STUDIES ON THE LATEST PRECAMBRIAN AND EOCAMBRIAN ROCKS IN NORWAY

No. 1.

SEDIMENTARY PETROLOGY OF THE SPARAGMITES OF THE RENA DISTRICT, S. NORWAY

By Knut Bjørlykke

Abstract.

Sediments of the Sparagmite group (Eocambrian/latest Precambrian) have been mapped at a scale of 1 : 50 000 in the Rena District, 180 km north of Oslo. This district is located along the southern margin of the Sparagmite basin which is downfaulted in the crystalline Precambrian basement. The sediments are made up by a series of conglomeratic arkoses interlayered with shales and limestones. Towards the top of the Sparagmite group the arkoses grade into a quartzite which is overlain by a thin conglomeratic layer of granules which forms the base of fossiliferous Cambrian (Holmian series). The evidence for an Eocambrian glaciation existing in the Moelv tillite is discussed in the light of grain size and fabric analyses.

Modal analyses and flamephotometric determinations of sodium and potassium content in the sandstones show decreasing sodium/potassium and plagoclase/microcline ratio as the total feldspar content decreases towards the upper formation in the Sparagmite group.

Spectrographic boron analyses suggest marine conditions during the deposition of the Sparagmite group, even if the analytical error of these analyses is rather high.

In Caledonian time the Vemdal sandstone in the upper part of the Sparagmite group was thrust south-eastwards over autochthonous Cambrian shales. The rest of the Sparagmite group is parautochthonous and folded within the basin up against its southern margin.

Introduction.

The present paper presents the results of field work in the Rena area in S. Østerdalen (180 km north of Oslo) in the summers 1960—62. Since then only shorter visits to this area have been made. This work is a part of a larger investigation in the Sparagmite Region undertaken by the Norwegian Geological Survey under the leadership of Professor S. Skjeseth (former State geologist). The broad outlines of the stratigraphy and tectonics in the Sparagmite region are dealt with by Holtedahl (1961), and Skjeseth (1963), and a review on the Eocambrian in Norway and Spitsbergen is presented by Spjeldnæs (1965).

Most of the present paper is condensation of a university thesis presented by the author for the cand. real. examination, but a few new observations have been added. Parts of the university thesis dealing with regional description are not included here, and for such details the reader is referred to my thesis «Sedimentologi og tektonikk i spargmitt-bergartene i Rena-området» (1964). Copies are available at the Geological Survey in Trondhjem and at the University of Oslo.

The mapped area is located 20—30 km north of Elverum (and 180 km N of Oslo) and Rena station is the local center. Geologically this is the southern margin of the (so-called) Sparagmite basin in which conglomeratic arkoses interlayered with shales and limestones were deposited. South and east of this basin the older crystalline Precambrian basement is encountered, consisting of red or grey granitic or granodioritic gneisses with bands of quartzites. Bodies of gabbroes (saussuritic) are also found. From Åsta (25 km N of Elverum) and southwards towards Elverum, sections in the valleyside show crystalline Precambrian overlain by autochthonous Cambrian shales which have been overthrust by the allachthonous quartzites of the Vemdal (quartz-sandstone) nappe. Remains of the Cambro-Ordovician sediments above the Vemdal sandstone are found along the inverted limb of a fold going from Åsta westwards to Brumundkampen, and can with some breaks be traced further west to the Ringsaker inversion south of Moelv.

North of this anticlinal structure running from Moelv eastwards to Åsta the folded complex of parautochthonous sediments of the Sparagmite group in the Sparagmite basin is found.

The area has been previously mapped by O. E. Schiøtz (1902) in scale 1 : 100 000 and this map has been of great help during the present field work.

The position of localities referred to in the text are indicated by coordinates on the map. All angles given in the text are in grades (∟ = 100 g).

Acknowledgements.

The present work is part of a larger investigation undertaken by the Norwegian Geological Survey under the leadership of Professor S. Skjeseth (former State geologist). I am grateful for the opportunity to participate in these investigations.

I express my sincere thanks to Professor T. Strand and Professor S. Skjeseth for their helpfulness during various phases of this work and

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From my wife, Unni Bjørlykke, I have received great help during the preparation of the manuscript.

Stratigraphy.

The broad outlines of the stratigraphy of the Sparagmite group in Southern Norway are now well established. The type-localities for the various formations of the Sparagmite group are all located near the northern part of lake Mjøsa. Sections in the Moelv area have been intensively studied by several geologists (Goldschmidt (1908), Vogt (1952), Spjeldnæs (1959), Skjeseth (1963), and the investigations are being continued by. L. Kirkhusmo.

The following stratigraphical sequence is now generally accepted,

			Cambrian shales	
Sparagmite group	Eocambrian	200 m	Vemdal formation (quartz sandstone)	Ringsaker quarzite Vardal sparagmite
		40 m	Ekre shale	
		20 m	Moelv tillite (conglomerate)	
		300 m	Moelv sparagmite	
	?			
	Latest Precambrian	50—250 m	Biri shales and limestone	
		0—300 m	Biri conglomerate	
		50 m	Brøttum shale and limestone	
		1500? m	Brøttum Sparagmite	

This stratigraphy has been compiled by a number of workers. A short historical review is given by Skjeseth (1963).

The base of the Eocambrian is now by some authors defined by the lower tillite horizon in the sections in Finnmark, Northern Norway

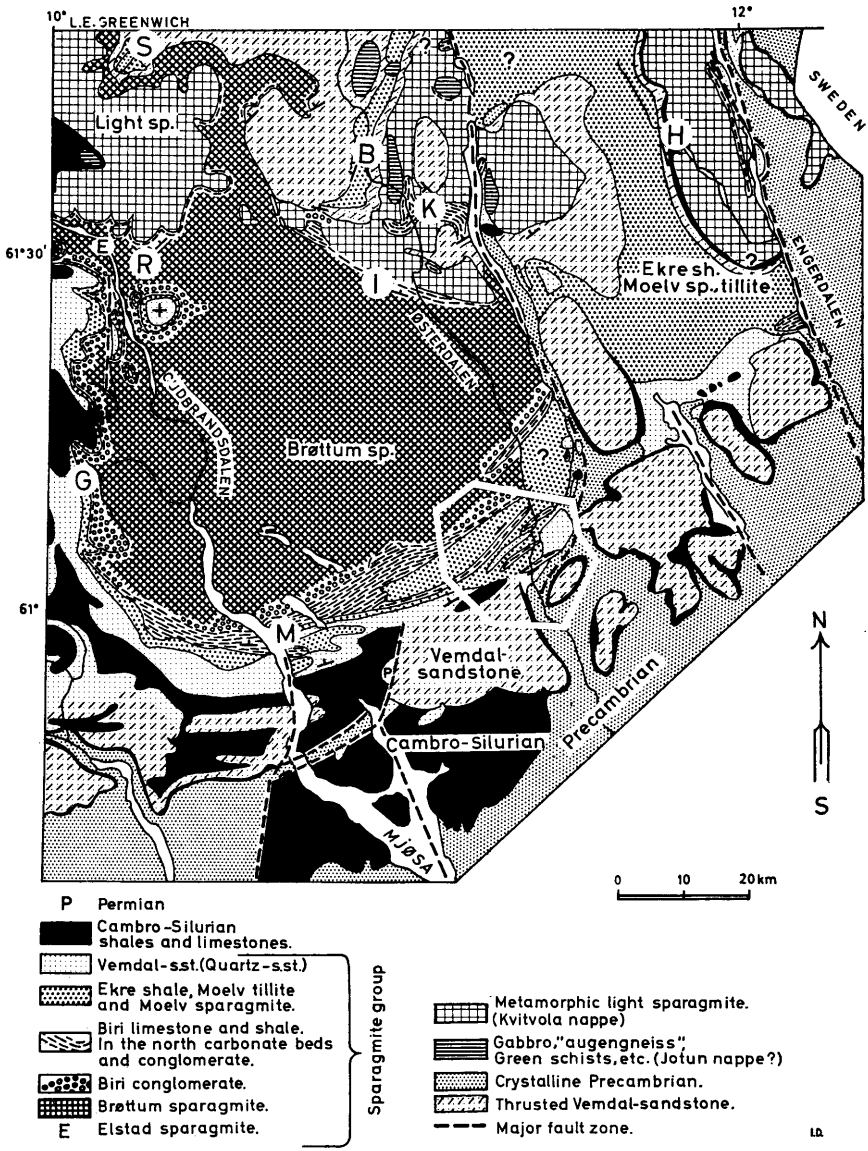


Fig. 1. Simplified map of the Sparagmite Region of Southern Norway (after K. Bjørlykke, 1965) showing the location (framed) of the mapped area.

S = Snødøla	K = Koppang	I = Imsdalen	G = Gausdal
B = Bjørånes	H = Høgberget	R = Ringebu	M = Moelv

(Holtedahl 1961, Spjeldnæs 1965), and this might correspond to a lower stratigraphical horizon than the Moelv tillite in Southern Norway.

The stratigraphy of the Sparagmite group is purely a lithostratigraphical one, and no good guide fossils have been found in these sediments. There is a possibility that microfossils like «Papillomembrana» from the Biri conglomerate (Spjeldnæs 1963), after further investigations, may be used for stratigraphical correlations with other late Precambrian basin deposits.

The sediments of the Sparagmite group are made up of alternating formations of coarse sandstones and more or less calcareous shales, and a marked regional variation in the lithofacies should be expected. Some deviations in the lithofacies are also observed in this area, compared to the type localities along Mjøsa; the author has not found it necessary, though, to introduce new lithostratigraphical units.

The Brøttum sparagmite, Moelv sparagmite and Vemdal sandstone usually have a characteristic appearance in the field. Although it may be difficult to classify these rocks by hand specimen or a single outcrop, the field relation to easily distinguishable conglomerates, such as Biri conglomerate and Moelv conglomerate, makes it possible to deduce stratigraphical relations.

It should be stressed that the stratigraphy developed in the Moelv—Rena area, characterises only the marginal facies of the basin. In the more central part of the basin, i.e. in the *Bjøråines* window (See fig. 1.), the Moelv sparagmite seems to be lacking, and a dark shale makes up the lower part of the sequence (K. Bjørlykke 1965).

Brøttum sparagmite.

Outcrops of Brøttum sparagmite are located in the northwestern part of the mapped area in Digeråsen, Engulsfj. and Hemmelsfj (B 2. See map). Brøttum sparagmite is also exposed in the upper part om the river Djupa (A 3—4). To the north the Brøttum sparagmite continues into map sheet *Stor-Elvdal* and is there described by P. Holmsen and Chr. Oftedahl (1956). Towards the south the Brøttum sparagmite grades into the Biri conglomerate by the appearance of boulder-beds. The Brøttum sparagmite is here made up of a coarse to medium-grained arkose with intercalated shaly and conglomeratic beds. (See p. 11). The arkose is usually so homogeneous that no distinct stratification is visible, and estimations of the thickness of this formation are thus rather speculative in this area. According to Skjeseth (1963) the thickness of the

Brøttum sparagmite is 1000—1500 m in the southern part of the Sparagmite basin. Along the southern border towards the Biri conglomerate the dip of the layers is close to vertical, the strike running 80—100 g E. Northwards the dip becomes less steep until there is a gentle northern dip only (See profile).

Southwards the Brøttum sparagmite becomes more and more conglomeratic, and one passes gradually into the Biri conglomerate. The pebble diameters in these conglomerates increase from 2—3 cm in the northernmost beds to 6—7 cm further south and up to 10—20 cm in the Biri conglomerate. Quartzite pebbles are most common but pebbles of quartz-porphyry are also found. The best outcrops are in the section along Skynna river 2—3 km downstreams from Skynndalen Seter. (C 2). No indication of a tectonically repeated sequence has been found here. Shales and limestones corresponding to the Brøttum shale and limestone as developed in the Moelv area, have not been found in the Digeråsen—Engulsfj. area. Westwards in Djupa (B 4) there is red and grey slighly calcareous shale which might correspond to the Brøttum sale, but in the section along Djupa the Biri conglomerate is absent, and there is therefore no distinct break between the Biri limestone and the calcareous shales of the Brøttum formation.

Petrology.

Modal analyses were carried out on 6 thin sections of Brøttum sparagmite, stained with sodium cobaltnitrite. It appears that the average content of potassium feldspar is about 27 %, with 10 % plagioclase, 57 % quartz and 6 % matrix.

The coarseness of some arkose samples may give a rather large error in the modal analyses.

Quartz: The large grains of some millimeters in diameter are well rounded, but the smaller grains are angular to subangular, partly due to recrystallisation and secondary overgrowth. Grains of relatively pure quartzite are common, and it is probable that most of the quartz has a metamorphic origin. The quartz grains are commonly intensely jointed, and the grain contacts may be crushed and undulatory extinction developed. Such contact undulosity is also described from sparagmites by Grender (Grender 1962). It is difficult to distinguish whether the commonly occurring ordinary undulatory extinction is produced after the deposition of the arkose or is a primary characteristic of sand grains from the metamorphic source rock.

Microcline: Crystals up to 3—4 mm occur and specially the larger ones are frequently well rounded. The microcline gridiron structure is usually well developed, but may be faint or absent. Most microcline fragments are quite fresh, but highly weathered grains are common and may be found next to the fresh ones. This suggests different degrees of predepositional weathering of the microclines.

Plagioclase: Grains up to 1—2 mm occur, and the roundness is very variable. The plagioclase is an albite or acid oligoclase and most fragments are weathered and sericitised.

Clay minerals: The matrix consists of sericite and chlorite minerals. The fibrous chlorite minerals fringe into other minerals and are probably recrystallised during rather weak metamorphism. Fine aggregates of sericite are probably also recrystallised, while the larger grains of light mica and also some biotite obviously are clastic, derived from a metamorphic source rock.

Accessories: Well rounded zircons are quite common and garnet is also observed.

Discussion.

Outcrops of Brøttum sparagmite is restricted to the northern part of the mapped area and the base of the Brøttum formation is not exposed. Graded bedding is observed but not as typical as in the sections in Brøttum sparagmite at Maihaugen in Lillehammer where graded bedding of the turbidity current type is found (Nelson 1963). The well sorted conglomeratic layers and the relatively low matrix content suggest a more shallow water origin of the Brøttum sparagmite in the areas NW of Rena, while deeper water more favourable for turbidity currents has existed in the Lillehammer District.

Biri conglomerate.

The Biri conglomerate is exposed south of the Brøttum sparagmite in the southern mountainside of Digeråsen and Engulsfjell (D 2 — E 2). The beds are nearly vertical and often slightly inverted.

The Brøttum sparagmite passes upwards into the Biri conglomerate by an increasing frequency of conglomeratic horizons, and it is therefore difficult to define the lower border of the latter formation. Exact measurement of the thickness of this conglomerate can therefore not be given, but at Digeråsen (E 2) an approximately 2—300 m thick sequence

is dominated by conglomeratic layers. The conglomerate seems to be thinning out somewhat westwards and is lacking in the section of the Djupa river (A 3—4).

The most common size of the pebbles in the conglomerates is 5—10 cm, but boulders as large as 20—30 cm are found and all are well rounded. The conglomerate is well sorted, and matrix is usually only present in the voids of the framework made up by the pebbles. The composition of the matrix is very similar to the Brøttum sparagmite but carbonate matrix is also found.

Petrology of rock fragments in Biri conglomerate.

Most of the pebbles are quartzites probably belonging to the pre-Sparagmitian crystalline complex. The size of the quartz grains in these quartzites is 0,1—0,3 mm. The quartzite is relatively pure and minor amounts only of feldspar (microcline) are found. Some light mica occurs in the matrix. A green to blue tourmaline with strong pleochroism is quite common. Some sphene is present.

A pale reddish quartz porphyry occurs quite commonly as pebbles in the Biri conglomerate. In these phenocrysts of both quartz and microcline are found in a very fine-grained matrix. The euhedral quartz grains often show perfectly developed rhombohedral faces. Both the quartz and the microcline crystals are often strongly corroded, probably by late magmatic solutions. The matrix is too fine-grained to allow the determination of the minerals, but the larger part of it seems to have a refractive index lower than that of Canada balsam and is stained yellow by treatment with sodium cobaltnitrite. This may suggest that the matrix mainly consists of fine-grained potash feldspar.

Discussion.

Skjeseth (1963, p. 29) has shown that the Biri conglomerate is restricted to the margins of the Sparagmite basin and is lacking in the more central parts. The present study of the Biri conglomerate in this area confirms this statement, as the conglomerate thins out westward from the eastern margin of the basin and is absent in the section in Djupa in the western part of the area. Further west at Elvestad in the Åsta valley the conglomerate is also reported to be absent (Skjeseth 1963). The quartz-porphyry pebbles in the Biri conglomerate are very similar to the Trysil porphyry east of Trysil river (O. Holte-

dahl, private communication). If the pebbles are derived from this complex, the length of transportation must have been 50—60 km. The Biri conglomerate has the appearance of a typical coarse river and delta deposit. The delta was probably produced by rivers running from east to west and must have extended 10—15 km out from the margin of the basin. This conglomerate is a shallow-water deposit, and the present author is inclined to interpret it as a conglomerate related to a regression rather than to a subsidence along the margins of the basin as suggested by Skjeseth (1963, p. 29).

Biri shale and limestone.

This formation has a very variable development in the investigated area, as shown by the simplified facies map, figure 2. The Biri formation is usually developed as a more or less calcareous shale, only locally we find real limestone as east of Glomstad (H 6—7) and partly also at Arnestad (F 3). In the section in Djupa river in the western part of

SIMPLIFIED FACIES MAP OF BIRI FORMATION.

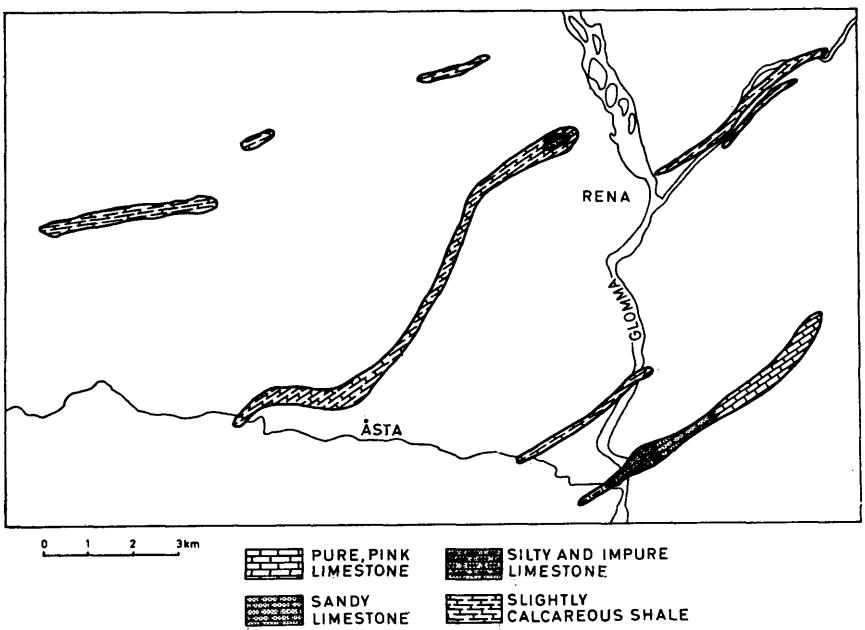


Fig. 2.

the mapped area a slightly calcareous dark and red shale occurs between the Brøttum sparagmite and the Moelv sparagmite. Thin sections of this red shale show ferruginous concretions with diameter about 1 mm and possible worm trails. Here the Biri conglomerate is lacking, and it is therefore hardly possible to distinguish between what belongs to the Brøttum shale and limestone and what corresponds to the Biri limestone. This is also the case further west at Elvedalen where the same dark and red shales occur in the section along Åsta river (Skjeseth 1963, p. 28). Further east there is a gradual change from a slightly calcareous shale at Åsta to an impure, partly dolomitised limestone at Glomstad and to the pure limestone (98 % $CaCO_3$) at Hemmesjøen and Østersjøen (I 5 — J 5). The basement of these limestones at Hemmesjøen and Østersjøen is not exposed, but crystalline Precambrian rocks crop out not far from these localities (See map). It seems probable that these limestone deposits are remains of a more extensive limestone transgressing out over the eastern margin of the basin. A possible connection in Biri-time between this area and limestone deposits at Jordet farther east has been suggested by Skjeseth (1963). It seems quite clear that the limestone deposits of the Biri formation are restricted to the marginal parts of the basin, and are synchronous with deposition of rather pure limestone in the transgressive areas outside the basin. A larger part of the transgressive limestone deposits was probably eroded at the time of deposition of the Moelv sparagmite and Moelv tillite. Boulders very similar to the Biri limestone are found in the Moelv tillite, especially in the Åsta area (See p. 27).

Petrology.

The pure pink limestone of the easternmost exposure at Hemmesjøen and Østersjøen is fine-grained and usually not recrystallised, but spots of recrystallised calcite occur. The recrystallised grains are surrounded by iron oxides. Only small amounts of impurities like quartz and mica are observed. The amount of terrestrial material increases towards the west, and a little east of Glomstad there is a sandy limestone with sand grains (30—40 %, mainly quartz and some feldspar) in a calcareous matrix. The clastic grains are cut by joints which tend to have a preferred orientation (Figure 3). There is also a preferred orientation of the apparent long axes of grains perpendicular to the joints, and the joints are therefore interpreted as tension joints. The quartz grains are corroded by the calcareous matrix, and this seems to some extent to have

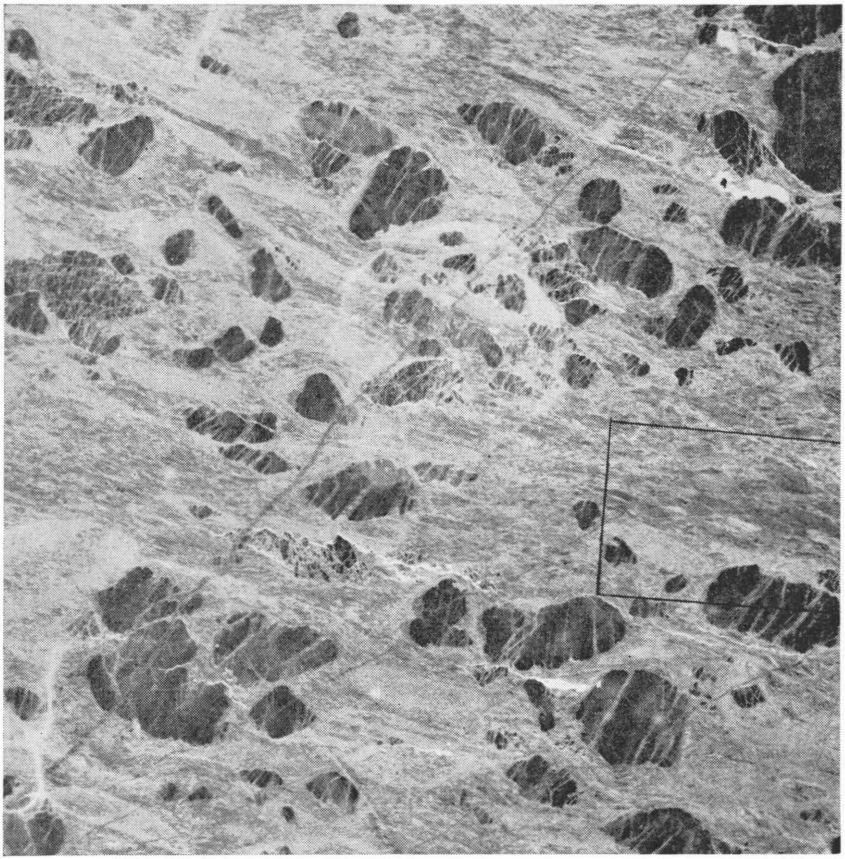


Fig. 3. Tension joints in quartz grains with calcite matrix. (Framed figure 4 a.)

widened the joints. Such corrosion has been studied experimentally by Dappels (1962), who showed that quartz is strongly unstable at PH 8 and EH+. The crystallised parts of the matrix show a distinct twin gliding in calcite (See figure 4 a). The traces of the rhombohedron form rhombs with a short diagonal parallel to the joints in the quartz. Similar patterns produced experimentally by Friedmann (1963), show that twin gliding usually is parallel to the negative rhombohedron $(01\bar{1}2)$. The experiments were carried out at pressures from 1—5 kilobar and temperaturès from 150—300° C. (See Figure 4 b.)

By use of universal stage the orientation of the tension joints was measured to be 70 g E dipping 35 g to the SE and 55 g to the NW.

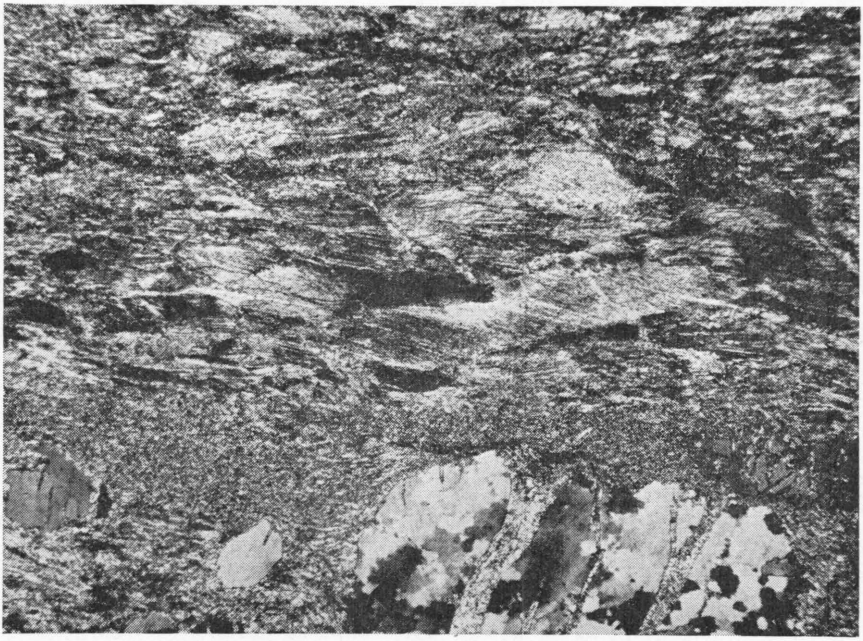


Fig. 4 a. Twin gliding in calcite (enlarged from fig. 3). The diagonal of the rhombs is parallel to joints in the quartz grains. 35 x.

These joints are thus parallel to the dominating fold axis direction in the field and perpendicular to the direction of tectonic transport. The lineation marked by the long axes of the sand grains parallel to the direction of tectonic transport, should then be characterised as an a-lineation. According to Kvale (1953) a-lineation is more common in the central part of the Caledonides in southern Norway than in the periphery.

Chemical analyses (See table 1) and X-ray diffractometer analyses show that the pink limestone at Hemmesjøen (I 5) is a pure limestone (only 2 % undissolved in HCl) without any trace of dolomite. The CaO/MgO ratio is high, between 110 and 156. From modern carbonate sediments at the Bahamas the CaO/MgO ratio is 20—30 in the near-shore sediments and 80—120 further out from the coast (Cloud 1962). Analyses from Glomstad and from the bank of Glomma show a variable MgO content and the presence of dolomite was indicated by X-ray diffractometer analyses. One sample contained almost exclusively dolomite. The author has found no obvious explanation why the limestones at Glomstad are partly dolomitised and not the lime-

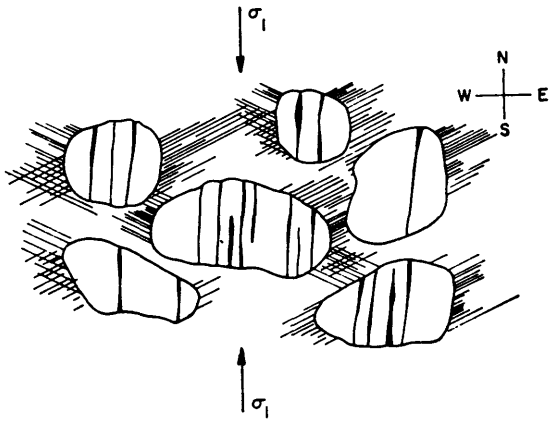


Fig. 4 b. Experimentally produced deformation of detrital grains (mainly quartz and feldspar) in calcite matrix. After Friedmann, 1963, p. 25.

stone further west at Hemmesjøen. In analogy with Ham (1951) and Landes (1946) it is tempting to relate this dolomitisation to the more severe tectonisation at Glomstad. A primary distribution of aragonite and calcite might also produce a selective dolomitisation due to the fact that aragonite is more easily dolomitised than calcite (Cloud 1962, p. 107).

Table 1.

Partial analyses of Biri limestone.

No	SiO_2	Al_2O	Fe_2O_3	CaO	($CaCO_3$)	MgO	($MgCO_3$)	Loss on ignition	Undissolved residue in HCl	Total
9	7,25	1,28	0,85	49,57	(88,52)	0,74	(1,55)	39,76	10,94	99,45
10	12,78	3,03	1,86	28,05	(50,10)	15,73	(33,03)	38,89	14,81	100,34
11	6,89	7,26	2,00	33,09	(50,09)	9,76	(20,42)	41,16	10,31	100,16
200				53,66	(95,73)	0,37	(0,77)		2,10	
201				53,44	(93,39)	0,49	(1,00)		2,20	
204				37,49	(66,82)	0,24	(0,50)		29,4	

Analyses Nos 9, 10 and 11 are from the Biri limestone at Glomstad, quoted from O. Holtedahl (1920). Nos 200 and 201 are from the pure limestone at Hemmesjøen, and 204 is from a sandy limestone at Holstad just east of Glomstad. Analyst: R. Solli.

Moelv sparagmite.

The Moelv sparagmite is a coarse red or grey arkose with interlayered shales and conglomeratic beds. The formation is rather thick and covers a large part of the mapped area, but no continuous complete section is exposed. Tectonic repetition by thrusting makes calculations of the thickness rather speculative. Skjeseth has suggested a thickness of the Moelv sparagmite of 250 m in the Moelv area (Skjeseth 1963, p. 30), and that seems to be a good estimate for this area too. Due to insufficient exposures it is difficult to get a detailed picture of the regional and stratigraphical variations within the formation. The best exposures are found in the road-cut section from Åsta to Rena and along Åsta river.

Transition of the Biri formation into the Moelv sparagmite is marked

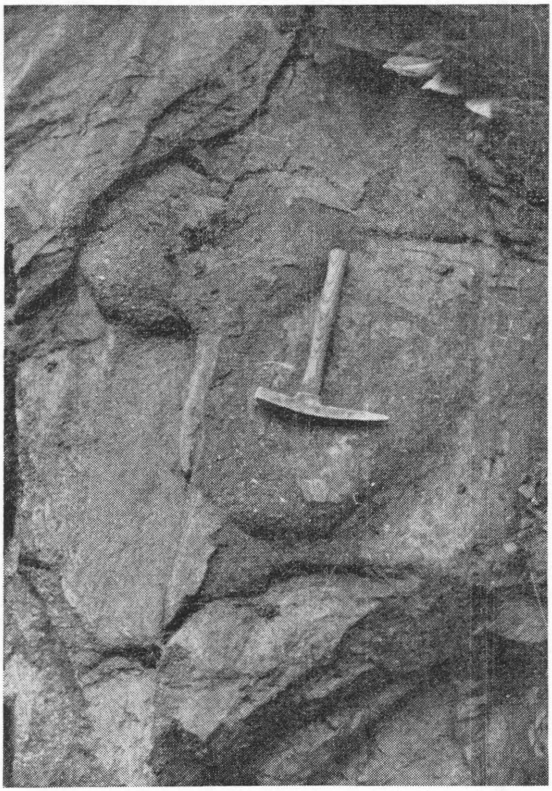


Fig. 5. Flute casts on inverted sole of coarse-grained Moelv sparagmite. Locality Jullussa (I 2, J 2).

by a decreasing carbonate content in the shale and by the interlayering of arkosic or conglomeratic beds. These beds are exposed in sections at Arnestad, Hole (near Åsta river) and in several localities near Åsta station. A road-cut section at Beks Minde (G 5) between Rena and Åsta is described separately.

Quartzite conglomerates in the Moelv sparagmite are common, especially in the eastern area near Glomma. Also beds with quartzitic pebbles of a diameter up to 2—3 cm are exposed in road-cuts between Åsta and Rena and cover large areas north of Arnestad. A particularly coarse red arkose is developed between the rivers of Glomma and Rena. Westwards along Åsta river the Moelv sparagmite has a varying grain

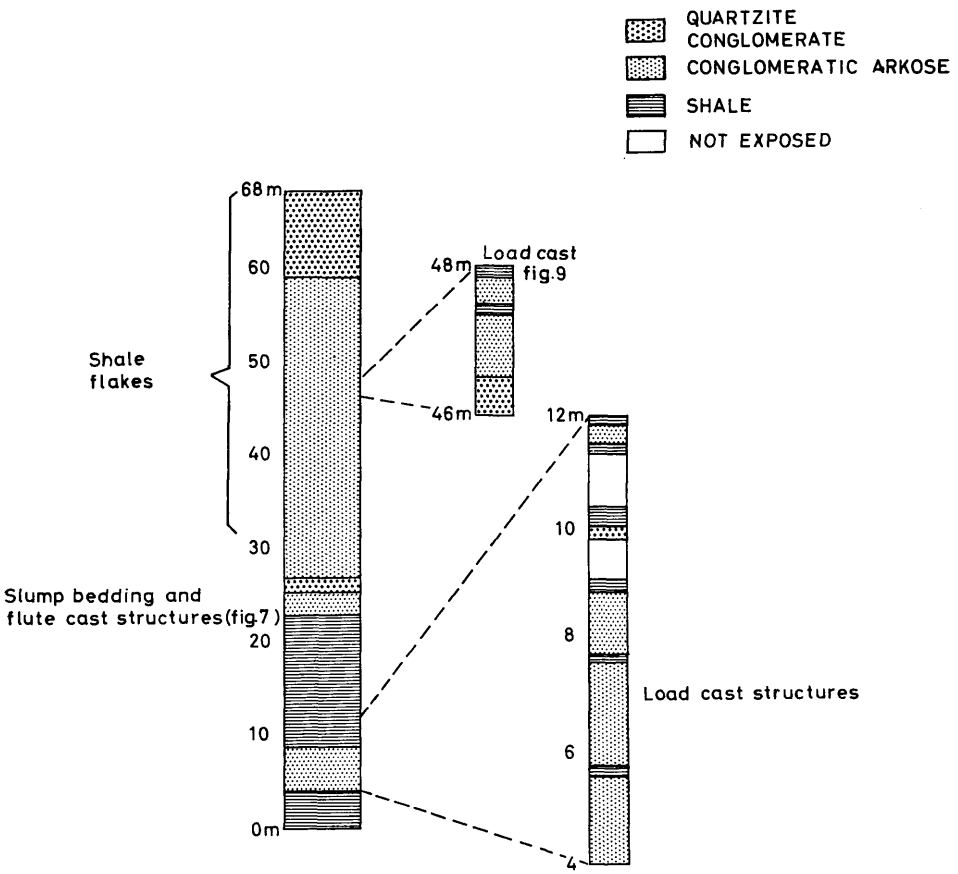


Fig. 6. The reconstructed section through the lower part of the Moelv formation at Beks Minde (G 6).

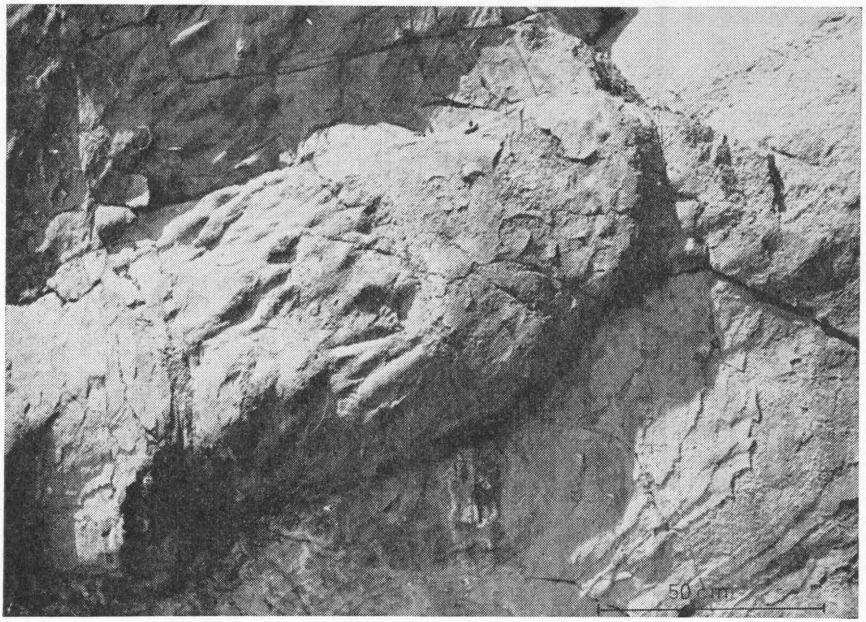


Fig. 7. Smaller flute cast superimposed on a larger flute cast structure on sole of coarse Moelv sparagmite. Beks Minde.

size, but is generally more fine-grained and contains more clay minerals. Graded bedding in arkose, with beds 30—50 cm thick, is found on the southern side of Åsta river, 1 km east of Åstadalen seter, but is not very common, Grey, red and green shale occurs in the lower part of the Moelv formation, at the transition to the Biri limestone. This shale at the base of the Moelv formation is by Skjeseth (1963) called Moelv shale. Thin beds of shale occur also within the thick and massive Moelv sparagmite.

Good exposures showing large flute cast structures are found in the road-cut just south of the bridge over Julussa (I 2), where this enters Rena river (See Figure 5). These flute casts are one of evidences of an inverted sequence south of Rena river. When reorientated to original position, these flute cast structures indicate a direction of transport towards NW (365 g). Ripple marks are found in road-cuts along the SE side of the Rena river and along the Åsta river.

The larger part of the Moelv sparagmite is very homogeneous, characterised by its lack of distinct bedding and of sedimentary structures. Cross bedding is observed, but is not very common.

At Beks Minde the lower part of the Moelv formation is well exposed in a fresh road-cut. Figure 6 shows a generalised profile through the section exposed. The lower part consists of alternating shale 1—2 m thick beds of massive arkose. The upper part is a series of arkose and quartz-conglomerates and some thin layers of shale. Fragments of dark and grey shale (5—30 cm) are found in the conglomeratic beds. At the base of this upper part well preserved flute cast structures are found. Figure 7 shows a large flute cast or a channel structure overprinted by small flute casts. Microscopic measurements of long axes close to these flute cast structures show a preferred orientation parallel to the direction indicated by the flute casts and upstream imbrication (See Figure 8). In the conglomeratic beds in the upper part of the section

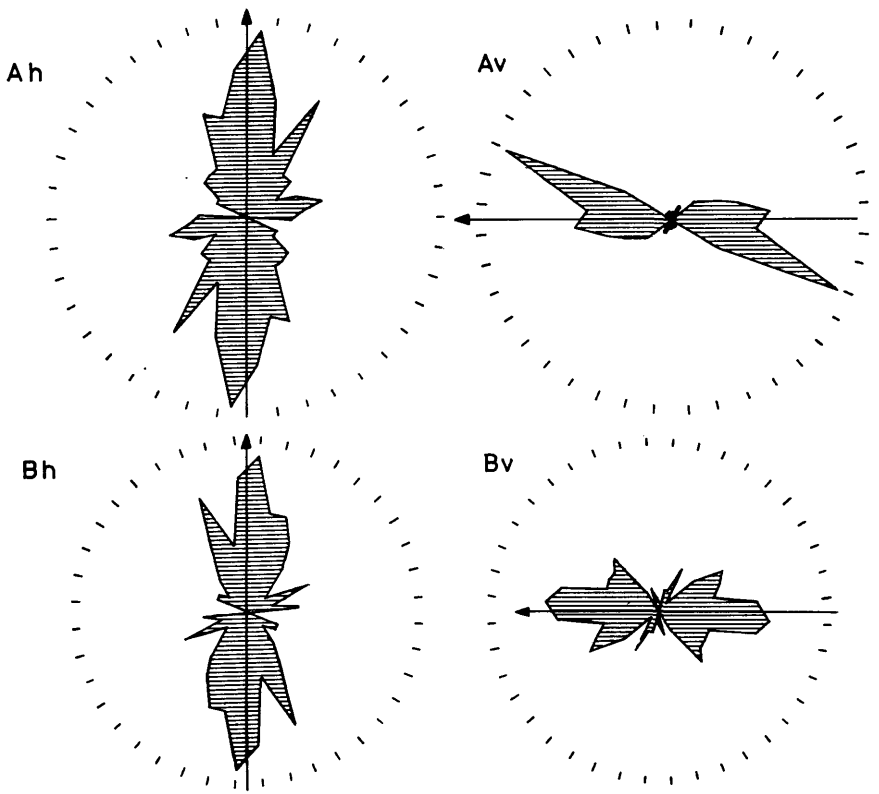


Fig. 8. Long axis distribution of grains on the sole of coarse conglomeratic bed (See Fig. 7) close to the flute casts. Ah and Bh parallel to bedding. Av and Bv perpendicular to bedding. Arrow shows current indicated by the flute casts.

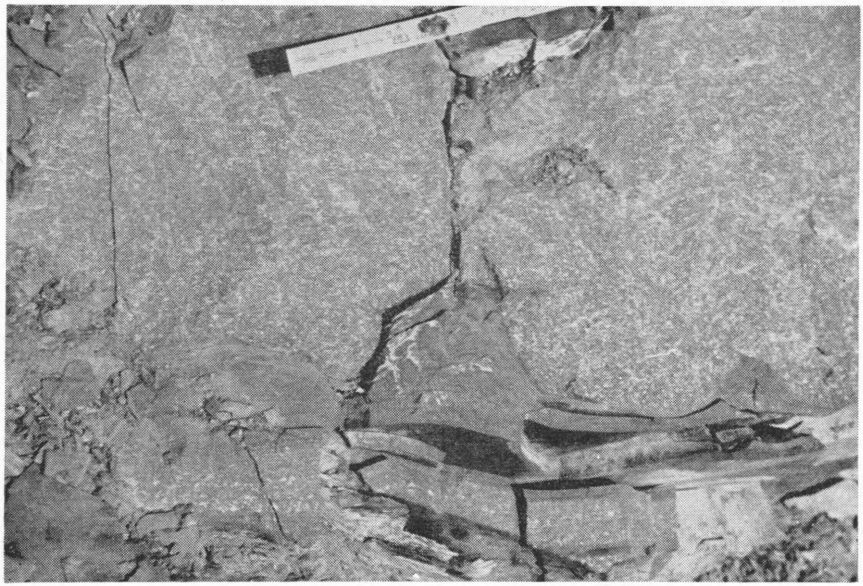


Fig. 9. Shaly bed in Moelv sparagmite deformed by load cast.

fragments of shale indicate that some of the underlying shale has been subjected to erosion during the deposition of the succeeding coarser beds. The conglomeratic beds are well sorted and mainly made up by well rounded quartzite pebbles, 2—3 cm in diameter. Load cast structures are commonly found on the transition between fine- and coarse-grained beds (Figure 9). These are often deformed by post-depositional movements, like slumping. In a middle part of the section isolated balls of coarse conglomeratic sparagmite are found in the more fine-grained sediments below, and it seems probable that this is due to slumping.

Petrology.

Modal analyses (p. 36) show that the composition of the Moelv sparagmite is close to that of the Brøttum sp., except for a little lower feldspar content. The general characteristic petrology of the Moelv sparagmite is also very close to that of the Brøttum sparagmite in this area (See p. 35).

Many of the microcline grains are fresh and perfectly rounded (See Figure 11) while others are angular, weathered and sericitised

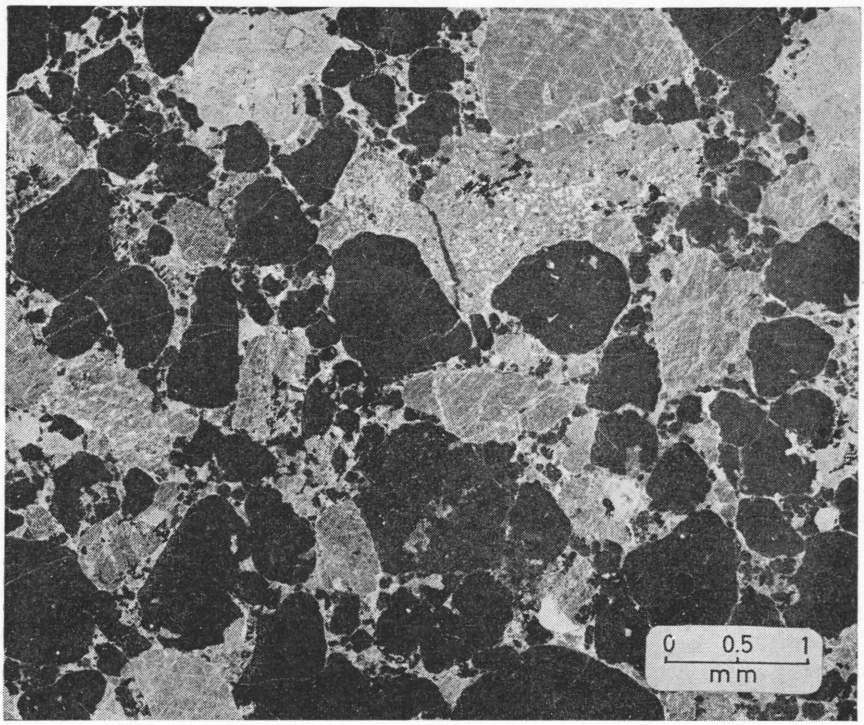


Fig. 10. Acetate peel of Moelv sparagmite (from Beks Minde G 6). A polished surface of the rock is etched with hydrofluoric acid before making the peel.

(Figure 10). X-ray diffractometer analyses of the shale in the lower part of the Moelv formation show somewhat broadened 10 Å reflections due to weathering of the illite.

In the lower part of the Moelv formation calcareous matrix may be found in the sparagmite. A sample of Moelv sparagmite just north of the Glomstad limestone (Biri limestone) is comprised of 30 % calcareous matrix, roughly 60 % quartz and 10 % feldspar. Here a carbonatisation of the feldspar and possibly also of the clay minerals has taken place. Some feldspar grains, mostly microcline, are slightly attacked only, while others are so completely carbonatised that just relicts of the original feldspar grains are visible. The variable carbonatisation of the feldspar grains may depend upon a varying degree of predepositional weathering because it is probable that the weathered grains were more easily carbonatised. This is an important metasomatic

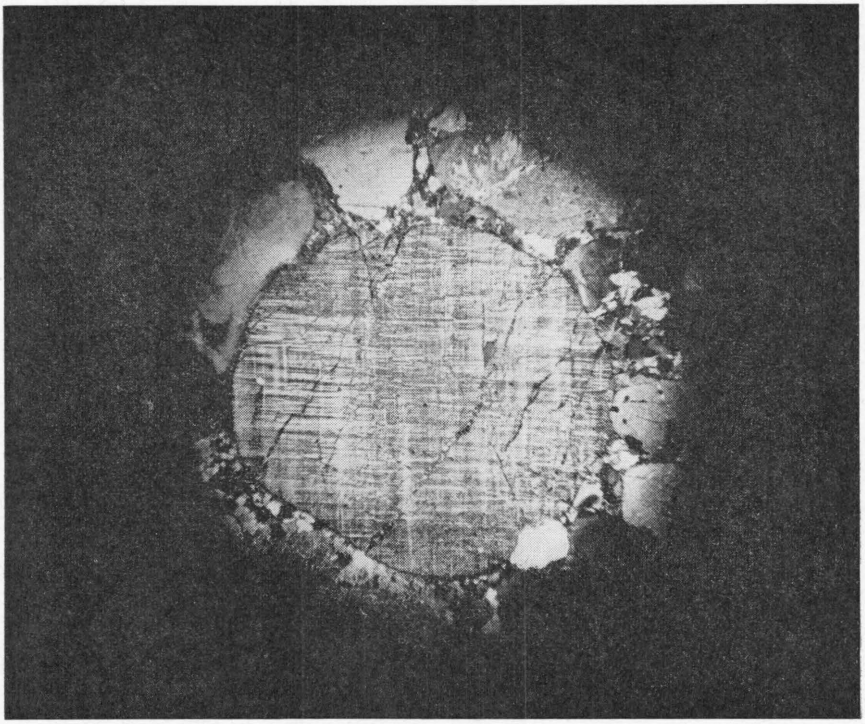


Fig. 11. Thin section photomicrograph of rounded microcline grain (3 mm in diameter).

process in the lower part of the Moelv formation, and it is probable that the calcareous solutions are derived from the underlying Biri limestone.

Discussion.

In the sections studied no indications of a break or an angular disconformity between the Biri and the Moelv formations have been found. Such a possibility cannot, however, be excluded, because none of the sections are exposed quite continuously, and also because of tectonic disturbances. Spjeldnæs (1959) has suggested that there is a break and a period of orogenic movements between the deposition of the Biri shale and the Moelv sparagmite. Spjeldnæs' assumption is based on indirect evidences, namely tectonically deformed carbonate boulders in the Moelv tillite. According to Spjeldnæs this deformation of the

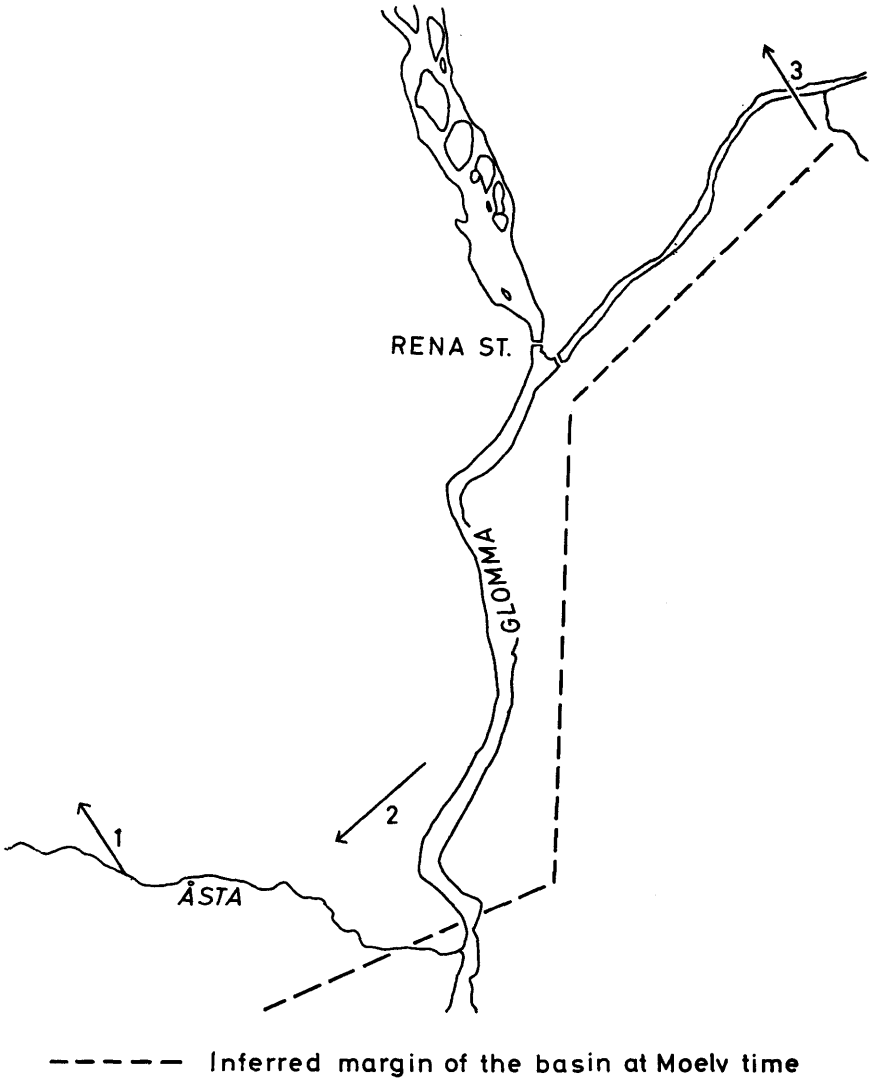


Fig. 12. Palaeocurrents in the Moelv formation.
1. Asymmetrical ripple marks. — 2. Flute casts at Beks Minde (probably tectonically rotated somewhat to the south). — 3. Flute casts at Julussa bridge.

carbonate boulders are predepositional. The boulders are supposed to be derived from the Biri limestone, and even if this is very probable, the possibility that the limestone boulders are older can not be excluded. It

might also be questioned whether it is relevant to relate a local recrystallisation of limestones to major orogenic movements. Such recrystallisation could also be produced by faulting along the margin of the basin, which probably took place at the beginning of the Moelv time.

The transition from the Biri formation to the Moelv sparagmite must represent an important change in the conditions of sedimentation. Such a change could most easily be explained by faulting along the margins of the Sparagmite basin, giving a stronger relief and a more rapid erosion. This theory is put forward by Holtedahl (1921) to explain the deposition of the Moelv sparagmite in Engerdalen near the eastern margin of the basin, and later as a more general statement by Skjeseth (1963, p. 30). The deposition of the Moelv sparagmite could also be explained as a rapid deposition of glaciofluvial material. Remains of the Moelv sparagmite are not found outside the margins of the basin and while the Biri formation was transgressive (See p. 14), the Moelv formation was probably regressive. Figure 12 shows the available palaeocurrent data from the Moelv formation, indicating a direction of transport roughly perpendicular to the predicted shoreline.

Sole markings like flute cast structures are often associated with

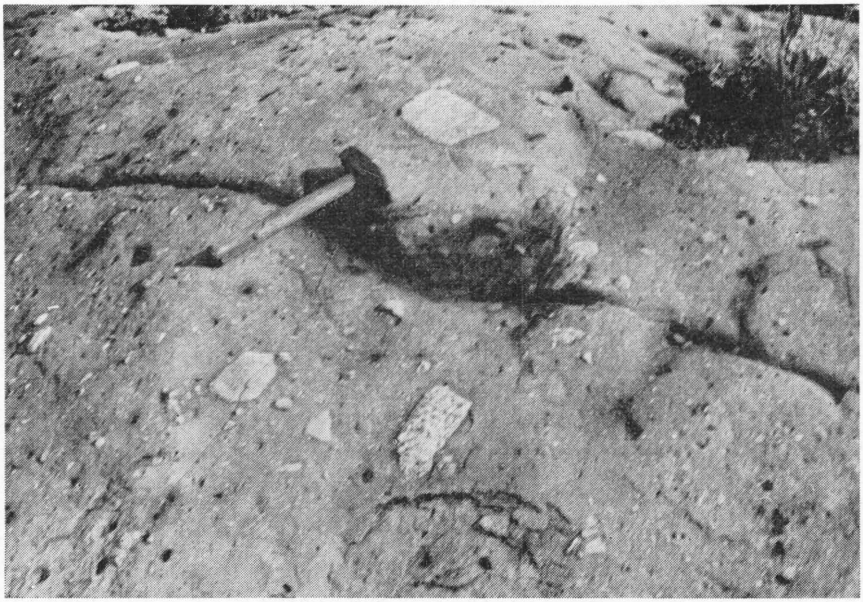


Fig. 13. Moelv tillite at Rønningen (H 4).

turbidites (Bouma, 1962, p. 135), but may also be found in shallow-water deposits (Rücklin 1938; K. Birkenmajer 1965). Graded bedding of the scale and repetitiveness typical of turbidites is rarely found. It seems very unlikely that the coarse and well sorted quartzite conglomerates could have been deposited by turbidity currents. The thick massive beds of coarse arkose can not be regarded as typical for turbidite deposits, at least not of the flysch type described by Bouma (1962). The author is inclined to interpret the Moelv sparagmite as a delta or relatively shallow water deposit along the eastern, southern and partly also the western margin of the Sparagmite basin. In Bjørånes north of Koppang which must represent a more central part of the basin, the Moelv sparagmite is lacking and a dark shale only is found below the Moelv tillite (K. Bjørlykke 1965).

Moelv tillite.

The border between the Moelv sparagmite and Moelv tillite is not sharp. The transition is a zone, 1—2 m thick, characterised by a gradually increasing frequency of scattered pebbles and boulders up to the typical Moelv tillite. The thickness of the Moelv tillite in the Rena District is about 15—20 m. The tillite is homogeneous and usually does not show any trace of bedding, but a lamination within parts of the tillite is found in some of the road-cut exposures from

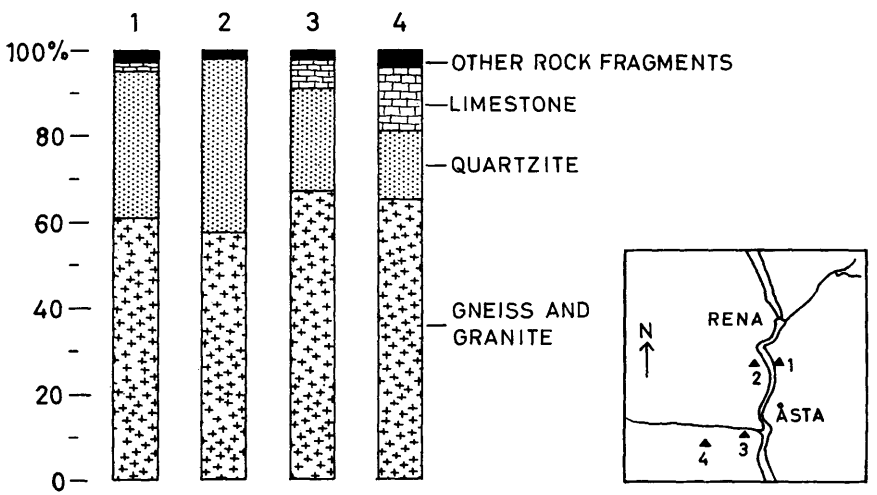
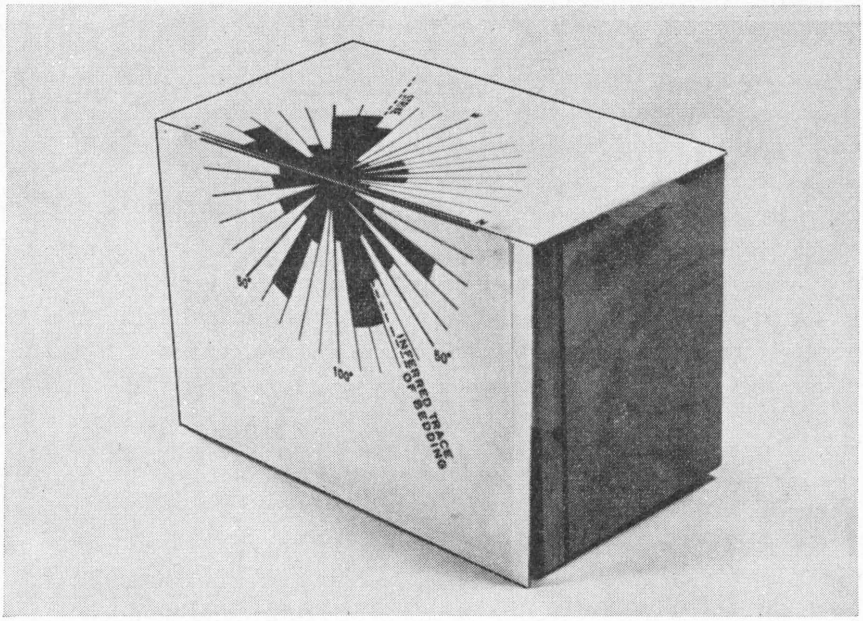
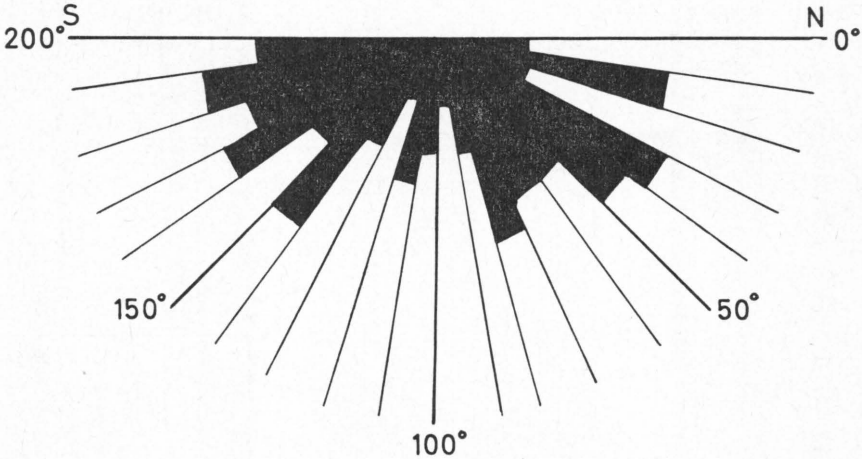


Fig. 14. Composition of pebbles (> 2 cm) in the Moelv tillite.



a



b

Fig. 15. Long axis distribution in Moelv tillite.

a. From road-cut at Gran 2 km south of Rena (100 readings). — b. From railway-cut 1 km south of Rena. Vertical cut (100 readings).

Fig. 16. Thin section photomicrograph of Moelv tillite. Note angular grains.

Åsta to Rena. The pebbles may be angular or well-rounded, and boulders exceeding 1 m in diameter are found. The matrix consists of sand, silt and clay minerals, and the composition of the pebbles are shown in Figure 14. In the westernmost tillite localities close to Åsta and Jernåen (D 6–7), there seems to be a lower frequency of boulders and a little more fine-grained matrix. This may be regarded as a transitional stage to the boulder-clay facies, which is thought to represent a facies of the more central parts of the basin (P. Holmsen 1954; K. Bjørlykke 1965).

The origin of the Moelv tillite.

The Moelv tillite (or Moelv conglomerate) has received attention from most geologists working in the Sparagmite area. With its unsorted character and large boulders it is easily distinguished from ordinary shore and delta conglomerates.

Holtedahl (1922) was the first to point out that this conglomerate had many features in common with Pleistocene till-deposits, and suggested that the Moelv conglomerate, like the Eocambrian tillites in

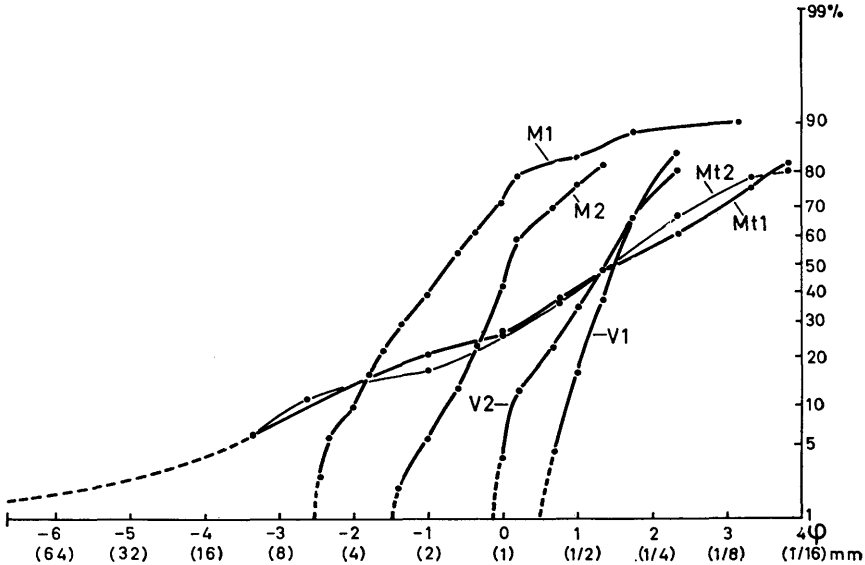


Fig. 17. Grain size distribution in Moelv tillite compared with other sparagmites. The measurements are made by use of point counting in thin sections and for the coarser grained sediments measurements were made on acetate peel prints (See fig. 10) and pebbles and boulders in the outcrop.

M 1 Moelv tillite. Locality Gran 2 km south of Rena (600 counts).
M 2 Moelv tillite. Locality Gran 2 km south of Rena station (200 counts).
V 1 Vemdal s.st. (Vardal sparagmite) 1.5 km south of Rena station (250 counts).
V 2 Vemdals s.st. (Vardal sparagmite) Locality Julussa NE of Rena (161 counts).
M 1 Moelv sparagmite. Locality Julussa NE of Rena (386 sounts).
M 2 Moelv sparagmite with calcareous matrix. Locality N. of Glomstad (330 counts).

Finnmark, had a glacial origin. Holtedahl was also aware that the Moelv tillites were not terrestrial tills but glacial sediments dropped from floating icebergs. In Finnmark, tillites of both terrestrial and marine type have been observed (Reusch 1891, Holtedahl 1918, and Føyn 1937). Good examples of striated boulders in these tillites are found in Finnmark (N. Norway) by Reusch (1891, p. 81), by the present author in the Bigganjargga tillite (unpublished results) and in Sweden (Kulling 1951, p. 4), but not in Southern Norway. In Southern Norway pebbles are very difficult to extract from the well-consolidated Moelv tillite and striations present could be caused by tectonic deformation. The interpretation of these conglomerates as glacial deposits has

been accepted by most Scandinavian geologists, probably because of their resemblance to some of the glacio-marine Pleistocene deposits.

In recent years alternative theories such as deposition by mudflows or turbidity current have been put forward to explain the origin of the tillites, or tilloids to use a more descriptive term (L. J. G. Schermerhorn, and W. I. Stanton 1963).

Nelson (1963) claims that probable turbidite origin for the S. Norwegian sparagmites affords an alternative hypothesis to that of glaciation for the Moelv conglomerate. However, indications of typical turbidite environments have only been found in the Brøttum sparagmite in a restricted area around Lillehammer. It should also be stressed that glacial and turbidite environments are not mutually exclusive of each other.

In the discussion of the possible glacial origin of the Moelv tillite the following facts should be stressed.

1. There is no trace of an erosional contract at the base of the Moelv tillite, but there is a gradual transition from the Moelv sparagmite into the tillite. This is also the case at the upper boundary with the Ekre shale.
2. Graded bedding or slumping are not observed in the Moelv tillite.
3. Angular boulders and blocks exceeding 1 m are found, and the sediment shows poor sorting (Figure 17).
4. The primary long axes fabric shows an almost random distribution (Figure 15).
5. The Moelv tillite has a wide distribution in Southern Norway and in corresponding beds in Sweden.

These facts fit well with what we should expect from a sediment deposited by dropping from floating icebergs, and with our knowledge of similar Pleistocene deposits. From the list above it should be apparent that the Moelv tillite has so few characteristics in common with turbidites that this mode of origin should be excluded. The theory that the Moelv tillite is a mudflow should not immediately be rejected, but the fact that the tillite in southern Norway only occurs in one single stratigraphical horizon over roughly 10 000 km^2 makes this origin less probable. On the other hand palaeomagnetic evidences indicating an equatorial position of Norway in Eocambrian time, do not fit well with a glaciation at that time (Harland 1965).

Although the author is inclined to support a theory of glacial origin of the Eocambrian tillites, no categorical statement to this problem should be made until we have more facts about these deposits.

Ekre shale.

Good exposures of Ekre shale are found in a railway-cut 1 km south of Rena station. Because of its poor resistance to erosion the Ekre shale is rarely exposed.

The varve-like lamination often reported in the Ekre shale (Holtedahl 1953), is found here, but is not always prominent. The colour of the shale is often dark grey, but alternating red and green beds are frequently found. The thickness is about 30 m.

Petrology:

Quartz and feldspar (30 %): Quartz, microcline and albite/oligoclase are observed. Grain size mostly below 0,1 mm, not exceeding 0,15 mm.

The phyllosilicates are muscovite, biotite and chlorite. These minerals are parallel-oriented, giving a good cleavage parallel to the bedding. Biotite and muscovite are probably clastic minerals derived from a metamorphic source rock. The chlorite, however, occurring in fibrous aggregates, seems to be recrystallised.

Vemdal Formation (Quartz sandstone formation).

The Vemdal sandstone is divided by Vogt (1924) into an upper quartzitic member (Ringsaker quartzite) with a low feldspar content, and a lower feldspathic sandstone (Vardal sparagmite). The border between these members is not well-defined, and the feldspar content gradually decreases upwards from the Vardal sparagmite to the Ringsaker quartzite. In the Rena District the Vemdal sandstone is in an allochthonous position in the Vemdal nappe on both sides of the valley from Åsta towards Elverum, resting upon Cambro-Silurian shale. Vemdal sandstone in a parautochthonus position is found east and south of Rena station. An almost complete section through the Vemdal sandstone is exposed in the road-cut 2 km south of Rena st. Also on the eastern side of Kletten (F 7—8) near Åsta the Vemdal sand-

stone passing into lower Cambrian shale is relatively well exposed. The sediments have a strong red colour due to iron oxides.

Vardal sparagmite is defined as the lower, feldspar-rich member of the Vemdal formation (Quartz s. st. formation) (Vogt 1924). The border towards the overlying Ringsaker quartzite is not defined more precisely.

Thin section examination of 9 samples of Vardal sparagmite (See Figure 20 b) revealed that the plagioclase content was low (0—4 %) in all specimens examined, and that the total feldspar content and the amount of matrix varies. The grain size is regularly lower than in the Moelv and Brøttum sparagmites, rarely exceeding 2 mm. The quartz and feldspar grains have commonly developed a net of fissures, and on the contact between two grains contact undulosity (See p. 10) is often observed. The matrix consists mainly of chlorite and sericite. Among the accessory minerals zircon is most common occurring both as single grains and as well-rounded crystals in grains of quartzite. Less common is tourmaline, sphene and small grains of apatite, usually found as inclusions in quartzite grains.

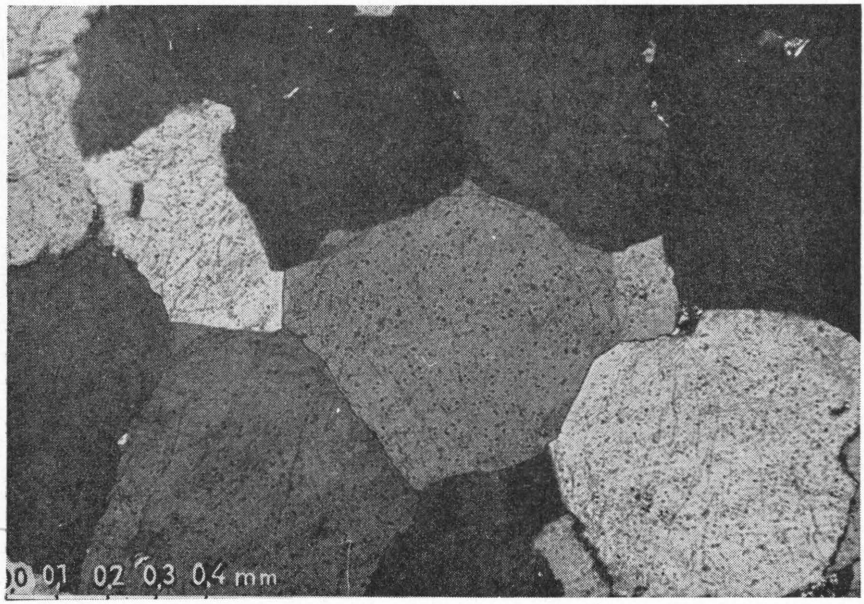


Fig. 18. Secondary overgrowth of quartz in optic continuity with the original grain which is indicated by the line of inclusions.

Fig. 19. Linguoid ripple marks in Lower Cambrian sandstone at Glomstad. Current from left to right (towards WSW).

The typical *Ringsaker quartzite* is a relatively pure and well recrystallised ortho-quartzite, most commonly with a greyish-blue colour.

Examination of thin section reveals solution marks between adjacent quartz grains and secondary overgrowth filling up practically all open pore space (Figure 18). This is probably due to welding during the diagenesis. Undulatory extinction, which is found in most grains is, at least partly, caused by post-depositional tectonic deformation. The small amount of matrix found between the grains, is mostly made up by iron oxides and some chlorite and sericite. As in the Vardal sparagmite zircon is the predominant heavy mineral, and tourmaline and sphene are less common.

Cambrian and Ordovician sediments.

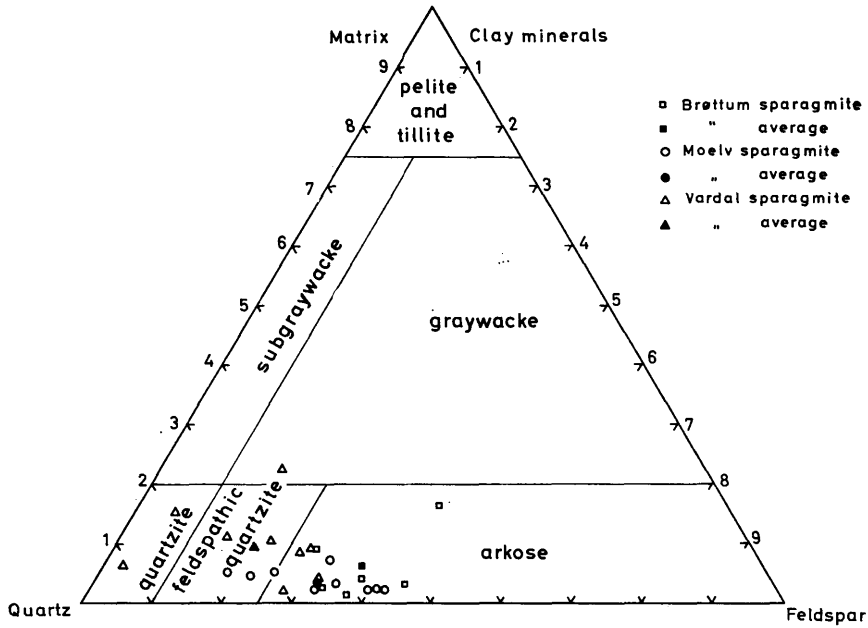
Fossiliferous Cambrian and Ordovician sediments overlying the Vemdal sandstone, have been preserved from erosion in the overturned syncline from Brumundkampen to Åsta in front of the Moelv anticli-

norium (See p. 43 and map.). Farther south towards Elverum, Cambrian shales are found below and between the allochthonous sheets of Vemdal sandstone. From these localities relatively detailed descriptions with fossil lists are published by Törnebohm (1896, p. 30 and p. 66), Schiøtz (1902, p. 16 and p. 17) and K. O. Bjørlykke (1905, p. 37—41). The best profile is found on the eastern bank of Glomma near Åsta station. Lower Cambrian sandy shales are here particularly well-exposed, showing ripple marks and worm trails. Figure 19 shows ripple marks of the linguoid type indicating a direction of transport towards WSW. These ripple marks may represent local conditions only.

The petrology of the Brøttum, Moelv and Vardal sparagmites.

In order to classify and characterise the Brøttum, Moelv and Vardal sparagmites, which in hand specimen may look rather similar, modal and chemical analyses have been carried out (See p. 36, 38). Numerous classifications of sandstone are introduced in sedimentological literature, and recent reviews on such classifications are given by Huckenholz (1962) and Klein (1963). Some of the classifications of sandstone as Folk (1954) distinguish between metamorphic rock fragments (metaquartzite included), igneous rock fragments and quartz. Such distinctions are not very sharp, and it may be difficult to decide whether a small rock fragment has an igneous or a metamorphic origin. The distinction between quartz and quartzite fragments might also cause problems. The author has therefore found the classification of Pettijohn (1949) best suited in the case of the present sparagmites. Figure 20 a shows the result of the modal analyses, and it appears that the difference in composition between the Moelv and the Brøttum sparagmites is relatively small and that they both should be classified as arkoses. The Vardal sparagmite (Vemdal formation) has a very variable and generally lower feldspar content and should be classified as feldspathic quartzite. Figure 20 b shows that the feldspar in the Vemdal formation is mainly microcline, while the Moelv and Brøttum sparagmites have a higher plagioclase content.

As a supplement to the modal analyses sodium and potassium analyses from the same formations were carried out (See figure 21). The result is in good accordance with the data from the modal analyses and shows a low sodium content for the Vemdal formation. The low Na_2O/K_2O or *plagioclase/microcline* ratio in the Vemdal formation is not a local



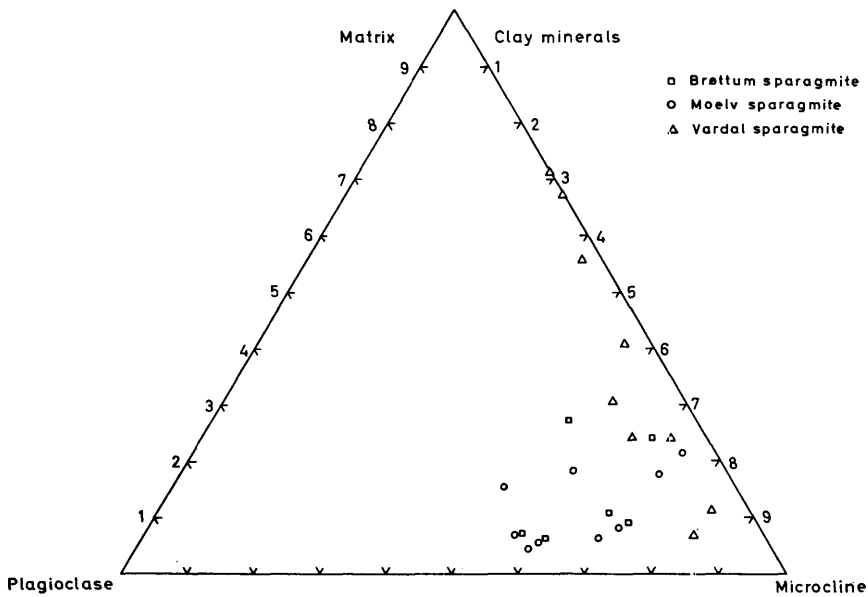


Fig. 20. Modal analyses of 25 sparagmites of the Rena District.
a) Plotted in a diagram after Pettijohn (1949). — b) matrix, plagioclase, microcline distribution when quartz is excluded.

phenomenon, and similar low plagioclase/microcline ratios relative to the older sandstone formations are found by Brit Løberg (University Thesis 1965) from Gausdal, and Englund (1966) from the Fåvang area south of Ringebu. Also in Herjedalen in Sweden the Vemdal formation shows a lower *plagioclase/microcline* ratio than the red and grey sparagmites corresponding to the Moelv sparagmite (Stålhøs 1956 and 1958 p. 221—22). The sparagmites in the areas mentioned are only slightly metamorphosed, and metasomatic processes with recrystallisation of the feldspar are not likely to have taken place. It seems therefore necessary to assume that the low plagioclase content in the Vemdal formation is due to a selective break-down of plagioclase relatively to microcline during the process of weathering and transportation. This is in good accordance with the data on weathering of granitic rocks published by Goldich (1938). While the sodium from the weathered feldspar is readily dissolved in the water some of the $K+$ ions are fixed to the negative colloid clay minerals, and some of the potassium may thus remain in the matrix of the sediment (V. M. Goldschmidt 1954). The Na_2O/K_2O ratio should therefore be a good maturity index for sandstones from a source rock of granitic or intermediate composition. In this case the Vemdal formation has both a lower total feldspar content and a lower NaO_2/K_2O ratio than the Brøttum and Moelv formations and should be characterised as being more mature than the latter. This is also supported by thin sections in which feldspar grains of the Vemdal formation appear more weathered than the feldspars of the older sandstone formations.

A higher sodium content in the granulites of the Opdal District than in the sparagmites further south (Gudbrandsdalen and Engerdalen) is interpreted by Barth (1938) as a result of an increasing sodium metasomatism as the metamorphism increases. This interpretation presupposes that the sparagmites primarily had a relatively homogeneous composition, but recent investigations show that sparagmites have been formed by denudation of source rocks of different composition and under variable conditions. Strand (1951) arrived at a similar conclusion to that of Barth, interpretating the plagioclase gneisses in northern Gudbrandsdal as a result of metasomatic replacement of potassium feldspar. However arkoses bearing almost exclusively plagioclase feldspar (25 %) (in the Moelv formation) have been reported by Englund (1966) farther south in the less metamorphic Fåvang District, showing that plagioclase gneisses may have a clastic and non-volcanic origin and are

not necessarily metasomatically altered. While the sparagmites in the southern and eastern part of the Sparagmite basin mainly are derived from granitic gneisses, the sparagmites in the NW seem to have had a more plagioclase-rich source.

Normative calculation of the feldspar content in arkoses based on alkali analyses.

In relatively pure quartz-feldspar-rocks such as the arkoses dealt with in this paper, nearly all sodium and potassium is present in the feldspars. The amount of potassium present in light mica is low in relation to the potassium present in microcline. Figure 22 shows the results of a normative calculation of the feldspar content based on alkali analyses (See Figure 21) compared with the results of the modal analyses on the same samples. All potassium is here calculated as microcline and all sodium + 10 % as plagioclase (An_{10-20}). Because of the sodium content in microcline the calculated microcline content is higher than the result of the modal analyses. As shown on Figure 22 the modal feldspar content determined by the two methods is quite similar. The low content of normative feldspar in Vardal sparagmite relative to the results of the modal analyses may be due to loss of sodium and potassium during the more severe weathering in the Vardal sparagmite. Such weathering may chemically change the feldspars without destroying the grains observed during point counting.

For the chemical analyses larger samples can be crushed and split up, reducing the possibility of an error in sampling. Thus, for coarse-

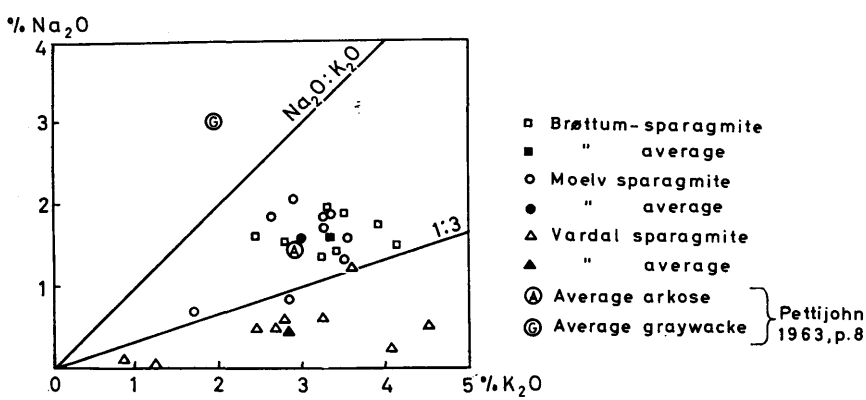


Fig. 21. Flamephotometric analyses of 27 samples of sparagmites from the Rena district.

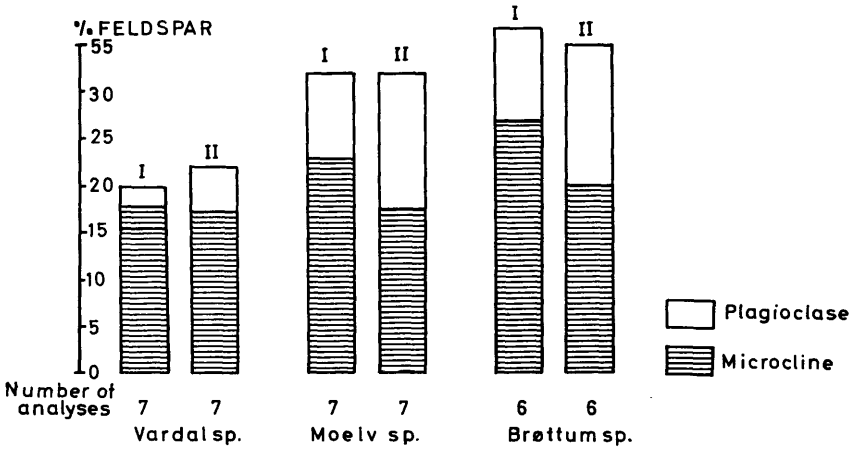


Fig. 22. The feldspar content in some sparagmites from the Rena area. 1. Modal analyses. — 2. Normative feldspar based on sodium and potassium analyses of the same samples.

grained sparagmites, the normative feldspar content is probably more reliable than the modal analyses from thin-sections.

Sedimentation and weathering and palaeoclimate.

The various formations in the Sparagmite group show a great lithological variation, including conglomerates, arkoses, shales and limestones. This contrast in the degree of maturity, or weathering, of the sediments not only changes from one formation to the other but also from bed to bed and even within the same hand specimen. In thin section one may observe some strongly weathered feldspars (both plagioclase and microcline) adjacent to fresh and unweathered feldspars. A similar variation in the degree of weathering is described by Krynine (1950) from the Triassic arkoses of Connecticut. Krynine concludes that this is the result of a mixture of sediments derived from at least two different environments. Figure 23 shows how fresh detritus is derived from the canyons and mixed with weathered sediments on both sides of the canyon.

Because of the fresh appearance of the larger part of the feldspar in most sparagmites, it has been suggested that the sparagmites were deposited during a period of dry climate (Holtedahl 1953, p. 162),

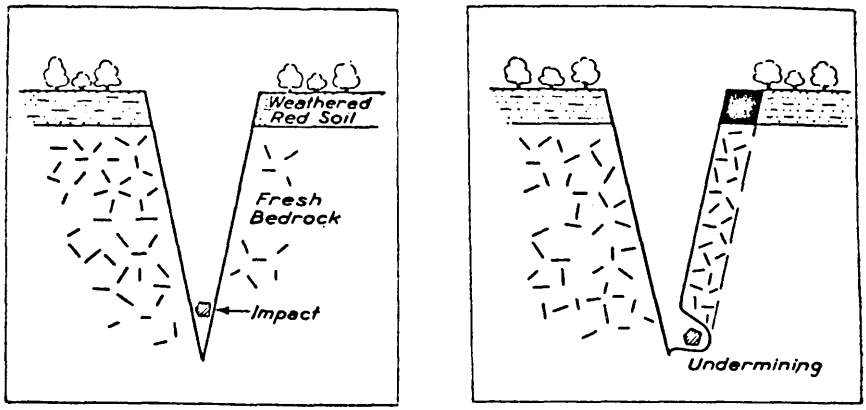


Fig. 23. Double locus of chemical weathering within canyons (after Krynine, 1950).

but as pointed out by Hadding (1929, p. 167) this implication can not be based on fresh feldspars alone. First of all, thin sections show that the weathered feldspars occur quite commonly, indicating that at least a part of the source rock had been subjected to severe weathering. Secondly, Krynine (1935) has shown that fresh feldspar is no indication of cold or dry weather since recent arkoses are reported from Mexico deposited in a humid climate. It is concluded that the weathering of the feldspars is related to mode of erosion and sedimentation rather than the climate.

The boron content in some Eocambrian and Cambrian rocks.

Goldschmidt and Peters (1932) have shown that boron is enriched in marine sediments mainly in the clay minerals. Analyses of the boron content in Norwegian sediments have been published by Landmark (1944) and Spjeldnæs (1962). The latter has published 92 analyses mainly from the Cambro-Silurian of the Oslo Region, but also some from the Sparagmite group. In table 2 the result of spectrographic analyses of sparagmites from the Rena District is listed. These spectrographic analyses have been carried out by Professor I. Oftedal who suggests that the errors may be up to 50 % by this method.

The boron content in the analysed sparagmites regularly shows a higher value than is expected for fresh water deposits (Goldschmidt 1932) and should therefore be indicative of marine environment, but no

definite conclusion should be drawn at this stage about the salinity of water in the Sparagmite basin. Because boron is supposed to be present in the clay minerals the amount of clay minerals should also be taken into consideration in this connection.

The basal tillites (placed in the author's disposal by Per Holmsen) show the same amount of boron as the other samples from the Sparagmite Region. The limestones show as expected low boron values (Goldschmidt 1932).

Table 2.

No.	Sample	Locality	Boron content p.p.m.
1.	Holmia shale	Tømten, Ringsaker	300
2.	Peltura limestone	Bank of Glomma (Åsta)	*
3.	L. Cambrian shale	Bank of Glomma (Åsta)	300
4.	L. Cambrian shale?	Engåen south of Rena station	100
5.	Vardal sparagmite	Hemmestad south of Åsta river	300
6.	Vardal sparagmite	Kletten	*
7.	Vardal sparagmite	Julussa NW of Rena station	*
8.	Shale-flake in Moelv sparagmite	Beks Minde	100
9.	Moelv shale	Beks Minde	100
10.	Moelv shale	Høistad NW of Rena station	100
11.	Moelv shale	Julussa NW of Rena station	100
12.	Biri shale	Skynna N of Rena station	100
13.	Biri limestone	Glomstad	*
14.	Brøttum sparagmite	Engulsfjell	*
15.	Moelv tillite	South of Rena station	100
16.	Basal tillite	Magnhildbrennskarven, Engerdalen	100
17.	Basal tillite	Andrå, Storsjøen	100
18.	Basal tillite	Møra, Rendalen	100
19.	Basal tillite	Mistraflaket, Rendalen	100
20.	Moelv tillite	Jernåsen S of Åsta river	300
227.	Ekre shale	Ringsaker, Moelv (Spjeldnæs 1962)	90
51.	Tillite	Tana, Finnmark (Spjeldnæs 1962)	200

* $<$ 100 p.p.m.

Tectonics.

The area investigated is located in a corner of the Sparagmite basin with crystalline Precambrian rocks south and east of the sediments of the Sparagmite group. Three different tectonic units can be distinguished:

1. Crystalline Precambrian basement with overlying autochthonous Cambrian sediments; locally also Vemdal sandstone.
2. Vemdal (quartz sandstone) nappe thrusted above Cambrian shales.
3. Folded, parautochthonous Eocambrian and Cambro-Ordovician sediments in the basin.

The Vemdal (quartz sandstone) nappe.

The overthrust position of the Vemdal sandstone on both side of the valley from Elverum to Åsta was first pointed out by Schiøtz (1902). Outliers of the Vemdal nappe with underlying Cambrian shale NE of Elverum and also a comparison between the sections in Øksna and Kletten west of Rena, made it possible for him to prove that the Vemdal sandstone was thrust above fossiliferous Cambrian shales for a distance of 25—40 km. Similar thrusting of the Vemdal sandstone was later described farther west around the northern part of Randsfjord (Holtedahl 1915), and this important tectonic unit is now known to extend from Hemsedal, in the SW, northeast-wards into Sweden, where the Vemdal sandstone is also known as Ströms quartzite.

Due to poor exposure the mapped area south of Åsta is not well suited for a study of the details within the nappe. It appears, however, from the repeated units of arkose or feldspathic sandstone (Vardal member) at the base and more pure quartzite (Ringsaker member) at the top, that the nappe has an imbricated structure, probably with thin sheets of Cambrian shales between each unit. No such shale has been observed in the mapped area, but further south in the rivercut of Øksna the imbricated structure with Cambrian shales between two units of Vemdal sandstone can be studied (Schiøtz 1902).

From what we can observe the nappe has a structure very similar to the quartzite nappe around Lake Ormsjø, Southern Lappland, Sweden, as described by T. Du Rietz (1960). On the basis of numerous drill holes through the nappe into the basement of crystalline Precambrian, Du Rietz was able to draw detailed profiles demonstrating the

imbricated structure of the nappe. It appears that the alum shale has served as a lubricating medium between each unit of Ströms quartzite (Vemdal formation).

Skjeseth (1963, p. 103) has described the contact between the quartzite and the alum shale at Hov west of Mjøsa, where the thrust plane is well exposed and he has given a detailed description of the imbricated nappe structure from a section in southern Ringsaker.

As pointed out by Skjeseth (1963), the underlying Ekre shale has served as a gliding horizon for the Vemdal nappe (quartz sandstone) in the basin. This nappe was thrust southwest-wards out of the basin for a distance of 25—40 kms on the Cambrian shales. Thus the overlying Ordovician sediments must have been folded or thrusted in front of the nappe and then eroded.

The folding of the parautochthonous sediments.

As it will appear from the map and the profile the sediments of the Sparagmite group are folded, and the competent arkose and sandstone formations have produced large anticlines and synclines. The synclines have in some cases been torn off into thrust faults. Smaller folds are mostly found in the incompetent shale and limestone formations. Observed fold axes and lineations are too rare for statistical treatment.

An important tectonic structure within this area is the large anticlinorium along the southern margin of the Sparagmite basin, named the Moelv-Rena anticline by Skjeseth (1963, p. 90). The southern inverted limb of an anticline belonging to this tectonic unit is found in Kletten west of Åsta st. The northern limb is exposed in the road cut section close to Engåen (G 4) south of Rena, where we find Vemdal sandstone with the Lower Cambrian basal conglomerate at the top (p. 32). The succeeding dark shales along Engåen are strongly tectonised and are probably remnants of Cambrian shales, although no fossils have been found here. Farther north a grey shale (Moelv shale) appears grading into Moelv sparagmite. This is a good example of a thrust fault with an upthrusted northern part.

The Biri shale is found along the Rena river making up the core of an anticline with Moelv sparagmite on both limbs. This is most probably a fold with the SE limb inverted (p. 20) and pressed up against the southern margin of the Sparagmite basin.

Northwards from Digeråsen and Engulsfjell the Brøttum sparagmite appears in a large anticlinorium with a southern vertical or inverted limb.

Another anticlinal structure is marked by the Biri shale and limestone in outcrops from Arnestad to Åsta river at Hole Seter (C 5—6) and as it appears on the map its fold axis must have been deformed to an *f* shaped flexure. Farther south there are no exposures between the Åsta river-cut and the road and railway sections along Glomma. A similar axial flexure must be assumed to exist in this area parallel with the Arnestad anticline.

The axial flexure is most easily explained as a drag effect towards the eastern margin of the basin east of Glomma, probably resulting in a vertical fold axis. Such vertical fold axes in a small scale are found at Brenna (D 5) along the Arnestad anticline.

P. Holmsen and Chr. Oftedal (1956) have suggested that not only the Vemdal nappe is allochthonous, but also that the rest of the Sparagmite group belongs to what they called the Sparagmite nappe. According to the interpretation by Skjeseth (1963), however, the sparagmite in the southern part of the Sparagmite basin (exclusive of the Vemdal nappe) is in a parautochtonous position and only folded against the margins of the basin of deposition. Both the palaeogeographical reconstructions (See p. 25) and the tectonic pattern in this area are evidently strongly influenced by the local relief in the crystalline basement, and seem to support Skjeseth's interpretation.

According to Schiøtz (1902, p. 103) the margin of the basin served as rigid fences or walls, against which the sediments of the Sparagmite group were pressed during the Caledonian folding producing asymmetrical folds. A similar interpretation has been put forwards by Skjeseth. It is, however, difficult to reconstruct the primary relief of the margin of the crystalline basement due to later faulting. It may be questioned whether the primary relief was strong enough to produce such large folds as the Moelv—Rena anticline. Asymmetrical folds along the margin of the basin may also be caused by a thinning-out of incompetent layers towards the basin margins (DeSitter 1956, p. 240). It is therefore possible that the Moelv—Rena anticline is also, at last partly, caused by the thinning-out of the Biri formation towards the margin.

Faults.

The Sparagmite basin is a down-faulted basin in a crystalline Precambrian basement complex, and to understand the Caledonian folding and the late Caledonian or Permian faulting it is necessary to know the Eocambrian fault-system controlling the topography of the crystalline basement. Prominent Eocambrian fault or flexure zones such as the Rendal fault (Skjeseth 1963) and the Engerdal fault (Holtedahl 1921) seem to coincide with late Caledonian or Permian faults. No faults of the magnitude of the above mentioned are found within the mapped area, but a more irregular set of faults has been mapped. The thrust plane of the Vemdal nappe is found on the east side of the Glomma valley in Kråkeberget approximately 500 m a.s.l., while the same thrust plane occurs 350 m a.s.l. on the western side. This must be explained by a N-S-going fault which caused a relative elevation of the eastern side. This fault seems not to have affected the sediments of the Sparagmite group farther north. To the NW the uplifted area around Kråkeberget is limited by a fault trending in a northeastern direction a little south of Åsta. A very marked red-coloured breccia in the Glomstad section along Glomma does probably belong to this fault zone. A breccia in the crystalline Precambrian south of Hemme-sjøen is interpreted as a continuation of the same fault. A red-coloured breccia at the ski-jump SE of the bridge over Julussa (I 2 — J 2) in the upper part of the Vemdal sandstone is very similar to the one at Glomstad and may represent a continuation southwards of the Rendal fault, but is difficult to trace farther south.

Along the Glomstad section on the eastern bank of Glomma a series of faults is encountered. This section is described in details by the following authors: Törnebohm (1896, p. 30), Schiøtz (1902, p. 19) and K. O. Bjørlykke (1905, p. 40).

The section is intensely faulted, usually in a NE—SW direction parallel to the fold axis, but a dextral wrench fault in a NW—SE direction is also observed on the transition between the Ringsaker quartzite and the Lower Cambrian.

Discussion.

The folding of the Sparagmite group may be described as a process of «décollement» with Ekre shale as the upper detachment layer for the Vemdal (quartz sandstone) nappe. A lower less pronounced detachment layer is the Biri shale and limestone which have served as a

incompetent gliding horizon during the folding of the sediments below the Vemdal nappe. An even lower detachment layer towards the crystalline basement may exist, but this contact is nowhere exposed. No indications of folding of the crystalline basement have been found.

To summarise the tectonic events in the area the following succession should be listed.

1. Thrusting of the Vemdal nappe out of the basin on Cambrian shales.
2. Folding of the parautochthonous sediments of the Sparagmite group, with formation of the Moelv-Rena anticline.
3. Vertical faults.

It is difficult to give absolute datings of this tectonic activity or to relate it closely to other tectonic events. Skjeseth (1963) has suggested that the thrusting of the Vemdal nappe was simultaneous with the thrusting of the Upper Jotun nappe and the Kvitvola nappe corresponding to the Ardennian or Erian phase (L. Devonian?) (Vogt 1928). The faults cut quite clearly through the fold-structures and the thrust plane of the Vemdal nappe, but the author has no means of deciding whether the faults are late Caledonian (U. Devonian) or Permian. They are, however, very similar to many of the faults for which a Permian age has been proposed.

Sammendrag.

Stratigrafi og sedimentologi i sparagmitt-bergartene ved Rena i Østerdalen.

Avhandlingen representerer et forkortet utdrag av forfatterens hovedfagoppgave ved Universitetet i Oslo, våren 1964. Nye observasjoner er kommet til, og på enkelte områder skiller konklusjonene i denne avhandlingen seg noe fra hovedfagoppgaven. Feltarbeidet ble foretatt i somrene 1961, 1962 og 1963 med økonomisk støtte fra Norges Geologiske Undersøkelse. Kartleggingen er en del av det geologiske kartleggingsarbeidet som har vært foretatt av N.G.U. i sparagmittområdet i S. Norge under ledelse av professor (forhenværende statsgeolog) S. Skjeseth.

Denne beskrivelsen av geologien i området omkring Rena (Åmodt herred) tar sikte på å vise hvilke statigrafiske enheter sparagmittberg-

artene her består av, og det viser seg at disse i store trekk er utviklet på samme måte som i Moelv-området lenger vest, der det foreligger en vel etablert stratigrafisk inndeling. Som et ledd i den petrografiske beskrivelse av sandstensbergartene (Brøttum-, Moelv- og Vemdal-formasjonene) blir det presentert modal-analyser, utført ved punkttelling i tynnslip, og natrium- og kalium-analyser av de samme bergartene. Prøver av kalkstenen og skifrene er undersøkt ved røntgen-diffraktometer for å karakterisere skiktsilikatene og karbonatmineralene.

I lagserien finnes også et konglomerat (Moelv tillitt) med blokker opptil 1 m. Kriteriene for at dette skal kunne tolkes som en glacial avsetning blir diskutert.

Spektrografiske analyser av sparagmittgruppens bergarter viser et bor-innhold av samme størrelsesorden som vanlig for marine sedimenter, uten at dette kan betraktes som noe helt sikkert bevis for et marint avsetningsmiljø. Sparagmittbergartenes feltspatkorn synes ved første øyekast å være friske og uforvitret, og man har vært tilbøyelig til å tro at dette skyldes avsetning i et kaldt og tørt klima. Nærmere undersøkelser viser imidlertid at en del av feltspatkornene er sterkt forvitret og man vet fra nutids-eksempler at feltspat-forvitringen vesentlig er avhengig av erosjonshastigheten i de forskjellige tilførselsområder, mens klimaet spiller en mindre rolle.

Kartbildet og profilene viser hvordan sparagmittgruppens bergarter er foldet under den kaledonske fjellkjededannelse og presset opp i en stor antiklinal langs den sydlige del av sparagmittbassenget (Moelv-Rena antiklinalen). Den øvre del av sparagmitt-lagrekken, Vemdal-formasjonen (Kvartssandstens-formasjonen) ble under denne foldningen skjøvet på den underliggende skiferen (Ekre skifer) og inn over de kambriske skifrene i syd (Alun-skifer). Dette dekket kan observeres i dalsidene langs Glomma-dalføret sydover fra Åsta mot Elverum. Senere ble området gjennomsatt av enkelte senkaledonske eller permiske forkastninger.

Description of an excursion route through the Rena district.

Driving from Elverum (150 km north of Oslo) northwards along main road 3, outcrops of crystalline Precambrian gneisses are seen along the road. Above the gneisses on each side of the valley the Vemdal nappe is found to be overlying Cambrian shales which are exposed in a few sections only (Øksna and Rustad).

Stop 1. Åsta bridge, Moelv tillite. (See Figure 24.)

Note the lack of grading or sorting of the conglomerate. The blocks of gneisses found in the conglomerate are very similar to the gneisses seen along the road further south. On the east side of the road the transition to Ekre shale is exposed. Silty and sandy beds of the Moelv formation are found in the river-cut under the bridge. Across the bridge turn to the right and cross the bridge over Glomma (not for buses).

Stop 2. Eastern bank of Glomma by Glomstad.

Close to the bridge folded Biri limestone is found. A small exposure of a mylonitised gabbroid rock is found between the Biri limestone and the Vardal sparagmite (K. O. Bjørlykke 1905, p. 41). Further south folded Cambrian shales crop out, and on the bedding surface of the lower Cambrian shale, worm trails and ripple marks partly of the lingular type are seen (See p. 35). The Vemdal formation further south is separated from the lower Cambrian sandstone by a dextral wrench fault. A red coloured breccia occurs in the southern end of this outcrop of Vemdal sandstone. Close to the crystalline Precambrian gneisses, tectonised Cambrian shales and limestone are exposed.

Back to main road and continue on to Beks Minde.

Stop 3. Long road-cut in Moelv sparagmite with shale (Moelv shale) at the southern part. Note flute casts at the bottom surface of the upper conglomeratic part of the section, and contorted bedding above. Shaly and silty beds are often deformed by load casts. In the upper part of the section clay pebbles are common indicating an erosion of some of the underlying shales. No regular grading characteristic of the turbidites is found, and the well-sorted quartzite conglomerate seems to be more indicative of a shallow water environment (See p. 19). Continue northwards along the road about 2 km through a probably repeated sequence of Moelv sparagmite.

Stop 4. Engåen, 2 km south of Rena.

Section from Moelv formation to Vemdal formation and possibly Cambrian shale.

Note the gradual transition between the Moelv sparagmite and the Moelv tillite. No trace of disconformity can be found and no concentration of larger boulders at the base of the conglomerate. This is not easily explained by turbidites or mudflows, but fits well in the

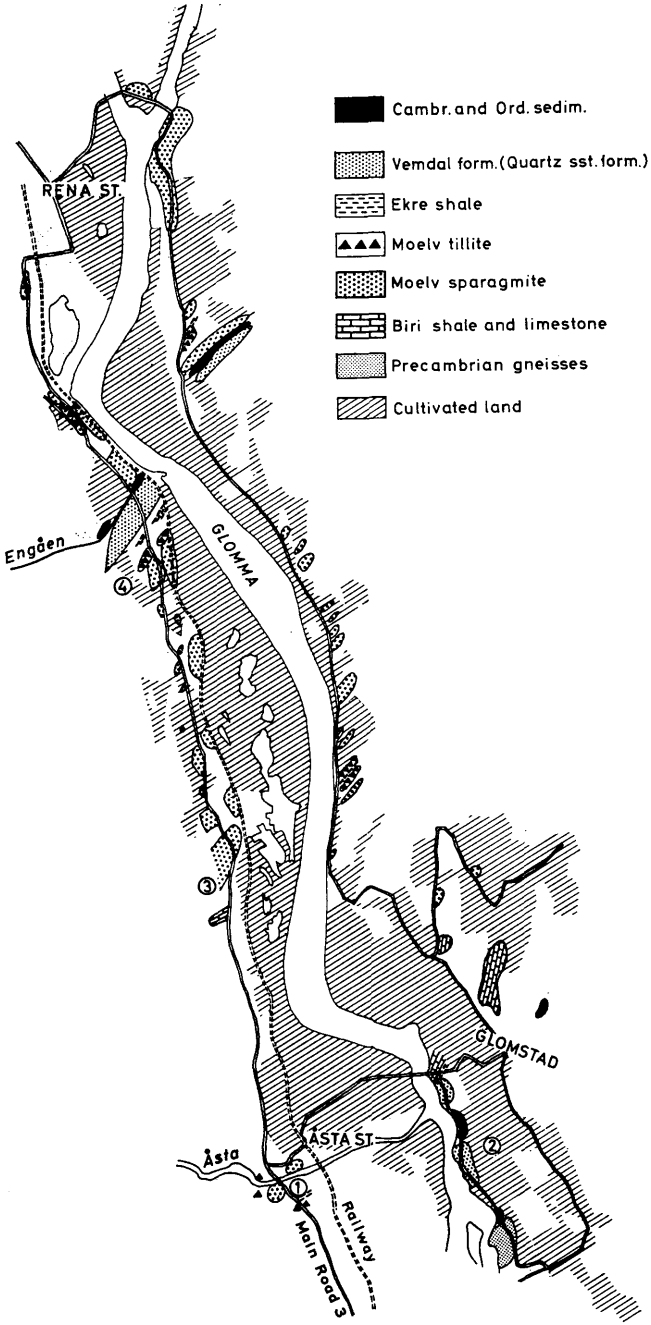


Fig. 24. Excursion map for the Rena District.

theory of an ice-drafted sediment. The Ekre shale crops out only in a small exposure on the west side of the road and further north we pass into the Vemdal sandstone. The lower part is arkosic (Vardal sparagmite) and the feldspar content decreases upwards to the Ringsaker quartzite. At the top of the Ringsaker quartzite close to the stream Engåen we have an approximately 2 m thick bed of quartzite gravel conglomerate which is very similar to the basal conglomerate of the fossiliferous Cambrian. The succeeding shales probably belong to the lower Cambrian, but no fossils are found in the strongly tectonised rock. The grey shale north of Engåen seems to belong to the Moelv formation as it grades into the Moelv sparagmite further north. A similar section is also found on the eastern side of Glomma. The break in the stratigraphic sequence and the tectonisation of the shales along Engåen indicate a fold-thrust along the northern limb of the Moelv—Rena anticline with the dislocation plane along Engåen. This fold-thrust can be traced further west to the Åsta river.

North of this section two outcrops of Moelv tillite are seen along the road, probably repeated by imbrication. If one continues along main road 215 across Glomma good exposures of strongly folded Biri shale are seen in small quarries along the road to Nordby. Ripple marks are seen on the sandstone beds, and just before crossing the Julussa river, flute casts on the bottom surface of the Moelv sparagmite can be seen, showing that the sequence here is inverted. This is an inverted limb of an anticline with fold axis parallel to Rena river.

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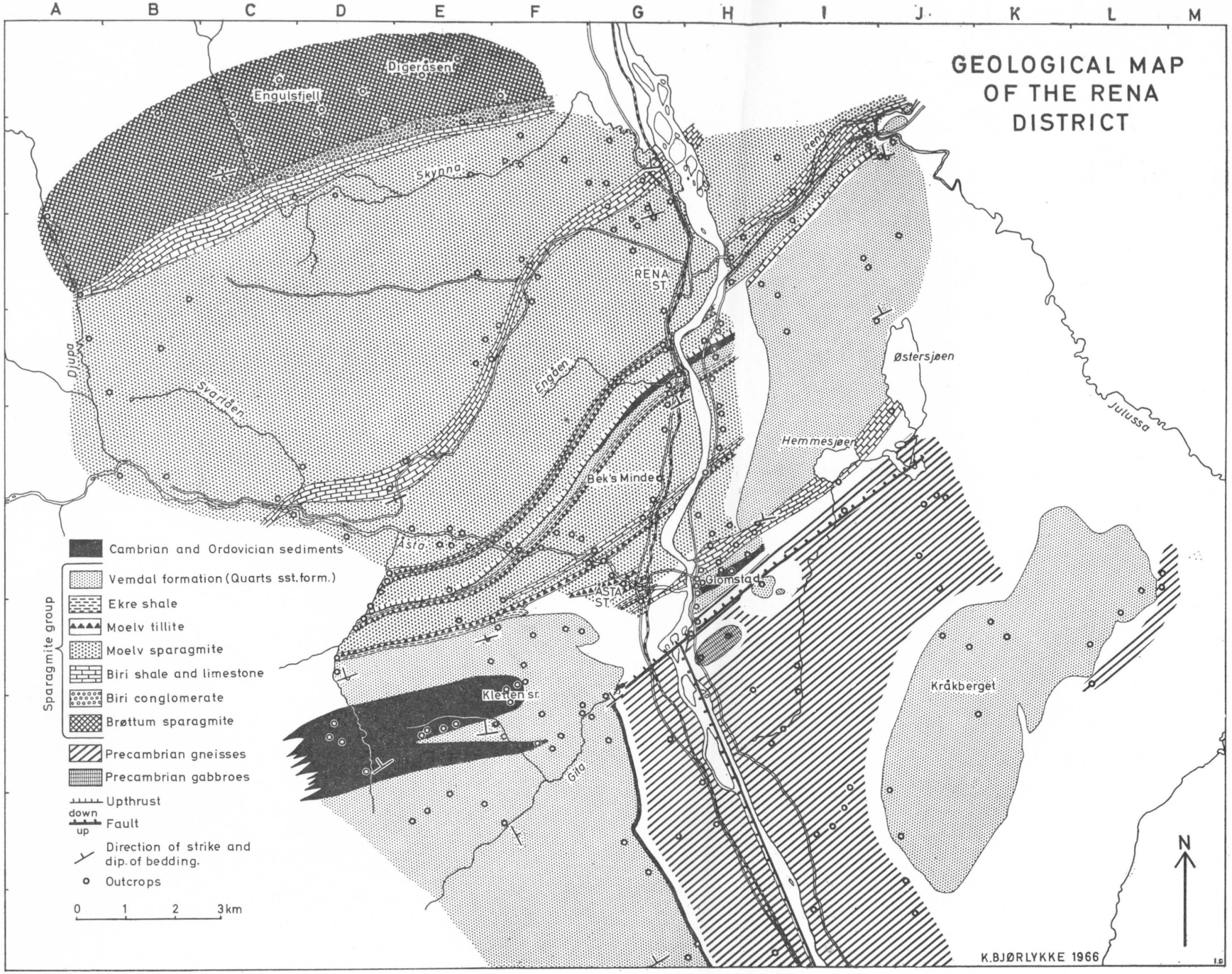

Fig. 25 Simplified profile through the mapped area.

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