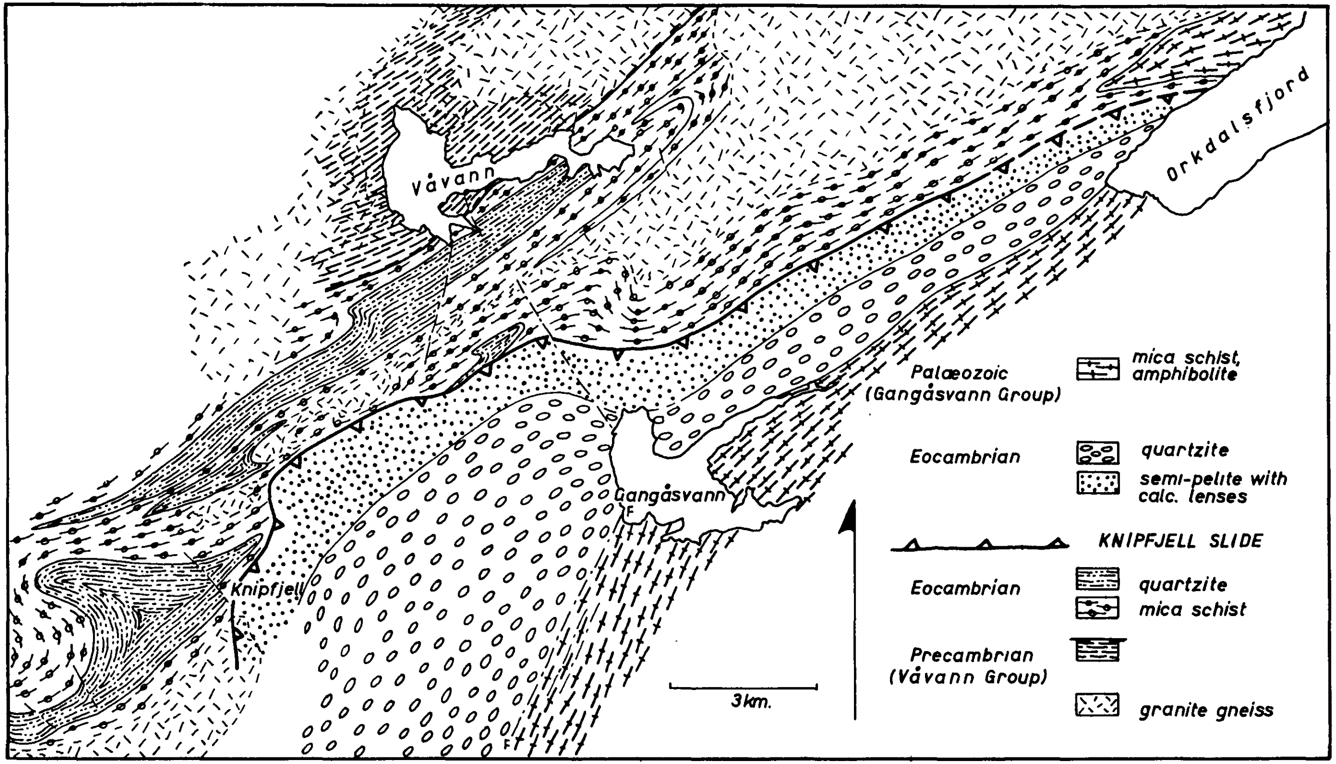

Fig. 2. Geologisk kart over Gangåsvann-området.

An important feature of the area is the Knipfjell slide, a plane of discontinuity dipping south-east, which runs north-eastwards and divides the outcrop of the supposed Eocambrian rocks into two. (Fig. 2.) At its northern extremity the foliation in the rocks above and below is virtually parallel, making the junction difficult to locate, and at its southern end the contact is masked by later metasomatic effects. But on Knipfjell, where late-stage movements have rejuvenated the slide, an angular disjunction can be observed. On a larger scale the presence of the slide can be detected by the difference of tectonic pattern on the two sides and, less obviously, by the difference of metamorphic grade.

Above the slide the rocks are remarkably similar to those of the Tømmerås area. The metamorphic grade is slightly higher and there has been more deformation but it is still to recognize the various groups. The Cambro-Silurian, called here the Gangåsvann Group, is represented by garnet-hornblende-mica schists and amphibolites, with or without garnet, whilst in the Eocambrian two units can be distinguished. The one above comprises microcline-bearing quartzites, whose correct stratigraphic position is confirmed by grading and cross-bedding, and beneath them lies a thickness of fine, dark semi-pelitic rocks containing characteristic small lenses of paler, calcareous, sandy material. The Knipfjell dislocation follows very closely beneath this unit with calcareous lenses and it now seems logical to extrapolate it north-westwards to the shore of Orkdalsfjord (Fig. 2).

Above the slide the metamorphic grade is lower and the degree of deformation less intense than in the rocks below. In the absence of analyses and mineral phase studies it is difficult to make precise comparisons of the grade but in general terms it can be said that whilst the rocks below may develop coarse garnet-kyanite assemblages, those above never become more than medium-grained biotite-garnet schists. Several generations of minor structures exist in the upper rocks but they are only weakly developed and do not greatly disrupt the stratigraphy.

As in the Tømmerås area basic igneous material is very scarce in the upper series of Eocambrian rocks, and whilst in the Cambro-Silurian there are abundant thicknesses of hornblende schist, no evidence of intrusive igneous textures has been observed.

Beneath the slide the Eocambrian is represented by alternating quartzites and mica-schists, cut by numerous sheets and lenses of hornblende schist which occasionally show transcurrent relationships and the remnants of ophitic texture. Although no primary sedimentary features have been seen in the host rocks it is presumed that they represent a sedimentary sequence and that the hornblende schists are the altered remains of a dolerite dyke swarm.

At least one reason for the absence of primary features in the quartzites and mica-schists is the intense deformation they have undergone. Two periods of major folding have produced remarkable lunate outcrops where the axes of Early ENE-trending folds are cut by later Main NE-trending fold axial planes. This complex pattern is sharply truncated by the Knipfjell dislocation, except at its northern end where the structural lines are roughly parallel (fig. 2). It now seems likely that, rather than dying out, the slide continues north-east to Orkdalsfjord, and that the rocks above it form a separate tectonic unit. The antiformal structure (see Peacey, 1963) which lies directly above the slide is probably a shear fold formed in response to the slip north-westwards on the dislocation and it is notable that the fold is most strongly developed where rejuvenation of the slide is most marked, i.e. on Knipfjell.

The Cambro-Silurian rocks beneath the slide, which occupy the core of a narrow, overturned syncline running into Orkdalsfjord, are again garnet-mica schists and amphibolites. Farther west there is also evidence of an older basal substratum which lies structurally beneath the Eocambrian. This is a variable complex, called in the area the Våvann Group, which comprises grey, plagioclase-rich gneisses with thin bands of quartzite, mica-schist and amphibolite. The evidence of several generations of pegmatites, highly-transformed basic sheets and metastable remnants of pyroxene suggest that these are an older suite of high-grade rocks, the basement upon which the Eocambrian was deposited. One episode, however, which was common to the basement and its Eocambrian cover, but not to the Palaeozoic rocks was the intrusion of the ophitic dolerite sheets. These predate the Early folding and also apparently, the deposition of the Cambro-Silurian.

When the geological histories of the three areas are tabulated (Table 1) some interesting comparisons can be made. If information from the Opdal area is correct, then the metasomatism there predates the emplacement of the low-grade Trondheim schists, whilst at Gangåsvann the Knipfjell slide and the rocks immediately above it are, in places, engulfed by granitisation. Less significant, is the appearance of the ophitic dolerite sheets which are restricted to the basement rocks of the Tømmerås massif. At Gangåsvann igneous activity took place between the

Eocambrian and the beginning of the Palaeozoic, whilst in Opdal it apparently did not occur before the Lower Ordovician.

The history of the rocks above the Knipfjell slide is, in many respects, similar to that of the Caledonian sediments in the Tømmerås area; certainly the facies, both sedimentary and metamorphic, is comparable and the Eocambrian is not cut by a dyke swarm. It is still not possible to say what the Knipfjell slide originally represented. Certainly in its later history it has acted simply as a plane of tectonic disjunction upon which the upper rocks have slipped north-westwards. But by analogy with the stratigraphy and tectonic setting of the Tømmerås area it is tempting to imagine it as an original sedimentary unconformity which has subsequently become a plane of structural dislocation. Thus one can visualize the cover of Eocambrian and Palaeozoic rocks being loosened from its basement and finally thrust into an allochthonous position.

Below the slide the geological history of the rocks shows plainly that they belong to the "Gneiss region" proper and thus here, as in Opdal, the margin of the Trondheim basin is a major tectonic break.

The exciting task now remains to map this dislocation south as it bends west into the Surnadal embayment and also to discover how far north towards the Grong culmination it can be traced.

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Table 1.

Comparative geological histories of the three areas.

Opdal	*Lower Gangåsvann*	*Upper Gangåsvann*	*Tømmerås*
Basement rocks formed	Basement formed, traces of very high-grade metamorphism and magmatic segregation	?	Basement rocks formed
			Intrusion of ophitic dolerites
Deposition of Eocambrian and Palaeozoic	Deposition of Eocambrian	Deposition of Eocambrian & Palaeozoic, accompanying vulcanicity	Deposition of Eocambrian & Palaeozoic, accompanying vulcanicity
Intrusion of dolerites, extrusion of lavas	Intrusion of dolerites		
	Deposition of Palaeozoic, accompanying vulcanicity	Weak metamorphism ?	Gentle folding & metamorphism, doming of the Tømmerås ridge
Multiple folding	Two phases of major folding, moderate metamorphism		
Metasomatism			
Emplacement of thrust sheet of lower-grade Palaeozoic rocks	Emplacement of thrust sheet of lower-grade Eocambrian and Palaeozoic rocks	Thrusting	
	Metasomatism	Metasomatism	

Sammendrag.

Det blir gjort en sammenligning av eokambriske avleiringer i to områder som tidligere er blitt beskrevet av forfatterinnen (Gangåsvann-området og Tømmerås-området) og Oppdals-området. I Gangåsvann-området er det en øvre avdeling av lavmetamorfe bergarter, tilsvarende bergartene i Tømmerås-området, som er skjøvet over en underliggende avdeling i vest av mer høymetamorfe bergarter. I den henseende er forholdene her tilsvarende forholdet i Oppdals-området, hvor Trondheimsfeltets lavmetamorfe bergarter ligger skjøvet over de sterkt metamorfe og foldete bergarter vestenfor i selve Oppdals-området.

STUDIES ON THE LATEST PRECAMBRIAN AND EOCAMBRIAN ROCKS IN NORWAY

No. 8.

STRATIGRAPHY AND STRUCTURE OF EOCAMBRIAN AND YOUNGER DEPOSITS IN A PART OF THE GUDBRANDSDAL VALLEY DISTRICT, SOUTH NORWAY

By Trygve Strand, University of Oslo

Abstract.

A sequence of five separable formations of assumed Eocambrian to Cambrian and earliest Ordovician age are separated by a thrust-plane from the overlying Otta nappe. A lowermost formation of alternating schists and sandstones (often calcareous or dolomitic) and dolomites contains boulder-bearing schists, correlated with the Eocambrian glacial horizon of south Norway (Moelv tillite). It is succeeded by a light feldspathic sandstone ("light sparagmite") a formation of alternating schists and sandstones (often calcareous or dolomitic), a thick pelitic sequence (phyllites) and an uppermost sandstone. In the eastern part of the area described the rocks of this sequence are folded on NW—SE axes, two phases of folding have been ascertained, in the western part the structure is largely monoclinal with dips to NW or NNW.

The present paper gives the results of field work in 1961 on Eocambrian and later (Cambro-Ordovician?) deposits of eastern (miogeosynclinal) facies in an area in the Gudbrandsdalen valley district, shown on Fig.s 1 and 2. In this area the crystalline massif and the overlying eugeosynclinal deposits of the Otta nappe make out an upper tectonic unit, not dealt with in the present paper. The area is a part of the Sel map area described by the writer (Strand, 1951), but very little is contained in that paper on the rocks here in question. Other publications dealing with the same area and rocks are those of Bjørlykke (1905), Holtedahl (1922), Werenskiold (1932) and Dietrichson (1950).

The mapping was done on the available maps in scale 1 : 50 000, enlarged to 1 : 25 000. The work has not been detailed enough to determine an order of deposition within any of the formations separated, in parts of the area with good exposures this might be possible by more painstaking work on large scale maps. A report with maps submitted to the Geological Survey after the close of the investigations in 1961 contains data of local importance, not included in the present paper.

Stratigraphy and lithology.

A light-coloured feldspathic sandstone, the "light-sparagmite" of Norwegian geologists, is a conspicuous rock unit in the area. It corresponds to the "upper light sparagmite" mapped and described by Werenskiold (1911) in the Søndre Fron map area east of the present area. According to the interpretation of the stratigraphy and the tectonics of the present area shown in Fig.s 1 and 2, there is a sequence of five formations, one below and three above the "light sparagmite." No names will at present be introduced for these formations. Two other geologists, A. Prost and J. O. Englund, are engaged in mapping the areas to the east and south-east of the present area and it is thought better to delay the naming until larger areas have been investigated.

The sequence is, from top to bottom:

Formation 5. Light or somewhere dark sandstone.

Formation 4. "Phyllite formation" of grey or somewhere dark carbonaceous phyllites.

Formation 3. Alternating phyllites, siltstones and sandstones, the latter often calcareous or dolomitic.

Formation 2. The "light sparagmite."

Formation 1 has generally the same alternation of lithologies as formation 3, but has in addition dolomites and conglomerates of a special type.

The rocks are metamorphosed at a low grade (greenschist facies). The pelitic rocks are completely recrystallized to fine-grained chlorite-sericite phyllites, while the sandstones have partly retained the clastic structure.

The lower unit, formation 1, consists of pelitic and silty grey schists with interbedded sandstones and dolomites. The sandstones, of light to greyish colour, form benches of thickness up to several metres, and are very often carbonatic, either calcareous or dolomitic. Carbonatic sandstones of the formation are well exposed along the road north of the fork in the road at Sjoa railway station. The dolomites occur in relatively thick layers, about 10 metres at a maximum. There are white crystalline rather pure dolomites and dark grey and fine-grained, presumably less pure dolomites with shale lamellae. The dolomites, accompanied by light quartzitic sandstones seem to occur in the upper part of the formation. Holtedahl (1922, p. 20) gave a map showing some

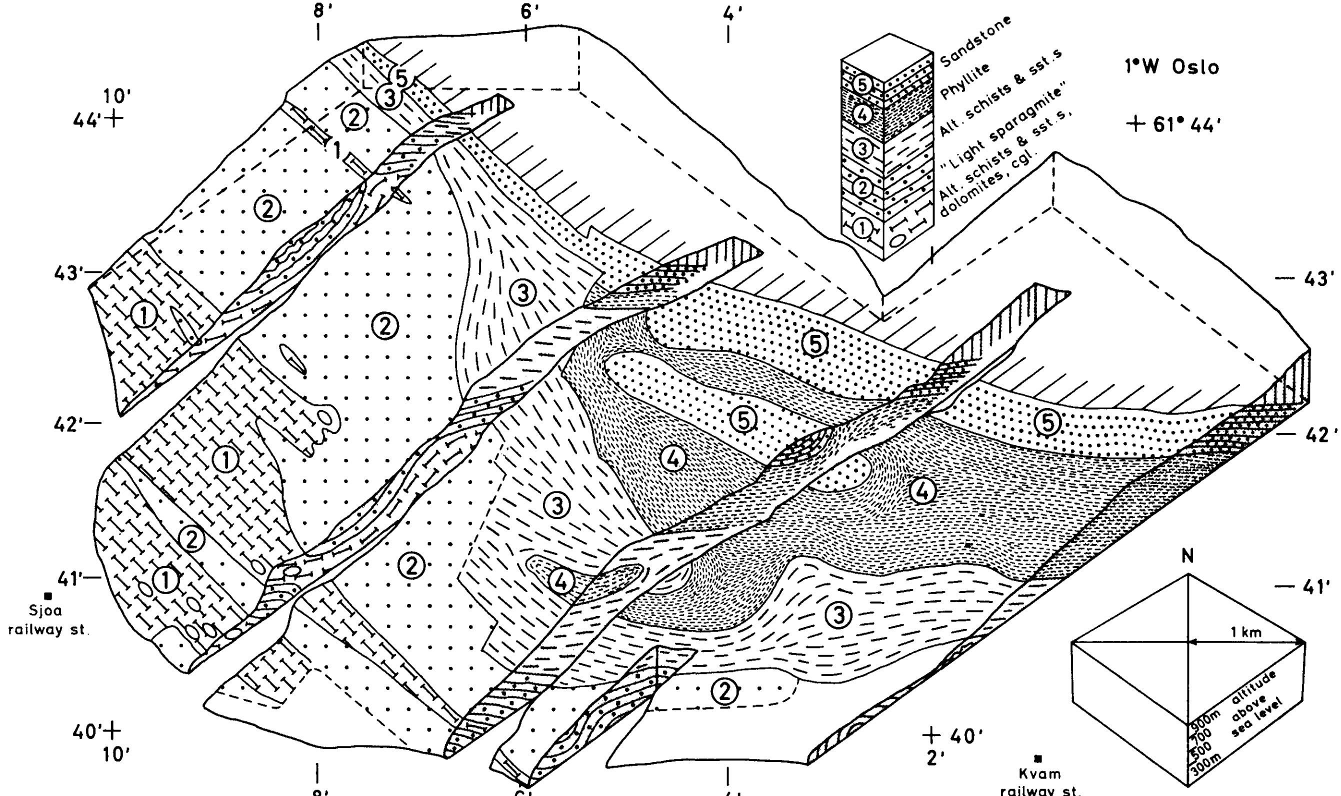

Fig. 1. Tectonogram of an area at the north side of the Gudbrandsdalen valley between Kvam and Sjoa railway stations, see Fig. 2 for location.

Fig. 1. Tektonogram av området på nordsiden av Gudbrandsdalen mellom Kvam og Sjoa jernbanestasjoner. Se fig. 2.

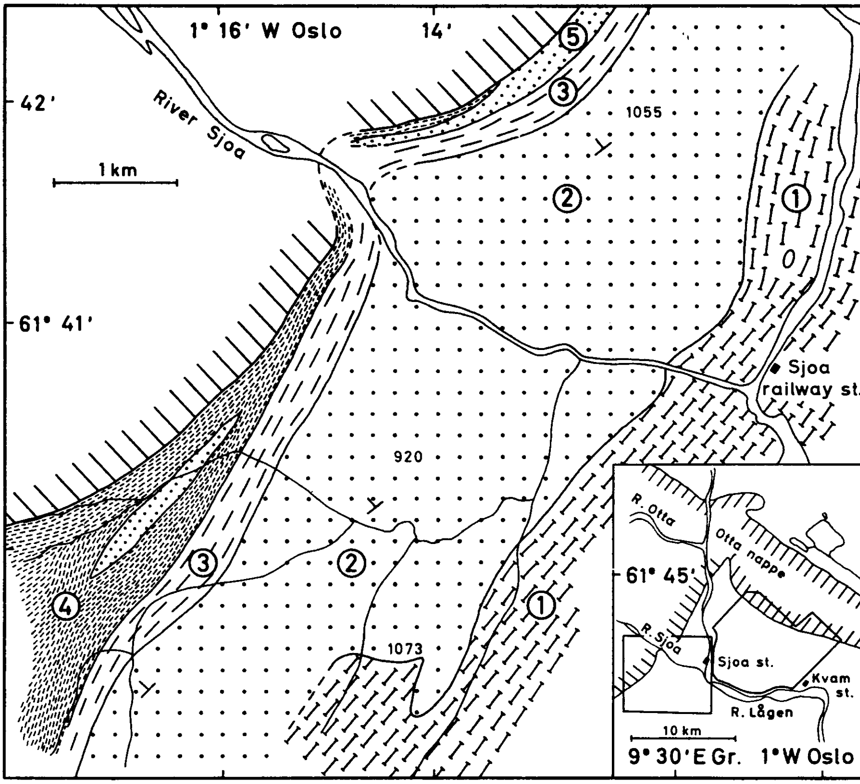

Fig. 2. Geologic map of an area at the lower part of the valley of River Sjoa, legend as in the tectonogram, Fig. 1. Map in corner shows location of the areas covered by the tectonogram, Fig. 1, and the present map.

Fig. 2. Geologisk kart over området ved den nedre del av Sjoas dalføre, tegnforklaring se fig. 1.

of the occurrences and published an analysis (showing 21.7 per cent of undissolved matter, the rest being carbonate very near to dolomite).

The formation contains conglomerates of an unusual type with boulders (maximum size observed is 47 cm.) and smaller fragments, occurring sparsely to wide apart in a matrix of pelitic or silty schist. At one locality, above (north of) the main road 2 km. south-east of the fork in the road at Sjoa railway station (40.3,9),[1] the boulders occur in a

[1] Minutes of latitude + 61°N and minutes of longitude + 1°W Oslo are used as coordinates.

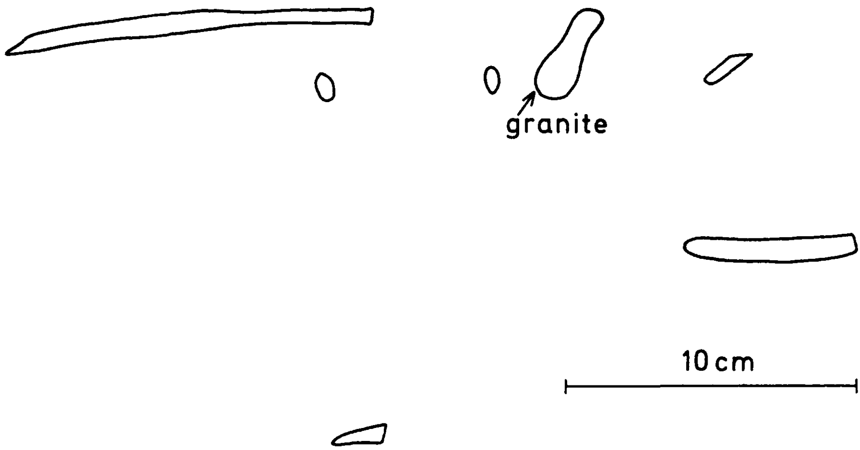

Fig. 3. Field sketch of a vertical section of "conglomerate schist" with fragments. Locality: north of the main road 2 km. south-east of the fork in the road at Sjoa railway station (40.3, 9).

Fig. 3. Skisse av en vertikal skjæring i «konglomeratskifer» med boller. Nord for riksveien 2 km sydøst for veiskillet ved Sjoa stasjon (40.3, 9).

frequency great enough to call the rock a real conglomerate, at the other localities marked on Fig.s 1 and 2 the boulders occur more sparsely. The conglomerate was first observed by Bjørlykke (1905, p. 218) and later by Dietrichson (1950, p. 77).

The boulders and fragments vary in form from rounded to angular and tabular, the latter form seems to be characteristic for fragments of sedimentary rocks (Fig. 3). Of sedimentary rocks among the fragments is a micaceous quartzite and fine-grained dolomites. Very common are greyish granitic rocks which under the microscope prove to be sodic quartz diorites with albite as the only or dominating feldspar, together with microcline. The albites in these rocks show a characteristic twinning pattern with truncate and tapering twin lamellae (Fig. 5). One of the rocks is a quartz porphyry. There are further strongly sheared gneissic rocks, a sampled specimen proved to be oligoclase gneiss.

The thickness of formation 1 is at least 200 m. in the mountain between Rivers Lågen and Sjoa where it is exposed between altitudes 300 m. (in the valley floor) and 500 m.

Formation 2, the "light sparagmite" is of a monotonous lithology, consisting of light feldspathic sandstones with a parallel lamination,

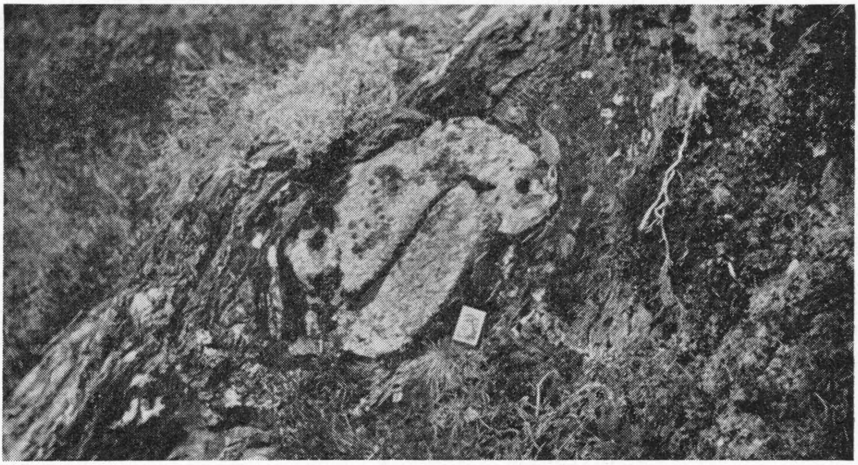

Fig. 4. Boulder of quartzite in schist. Locality: west of Koloseter (41.6, 7.5).

Fig. 4. Kvartsittbolle i skifer. Vest for Koloseter (41.6, 7.5).

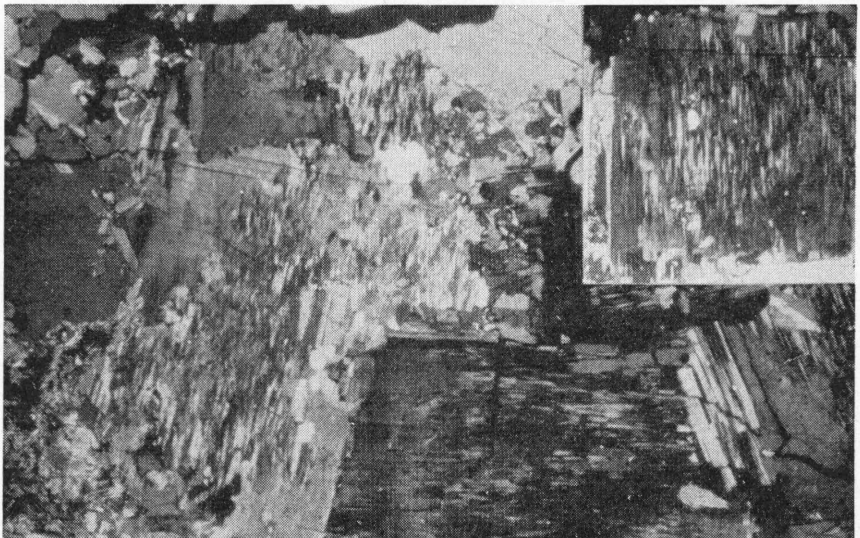

Fig. 5. Microphoto showing albites in granitic rocks occurring as boulders in "conglomerate schist." x 33. Locality as in Fig. 3.

Fig. 5. Mikrofoto av albitter i granitt som finnes som boller i «konglomeratskiferen». Lokalitet som fig. 3.

very often thin layers especially rich in mica form greenish streaks in the light or faintly yellowish rock. The parts of the sandstone especially rich in mica have greenish colour, while rocks with little or no mica have the appearance of quartzites. Dark or greyish sandstones occur as a subordinate part of the formation. The sandstone are parted in benches about 2 dm. thick, the thickness decreasing or increasing with the grain-size of the sandstone. Alternation of siltstones and sandstones, partly calcareous, is an especially fine-grained facies found in parts of the area. Cross-bedding is rare and mostly indistinct. Good cross-bedding was observed at one locality, at the bridge across the Sjoa at Åmot (40.8, 12), indicating that the sandstone is right side up. The formation has a maximum thickness within the area of 500 to 600 m., but thins to some 150 m. in the north-west part of the area.

Formation 3 has lithologies similar to those of formation 1, especially the light calcareous sandstones of the two formations can not be distinguished. Characteristic of the formation is alternations of greenish chlorite-rich schists with thin bands of light sandstone with brownish weathering (probably due to contents of iron-bearing carbonate). Boulder-bearing schists have not been found within the formation, which also lacks the dolomites of formation 1, only locally there are thin layers of limestone. But the sediments very often contain carbonates (calcite or dolomite). As will appear from Fig.s 1 and 2 the formation has a large extension and thickness in the eastern part of the area, but is much reduced in thickness towards the north and west.

Dietrichson (1950, Fig. 4, p. 79) published a NE—SW section through the present area showing great inversions and overfoldings towards SW on the assumption that formations 1 and 3, here distinguished, were the same stratigraphic horizon. This interpretation can not be rejected as an impossible one, but it must imply that the "light sparagmite" is in the core of a very large recumbent fold throughout the whole of the present area.

Formation 4 consists exclusively of dark phyllites. Black carbonaceous phyllites apparently form an upper horizon in the formation near below the sandstones of formation 5. Like the underlying formation 3 and the overlying formation 5 the phyllites form a very thick pile in the south-east part of the area, but thin to very small thickness or disappearance in the north and west, a thinning that can probably be ascribed to tectonic processes. In the western part of the area (map. Fig. 2) the black schists commonly occur at the thrust-plane of the overlying Otta nappe. A sample from this part of the area was shown by radiation measurement to contain some 40 p.p. m. of uranium (with an estimated allowance for the radiation caused by the potash contents of the rock).

Formation 5 at the top of the sequence is a light sandstone, but the colour changes to dark grey in the northern and western parts of the area. Commonly the sandstones form thin benches separated by thin seams or layers of light or greenish schist with a rusty weathering. The more fine-grained types thus get a flaggy parting in layers of thickness down to one centimetre.

Some 26 thin-sections of sandstones have been examined and the mineral composition determined by point-counting, as shown in Fig. 6. As previously mentioned the sandstones have partly retained their clastic structure, especially the larger grains of feldspar have kept their characters of perthite structure and twinning pattern, while the quartz is more or less recrystallised. The phyllosilicates (commonly light mica, more seldom biotite and/or chlorite) occur in relatively large grains of nearly equal size, certainly formed by recrystallisation. The grain size commonly varies between 0.1 and 0.3 mm, larger grains are found in a few of the rocks.—More than half of the rocks fall by their mineral composition in the field between 10 and 25 per cent of feldspar and 0 and 20 per cent of phyllosilicates and are to be classed as feldspathic quartzites. As indicated in the diagram, Fig. 6, a majority of the rocks have a feldspar composition dominated either by potash feldspar (80 per cent or commonly more of the total feldspar) or by albite to an equal or a still higher degree. Among the different types of potash feldspar are string perthites (lenticular sections of the perthite inclusions). Feldspars of this type, characteristic of charnockitic rocks, were recorded from sandstones of the same sequence by Dietrichson (1950, p. 76). A number of the albite grains show the same twinning patterns as do the albites of the granitic rocks occurring as fragments in the conglomerate schists in formation 1. The difference between the two types of sandstone is certainly a significant one, showing that sediment must have been derived from two different source areas. Even if there are some exception to the rule, the sandstone rich in potash feldspar are dominating in formations 2 and 5, while the albite-rich sandstones are characteristic of formations 1 and 3 (most of these sandstones are calcareous or dolomitic). In a group of their own are two arkoses with about 50 per cent of feldspar from formation 2 in the northern part

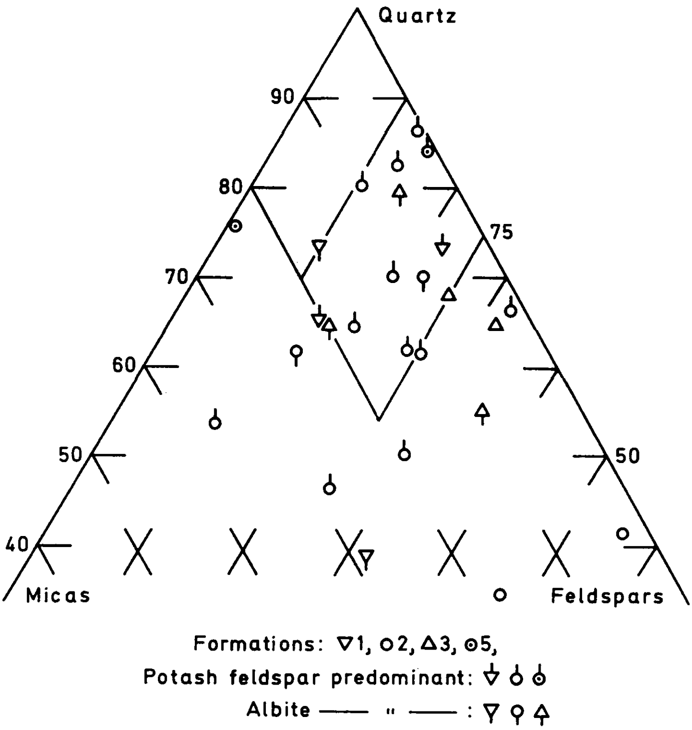

Fig. 6. Diagram showing mineral composition of 26 sandstones.

Fig. 6. Diagram som viser mineralsammensetning av 26 sandstener.

of the area with potash feldspar and plagioclase in roughly equal amounts. They also contain epidote.

Pelitic or silty schists with boulders, the "Conglomerate schists," of exactly the same type as in the present area are known from the Østerdalen district in the east part of the south Norwegian Sparagmite region (Bjørlykke, 1905, p. 61 f.; Holtedahl, 1921, p. 38 f.; Holmsen 1954; Holmsen & Oftedahl, 1956, p. 88 f.). The "conglomerate schist" horizon has been correlated with the Moelv tillite in the south Norwegian Sparagmite basin and considered as a glacial marine sediment deposited at some distance from the glaciated areas in the east.[1]

[1] It may be thought improbable that tabulate fragments like those shown in Fig. 3 could have been transported and worn by a glacier. But rafting by ice formed in fjords and bays is a possible way of transporting material. According to Johansen (1955) large quantities of flint have been brought into the Oslofjord area by ice drifting in

The "light sparagmite" of formation 2 can be correlated with the Vemdal sandstone, which is separated from the Moelv tillite by the intervening Ekre shale formation. The Vemdal is a widely transgressive formation of latest Eocambrian age. The overlying deposits of formations 3 to 5 should thus be Cambrian or younger. The black carbonaceous schist in the upper part of formation 4 can tentatively be correlated with the widely distributed alum shales mainly of Upper Cambrian and earliest Ordovician age, in accordance with Dietrichson (1950). In support of this correlation is the concentration of uranium found in the rock. This should give an early Ordovician age to the sandstone of formation 5.

The "conglomerate schists" of Østerdalen, previously referred to, belong to a sequence containing sandstones of "light sparagmite" types and dolomites, very similar to the sequence in the present area. The Østerdalen rocks in question belong to the Kvitvola nappe, overthrust above Eocambrian and Cambro-Ordovician sediments. The sediments of the Kvitvola nappe display a characteristic facies of deposits of about Eocambrian age, distinct from the parautochthonous sequence of the same age in the Sparagmite basins in central south Norway. Deposits of the latter facies occur in the Fåvang area, 40 km. south-east of the present area (Englund, 1966). According to personal communications from A. Prost and J. O. Englund there seems to be a tectonic boundary between the sequence of "Sparagmite basin facies" and an overlying sequence of "Kvitvola facies," extending into the present area. These rocks should thus be a western equivalent of the Kvitvola nappe, stratigraphically as well as tectonically, as was indicated by Oftedahl (1954).

Structures.

In the area at the north side of the main valley of Gudbrandsdalen, shown in the tectonogram, Fig. 1, the structural pattern is wholly governed by folding on WNW axes, by which the Otta nappe north of the area was folded down in a broad synformal structure. The mega-

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during late-Glacial and post-Glacial times. Boulders of flint measuring 3 dm.^{3} in volume have been found. Also at present material is being transported in the Oslofjord by drifting ice in cold winters. According to a personal communication from Mr. Johansen rock fragments much larger than the above-mentioned flint boulders can be moved in this way.

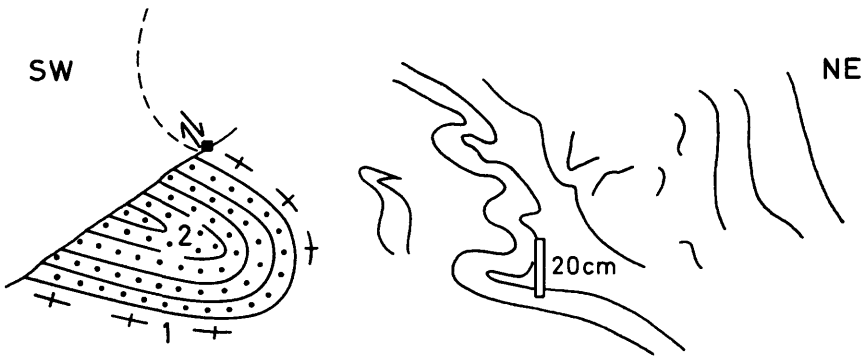

Fig. 7. Parasitic folds or "drag-folds" in a thin quartzite layer in dolomitic schist, formation 1. Locality: At brook north-east of Bjørkerusten farm (40.3, 7.5). The section to the left shows the situation of the locality. The sense of movement of the "drag-folds" indicate an anticline to the right and up and a syncline to the left and down, in accordance with the writer's interpretation.

Fig. 7. Parasittiske folder eller «drag-folds» i et tynt kvartsittlag i dolomittførende skifer, formasjon 1. Ved bekk nordøst for Bjørkerusten (40.3, 7.5). Foldene tyder på en antiklinal opp til høyre og en synklinal ned til venstre (se profilet til venstre).

scopic structures will appear from the tectonogram. Strong folding on a megascopic scale is found in the south-west part where the sandstone of formation 2 forms an overfolded syncline followed to the north-east by an anticline with rocks of formation 1 in the core, inverted above the sandstones of formation 2. Towards north-west the folding structures seem to smoothen out, towards south-east they disappear beneath the cover in the valley floor. As shown in the south-westernmost part of the tectonogram, the rocks of formation 1 are underlain by sandstones not to be distinguished from the sandstones of formation 2, possibly forming a second overfolded syncline, most of which is concealed in the valley floor. Large folds overfolded to the south-west are known south-east of the present area, in Teigkampen and at the north side of the Vinstra valley (Bjørlykke, 1905, p. 197; Dietrichson, 1950, p. 77 f.).

In the area at the west side of the Gudbrandsdalen valley, shown on the map, Fig 2, the megascopic structure is simply a monocline dipping SE or ESE. The trend of the large synformal structure with the Otta nappe has here turned from a WNW to a NNE direction.

The folded complex is transsected by a number of major joints directed NNE. They can clearly be seen on air-photos and some of them can be followed in the field as clefts and depressions. A number of smaller rivers and brooks following the same direction have eroded deep ravines. The joints were earlier mentioned by Bjørlykke (1905, p. 205), and Werenskiold (1932).

In parts of the area faulting has taken place along the joints, as shown on the tectonogram, Fig. 1. Apparently the faulting does not affect the whole complex of rocks transsected, it has not been possible to detect any offsets in the syncline of sandstone of formation 2 in the south-west part of the area. This can be understood on the assumption that the movements along the joints took place during the folding, the different parts of the complex separated by the joints could thus be folded independently of the others, resulting in a number of transcurrent faults by which the rocks east of the joints were moved more strongly to south-west than were those at the west side.

Mesoscopic structures are folds of dimensions between some 10 metres and a few centimetres, minute crenulations in the incompetent schists and a lineation structure by parallel arrangement of grains in the sandstones. The latter structure must have had its origin during the recrystallisation of the rocks. It may here be remarked that no observations indicate the presence of structures of an order of size intermediate between the megascopic structures shown in Fig. 1 and the mesoscopic structures mentioned in the preceding.

The mesoscopic folds are of different styles. Folds of concentric type, some metres wide, are exposed along the road along the Veikla river north of Kvam railway station (40.5, 2) in sandstones of formation 2. At other localities the rocks of the same formation show small folds of a similar type with greatly thickened hinges. A number of observations show structures in two different directions, indicating two (or more) phases of deformation. The clearest evidence was given by an exposure at the road 1 km. north-west of Kvam railway station (40.1, 2) where a micaceous quartz-schist (formation 2) shows folding with the axis parallel to a lineation pitching faintly 320 g, the lineation is folded by a younger fold with axial direction 360 g. An observation made in a phyllite in Tjørnseterfjell east of Haugseter (61° 44.5'N, 0° 58'W Oslo, north-east of the area here described) shows small scale folds pitching about 40 g in direction 280 g, and overturned to the north. These folds are bent and twisted, apparently by a deformation that made minute crenulations directed 370 g. Whether the east-west folding here observed represents the same phase as the folding and lineation

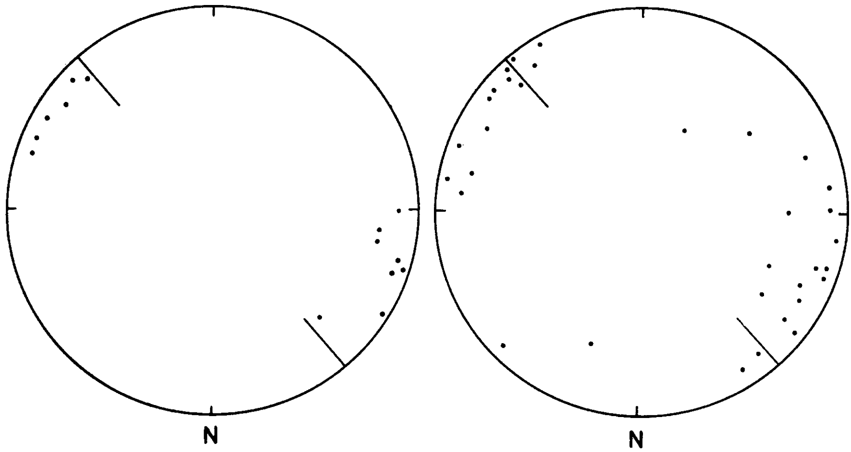

Fig. 8. L structures mainly from the area of the tectonogram, Fig. 1. Equal area projection, lower hemisphere.
Right diagram: Fold axes of mesoscopic folds. Left diagram: Directions of parallel arrangement of mineral grains.

Fig. 8. Linjestrukturer vesentlig fra området for tektonogrammet fig. 1. Flatetro projeksjon, under halvkule.
Til høyre: foldningsakser til mesoskopiske folder. Til venstre: retninger for parallellordning av mineralkorn.

directed 320 g can not be decided. The diagrams, Fig. 8, show observed directions of fold axes and of lineations by parallel arrangement of mineral grains. It is seen that a number of observations of fold axes are in the interval of directions 350—370 g, not occupied by lineations. This seems a confirmation of the direct observation recorded in the preceding, indicating the presence of a folding and lineation with direction about 330 g, followed by a younger folding at an angle of trend some 30 g clockwise to the direction of the former one.

In Prestberget, some 40 km. north-west of the present area, Strand (1964) described the structures in the Otta nappe and underlying sediments, corresponding to those in the present area. Here a folding on west-north-west axes (F_2) with a strong lineation structure has affected the Otta nappe and the underlying sediments subsequently to the emplacement of the nappe, and was followed by a fainter folding (F_3) with axial direction nearer to the north. The two phases of folding in evidence in the present area can thus be correlated with the two later phases in Prestberget. Structures corresponding to the phase F_1 in Prestberget, probably connected with the emplacement of the nappe, have not been ascertained in the present area.

Sammendrag.

En lagrekke av antatt eokambrisk til kambrisk og eldste ordovicisk alder ligger under Otta-dekket i området omkring Kvam og Sjoa jernbanestasjoner. Den underste formasjon i lagrekken består av vekslende skifrer og sandstener (ofte kalkholdige eller dolomitiske) og dolomitter. Den inneholder «konglomeratskifrer» med opptil halvmeterstore spredte boller, som blir oppfattet som et ishavssediment samtidig med Moelv-tilliten. Den overleires av lys feltspatførende sandsten («lys sparagmitt»), en formasjon av vekslende skifrer og sandstener (ofte kalkholdige eller dolomitiske), en formasjon av fylliter og øverst av en sandsten. I den østlige del av området (Fig. 1) er lagene sterkt foldet med akseretning nordvest—sydøst, i den vestlige del (Fig. 2) ligger hele lagpakken stort sett med ensartet nordvestlig til nord-nordvestlige fall.

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