THE ORDOVICIAN OF THE DISTRICTS AROUND MJØSA

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The object of this part of the excursion is to study the late Ordovician strata in the Toten and Nes-Hamar areas represented by a ca. 100 m thick predominantly carbonate sequence, named the Mjøsa[1] Limestone, and its various members (Harland 1981; Opalinski & Harland 1981). This formation is distinct from underlying and overlying clastic units (Furuberg Formation and Helgøya Quartzite) of respectively Middle Ordovician and Silurian age. Time does not allow us to examine other parts of the succession; for details of this and references to older papers the reader is referred to Størmer (1953) and Skjeseth (1963).

HISTORY OF RESEARCH

The first real scientific paper describing the Ordovician of the Mjøsa districts was that of Kjerulf (1857). The classical, and still fundamental papers are by Kiær (1897, 1908); the latter is on the Silurian but contains valuable information on the youngest Ordovician. This includes the naming of the Mjøsa Limestone and the first attempt to subdivide it formally. Holtedahl (1909, 1912) supplied information on the lower part of the Middle Ordovician and additional data on the lower beds was given by Bjørlykke (1905). Raymond (1916) suggested that the Mjøsa Limestone was of Middle, not Upper Ordovician age as believed at

[1] Following a decision by the Norwegian Language Council in 1981, the author maintains that the correct spelling is Mjøs Limestone, and consequently drops the definite article -a-ending. The editors disagree and maintain that Mjøsa, the name of the lake and that to be found on all maps, is the more correct. Moreover, the name Mjøsa has been used in all standard works published in English since 1908, and it appears in Strand & Størmer (1956 Lexique stratigraphique international Vol. 1, Fasc. 2a Norvege, 44). The law of priority would therefore seem to apply. In addition, retention of the name Mjøsa would lead to nomenclatorial stability.

that time. This was accepted and elaborated on in a number of papers by Kiær (1920, 1921, 1922, 1926). Rosendahl's study (1929) was concentrated on the Brumunddal area (Ringsaker district). Reference to publications on fossils from the Mjøsa Limestone are given in the following text or are to be found in the cited 'Middle Ordovician Series' and general reference lists.

STRUCTURAL SETTING

The early Palaeozoic rocks around Lake Mjøsa occur in four districts, namely Toten, Nes and Hamar in the south and Ringsaker (sometimes regarded to be outside the Oslo Region proper) north of the Solbergås horst. The area is a deeply eroded rift which was infaulted during Permo-carboniferous times with possibly some movement continuing into the Triassic (Ramberg & Spjeldnæs 1978). The area was faulted into a number of blocks which now dip gently in a variety of directions.

The early Palaeozoic beds were intensely folded during the Caledonian Orogeny, the maximum probably occurring in the Lower Devonian. There are two models for the tectonic history of the area, both focussing on the several kilometre thick, late Precambrian Hedemark Group found to the north of the Mjøsa district. In the commonly accepted model (Bjørlykke 1978 and others), the Hedemark Group is regarded as para-autochthonous having been deposited in the basin where it is now found, but compressed into an imbricate structure by pressure from the north. The Ordovician beds now found in the southern districts must have been deposited on top of the Hedemark Group, but were later peeled off by thrusting onto the crystalline Precambrian basement where they are now found. The Ordovician of the Ringsaker district must be allochthonous or para-autochthonous in relation to the underlying Hedemark Group, in the same way as the Ordovician of the southern districts is para-autochthonous in relation to its present basement.

The second model has been proposed by Nystuen (1981) who suggests that the whole of the Hedemark Group is allochthonous, and was originally deposited in a northern basin before being transported into its present position as part of a huge thrust sheet, the Osen-Røa Nappe Complex. In this model it is suggested that the Ordovician of the southern districts was deposited on the Precambrian basement, or on unknown sediments now depressed deeply under the Hedemark Group, and was scraped off during the advance of the nappe complex. The Ordovician of the Ringsaker district is therefore basically autochthonous on the Hedemark Group, but allochthonous in relation to the common basement of the nappe complex.

Regardless of which tectonic model is chosen, there are two features which are important:

1 The Ordovician has been considerably shortened due to décollement folding over the Precambrian basement. The Ordovician rocks found in the southern districts must therefore have been deposited at least 100-150 km to the north, a fact which must be considered in palaeogeographical and palaeoecological studies of the area.
2 The Ordovician sediments of the southern districts and those of the Ringsaker district were probably deposited in two different basins under rather different structural conditions, even if the distance between the basins was not necessarily much greater than the present one.

The Furuberg Formation consists of shale, with siltstone and limestone bands, mostly thin, but in the upper part more than 10 cm thick. The siltstones show many sedimentary structures, lamination, crossbedding and deformation structures, indicating that they were not bioturbated after deposition. The limestone beds contain a rich fauna of bryozoans, brachiopods, echinoderms, trilobites, molluscs and calcareous algae, which together with the sediment have been transported during periodic storms from a near-by carbonate platform. Very few, if any, of the fossils in these beds appear to have lived in the area. The same appears to be the case with the fossils in the siltstone beds, with the exception of some beds with a *Sowerbyella*-dominated association, which may be in life position. The shales are mostly unfossiliferous, but at some localities (Furuberget N) there are numerous hat- or bun-shaped trepostome bryozoans, and brachiopods thought to be *in situ*.

In the Hamar-Nes Districts, the cross-bedding of the silt- and limestone beds indicates current directions from north or south, in some cases towards the axis of the present synclines from both sides. The pure carbonate beds often show a transport direction from the west. In the upper part of the Furuberg Formation, and the Mjøsa Limestone, the transport direction shows a wider spread, and it is difficult to discern a consistent pattern. The cross-bedding pattern observed in the lower part of the Furuberg Formation is interpreted as indicating a palaeoslope from west to east. A carbonate platform to the west formed the source of carbonate material which was occasionally washed into the eastern, clay-dominated areas, transport possibly being concentrated in broad channels.

Series	Toten - Nes - Hamar Mjøsa south	Ringsaker Mjøsa north
Tretaspis Series	HIATUS	HIATUS
Chasmosp Series	Mjøsa Limestone (reef and algal limestone Furuberg formation { Cyclocrinus beds Coelosphaeridium beds Hovinsholm Shale	Mjøsa Limestone (red and shaly in upper part) Furuberg formation { Cyclocrinus beds Coelosphaeridium beds Hovinsholm Shale (= Robergia beds)
Ogygiocaris Series	Cephalopod shale Ogygiocaris shale Upper Didymograptus shale	Ogygiocaris shale Upper Didymograptus shale
Asaphus Series	Helskjær shale and limestone Endoceratid limestone Asaphus shale Megistaspis limestone Lower Didymograptus shale	Stein Limestone (= Orthoceras limestone Heramb Shale and limestone Lower Didymograptus Shale Stein Shale and limestone
Ceratopyge Series	Ceratopyge limestone Ceratopyge shales Dictyonema shale	Ceratopyge limestone Ceratopyge shales Dictyonema shale

Figure 1. Stratigraphy of the area visited (modified after Skjeseth 1963).

The carbonate beds, now found in the synclines, are therefore not the remains of continuous sediment cover but are 'fingers' from the western carbonate platform. These have escaped intense folding because of their relative competence. This model applies only to the Furuberg Formation; the upper part of the Mjøsa Limestone may have been a blanket deposit covering the whole area.

Correlation between the typical section of the Mjøsa Limestone at Bergevika south and the type section of the Furuberg Formation at Furuberget south indicates that, at the latter, the upper half of the Furuberg Formation corresponds to the lower half of the Mjøsa Limestone at Bergevika south. Based on the contained fauna both can be correlated with the Oandu Stage of Estonia (for example, there are 16 species of bryozoa common in Norway and Estonia), and more indirectly with the Upper Chasmops Limestone in the Oslo district. The lower part of the Furuberg Formation may be older, and at Sund (Einavann) in the Toten area they contain <u>Kullervo</u> sp. and <u>Christiania holtedahli</u>, known from the Lower Chasmops Shale in the Oslo district.

<u>Mjøsa Limestone</u> This formation was first named "der Mjøsen-Kalk" by Kiær (1908, p. 405), who supposed it to be Upper Ordovician. The lithology is highly variable (Opalinski & Harland 1981; Harland 1981). Because of the rapidly changing facies it is difficult to apply formal lithostratigraphy in a meaningful way and the author has attempted to use a series of informal units, based on rhythmic changes in sea level, which are supposed to be contemporaneous in the different localities. This system has been worked out in the Hamar—Nes districts. In the Toten district the limestones were deposited in shallower water and are to a large extent represented by intertidal, recrystallised and sparsely fossiliferous rocks, possibly originally calcareous muds. The shallow water units in the eastern districts of Toten contain surfaces of erosion, some with karst features.

The section at Bergevika south (Fig. 2, loc. 7) is regarded by the author as being the type section for the Mjøsa Limestone which is contrary to that of Opalinski & Harland 1981. [In doing this the author follows Størmer 1953 and Skjeseth 1963. Skjeseth 1963 p. 66 refers to Helgøya

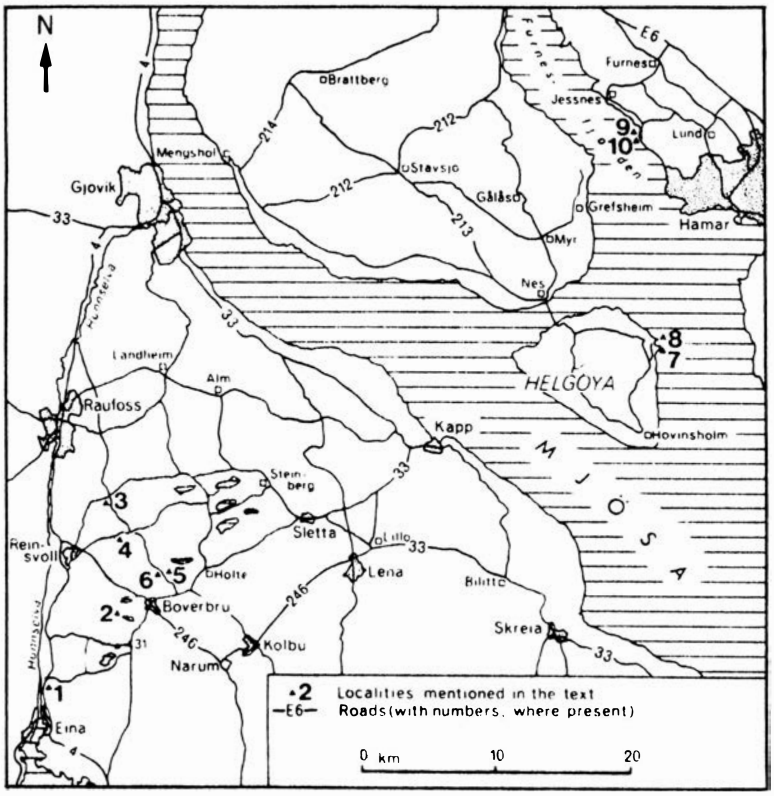

Figure 2. Map of the Toten and Nes—Hamar areas with stops marked (modified after Opalinski & Harland 1981).

and Furuberget as type localities while Størmer 1953 p. 106 refers to these as "classical". Strand and Størmer 1956, do not define a formation stratotype for the Mjøsa Limestone. Eds.]

In the section at Bergevika south the following units can be recognised:
Unit I is developed in the Furuberg Formation facies and consists of shales with dense, 3-8 cm beds of silt and limestone. These were probably storm-generated, containing upward-fining sequences and a number of sedimentary structures. The upper boundary is sharp but mostly deformed by slumping.

Unit II A limestone unit with massive *Solenopora* beds at the base. These beds are partly slumped and contorted. Higher up the bedding is irregular and the initial stages of mound and roof formation are common, although well developed structures are absent. Small, irregular lenses of unbedded limestone alternate with bedded, washed limestone. Typical features are large (up to 1 m high and 2 m wide) colonies of a *Catenipora* sp. and occasional rugose corals. The stromatoporoids are better preserved here than in Unit IV, the unit from which Webby's (1979) described material originated, and are mostly crustose forms, although some branching forms occur in sheltered, mud-filled cavities. The large 'bun-shaped' colonies from reefs in Unit IV are very rare in Unit II. The fauna is dominated by bryozoans which include 16 species known also from the Oandu Stage of Estonia. Some of these and others are known from Unit I and from the Furuberg Formation at Furuberg. This unit is a veritable

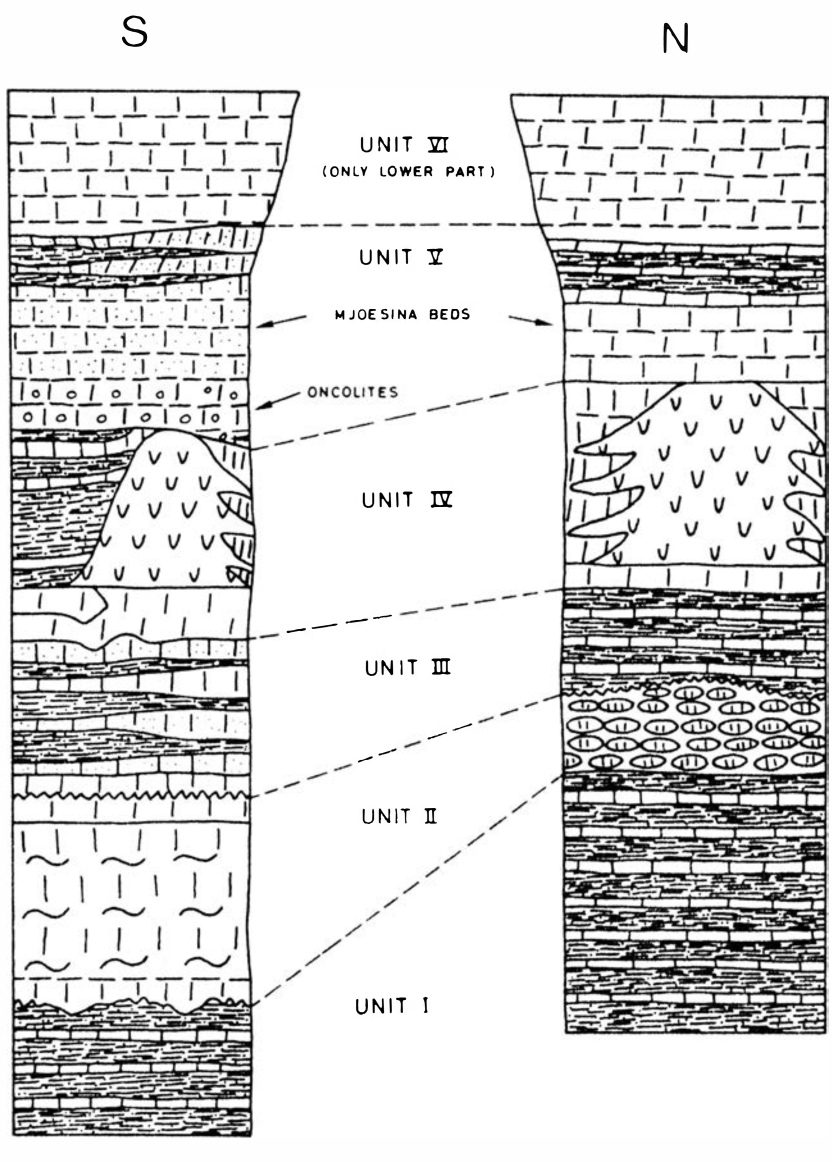

Figure 3. Sections through Units I-IV of Mjøsa Limestone and Furuberg Formation from Bergevika N and S. For explanation of the individual units, see text.

museum of sedimentary structures both primary ('tadpole nest' ripple marks) and secondary (vertical stylolites). Dolomite rhombs occur with stylolites and bedding planes. Both horizontal and vertical stylolites are common. Reconstructions of fossils to their original shape show that they lost more than 60% of their original volume during compaction. In contrast to Unit I, which was probably deposited below wave-base and eroded only during rare, periodic storms, Unit II was evidently deposited above wave-base and probably in the highest subtidal to low intertidal areas.

Unit III This is a dolomitic silt with fining-upwards carbonate beds 1-6 cm thick. The boundary with Unit II is sharp and erosive; both in the upper and lower parts there are thicker carbonate beds. This type of deposition resembles that of Unit I but the facies changes more rapidly in less than 1 km lateral distance, from dominantly silty, current bedded carbonate with small amounts of shales at the eastern tip of the southern peninsula at Bergevika, to dark shales with siltstone-carbonate beds (Furuberg Formation lithology) in the eastermost road section. In the more shaly parts, the fauna is dominated by a *Sowerbyella* association, while in the more carbonate-rich beds bryozoans are dominant. Algae are rare except for a few scattered *Solenopora* specimens in the lowest and upper beds, and all but a few rugose corals are absent. The environment was probably similar to that in Unit I, with the possibility of an east-west gradient, although this could also be due to changes in supply of clastic material.

Unit IV This reef horizon sits directly on a massive *Solenopora* limestone which, as in Unit II, contains prominent slump structures. The reefs consist of fairly large, 'bun-shaped' stromatoporoids and several species have been identified (Webby 1979). Corals are few in number in the reef mass itself, most being found on the flanks in a more impure, argillaceous limestone. The corals include bushy colonies of *Eofletcheria* which hosted a rich epifauna with an infauna in the interlying sediment. The reef mass has been exposed to intense pressure solution which has altered its original morphology and reduced the volume by more than half. This must be taken into consideration when reconstructing the topography of the reefs, and has resulted in the loss of any cryptic faunas and epifaunas. A few mud-filled cavities however contain a fauna including brachiopods and stromatoporoids. Lateral equivalents to the reef occur in the steep cliff section and are similar in lithology to the main part of Unit II.

Unit V The contact between this and the reef unit is sharp. The lower part contains a massive bedded limestone with oncolites, oolites and numerous calcareous algae including Dimorphosiphon rectangulare Høeg. The presence of oncolites suggests deposition in the intertidal zone. It is overlain by fine-grained limestones, the 'Mjoesina beds' of Spjeldnæs (1957) of shallow water origin, and dolomitic siltstones with carbonate beds, similar to those of Unit III. The lower bed contains both in situ faunas and transported ones derived from a purer carbonate environment. The transported faunas are similar to those found in the shallow water carbonates, while the in situ fauna is dominated by Sowerbyella, Vellamo dalmanellids, rhynchonellids and large bivalves, often alone or in low-diversity assemblages. Spjeldnæs (1957, text-fig. 22) showed that no appreciable size-sorting had occurred in populations of Sowerbyella, although disarticulation and current orientation was present. Laterally, the lower part of Unit V grades into peloidal limestones, resembling those of the overlying unit but without the reticulate structure. Some of these beds are extremely rich in recrystallised mollusc shells.

Unit VI This is a uniform limestone, at least 60 m thick, consisting of peloidal limestone with a characteristic reticular structure resulting from internal solution. This is probably one of the best examples of the formation of nodular limestones according to the model suggested by Bjørlykke (1973). The fauna appears to be poor in comparison to the other units as fossils are difficult to extract. However, large gastropods, cephalopods, bryozoans and (?)sponges occur. The fauna appears to be uniform throughout the unit and there is no visible horizontal change related to facies. Superficially, this limestone looks rather homogeneous, but this is partly an illusion because of the secondary reticulation. Detailed examination reveals 'nests' of fossils, small-scale chanelling and variations in clastic content and grain size. The boundary with the overlying Silurian Helgøya quartzite is a sharp, erosive one. The contact is not exposed at Bergevika, but at Furuberget and Snipsand there is a thin (0.5-0.7 m) sandy carbonate horizon between the typical Unit VI and the typical Silurian sandstone. This unit contains, amongst others, colonies of Solenopora and Palaeofavosites. In the author's opinion, these beds are of Silurian age but contain reworked Ordovician fossils.

At Bergevika north (Fig. 2, loc. 8) Unit I is the same as at Bergevika south, but Unit II is much thinner and developed as a nodular limestone. Its fauna includes numerous small, globular colonies of Nyctopora. Unit III contains current-bedded carbonates, including some spectacular beds with isolated ripples of pure carbonate sand in silty shale. The ripples are 5-10 cm high with a crest distance of 70-100 cm and indicate a current from the west. Unit IV contains reefs which are similar to those at Bergevika south. However, the interreef facies resembles that of Unit II at the southern locality, with many encrusting stromatoporoids, some corals (including a different Catenipora from Unit II) and horizons of massive carbonate. The reef-like rocks interfinger with massive, clastic carbonates. The basal Solenopora limestone is much thinner here than at Bergevika south, as are the basal oncolitic beds of Unit V. The 'Mjoesina beds' are similar to those of the southern locality, as are the silty dolomitic beds and the succeeding limestones of Unit VI.

The classical section of the Mjøsa Limestone is at Furuberget. Here beds equivalent to the lower part of the section at Bergevika south are developed as the upper part of the Furuberg Formation at the type section in the railway cutting at Furuberg south. This is shown both in the resemblance of the faunas, especially the bryozoans, and in a lithological correlation with the upper parts of the formation. A series of thick, closely spaced silty limestone beds in the middle part of the upper Furuberg Formation may represent Unit II. Beds equivalent to the reefs of Unit IV are developed as massive limestones containing Solenopora and rhynchonellid brachiopods. These beds are followed by more massive silty limestones, which grade into the typical reticulate peloidal limestones of Unit VI. This unit is more than 60 m thick and the reticulation is often less marked than at the other localities. Near the top of the limestone some beds are rich in fossils but identification is hindered by strong recrystallisation.

Model of deposition It is suggested here that the Mjøsa Limestone was formed on an eastward dipping slope with a carbonate platform dominated by intertidal conditions in the west and soft-bottom (clay) conditions in the east. Gradually, the amount of carbonate supplied to the eastern region increased, first in rare, periodic storms, and later in large channels where reef development occurred along the edges. Because of differential compaction of the argillaceous and carbonate sediments, the channels developed as rather thick bodies which 'preformed' the present synclines. The final step appears to have been a massive, uniform deposit of peloidal carbonates representing Unit IV.

Units II and IV represent periods of shallowing with reef and near-reef conditions, water depth in the Hamar—Nes districts ranging between upper sub-tidal and low intertidal to partly hypersaline lagoons. These two periods may be represented in the Toten district by periods of karst erosion (Skjeseth 1963, text-fig. 23; Jørgensen & Spjeldnæs 1964, p. 438).

Most modern studies on carbonate platforms are made in regions where the platforms are bounded by steep slopes towards the deep ocean, or in regions with a very sparse supply of terrigenous clastics. Analogies with such deposits must be used with some reservations when applied to the Mjøsa Limestone, deposited on a gentle palaeoslope, where the carbonate platform graded into a clay-filled, slowly sinking intra-cratonic basin. This is reflected particularly in the Furuberg Formation, with its dominantly transported fauna, and in the argillaceous beds lateral to the stromatoporoid reefs in Unit IV at Bergevika south.

1:3 EINA (Fig. 2, loc 1) A series of old, partly overgrown limestone quarries in the Mjøsa Limestone. The rock types (Fig. 4) are those described in Opalinski & Harland (1981).

1:4 HOLE KALKVERK (Fig. 2, loc. 2) A group of quarries located within a complex of westward plunging, tightly folded synclines of Mjøsa Limestone. Here rock types are the same as seen at 1:3, but the erosional terrestrial karst surface contact with the Silurian Helgøya Quartzite is exposed. Karst surfaces occur elsewhere within the Mjøsa Limestone and these probably correspond to periods of low sea level (see Units II and IV in the Hamar—Nes districts). The boundary between the Mjøsa Limestone and the underlying Furuberg

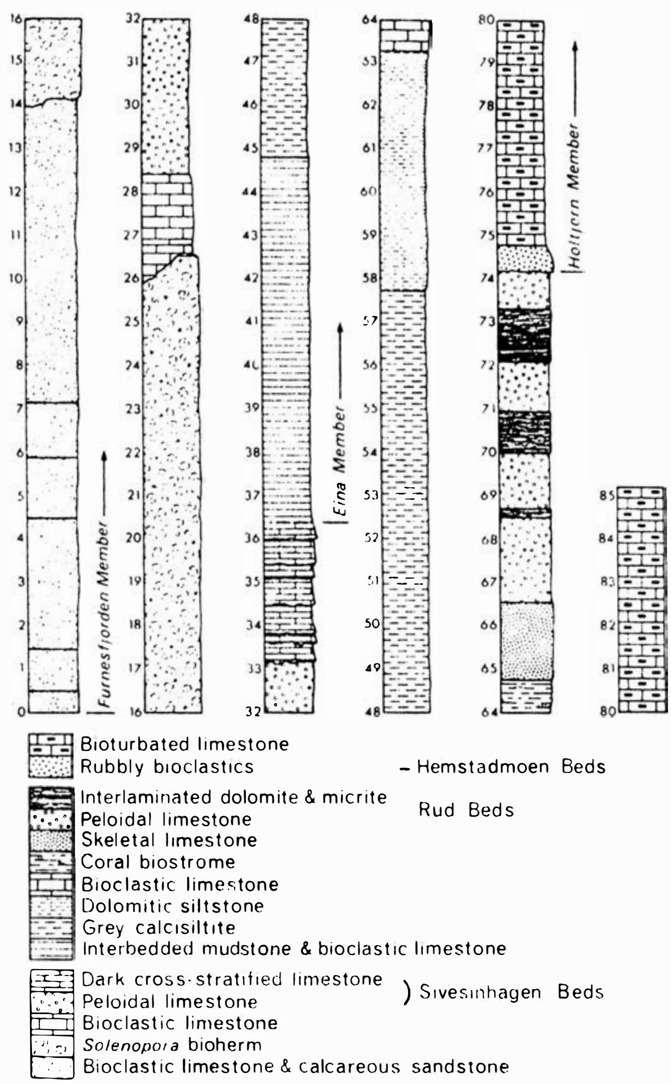

Figure 4. Detailed section through the middle part of the Mjøsa Limestone at Eina (Loc 1, Fig. 2) (from Opalinski & Harland 1981).

Formation is also exposed near these quarries.

1:5 Karst surfaces will be studied in greater detail at either Ånnerud (Fig. 2, loc. 3), Kyset (Fig. 2, loc. 4) or Rud (Fig. 2, locs. 5, 6) depending on quarrying activity.

If time permits, we will stop at a section of 'Mjøsa Limestone' (Kiær 1908, 407-408) before proceeding to Gjøvik. To the west of this locality is the (?)Permian Hundselv fault line which forms the western boundary of the Oslo Graben. This fault continues south and forms the boundary between the Lower Palaeozoic sediments and the crystalline Precambrian. The sediments were probably deposited a considerable distance to the west. Immediately to the north of Gjøvik is the 'Caledonian Front' where the dêcollement-folded sediments and the imbricate thrust-faulted rocks meet in a rather complex structure. The Permo-Carboniferous and (and ?Triassic) rifting adds to the tectonic complexity as some of the major faults, including the Hudselv fault, the Solbergås horst (see below) and the Brumunddal fault, cut obliquely through the critical area.

NIGHT AT GJØVIK

In the morning the ferry will be taken from Gjøvik across the lake to Mengshoel at the northern side of the Precambrian Solbergås horst and then south-east to Helgøya (Holy Island). The landscape clearly reflects the underlying geology, and farms are situated on ridges formed by the Orthoceras Limestone (Arenig—Llanvirn). The Mjøsa Limestone and the overlying Silurian forms broad, open synclines which appear as tree-covered ridges of pine and spruce. The cultivated land is mainly on the flat terrain formed by the deeply weathered Ordovician shales. A thin veneer of glacial sediments covers most of the area which is among the richest and most fertile agricultural areas in Norway.

2:1 BERGEVIKA SOUTH (Fig. 2, loc. 7) The road section (Fig. 5, loc. 9) shows the reef (Unit IV) and 'backreef' facies of marl beds in mudstone. The reef is rather recrystallised but the basal beds of *Solenopora* limestone are well exposed. The latter and the lower part of the reef seem to grade laterally into Unit III, developed in the same facies as the Furuberg Formation. Dendroid graptolites occur in shale partings near the top of the reef. En route to the quarry, two small sections (Fig. 5, locs. 7, 5) show the reticulate peloidal limestone of Unit VI, and Unit III. In the quarry the lowest beds are the basal *Solenopora* limestone of Unit IV with some slump structures. The reef contains large, dome-shaped stromatoporoids with little matrix or other organisms. The original shape of the colonies is destroyed because of secondary solution. The marl-mudstone lateral facies is seen between two reef mounds and on the

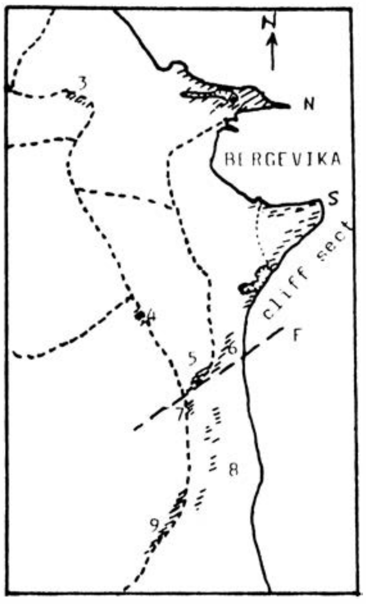

Figure 5. Sketch map of Bergevika, Helgøya, Mjøsa. Main exposures are hatched. The localities are (except for the northern peninsula (N), and the southern peninsula with the cliff section): 3 = Northern road section (Units IV-V), 4 = small road section (Unit VI), 5 = road section (Unit III in Furuberg Formation lithology), 6 = inland cliff section (Unit II, with base of III at top), 7 = road section (Unit VI), 8 = scattered smaller cliff sections (Units II-III), 9 = long road section (Unit IV, with parts of II and V). F = prominent fault. Drawn from aerial photograph.

eastern flank of one of the reefs there is a rubbly limestone rich in corals and more complete stromatoporoids. The reefs are overlain by an oncolite-algal limestone belonging to the base of Unit V, which contains oncolites, ooliths and a number of transported fossils, mainly bryozoans, brachiopods, and fragments of Dimorphosiphon rectangulare Høeg, 1927, an Halimeda-like algae. This is the type locality for this taxon. The oncolitic limestone grades upwards into a dark, partly peloidal limestone, the 'Mjoesina beds', containing bryozoans and thin-shelled brachiopods. These grade into silty dolomitic beds and occasional carbonates which were apparently storm generated. The transition to Unit VI with reticulate-peloidal limestone is seen along the old railway tracks leading to the disused kiln at the southern shore of

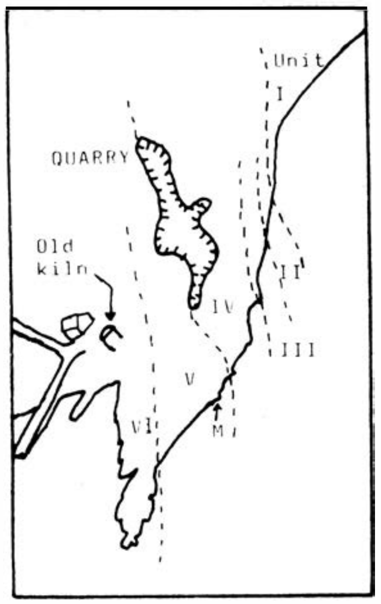

Figure 6. Sketch of Bergevika North. The distribution of the units of the Mjøsa Limestone is shown. From an oblique aerial photograph.

Bergevika.

2:2 BERGEVIKA NORTH (Fig. 2, loc. 8, Fig. 6) We shall endeavour to examine this section, lake level permitting, in order to compare and contrast the equivalent units at the previous localities (see text).

On leaving Bergevika, the bus will drive north, back to the mainland *via* Nes and cross the inner end of Furnesfjord to join route E6 south. From here the road passes through Brumunddal to Furnes. Roadcuts of folded Orthoceras Limestone (Arenig—Llanvirn) will be pointed out from the bus. Leaving the E6, the bus follows a route past Furnes Church to Furuberget (Pine Mountain; Fig. 2, locs. 9-10).

2:3 FURUBERGET (Figs. 7, 8) Shore line and road sections along the railway line provide the only complete sequence through the Furuberg Formation. The railway section itself is not accessible for field parties. At the type section, the lower

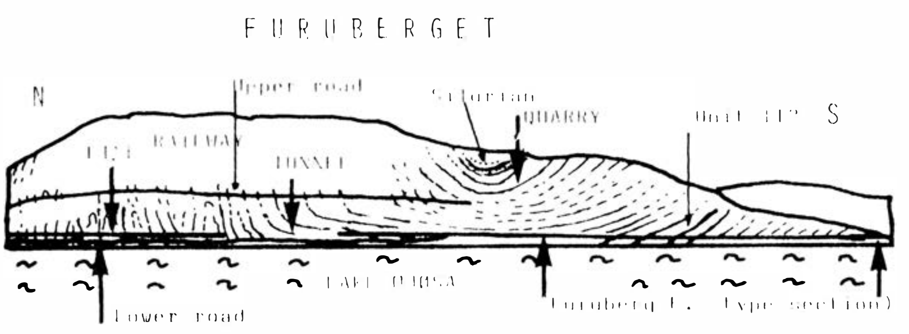

Figure 7. Sketch of the Furuberget section, looking east approximately along axis of syncline. The northern part of the section, north of the railway tunnel, is tectonically disturbed. The section of Holtedahl (1909, p. 18, fig. 8) is only from the railway section.

part is more shaly than the upper, which contains more massive limestone thought to be equivalent to Unit II at Bergevika south. The fossils in the type Furuberg Formation, especially the bryozoans, are the same as those in the lower part of the Mjøsa Limestone at Bergevika south. At the northern end of the quarry above the railway-line, a section shows the junction between the Furuberg Formation and the lower part of the Mjøsa Limestone represented by Solenopora limestone with some cross bedding and slump structures. In the quarry proper, the contact between the Ordovician and Silurian will be demonstrated along the south-west rim.

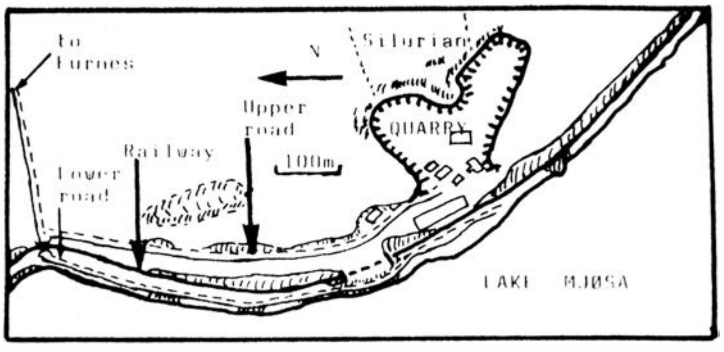

Figure 8. Sketch of the Furuberg locality. Main exposures are hatched (modified after Hamar MS).