INVESTIGATIONS AT THE SOUTH-WESTERN BORDER OF THE SPARAGMITE BASIN (GAUSDAL VESTFJELL AND FÅBERG VESTFJELL), SOUTHERN NORWAY

by

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Abstract.

Descriptions are given of lithologies deposited in the original Sparagmite Basin. These rocks can be classified into a parautochthonous older part and an allochthonous younger unit. Most of the formations of the Sparagmite Group can be traced from the lake Mjøsa, where they have their typical development, to the Gausdal area without any great changes of the lithology.

The Biskopåsen Conglomerate (earlier Biri Conglomerate) is found in four separate bodies (three of them lens-shaped) indicating deposition in deltaes. The Biri Limestone in Gausdal is a facies variant of the Biri Limestone at Mjøsa. Among the carbonate deposits in Gausdal there are sandstones, conglomerates (with boulders of carbonate rocks, granites and quartzites), and beds with ooliths. The Moelv Tillite in Vestre Gausdal is developed as a shale conglomerate with a matrix consisting of graded bedded silt and clay. The boulders consist mostly of grey granite, light quartzites and the underlying carbonate rocks.

In the Gausdal area the deposits within the Sparagmite Group indicate a transport of the material from a westerly point, and that most of the clastic material was weathered before deposition. Some of the formations display rapid changes of sedimentary facies.

The structures have disclosed that the youngest rigid members behaved differently from the older members during the Caledonian orogeny, the former being derived allochthonously from the parautochthonous and folded older members. The rigidity of the south-western border of the basin resulted in a dragging of the fold axes, and to the west even a sheltering effect where folds die out.

Introduction.

Location of the area.

The area studied is located between 61° 0′ and 61° 15′ N. Lat. and 0° 30′ and 0° 46′ Long. West of Oslo. The maps which were used are:

Synnfjell 1 : 100 000 Gradteigen F 31 aust.

Deutsche Heereskarte, Norwegen 1 : 50 000, F 31 0 Synnfjell.

Norway–Norge 1 : 50 000, Sheet 1717 II Ams series M 7 II Synnfjell. In addition to these, preliminary copies of a new 1 : 50 000 map being prepared by the Geographical Survey of Norway were also used. From 1960 aerial photographs of the eastern part of the area were available, and the map Fig. 2 is based on them.

Aim and means of study.

The purpose of the investigations was to determine firstly the position of the western and south-western border of the Sparagmite Basin within the Vestre Gausdal area, and secondly the influence of the border on the sediments deposited in the basin and on the tectonic development of the area.

The rocks of the area are mainly coarse-grained ranging from sandstones to conglomerates; generally they are rudites with angular fragments (sparagmites). Sedimentary structures are few. As most of the rocks are coarse and display marked lateral variations, it is difficult to choose representative samples. Nevertheless, many specimens were collected and the minerals and textures seen in thin-sections have been described.

Of the tectonic structures observed in the field lineations are the most numerous and tend to be prominent in limestones and shales. Folds are rarely seen. All measurements are based on the 400° scale, and planes of bedding and joints have been projected on to the upper hemisphere of a Schmidt net. As the bedrock is poorly exposed, the geological maps have entailed a good deal of interpretation.

Previous investigations of the area.

The first description of the area was that of Hiorthøy in 1785. He found that the rocks were usually grey in colour and rich in quartz. In 1826 Keilhau estimated the position of the southern border of the Sparagmite Basin from west to east not far from where it is now suggested to lie.

Kjerulf (1857) mentioned a limestone occurring at Bratland and Forsetseter which could be traced to Biri. In 1873 he described a peculiar limestone and grey sparagmite together with a coarse conglomerate. These lithologies could be traced from Mjøsa to Gausdal. He found that above the conglomerate in Gausdal there is a younger limestone at a higher level than the one at Biri. In 1879 Kjerulf described a section from the Herfjell area (Fig. 1, E 3):

Glistening shale with lumps of quartz

Blue-quartz-sandstone and
limestone alternating 700′
together with other quartzites

Conglomerate with fragments of granite (grey granite),
fine-grained grey sparagmite and shale, limestone like the Glomstad-limestone.

Bjørlykke (1891) described the Biskopåsen Conglomerate as grey granite boulders in a matrix of grey sparagmite. He remarked on the different varieties of limestone and estimated their total thickness as ca. 120 m (in Roppa). Above the limestone he found 6 m of dark shale and 12 m of quartzite: these are overlain by a graptolite-bearing shale.

Münster (1891) described the limestone from Roppa to Slåtbakken seter (Dekken seter on the map Fig. 1, J 4). He suggested that this was the Biri Limestone.

Bjørlykke (1893) introduced the name «The Sparagmite Formation» for those deposits older than the Biri Limestone. He followed the limestone from the west slope of Vestre Gausdal under Herfjell to Biri. The upper boundary of the Biri Limestone he described as a calcareous sparagmite with fragments of granite and quartz. He found that the limestone was overlain by a shale containing fragments 3—9 cm in diameter. Above this shale is a thinner shale which is in turn overlain by a 5—50 m thick quartzite. Bjørlykke asserted that the secondary cleavage is steeper than the primary one of the area.

Törnebohm (1893) presented a thorough description of the limestone in Gausdal. Under the Biri Limestone he found a coarse conglomerate extending from Biskopåsen at Mjøsa to Hindalssjøen (Fig. 1, F 4). He established that the boundary between the conglomerate and the Biri Limestone was of some importance — since the two formations were deposited under essentially different conditions. Furthermore he found limestone at several levels. The limestones he found drew an arched boundary. Inside the boundary he thought there were uniform grey sparagmites and shales, whereas outside there were various other rock types.

Törnebohm (1896) repeated his earlier (1893) views in considering the geology of this area but did, however, add that the coarse sparagmites show rapid changes of sedimentary facies, and that rocks of similar lithology are to be found at all horizons. He also mentioned that the

Biskopåsen Conglomerate (earlier Biri Conglomerate) could be followed from Fåvang to Skjellbreidvatn (Fig. 1, G 5).

Münster (1900) referred to all limestones in the area by the name Biri Limestone. He noticed that the limestone is overlain by a grey shale containing fragments, especially of granite, and he found that the younger sparagmite could be mistaken for the Biskopåsen Conglomerate.

Münster travelled from Mjøsa to Herfjell and Verskei (Fig. 1, D 2) without finding what he called «the younger formation» (at Ringsaker he measured it as being 350 m in thickness). At Herfjell he found that the shale containing fragments was overlain by a shale without fragments, and above the shales was a «sparagmite-sandstone». He thought the Biri Limestone had its maximum thickness to the north-west, and that the younger sparagmite in the north-west is very thin, increasing in thickness towards the south-east. He supposed that calcareous arkoses within the younger sparagmites at Ringsaker and Biri were equivalents of calcareous arkoses in Gausdal. Thus he concluded that the conglomerate at Moelven railway-station (the Moelv Tillite) corresponds to the shale conglomerate at Nyseter and Herfjell (Fig. 1, E 3).

Bjørlykke (1905) drew the southern and western border for the older dark sparagmite (with conglomerate and limestone) along the valley Vismunddalen (Fig. 1, I 6) and the mountain Herfjell to the hill Evenvoldkampen (between Vestre Gausdal and Østre Gausdal). He remarked that here there were various fold systems, and thrusts with imbricate structure.

Holtedahl (1920) studied the limestones of south-eastern Norway and found that the Biri Limestone at Brattland (Fig. 1, A 3) is a very pure carbonate deposit.

The present investigations in this area were started in 1959 and continued until 1962.

Outline of the geology.

The Brøttum Sandstone and Shale is the oldest formation within the area. It can be traced from Mjøsa without any lithological changes. Upwards it grades into the overlying Biskopåsen Conglomerate. The Biskopåsen Conglomerate is found in four separate bodies; the uppermost parts of the conglomerate are calcareous.

Within this area the Biri Limestone is a facies variant of the Biri Limestone at Mjøsa. It may be divided into four interdigitating members:

Nyseter Limestone	ca. 0—20	m
Fjello Sandstone	» 0—200	»
Vismund Limestone	» 0—20	»
Åltjerna Limestone	» 0—15	»

The Åltjerna Limestone is a black limestone and shale alternating with compact black limestone with white calcite veins. It is this part of the formation that most closely resembles the Biri Limestone at the type locality. The Vismund Limestone is a coarse calcareous arkose with gravel conglomerates, and displays graded bedding. The Fjello Sandstone is either a coarse arkose or a medium-grained feldspathic sandstone. It resembles the Ring Sandstone at Mjøsa, which it is a part of. The Nyseter Limestone resembles the Vismund Limestone, but upwards it is enriched in carbonate and contains oolitic layers in its uppermost parts.

Within the area there is a sharp boundary between the Biri Limestone and the Moelv Tillite. This is exposed at Nyseter (Fig. 1, E 3), south of Herfjell (Fig. 1, E 3) and in the stream Briggebekken (Fig. 1, D 4). Up to the present time these are the only places known in Southern Norway where the tillite rests on limestone in an autochthonous position.

The Moelv Tillite in this area is a boulder clay. The clay matrix has varves which bend conformably around the boulders. The boulders measure up to 1 m and comprise fine-grained quartzites, coarse grey granite, fine-grained light granite, gneisses, mylonites, limestone, pegmatite-quartz, shale fragments and metaamphibolites. The tillite grades upwards into the overlying Ekre Shale by a decrease in the boulder content. The Ekre Shale, in this area, is a varved shale which grades upwards into the overlying Vangsås Formation, the transition marked by an increasing number of sandstone beds.

The Vangsås Formation comprises the members Vardal Sandstone and Ringsaker Quartzite. Since they are difficult to separate in the field, a hypothetical boundary has been drawn on the maps and sections. The Vangsås Formation can be followed from Mjøsa to Gausdal without facies variations. In Vestre Gausdal it grades into the overlying Cambrian shales; the transitional zone is ca. 1 m in thickness.

It is supposed that the Sparagmite Basin, as a separate basin of sedimentation, was brought to an end during the lower Cambrian transgression.

Thin-sections show that most of the clastic feldspar in all formations is weathered, a feature suggesting that material supplied to the Sparagmite Basin was derived from weathered Precambrian rocks. Some of the weathering may, however, be post-depositional. Fjello Sandstone and younger deposits have clastic grains of dark quartz and feldspar. All rocks in this area are metamorphosed to the lower part of Eskola's greenschist facies.

During the Caledonian orogeny the rocks deposited in the Sparagmite Basin were compressed in a southerly direction. The rigid Vangsås Formation (earlier the Quartz-Sandstone Formation) was thrust out of the basin while the older formations were folded up against the south-western border. The folds formed in connection with the «Quartz-Sandstone nappe» (Skjeseth, 1963) die out westwards, possibly because the deposits in the west were sheltered by the rigid block forming the western border of the Sparagmite Basin. A change of trend of fold axes may be due to a dragging effect along the western margin. The joints may be either tension joints perpendicular to the fold axes or post-Caledonian fissures of north-south trend.

Acknowledgements.

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I. Dillan has drawn all the illustrations, and O. Brynildsrud, M. Moen and H. Gjølme have made the photographs. Dr. D. Roberts has kindly corrected the English manuscript.

Stratigraphy and Petrography.

In Gausdal and Fåberg Vestfjell area have the rocks belonging to the Sparagmite Group (Late Precambrian and Eocambrian) been divided into several lithostratigraphical units. The stratigraphical terminology used is the one proposed by Henningsmoen (1955).

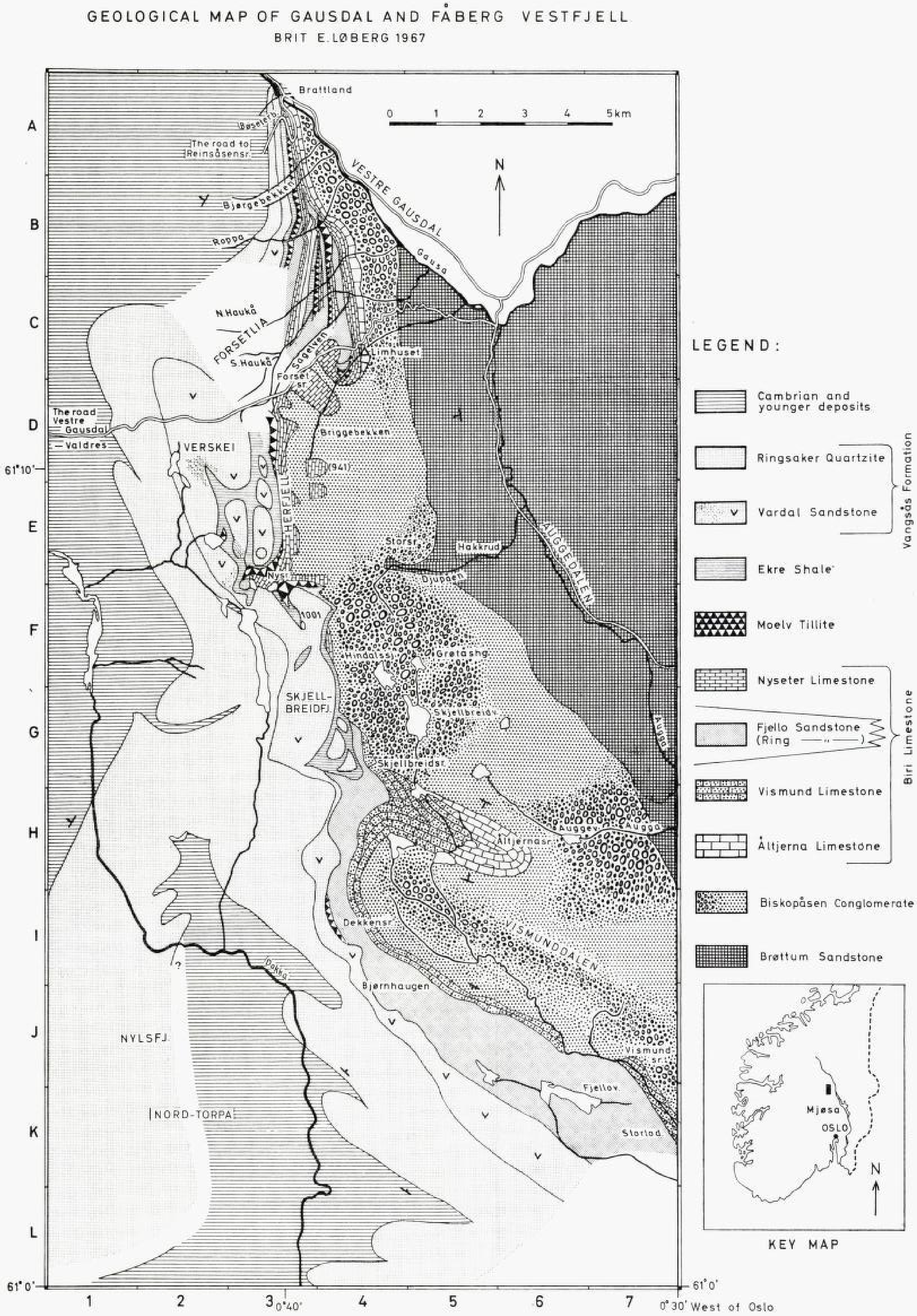

Fig. 1. Geological map of Vestre Gausdal and Fåberg Vestfjell.

Some of the classical names for formations of the Sparagmite Group have recently been changed (Bjørlykke, Englund and Kirkhusmo, 1967) and here the revised names will be used.

Nomenclature for latest Precambrian and Eocambrian formations in S. Norway:

Vogt (1924), Holtedahl (1960) and Skjeseth (1963)	Bjørlykke, Englund and Kirkhusmo (1967)	This paper
Ringsaker Quartzite } Quartz Vardal Sparagmite } Sandstone	Ringsaker Quartzite } Vangsås Vardal Sandstone } Formation	{ Ringsaker Quartzite { Vardal Sandstone
Ekre Shale	Ekre Shale	Ekre Shale
Moelv Conglomerate (= Moelv Tillite	Moelv Tillite	Moelv Tillite
Moelv Sparagmite	Ring Formation	Biri Shale Fjello Sandstone > and
Biri Shale and Limestone	Biri Shale	Limestone
Biri Conglomerate	Biskopås Conglomerate \ / and	Biskopåsen Conglomerate
Brøttum Shale and Limestone	Limestone	Brøttum Sandstone and Shale
Brøttum Sparagmite	Brøttum Formation	
Elstad Sparagmite	Elstad Formation	

Brøttum Sandstone and Shale

The Brøttum Sandstone and Shale is the oldest formation in the area. The formation consists of closely alternating dark feldspatic greywackes and dark shales, the thickness of each layer varying from a few centimetres to several metres. The formation is only found in the eastern part of the area, where it dips westwards under younger strata. The base is not exposed.

In the river Søndre Haukå (Fig. 1, C 3-4) the formation gradually changes upwards to a coarse conglomerate (the Biskopåsen Conglomerate). The transitional zone is more than 100 m in thickness.

As the section shows (Fig. 3) the Brøttum Sandstone and Shale at the south-western border of the basin is apparently 785 m thick, discounting possible disturbances. In the southern part of the Sparagmite Basin, Skjeseth (1963) estimated the thickness of the formation to be 1000–1500 m.

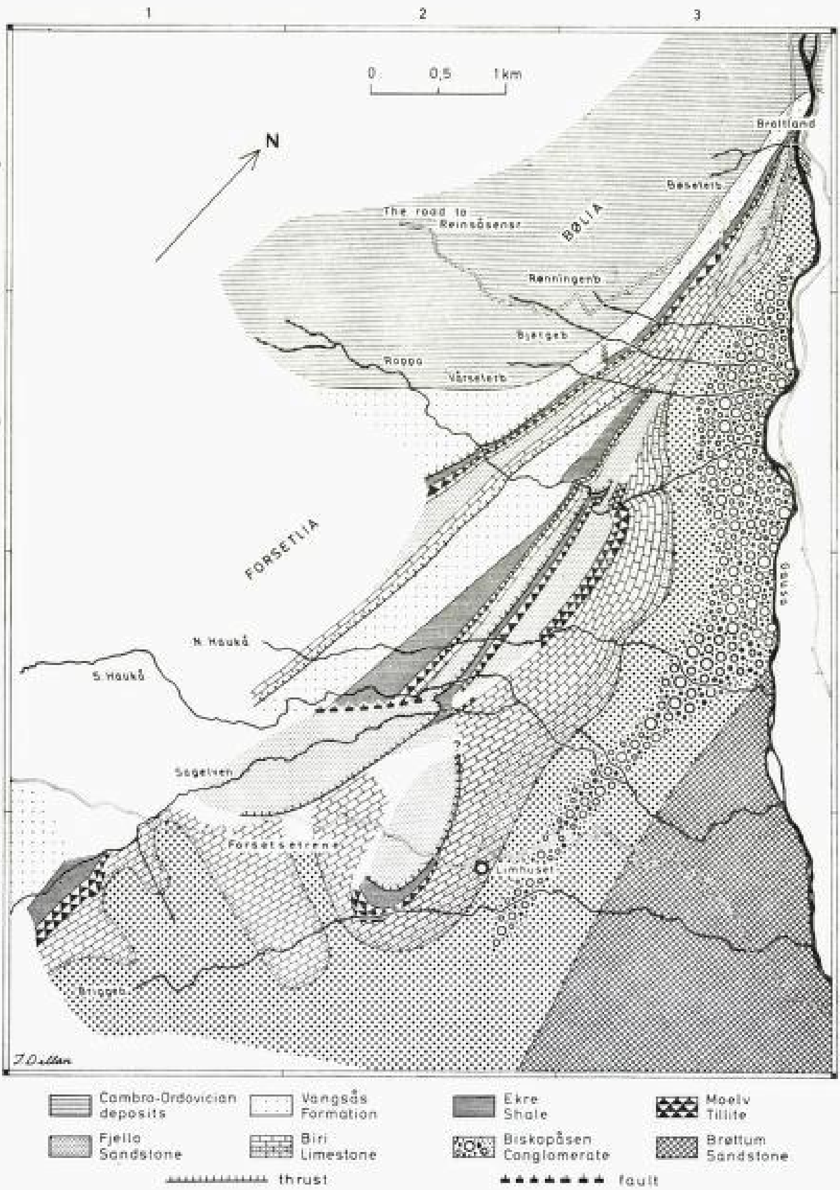

Fig. 2. Geological map of the western slope of Vestre Gausdal.

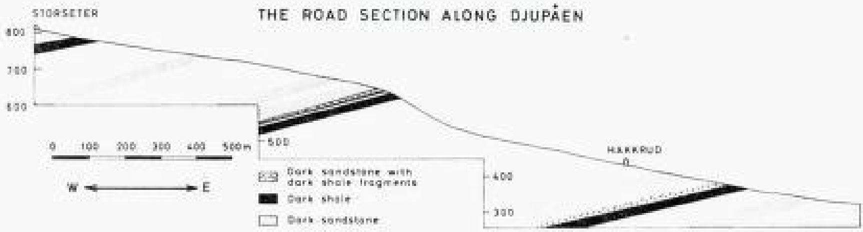

Fig. 3. Section along the river Djupåen. The heights are in metres above sea level.

The grain size of the Brøttum Sandstone ranges from that of the matrix (less than 0.05 mm) to ca. 1 cm in diameter. Grains smaller than 1 mm are angular, while those of 1 mm or more are angular to subrounded and are fractured. Open fractures are filled with matrix or recrystallized quartz. The clastic material is dispersed in a dark matrix consisting of sericite, chlorite, fine-grained quartz, small pyrite crystals and finely disseminated graphite. The rock fragments are quartzite, shale and granite. Most of the clastic material consists of grains of quartz with strongly undulose extinction, and feldspar (mainly K-feldspar) moderately to strongly sericitized. All feldspar material is coloured light brown. Plagioclase is albite and Na-rich oligoclase. Clastic grains of biotite are less than 0.5 mm in size. Their colour varies from tan to light reddish brown, and they are bent so producing a wavy extinction.

From the character of the Brøttum Sandstone and Shale within the area, it is clear that the material was transported only a short distance before its subaqueous deposition. It evidently came from an area where quartzite, shale and granite were undergoing erosion.

Biskopåsen Conglomerate.

The Brøttum Sandstone and Shale gradually passes up into the overlying Biskopåsen Conglomerate. No sharp boundary has been found. In the transitional zone in Søndre Haukå, the Brøttum Sandstone contains intercalations of conglomerate beds. The Biskopåsen Conglomerate forms the floor of the valley Vismunddalen (Fig. 1, I-J 5-7), and the western slopes of the valleys Auggedalen (Fig. 1, E-H 4-7) and Vestre Gausdal (Fig. 1, A-C 3-4).

Within the area the Biskopåsen Conglomerate crops out in four separate bodies as shown on the map (Fig. 1). These bodies are connected to one another by dark arkoses which grade laterally into the conglomerates. The matrix of the conglomerates is a coarse-grained dark arkose, freequently containing some calcite.

Three of the conglomerate bodies exhibit a lenticular outcrop pattern. The one at Augga (Fig. 1, H 7) is ca. 100 m in maximum thickness, the one at Skjellbreidvatn (Fig. 1, F-G 4-5) more than 150 m thick, and the one in Vestre Gausdal (Fig. 1, B 4) at least 170 m in thickness.

In Vismunddalen (Fig. 1, I 6), although good exposures are lacking a zone of coarse conglomerate can be followed along the length of the valley. In the coarser parts the long axes of the boulders reach a maximum of 25 cm, decreasing to less than 4 cm 1 km to the north and south. The boulders are well rounded and consist of light quartzite, pegmatite quartz and grey granite.

At Augga (Fig. 1, H 7) the conglomerate is well exposed in the river where it is ca. 100 m in thickness. The boulders are 20—30 cm across and well rounded. They consist of grey granite, light quartzite and gneiss. Upwards the grain size decreases, and the pebble material then consists mainly of light quartzite. The coarsest part of the conglomerate at Augga is exposed near the lake Auggevatn (Fig. 1, H 6), in the river Augga and along the road that runs parallel to the river.

Southwards from the lake Auggevatn the conglomerate thins out and the boulders (mainly of light quartzite) diminish in size and are scattered in a matrix which gradually becomes more fine-grained. The southern margin of the Augga conglomerate body is situated approximately two kilometres south of lake Auggevatn.

North of Auggevatn abundant erratics (2—5 m^3 in size) of conglomerate with well rounded boulders 15 cm in diameter suggest that the conglomerate at Augga extends northwards for at least one kilometre. Westwards the conglomerate is overlain by a dark arkose which, although devoid of boulders, contains some scattered fragments (1.5 cm) of white quartzite. This dark arkose is the youngest exposed stratum of the formation at Augga.

A plateau ca. 900 m a.s.l. surrounds the lake Skjellbreidvatn (Fig. 1, G 5). Here the Biskopåsen Conglomerate is extencively exposed on all hills and in all the river beds. The matrix of the conglomerate in this particular body contains more calcite than at any other locality within the area. This calcite is thought to be primarily of clastic origin, probably derived from a source outside the area and possibly from the «Brøttum Limestone» between the Brøttum Sandstone and Shale and the Biskopåsen Conglomerate (Skjeseth, 1963, p. 28).

The oldest part of the Biskopåsen Conglomerate at Skjellbreidvatn is found at the top of the steep slope west of the valley Auggedalen and on the east slope of the hill Grøtåshaugen (Fig. 1, F 5). There it is a dark arkose with fragments of light quartzite, similar to the upper layer of the conglomerate at Augga.

The size and number of boulders increase westwards. In a zone between Grøtåshaugen and the lake Hindalssjøen (Fig. 1, F 5) the maximum long axes of the boulders measure 30—40 cm. The thickness of the conglomerate and the size and number of the boulders decrease northwards and southwards from Hindalssjøen. West of Hindalssjøen lengths of boulders rarely exceed 10 cm. Further west the size and number of the boulders decrease, and the uppermost part of the deposit is represented by a bluish-grey calcareous arkose.

In its coarsest parts, the conglomerate contains boulders which consist almost exclusively of a coarse-grained grey granite, sometimes porphyric. The matrix is a coarse calcareous gravel with angular pebbles. Outside the very coarsest zone, the conglomerate contains a larger number of boulders of gneiss and quartzite. Pebbles in the fine-grained conglomerate at the margins of this body consist almost solely of quartzite.

In Vestre Gausdal the Biskopåsen Conglomerate is best studied along the 50 m deep canyon of the river Roppa (Fig. 1, B 3-4). A section is drawn along the edge of the canyon (see Fig. 4). The oldest part of the conglomerate in the Vestre Gausdal area is found in the river Søndre Haukå (Fig. 1, C 3-4) where the Brøttum Sandstone and Shale gradually passes up into the conglomerate. In the lower and upper beds of the conglomerate the boulders are scattered, while in the central parts of the body boulders are observed to be tightly packed and their maximum lengths frequently exceed one metre: the boulders are elongated but well rounded. In the coarsest part of the conglomerate the boulders consist almost entirely of grey granite. Where the conglomerate is moderately coarse, the boulders comprise grey granite, gneisses, light quartzite, dark sandstone and dark quartzite. In the most fine-grained horizons near the top of the deposit, the pebbles consist of light quartz and quartzite. Imbrication of the boulders indicates a transport of material from the west or north-west. The uppermost layer of the conglomerate in Vestre Gausdal is a bluish-grey arkose which gradually passes up into a calcareous arkose and the overlying Biri Limestone.

The matrix of the Biskopåsen Conglomerate in Vestre Gausdal has been studied in thin-section. The clastic material is the same as that of the Brøttum Sandstone and Shale, but the ratio clastic material: fine-grained matrix is higher for the conglomerate.

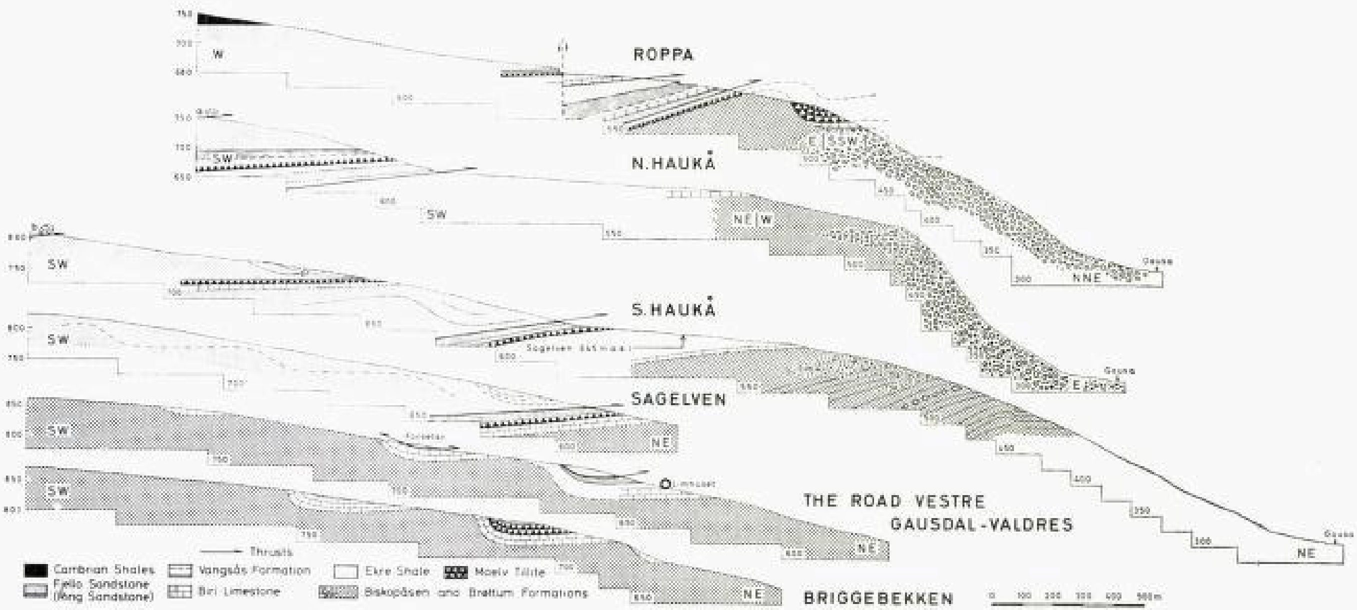

Fig. 4. Sections in Forsetlia, a and b are blocks of limestone. The vertical scale is twice the horizontal scale, the heights given as metres above sea level. (See also Fig. 21).

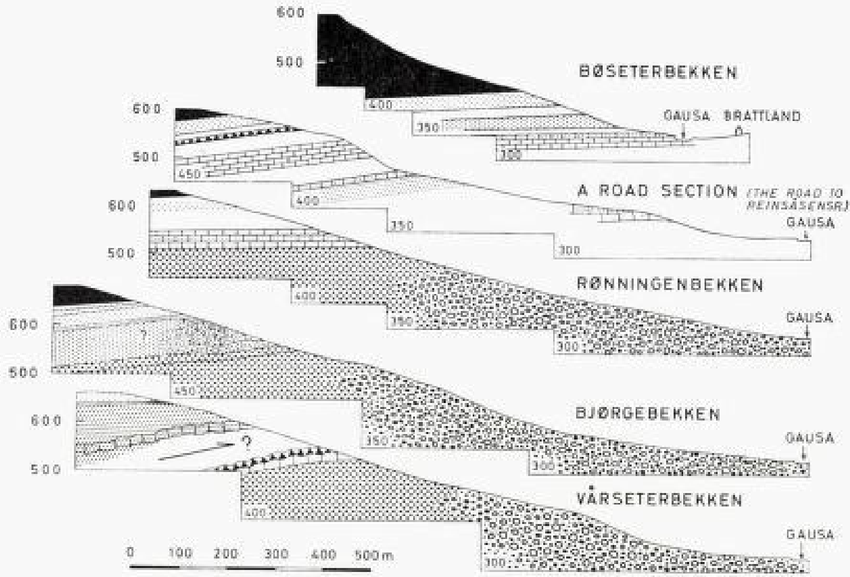

Fig. 5. Sections in Bølia; horizontal and vertical scales equal. (See also Fig. 21).

Fractures in the clastic grains are filled with recrystallized quartz or sericite and occasionally by chlorite. The chlorite, which sometimes penetrates clastic grains of quartz and feldspar, is greyish green (weak pleochroism) with an anomalous blue interference colour and positive elongation.

In consideration of sedimentation conditions and environment, it is likely that the conglomerate bodies were deposited as river deltaes along the south-western coast of the Sparagmite Basin. Whether the conglomerates are of exactly the same age is not known, though as they are all younger than the Brøttum Sandstone and Shale and older than the Biri Limestone, they must have been deposited at approximately the same time. With regard to the changing lithological character of the sediments, from greywackes of the Brøttum Sandstone and Shale to the conglomerates and arkoses of the Biskopåsen Formation it would appear that crustal movements must have occurred around that time. These lithological changes can be studied along the western, south-western and southern borders of the Sparagmite Basin. The coarseness and roundness of the hard boulder material of the Biskopåsen Conglomerate indicates that the gradients of rivers increased and that the material was transported over considerable distances. This favours the idea either that the crustal movements took place outside the basin of deposition, or that a general uplift of the area possibly occurred rather than an actual subsidence of the basin itself. Gradually the deposition of cobbles was followed by pebbles, then gravel and arkoses, and in turn there followed a period with sedimentation of the Biri Limestone.

Biri Limestone.

Above the Biskopåsen Conglomerate there are carbonate deposits which are partly arkosic. This formation, the Biri Limestone, is exposed from Storlodammen (Fig. 1, K 7) in the south to Brattland (Fig. 1, A 3) in the north. The transition from the Biskopåsen Conglomerate to the Biri Limestone in this area is best seen at the mountain Herfjell (Fig. 1, E 3) and in the stream Bjørgebekken (Fig. 1, B 3).

As mentioned earlier (pp 161 and 165), the Biri Limestone of the Vestre Gausdal area differs from the Biri Limestone at the type locality at Mjøsa. In Vestre Gausdal it can be divided into four members:

Nyseter Limestone	ca. 0– 20	m	thick
Fjello Sandstone	» 0–200	»	»
Vismund Limestone	» 0– 20	»	»
Åltjerna Limestone	» 0– 15	»	»

To a large extent these members interdigitate and no sharp boundaries have been observed between them.

Åltjerna Limestone.

The Åltjerna Limestone is the oldest member and the one that mostly resembles the Biri Limestone from the type locality. It can be traced from the type locality to the Vestre Gausdal area. At Storlodammen (Fig. 1, K 7) and Vismundseter (Fig. 1, J 7) the Åltjerna Limestone is a sequence of alternating dark limestones and shales, the layers 2–5 mm in thickness. At Åltjerna setrene (Fig. 1, H 6) and in Vestre Gausdal it is a dark limestone with white calcite veins. In Vestre Gausdal it is overlain by an interbanded grey limestone and shale alternating rapidly in 2–5 mm thick layers. By the confluence of the rivers Sagelven and S. Haukå (Fig. 1, C 4) the interbanded grey limestone and shale is resedimented, a current from the west has moved the limestone fragments a few centimetres.

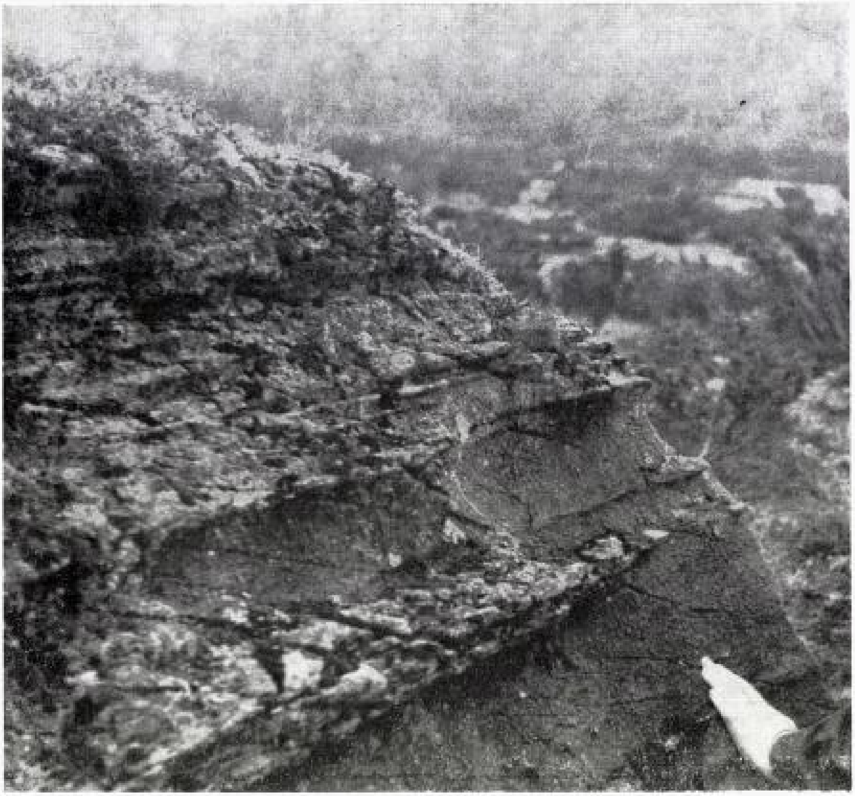

Fig. 6 A. Nyseter Limestone from Nyseter.

Vismund Limestone.

In the valley Vismunddalen the Vismund Limestone is exposed in the lowest parts of the surrounding hills. It is evidently younger than the Åltjerna Limestone though the actual contact is unexposed. The Vismund Limestone contains an admixture of coarse clastic material, and so is partly a calcareous arkose which sometimes displays graded bedding. Upwards it gradually passes into the overlying Fjello Sandstone.

Fjello Sandstone.

The formation Ring Sandstone at Mjøsa can be traced into this area. It thins out westwards and then has limestones both below and above it; in Vestre Gausdal, this sandstone is a member (the Fjello Sandstone)

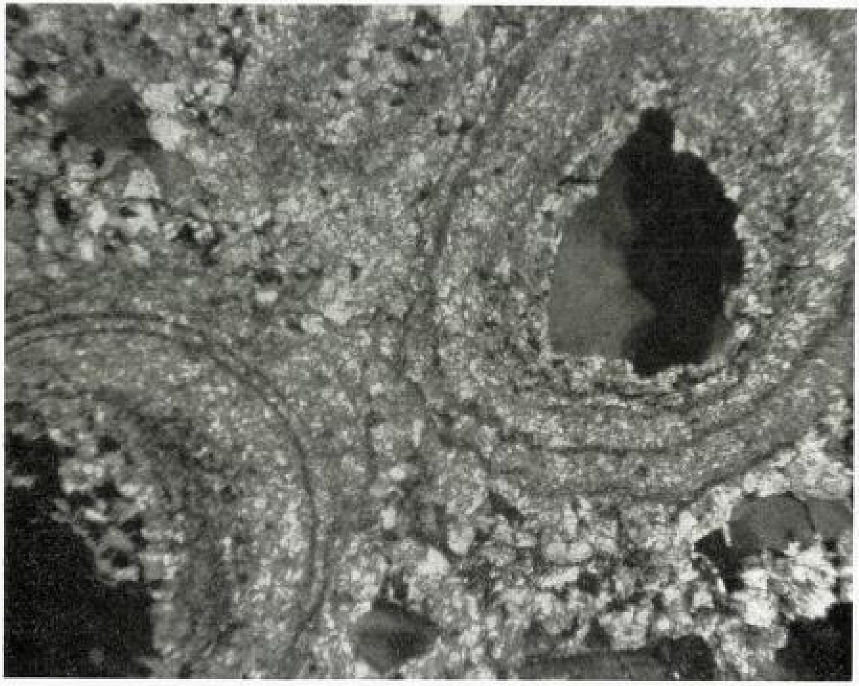

Fig. 6 B. Oolitic texture of the rock at Fig. 6 A, crossed nicols. (Enlarged ca. 50x).

of the Biri Limestone formation. In the southern part of the area, the Fjello Sandstone (Ring Sandstone) is a thick deposit of bluish-grey arkose which is very coarse and partly calcareous. At the lake Fjellovatnet (Fig. 1, K 6) it is ca. 200 m thick but thins out north-westwards to ca. 100 m on the hill Bjørnhaugen (Fig. 1, J 4). The uppermost layers are not exposed.

The Fjello Sandstone in the northern part of the area is mostly a medium-grained dark feldspathic sandstone which rarely exceeds 10 m in thickness. Similar rock types are very common among older and younger formations, but the Fjello Sandstone can be identified in particular by its upward enrichment in carbonate.

Nyseter Limestone.

The Nyseter Limestone crops out from the eastern slope of the mountain Skjellbreidfjell (Fig. 1, F 4) in the south, to west of the farm Brattland (Fig. 1, A 3) in the north. It does not differ from the Vismund

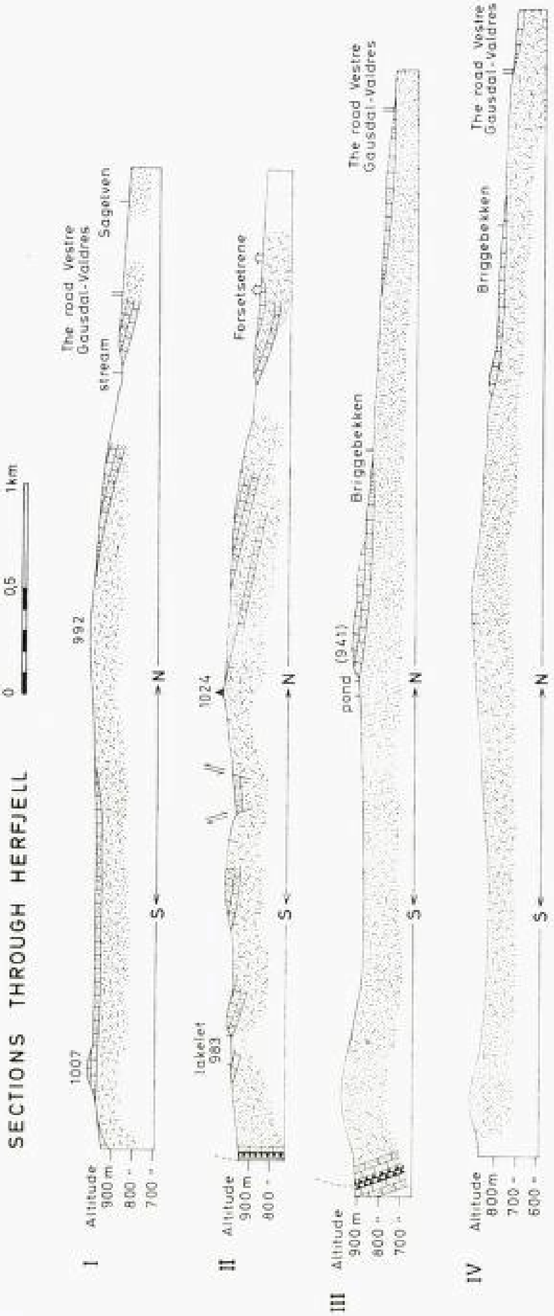

Fig. 7 A. North-south sections across the mountain Herfjell. Ca. 400 m between the sections. For legend, see Fig. 7 B, p. 178.

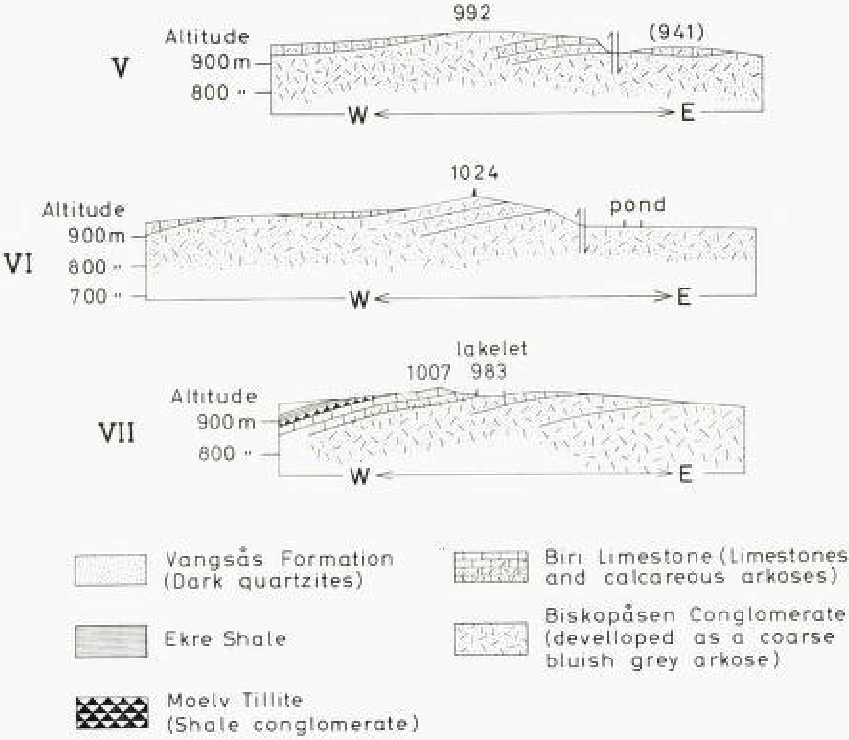

Fig. 7 B. East-west sections across the mountain Herfjell. Ca. 0,5 km between V and VI, and ca. 1,5 km between VI and VII.

Limestone, other than in its stratigraphical position. The Vismund Limestone rests on Åltjerna Limestone and grades upwards into the Fjello Sandstone, while the Nyseter Limestone rests on arkoses (the top layer of the Biskopåsen Conglomerate) and is overlain by the Moelv Tillite. The Nyseter Limestone is the most exhaustively studied member of the Biri Formation within the area. It is well exposed at Nyseter and Herfjell (Fig. 1, E 3) where it has its maximal thickness and shows a good deal of facies variations. At these particular localities no other members of the Biri Formation are present.

The rocks of Herfjell represent a transitional zone between the Biskopåsen Conglomerate and the overlying Biri Limestone. The transitional zone from the arkose at the top of the Biskopåsen Conglomerate to the Nyseter Limestone is ca. 100 m in thickness; the Nyseter Limestone is

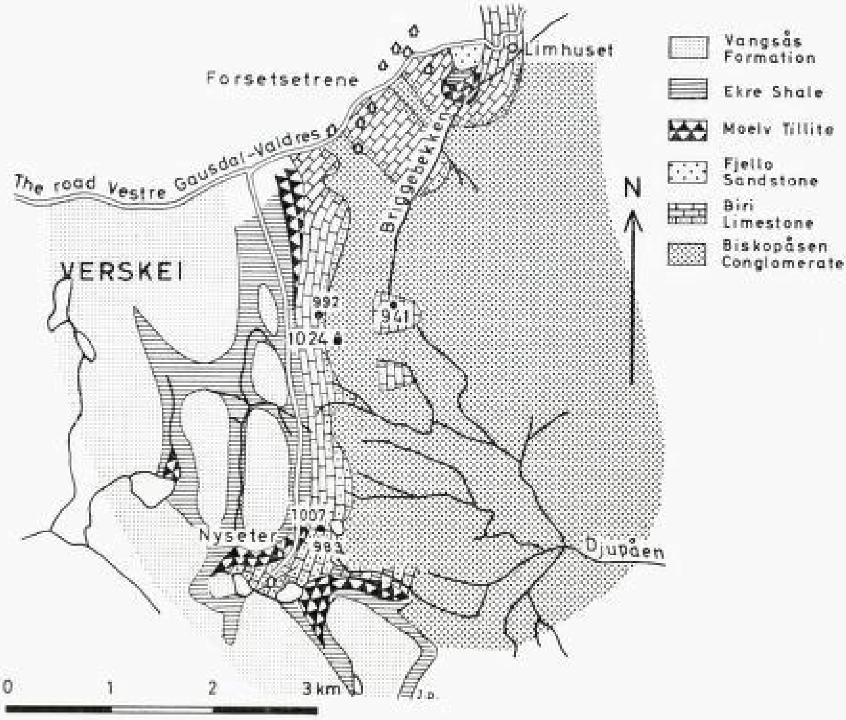

Fig. 7 C. Geological map of the Herfjell area.

ca. 20 m thick. Because of the transition it is difficult to estimate or measure the thickness with any accuracy. The local stratigraphy is sketched in Figs. 7 and 8. Upwards (northwards and westwards on the map, Fig. 1), the rocks at Herfjell are gradually enriched in limestone beds 2–3 cm thick with intercalated 0.2–2 m thick arkose units. Limestone layers become more and more numerous higher up in the sequence,

Fig. 8 A. Light bluish-grey silty limestone interbanded with a conglomeratic limestone in the south wall of the hill (941) east of Herfjell.

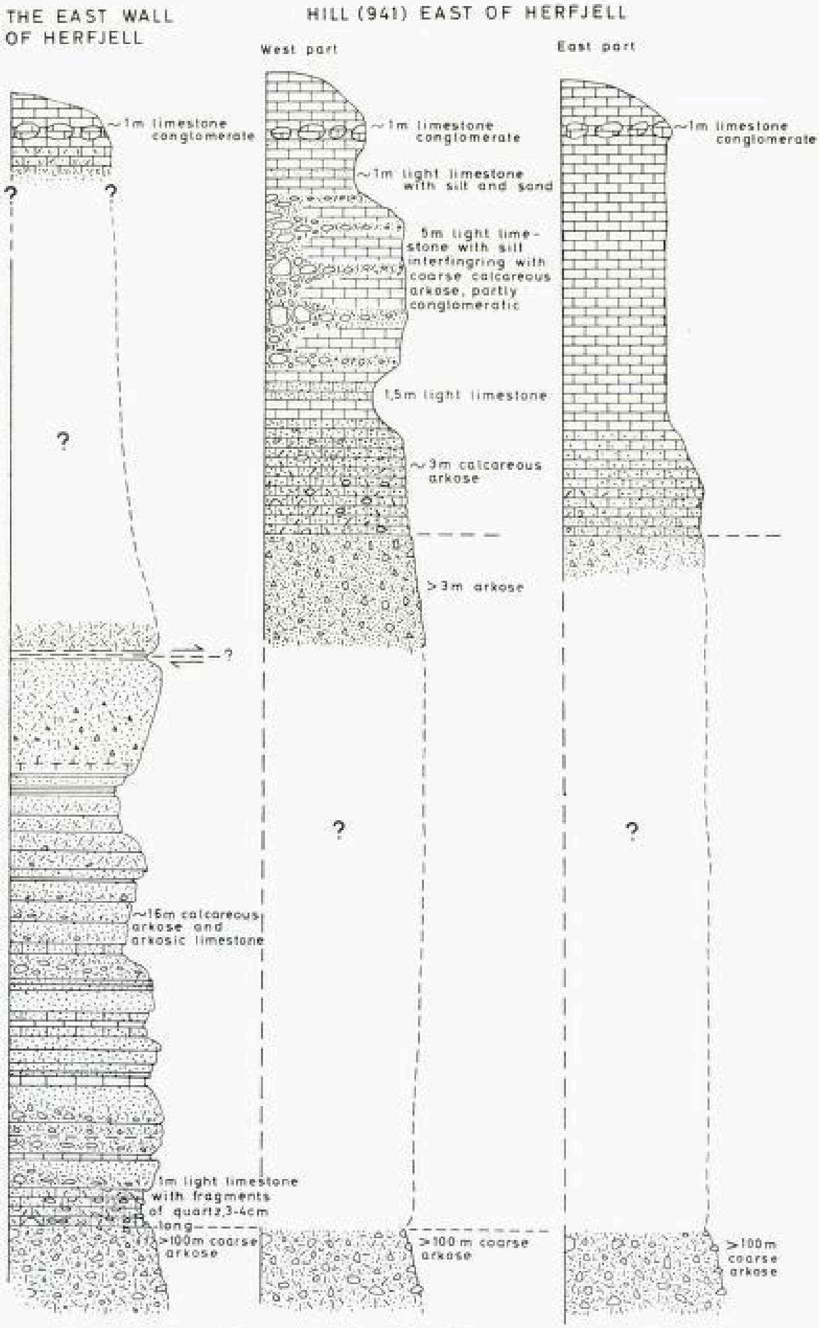

Fig. 8 B. Detailed sections through calcareous rocks at Herfjell.

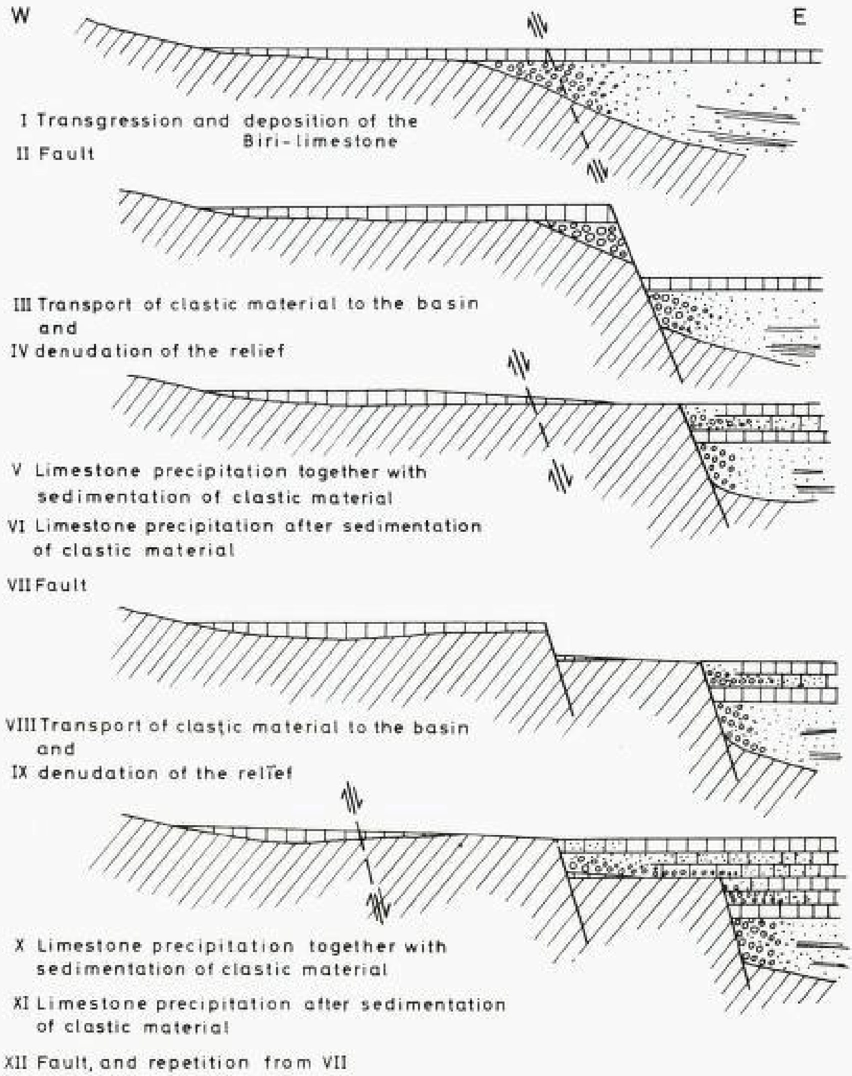

Fig. 9. A sketch of the south-west border of the Sparagmite Basin as it may have been during the time of Biri Limestone deposition.

and at the same time the matrix of the arkose interbeds is enriched in carbonate. A limestone-conglomerate occurs near the top of this Nyseter Limestone (Fig. 8 B).

The uppermost layers show graded bedding. Near the top the calcareous arkoses have an oolitic texture (Fig. 6). These layers interdigitate irregularly with a light silty limestone, ca. 2 m thick: this limestone marks the top of the Nyseter Limestone.

Thin-sections of dark limestones show a very fine-grained matrix of calcite and graphite with dispersed fragments of quartz and feldspar, usually ca. 0.1 mm in diameter. The fragments are corroded by the calcite of the matrix and have lobate outlines. The quartz grains show irregular extinction. Most of the K-feldspar grains are microcline, but some of them are too small to show any visible microcline or perthite textures. Plagioclase has not been observed. Crystals of vein calcite occur in all sizes up to ca. 1 mm. Secondary quartz or feldspar is not observed.

It is likely that parts of the Biri Limestone in this area are the temporal equivalents of the Ring Sandstone, especially as the Biri Limestone contains arkosic layers (the Fjello Sandstone). On the other hand, the Fjello Sandstone may be regarded as a near-shore facies of the Biri Limestone as indicated in Fig. 9. The variation in facies and thickness of the Biri Limestone may partly be due to irregularities of the sea bottom ensuing the deposition of the Biskopåsen Conglomerate.

The most obvious near-shore facies of the Biri Limestone within the area is found near the confluence of the rivers Sagelven and Søndre Haukå (Fig. 1, C 4 or Fig. 2, C 2-3). Here the original limestone and shale has been broken and resedimented, and the fragments moved but a few centimetres indicating currents from the west. The shore-line at the time of deposition of the Biri Limestone must have been situated a little to the west of this locality.

The oolitic layers at the top of the Nyseter Limestone also point for deposition near the shore. Illing (1954, pp 35—44) found that ooliths are inorganic growths formed in warm marine waters washing along shores with carbonate sands. He defines ooliths as grains of different origin surrounded by one or more concentric layers of fine-grained carbonate. According to this definition and origin the Nyseter Limestone with ooliths may have been a gravel in the littoral zone, and it may indicate where the shore of the basin was located during the deposition of this particular formation.

Moelv Tillite.

Within this area the Moelv Tillite is a boulder-bearing shale (Fig. 10). It is found from Nyseter (Fig. 1, E 3) in the south to Bølia (Fig. 1, B 3) in the north. The shale matrix is dark grey and usually shows a greenish

Fig. 10. Moelv Tillite in the river Sagelven (Fig. 2, C 2).

grey weathering surface. West of Dekken seter (Fig. 1, I 4) there are some erratics, > 1 m^3, of a coarse conglomerate with angular boulders; these are also interpreted as Moelv Tillite.

The tillite rests on the Nyseter Limestone, and this boundary can be seen at Nyseter (Fig. 1, E 3), south of Herfjell (Fig. 1, E 3), and in the stream Briggebekken (Fig. 1, D 4). These localities are (so far) the only ones known in Southern Norway where the tillite is resting on limestone in an autochthonous position. The contact itself is sharp. The tillite also occurs allochthonously within the area (Figs. 4, 5 and 21). In such cases it is mostly crushed or mylonitized, but still recognizible.

The thickness of the formation varies from ca. 30 m at Roppa (Fig. 1, B 4) to 2.5 m in the upper thrust sheet at Roppa and Bjørgebekken (Fig. 1, B 3). In all probability the variation in thickness is partly due to tectonic deformation.

The tillite is markedly polymict, the boulders and pebbles varying in size from 1 m down to the fine grains of the matrix. The matrix of the deposit displays a varved structure and consists mainly of laminated silt, each lamina ca. 1 mm thick.

Throughout the area the most common material of the boulders and blocks are fine-grained light quartzites, grey granite, and a fine-grained light granite. Boulders of gneisses, limestones and mylonites are frequently seen, but those of pegmatite quartz, shale fragments and meta-amphibolites are rare. On the northern slope of Herfjell (Fig. 1, D 3) one pebble of red granite has been found in the tillite, while at Nyseter (Fig. 1, F 3) a 30 cm long boulder of Nyseter Limestone with graded bedding was deposited, and as this particular rock is too brittle to have been transported over long distances without disintegrating, its presence as a sizable boulder at Nyseter would appear to confirm the local derivation.

In thin-sections the laminae of the matrix are seen to bend conformably around the clastic fragments. The fine-grained matrix consists of scattered chlorites, sericite, granulated quartz and small pyrite crystals. Most clastic grains consist of quartz and quartzite of variable size and roundness. All quartz displays irregular extinction. Rock fragments are of the same material as the pebbles, boulders and blocks. Many of the feldspar grains are light brown or mottled brown and some of them are strongly sericitized and they are often corroded by carbonate. Many of the plagioclase (albite) grains have bent twin lamellae. Clastic grains of brown biotite (partly altered to chlorite), muscovite, phlogopite, zircon and ore have been observed but these are rare (Fig. 11).

As shown in Fig. 11, in thin-section the rock looks like a greywacke. According to Pettijohn (1957, pp 272—273) pure tillites will resemble greywackes, having a matrix rich in chlorites and micas.

The unsorted character of the boulders together with the finely stratified matrix indicate that the boulder clay within the area has been deposited under water. Kulling (1938, pp 292—296) found that unsorted angular material dispersed in a laminated matrix where the layers bend conformably around the clastic fragments is indicative of a glacial origin.

Holmsen (1954, pp 105—119) described facies variations of the Moelv Tillite. He interpreted the type found at Moelv (Holtedahl, 1922, pp 168—172) as a near-shore facies, and the boulder-bearing shale as having been deposited farther from the coast, the boulders being ice-rafted. Earlier, Münster (1901, pp 18—19) had compared these deposits, and thought that the cleavage in the tillite was formed during the regional metamorphism of the area. Englund (1966, pp 77—79) described a boulder-bearing shale at Fåvang (ca. 20 km north of this area) in a similar stratigraphic position, and he maintained that was of glacial origin.

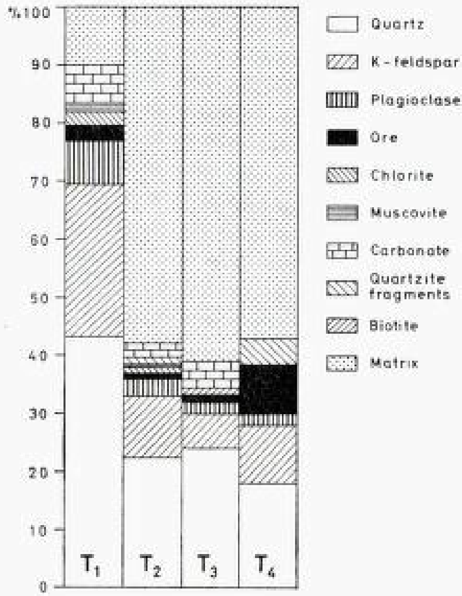

Fig. 11. Modal analyses of Moelv Tillite from the area.

T_1 = Light variety with sand and silt in matrix, from Nyseter.
T_2 = Dark shaly variety from lower thrust sheet in Roppa.
T_3 = Light shaly variety from 2 km north-west of Nyseter.
T_4 = Dark brown, strongly tectonized variety from 1 km south-east of Nyseter.

As the matrix of the tillite west of Herfjell consists mainly of silt, this suggests that the boulder clay here was deposited nearer to the shore than the equivalent deposits north and east of Herfjell. The boulder of Nyseter Limestone found in the tillite at Nyseter indicates that the top of the Biri Formation was eroded. Its occurence also suggests that the border of the Sparagmite Basin was situated not far west from Herfjell during the time of deposition of the Moelv Tillite.

The contact between the Nyseter Limestone and the Moelv Tillite can be correlated with a sudden change in climate at the same time as areas west of the Sparagmite Basin were being uplifted. The nature of the boulders of the tillite provides evidence that the area west of the Sparagmite Basin consisted mainly of quartzites and grey granites at the time of deposition of the Moelv Tillite. The quartzites found in the tillite resemble the rocks described as quartzites and quartzitic gneisses by Bugge (1939, pp 20—29) from the areas Hemsedal and Gol (ca. 80 km south-west of this area). Grey granite occurring as boulder material is similar to the granites described by Smithson (1963, pp 36—37) from Hedal (ca. 70 km SSW of this area). The Precambrian areas that supplied material to the Sparagmite Basin are to-day covered by younger deposits, and it is difficult to locate the source of these particular boulders. However, some of the rocks are thought to resemble lithologies from the Precambrian in Valdres (Strand, 1943). (Valdres is ca. 70 km west of this area.)

Ekre Shale.

The Ekre Shale is commonly a grey or greenish grey silty shale (Fig. 12) similar to the matrix of the tillite. It is exposed from the southern part of Skjellbreidfjell (Fig. 1, G 4) to Bølia (Fig. 1, A-B 3).

No sharp sedimentary contact has been seen, either to the tillite below or to the formation above the Ekre Shale. The thickness of the Ekre Shale varies from ca. 40 m at the northern part of Skjellbreidfjell where it is relatively undisturbed to ca. 0.5 m at the southern part of Skjellbreidfjell where it is squeezed between allochthonous units: on the map, Fig. 1, the Ekre-Shale is drawn with exaggerated thickness. The silt content of the Ekre Shale decreases northwards as does the silt content of the matrix of the tillite.

Thin-sections of this lithology show that it is a laminated clay-silt rock. Each layer is 0.3—4.0 mm thick, those more than 1 mm in thickness sometimes showing graded bedding. The lighter layers consist of fine-grained sericite and chlorite with some scattered clastic grains of angular quartz up to 0.05 mm in diameter. There are also some 0.5 mm long flakes of bent muscovite and 0.2 mm long flakes of biotite. In the light layers the ratio of clastic grains : matrix varies from 1 : 5 at Skjellbreidfjell to 1 : 8 at Roppa (Fig. 1, B 3). The dark layers consist mainly of dark clastic material packed in a graphite-rich matrix. Most of the clastic grains are ca. 0.1 mm in diameter, but 0.2 mm grains are also present. The quartz and K-feldspar are dark because of numerous inclusions. The quartz displays undulose extinction, and the K-feldspar is a «patchy» perthite. Plagioclase is rare, only two small grains having been observed. Although clastic muscovite and biotite are present, they appear more frequently in the lighter layers. Biotite is partly altered to chlorite. Haematite and limonite are found as inclusions, 0.1 mm or smaller, in biotite-chlorite individuels. In the darker layers the clastic grains : matrix ratio varies from 3 : 2 at Skjellbreidfjell to 1 : 2 at Roppa.

Kuenen and Migliorini (1950, p. 119) maintained that floculation of lutite in marine waters will make it settle together with the silt so that varves cannot be developed. When the ice that deposited the tillite melted, it is possible that big rivers from the melting glaciers ran into

Fig. 12. Ekre Shale from 1 km ESE of Nyseter (¼ size).

the Sparagmite Basin and so made the water near the mouths of the rivers brackish or fresh. The turbulent water that brought material into the basin at the time of deposition of the Ekre Shale was probably so cold and heavy that it sank on entering the basin. Its load is thought to have been deposited under quiet conditions in brackish water with the concomitant development of graded bedding.

K. Bjørlykke (1963, pp 90–92) described the Ekre Shale from the eastern border of the Sparagmite Basin, and Englund (1964, pp 108–111) has presented a description of this same formation occurring at Fåvang (ca. 20 km north of this area). Neither of them, at that time, found laminated rocks in those areas. K. Bjørlykke suggested that the constituents of the shale were derived from rocks rich in clay minerals. The lack of lamination may imply deposition in saline waters further away from the river estuaries. Later, however, both K. Bjørlykke (1966 p. 32) and Englund (1966) reported the localized occurrence of a varve-like lamination in their areas.

The average varve within the area is ca. 1 mm thick. If the varves represent seasonal deposits and the thickness of the Ekre Shale at Skjellbreidfjell (ca. 40 m) is close to the true thickness, the Ekre Shale of the area was deposited probably during a period of ca. 40 000 years. The presence of clastic grains of dark quartz and feldspar similar to those found in the Fjello Sandstone indicate that the same source rocks were being eroded over a long period of time.

As the Moelv Tillite is a glacial deposit, the oldest part of the Ekre Shale is a late-glacial to post-glacial sediment. The boulder material of the tillite gradually decreases, a feature possibly signifying a gradual withdrawal of the ice. If the water of the Sparagmite Basin was saline at that time, it was almost certainly warmer than that of the rivers which flowed into it.

The Vangsås Formation.

The Vangsås Formation comprises the two members Vardal Sandstone and Ringsaker Quartzite. The older member the Vardal Sandstone, gradually passes into the Ringsaker Quartzite with decreasing grain-size and feldspar content; the border as indicated on the maps and sections is therefore transitional.

Vardal Sandstone.

The Vardal Sandstone is mostly a dark arkose with a tectonic contact to the Ekre Shale, but on the west side of Skjellbreidfjell (Fig. 1, F 3) a sedimentary boundary can be observed. At this boundary there are alternating layers of shale and arkose, the arkosic beds thickening upwards while the layers of shale diminish in thickness and number. The Vardal Sandstone has its maximum thickness (ca. 100 m) in the south of the area; this decreases northwards to ca. 5 m in the stream Bøseterbekken (Fig. 1, A 3).

The Vardal Sandstone is well exposed in all hills west and south of Vismunddalen. The mountain Skjellbreidfjell is built up of Vardal Sandstone lying in both autochthonous and allochthonous positions. On the west side of the hill Verskei (Fig. 1, D 2) the Vardal Sandstone is developed as a conglomerate with pebbles of white quartzite and a matrix of dark arkose. No imbrication has been observed. The weathered surface of the conglomerate is reminiscent of the Fjello Sandstone. A more fine-grained variety of the conglomerate is found in some of the hills west of Nyseter (Fig. 1, E 3) and in the river Søndre Haukå (Fig. 2, C 2). In Søndre Haukå there is a 20 cm wide zone of coarse arkose (7 mm-size

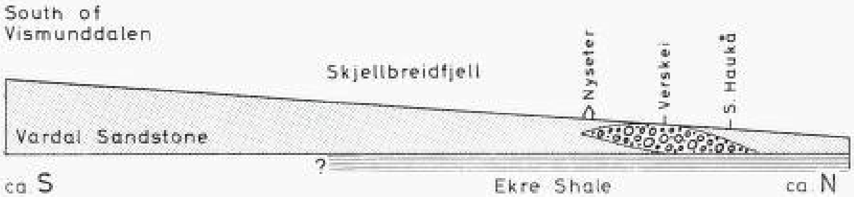

Fig. 13. Facies variations in the Vardal Sandstone.

grains) between the Ekre Shale and the ordinary Vardal Sandstone. Fig. 13 illustrates a possible explanation of the field relationships and facies variations of the Vardal Sandstone.

Microscopic examination shows that in this area the Vardal Sandstone is an arkose which grades upwards into a feldspathic sandstone. The upper part of the feldspathic sandstone is recrystallized. The lower part of the arkose has clastic grains surrounded by some matrix, while the upper part consists of tightly packed clastic grains with little or no matrix, the grains, however, being partly crushed. The clastic material consists mainly of quartz and feldspar, the size of the grains decreasing upwards. The grains are subrounded to well rounded. Quartz shows irregular extinction, and in the crushed individuals this is strongly undulose. The feldspar is mainly microcline and perthites; plagioclase is uncommon — only albite is present. The feldspars are usually light brown or mottled brown. Clastic muscovite is present, but biotite has not been found. Accessory minerals are zircon, haematite and leucoxene. The matrix consists of sericite, fine-grained quartz and some chlorite.

Although the Vardal Sandstone may resemble a fine-grained variety of the Fjello Sandstone, it has less plagioclase and also lacks biotite. Moreover the grain-size and roundness indicate that the material of the Vardal Sandstone has been transported over longer distances (or for a longer time) than that of the Fjello Sandstone.

The conglomerate at Verskei may be interpreted as a lensshaped body thinning out northwards and southwards as indicated in Fig. 13. It has not been found east of Verskei. The character of this conglomerate suggests rather near-shore conditions with a transport of material from a westerly source.

Vogt (1923, pp 327—329) described the Vardal Sandstone from Mjøsa (ca. 40 km south-east of this area). He assumed that the deposition was caused by a rapid uplift of the areas surrounding the basin. This uplift, or uplifts, is thought to have continued irregularly and as a result there are several zones of coarse-grained beds rich in feldspar within the profile. Vogt suggested that the upward decrease in feldspar content corresponded with gradually quieter conditions: the land-mass supplying material to the Vardal Sandstone was gradually being worn down and the transport velocity of the material decreased so that most of the feldspar disintegrated before deposition. This is in agreement with the present writer's observations.

Skjeseth (1963, pp 32—34) described the lower part of the Vangsås Formation in the Mjøsa district as a grey arkose which gradually changes upwards to a white quartzite. Layers of Vardal Sandstone in the Ekre Shale mark the transition from Ekre Shale to Vardal Sandstone. He described a conglomerate occurring in the middle of the deposit along the southern border of the Sparagmite Basin: it is characterised, by white quartz pebbles in a grey sandstone matrix. Skjeseth's descriptions might well be applied to the observations from this area.

The varying thickness of the Vardal Sandstone from north to south in the area can be understood in terms of transport of material from south to north, but then it becomes difficult to explain the even grain-size and the conglomerate at Verskei. As the grain-size, roundness and feldspar content is quite constant throughout the area, it is therefore more likely that the material was brought in from a westerly direction. As indicated in Fig. 13, the sedimentation of the Vardal Sandstone may have lasted for a longer time in the south than in the north of the area.

The rocks that supplied material for the deposition of the Vardal Sandstone were most certainly the same as those which gave material to the older formations: acidic rocks with dark quartz and feldspar, and light quartzites that yielded pebbles for the conglomerate at Verskei. The western border of the basin at that time was probably situated near the area of deposition of this conglomerate.

Ringsaker Quartzite.

The Ringsaker Quartzite within the area is mostly a dark grey to black feldspathic sandstone. This sandstone gradually passes into the overlying Cambrian shales through a transitional zone ca. 1 m thick (Fig. 14). This boundary is seen in the stream Bjørgebekken (Fig. 1, B 3). At other places within the area the boundary has been disturbed by tectonic movements. The Ringsaker Quartzite is found from Nord-Torpa (Fig. 1, K 2) in the south to Vestre Gausdal (Fig. 1, A-B 3) in the north, homogeneously developed, though its thickness (as with the Vardal Sandstone) decreases northwards. At Nylsfjell (Fig. 1, J 1) the thickness is more than 65 m, south of Vismunddalen (Fig. 1, K 5-6) more than 50 m, and at Brattland (Fig. 1, A 3) ca. 10 m.

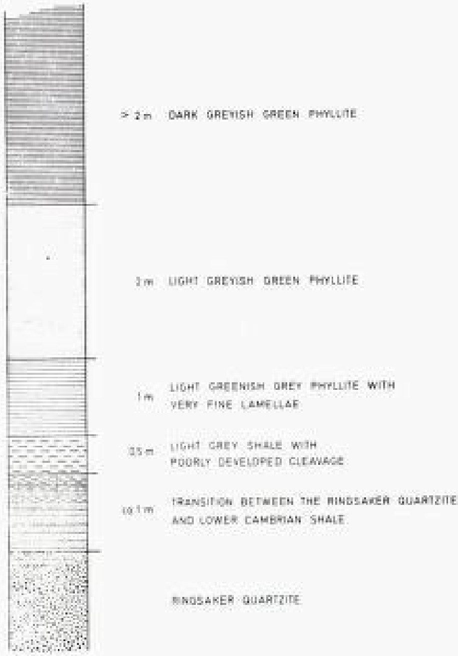

Fig. 14. The transitional zone from Ringsaker Quartzite to the Cambrian shales as developed at Bjørgebekken (Fig. 2, B 3).

In Bjørgebekken (Fig. 2, B 3) there are cyclothems ca. 1,5–2 m thick; the bottom layer of each cyclothem may be conglomeratic. The conglomerates are 1 cm thick and consist almost exclusively of well-rounded grains of dark quartz 7–10 mm in diameter. The thickness and grain-size of the cyclothems decrease upwards in the profile at the same time as thin shale lamellae increase in number and thickness. At the top of the member there is a transitional zone, as shown in Fig. 14, wherein the sandstone layers rarely exceed 2–3 mm in thickness.

Specimens of the Ringsaker Quartzite studied in thin section are found to be feldspathic sandstones and orthiquartzites. Although they are recrystallized, the primary outlines of the clastic grains are still visible under parallel nicols. The grains are closely packed and there is very little matrix. The matrix consists of fine-grained quartz, sericite, finely disseminated graphite and small crystals of pyrite. The clastic grains are usually ca. 1 mm in diameter and well rounded in the lower part of the member, decreasing upwards to ca. 0.05 mm and subrounded to angular near the top. Clastic material consists of quartz and feldspar; other minerals have not been observed. Most of the quartz and feldspar is dark on account of numerous small inclusions. The quartz displays a strongly undulose extinction. Feldspar is light brown or mottled brown. The K-feldspars are microcline and perthites; plagioclase is rare, but where present is albite.

Thin-section studies show that the Vardal Sandstone carries haematite while the Ringsaker Quartzite contains pyrite. This may indicate that the Vardal Sandstone was deposited in an oxidizing milieu and the Ringsaker Quartzite in a reducing environment within the area: it is possible, however, that the pyrite may have been introduced diagenetically.

As the Ringsaker Quartzite in this area is fine-to-medium-grained, this would suggest that quieter conditions of sedimentation prevailed at this time than during the deposition of the Vardal-Sandstone. Vogt (1923, pp 329—331) asserted that deposition of a pure quartzite represents a greater span of time than does an equivalent thickness of arkose. He found that the Ringsaker Quartzite at Ringsaker (ca. 40 km southeast of this area) is 240 m thick, thinning out remarkably towards the north. This led him to suggest that the land adjacent to the basin was uplifted from north to south. Oftedahl, however, (1947, pp 167—168) proposed that the Ringsaker Quartzite was thin in the middle of the basin, and that might be the reason why it is thin in Vestre Gausdal and thicker further south. This agrees with the recent observations.

Skjeseth (1963, p 34) found Scolithus in the Ringsaker Quartzite at Mjøsa indicating near-shore conditions there. No criteria have been found within the area that can help prove that the Ringsaker Quartzite is a near-shore deposit, but as it is possible to follow this member as a continuous unit from the Mjøsa districts into the present area, it is tempting to think that it has been developed under rather similar conditions.

As the Ringsaker Quartzite within the area becomes finer grained upwards in the profile at the same time as it is intercalated with shale lamellae of increasing thickness, it would seem as if it was being deposited gradually further away from the coast; alternatively, the sea may have transgressed to the south and west beyond the border of the original Sparagmite Basin. Quite possibly the thick layers of quartzite in the south-western part of the area mark the position of the border of the Sparagmite Basin during the deposition of most of the Ringsaker Quartzite. The rocks which provided material for the Ringsaker Quartzite were most likely the same as those that supplied material to the Vardal Sandstone. The upward enrichment of quartz within the profile may be due to a longer transport of the material before its actual deposition.

Cambro-Ordovician Shales.

In this area the Ringsaker Quartzite is everywhere overlain by at least 0.5 m of light grey shale (Fig. 14). It is mainly slightly phyllitic, but the cleavage is only poorly developed.

Dapples, Krumbein and Sloss (1938, p. 1932) described shales from stable shelf areas as having certain significant characteristics that suggest their correspondance to quartz sandstone, and that they represent the fine-grained equivalent of the latter. They differ more in grain-size than in mineralogy; however, the clay minerals settle with the same velocity as the very fine quartz grains. Such very fine silt-shales are uniform over great areas and show a gradual transition to sandstones without abrupt contacts. The colour is often greenish grey though this is not diagnostic. This description suits rather well the lowest part of the Cambrian shales within the area, and strengthens the supposition that the Ringsaker Quartzite is closely related to the overlying Cambrian shale.

The Cambro-Ordovician deposits and their fossils from the area have been described thoroughly by Bjørlykke (1891, pp 1—10) and Münster (1891, pp 22—34). Clearly the transgression which occurred in Lower Cambrian times extended far outside the present area.

Brief comments on the sediments.

From the examination of thin-sections of lithologies from several of the formations it can be seen that most of the clastic feldspar is weathered. The feldspar is usually brown or mottled brown in colour, regardless of grain-size. Holtedahl and Schetelig (1923, p. 16) described weathered Precambrian overlain by Cambrian basal conglomerate at Brandbukampen (ca. 80 km south of this area), and they found that this weathered Precambrian continues northwards. Weathered Precambrian most probably existed close to the Sparagmite Basin and supplied material for the deposition of the sedimentary rocks which occur there today. However, some of the weathering and alteration of the feldspars may be a post-depositional phenomenon.

Clastic grains of dark quartz and feldspars are found in the younger formations, their darkness caused by the presence of numerous small inclusions. These have not been studied, but a thorough investigation could probably throw light on the provenance of the Ringsaker Quartzite and other dark quartzites occurring along the Caledonian orogen.

All clastic quartz observed in thin-sections has an irregular extinction, as well as often being crushed. This indicates that the rocks of the area have been involved in tectonic movements. The presence of chlorites and altered biotite points to a low grade metamorphism, most probably the lower part of Eskola's greenschist facies. James (1955, pp 1455–1488) has referred to this part of the greenschist facies as the chlorite zone. In sedimentary rocks with chlorite, sericite, carbonate, clay material and clastic mica this zone is signified by the presence of a cleavage parallel to the bedding.

A feature of particular interest in this area is the occurrence of limestone overlain by tillite. The contact is abrupt. Similar boundary relationships are found at other places in the world and they have been interpreted as indicating a sudden change of climate.

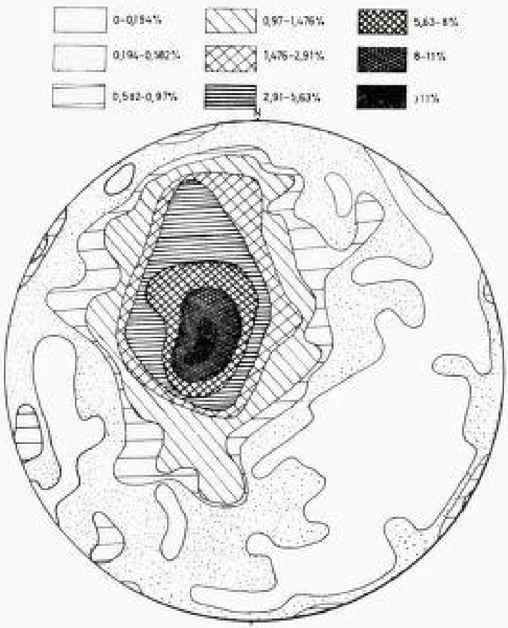

Fig. 15. Projection of bedding planes of the area, 515 observations. (Schmidt net, upper hemisphere.)

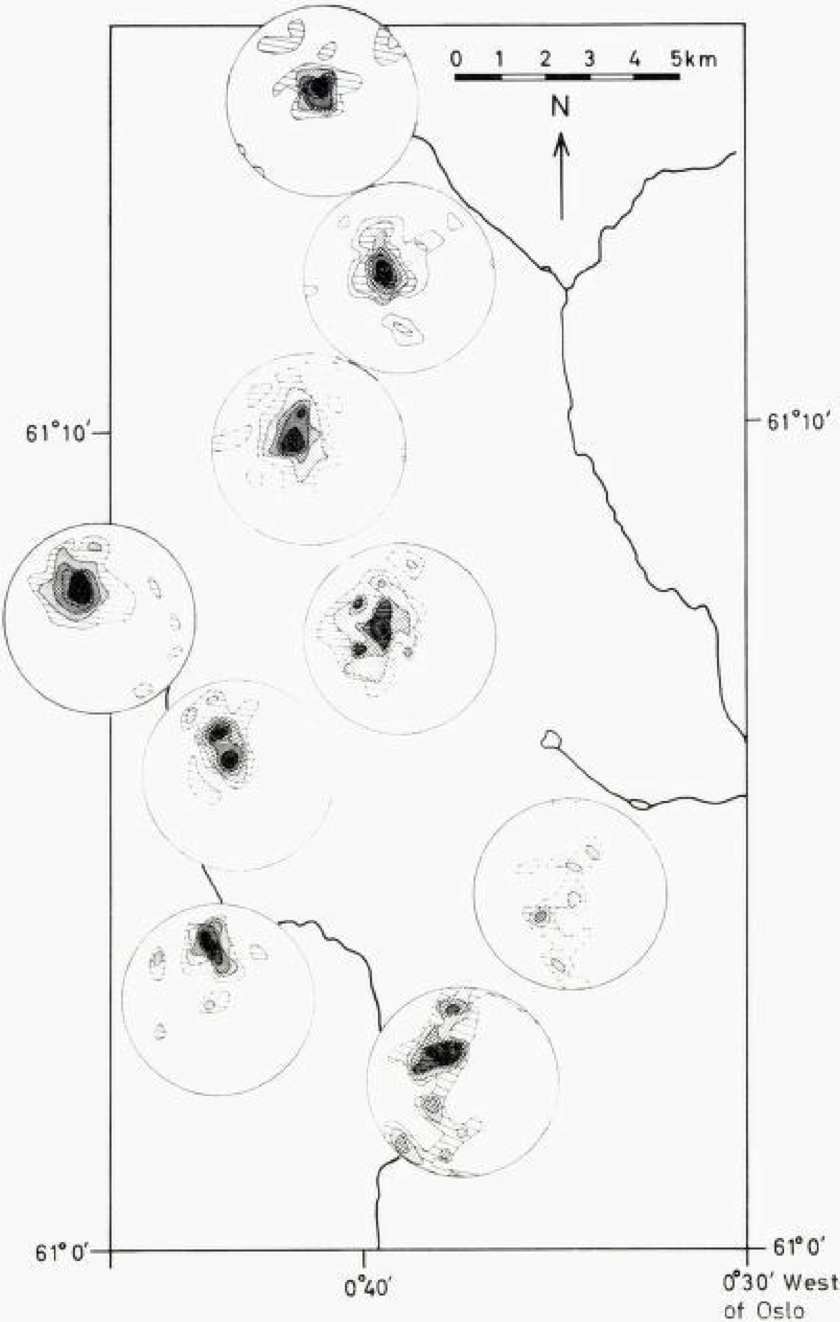

Fig. 16. Bedding within the area (Schmidt net, upper hemisphere).

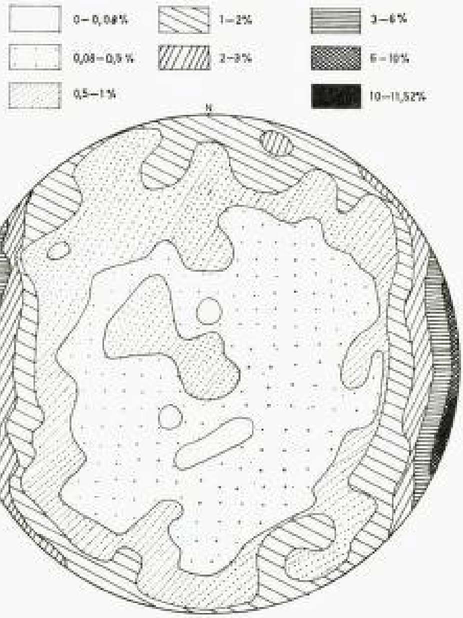

Fig. 17. Projection of faults and joints from the area, 1230 observations (Schmidt net, upper hemisphere).

Structure.

Regional tectonics.

During the Caledonian orogeny, the rocks which now occur in this area were transported towards the south-east from their original site of deposition. The rocks of the Sparagmite Basin were moved southwards against the border of the basin and partly beyond it. In this account only the main structural features of the area will be described.

Bedding commonly dips gently to the north-west (Figs. 15 and 16). Folds of any size are rarely seen in the field, but a lineation is conspicuous in conglomerates, limestones and shales (Figs. 19 and 20). The joints of the area are mainly vertical and show a north-south trend (Figs. 17 and 18); gently dipping joints may be interpreted as minor thrusts. Faults can be demonstrated within the area but are rare (Fig. 20). From a tectonic structural standpoint three groups of rocks can be recognized within the area:

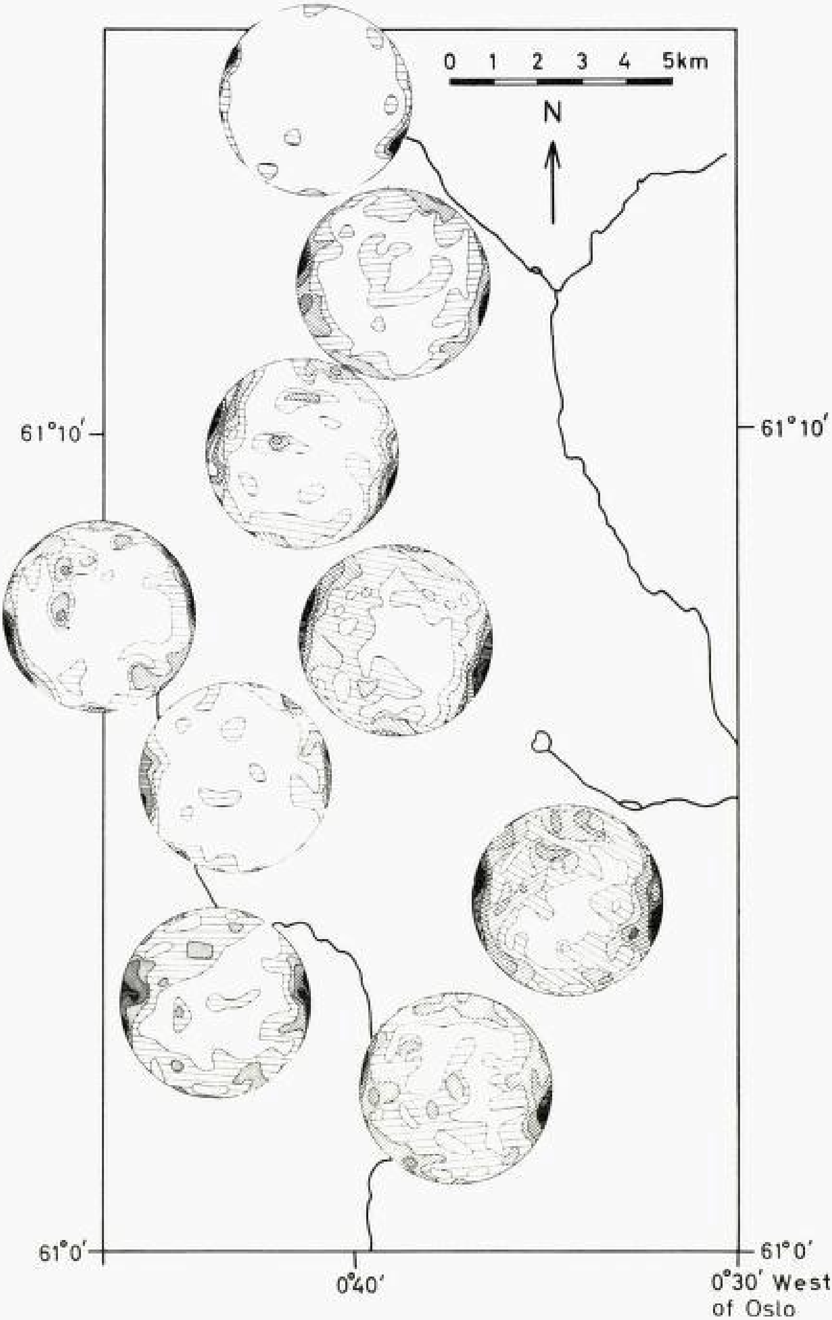

Fig. 18. Joints and faults of the area (Schmidt net, upper hemisphere).

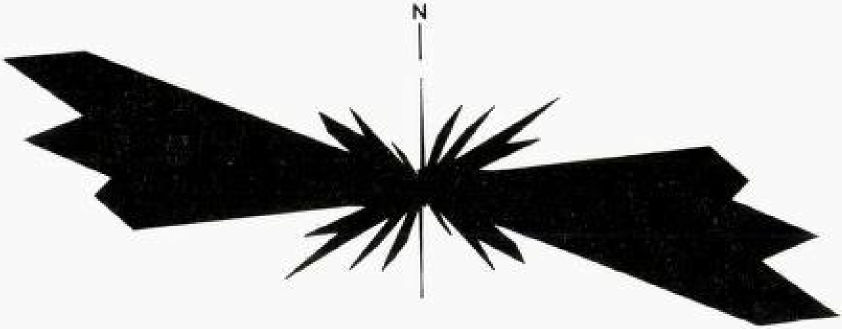

Fig. 19. Orientation of quartz-grains and conglomerate boulders and pebbles. 215 observations.

Allochthonous rocks
Folded rocks
Autochthonous rocks.

Allochthonous rocks (thrusts).

In the south-eastern part of the area the Vangsås Formation has been thrust southwards out of the Sparagmite Basin and inverted, such that parts of it rest on Cambrian shales (Fig. 1, J-L 3-6) and constitute a continuation of the Ringsaker Inversion (Skjeseth, 1963).

The mountain Skjellbreidfjell (Fig. 1, G 4) is mainly built up by Vardal Sandstone and Ekre Shale in imbricated thrusts (Fig. 20).

The maps (Figs. 2 and 20) and sections (Figs. 4, 5 and 21) show that some thrusts are present in Forsetlia (Fig. 1, B-C 3-4): the rocks are very little folded. The thrust planes, where exposed, are smooth and the contact to the underlying rocks is sharp. The underlying rock may be crushed, as is the tillite at Roppa, but as the Ekre Shale and Cambrian shales mainly acted as lubricants, rocks near the thrust planes are only mylonitized close to the contacts if tectonized at all.

Folded rocks.

Most of the rocks of the Sparagmite Group within this area are folded to some extent, though as indicated in Fig. 22 the intensity of the folding increases southwards. Folded sequences are best exposed along the river Roppa and on the mountain Herfjell.

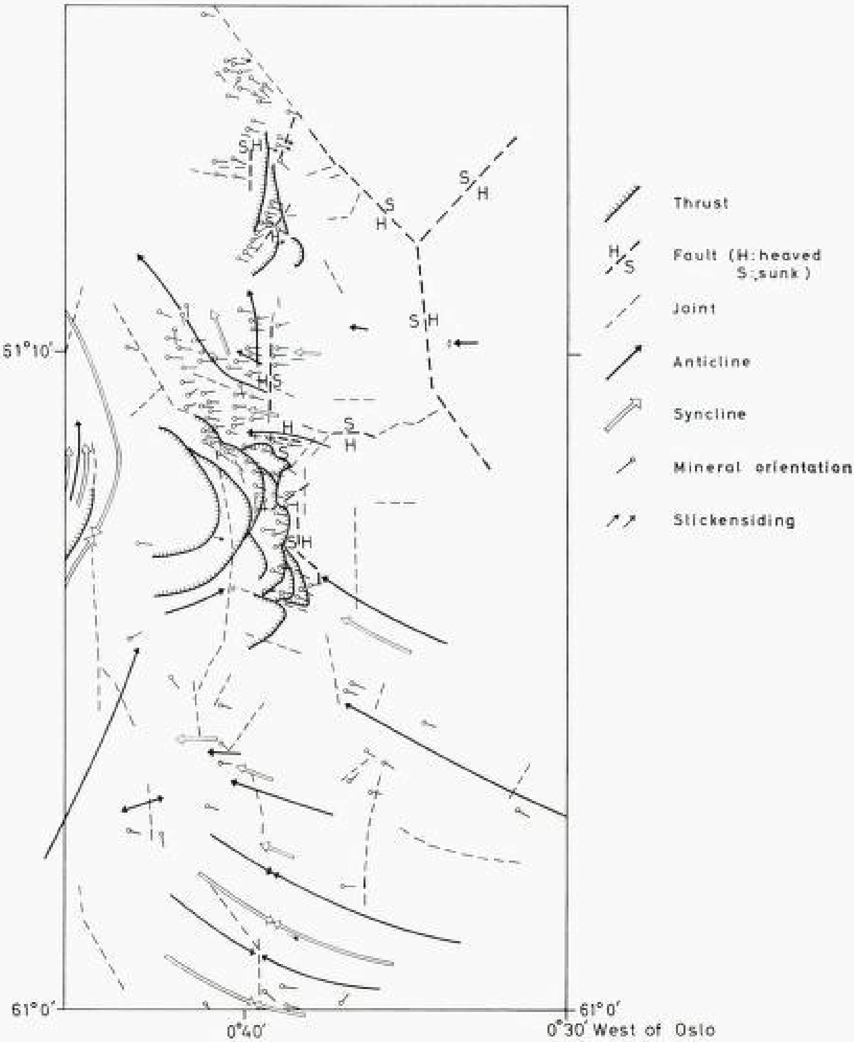

Fig. 20. Structural map of Vestre Gausdal and Fåberg Vestfjell.

The Roppa section.

The river Roppa cuts through both folded and thrusted rocks as shown in Fig. 4. In the lower part of the river gently folded rocks can be observed in the walls of a 50 m deep canyon; the fold axes are ca. north-south and the axial plane dips steeply to the west. The wavelength

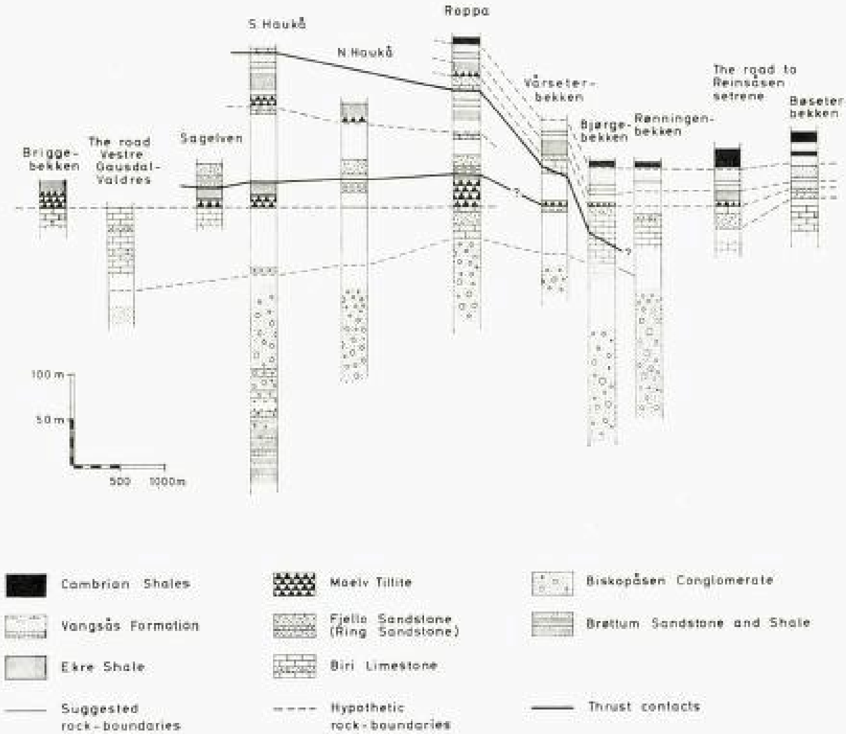

Fig. 21. Sections in Vestre Gausdal (Bølia and Forsetlia).
(See also Fig. 2, 4 and 5.)

is ca. 50 m and the amplitude ca. 10 m. Even the Biskopåsen Conglomerate is folded at this locality, the longest axes of the pebbles and boulders trending east-west (Fig. 19). As indicated in Fig. 4, the Biskopåsen Conglomerate has suffered from tectonic deformation at some levels. Immediately above the Biskopåsen Conglomerate the Biri Limestone is quite undisturbed, but higher up in the section it is folded and thrusted.

Where the Roppa shows a sharp change of direction (Fig. 2, B 3), the Moelv Tillite occurs within a syncline. The thickness of the tillite, here ca. 30 m, has almost certainly been exaggerated by tectonic movements. West of the tillite is an anticline in the core of which is the arkosic top layer of the Biskopåsen Conglomerate (as shown in Fig. 4). The lower thrust sheet in the Roppa valley rests on the western limb of this anticline. This sheet moved forwards over a layer of Ekre Shale and Moelv Tillite. Although these have been thinned to ca. 5 m, they are still recognizible. The thrust sheet itself is ca. 50 m thick and is comprised of strata from the Fjello Sandstone to the Vangsås Formation (Fig. 21).

The upper thrust sheet in this Roppa area rests directly upon the lower one. It evidently moved from west to east on Biri Limestone. The thrust sheet is ca. 50 m thick and comprises strata from the Biri Limestone to the Cambro-Ordivician shales. The folding possibly took place before the thrusting at Roppa, as the thrust sheets seem to stop against the fold.

The Herfjell anticlinorium.

As indicated in Figs. 7 and 22, the mountain Herfjell lies within an anticlinorium. Strata in the south-eastern part of the mountain are inverted, the fold axes dipping at 10° to the WNW. Both the axes of small-scale folds and a mineral lineation follows this direction. Fracture cleavage dips to the north (Fig. 6 A).

With the exception of parts of Nord-Torpa, in the Vangsås Formation (Fig. 1, J-L 47), Herfjell is the only locality within the area where rocks are found in an inverted position. The bedding attitude changes from nearly horizontal at Nyseter through vertical 0.5 km east of Nyseter to inversion 1 km east of Nyseter where the fold is overturned, its southern limb dipping steeply to the north (Fig. 7 A).

It is evident that a strong frictional dragging effect occurred along the western border of the Sparagmite Basin when the rocks of the Sparagmite Group were folded and pushed southwards. The calcareous rocks of Herfjell are less competent than the corresponding rocks further south in the area, and this may be the reason why they were inverted in Herfjell.

The fold causing the inversion in the southern part of Herfjell shows a change of axial trend from a WNW-direction in Herfjell to a more NW-direction in the hill Verskei (Fig. 1, D 2) where the fold dies out (Fig. 20).

The folded area south of Herfjell.

South of Herfjell the lithological sequence in the Sparagmite Basin seems to be gently folded. On the plateau west of Auggedalen (Fig. 1, F-G 4-5) no folds are seen; however, the Biri Limestone at Skjellbreidseter (Fig. 1, G 4) has boudinage structures indicating a compression from the north, the boudins being aligned east-west.

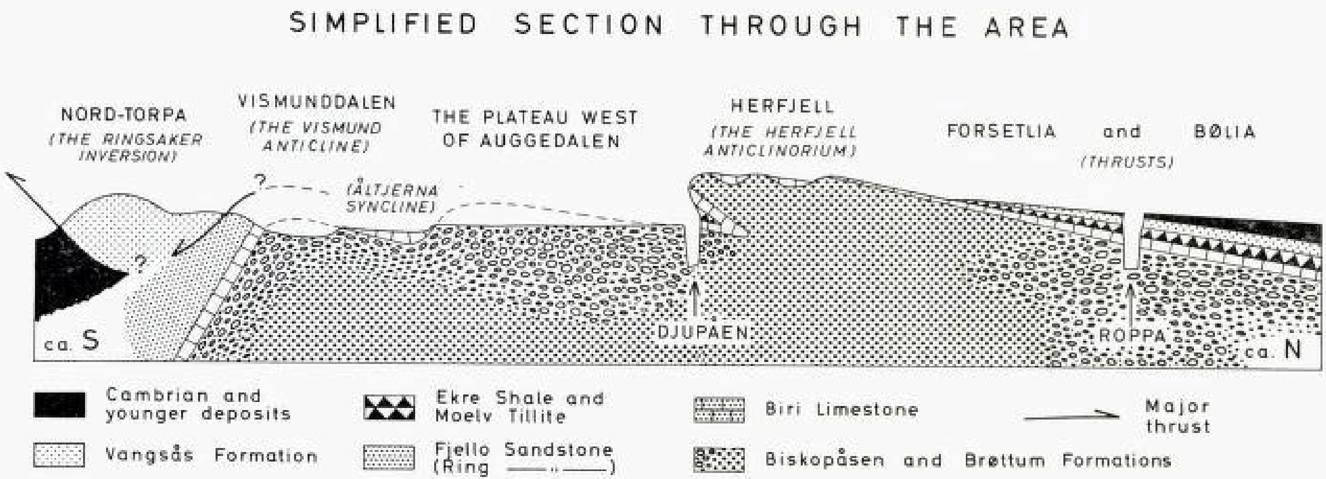

Fig. 22. A simplified section from ca. NNW to ca. SSE through the area.

The flat area around the Åltjerna setrene (Fig. 1, H 5) displays a gentle synclinal structure, the Åltjerna syncline.

An anticline (the Vismund anticline) is exposed in the flat bottom of the valley Vismunddalen (Fig. 1, I-J 5-7). To the east the anticline is well developed with a steep southern limb, while to the west the anticlinal structure dies out. The Vismund anticline is a western continuation of the Moelv anticline (Skjeseth, 1963, pp 89—91).

As indicated in Fig. 22, all the folds south of Herfjell are asymmetrical with southern limbs dipping more steeply than the northern ones. The axes dip gently to NW (Fig. 20).

Autochthonous rocks.

Strata to the north of Roppa are less disturbed than in any other part of the area. Folds here are gentle and, as seen from Fig. 16, the bedding is nearly flat. The thrusts found in the Roppa valley die out northwards, as shown on the maps. Joints are uncommon. Their main trend is NNE-SSW as shown in Fig. 18: the lower part of the river Roppa follows this direction. The ground north of the Roppa valley is that part of the area where fossils (in Cambro-Ordovician strata) and primary sedimentary boundaries are best preserved.

Synopsis of the tectonic history.

The tectonic history of the area may be summarized as follows:

1) The Vangsås Formation, with overlying Cambrian shales, was thrust out of the Sparagmite Basin.
2) The older formations were compressed and folded against the southwestern border of the basin, the fold axes being approximately parallel to the border.
3) Thrust sheets were transported towards the east (e.g., Roppa).
4) Faulting took place and joints were developed; some faults, however, were initiated contemporaneously with the folding, and some of the joints are also thought to have developed at that time.
5) Some of the vertical joints of north-south trend may be of post-Caledonian age.

Within the area there are many structural problems as yet unsolved: here only the main features have been outlined.

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Abbreviations:

GFF : Geologiska Föreningen i Stockholms Förhandlingar. Stockholm.
J. Geol.: Journal of Geology. Chicago.
NGT : Norsk Geologisk Tidsskrift. (Kristiania) Oslo.
NGU : Norges Geologiske Undersøkelse. (Christiania) (Kristiania) Oslo.
SGU : Sveriges Geologiska Undersökning. Stockholm.

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