THE UPPER ORDOVICIAN (ASHGILL) OF RINGERIKE

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The Lower Palaeozoic succession in Ringerike is gently folded and youngs southeastwards (Fig. 1). The very open folds contrast strongly with the much tighter style of folding in Hadeland to the north.

The Ordovician rocks of Ringerike comprise alternating limestone and shale units with an interfingering of sandstone and limestone facies in

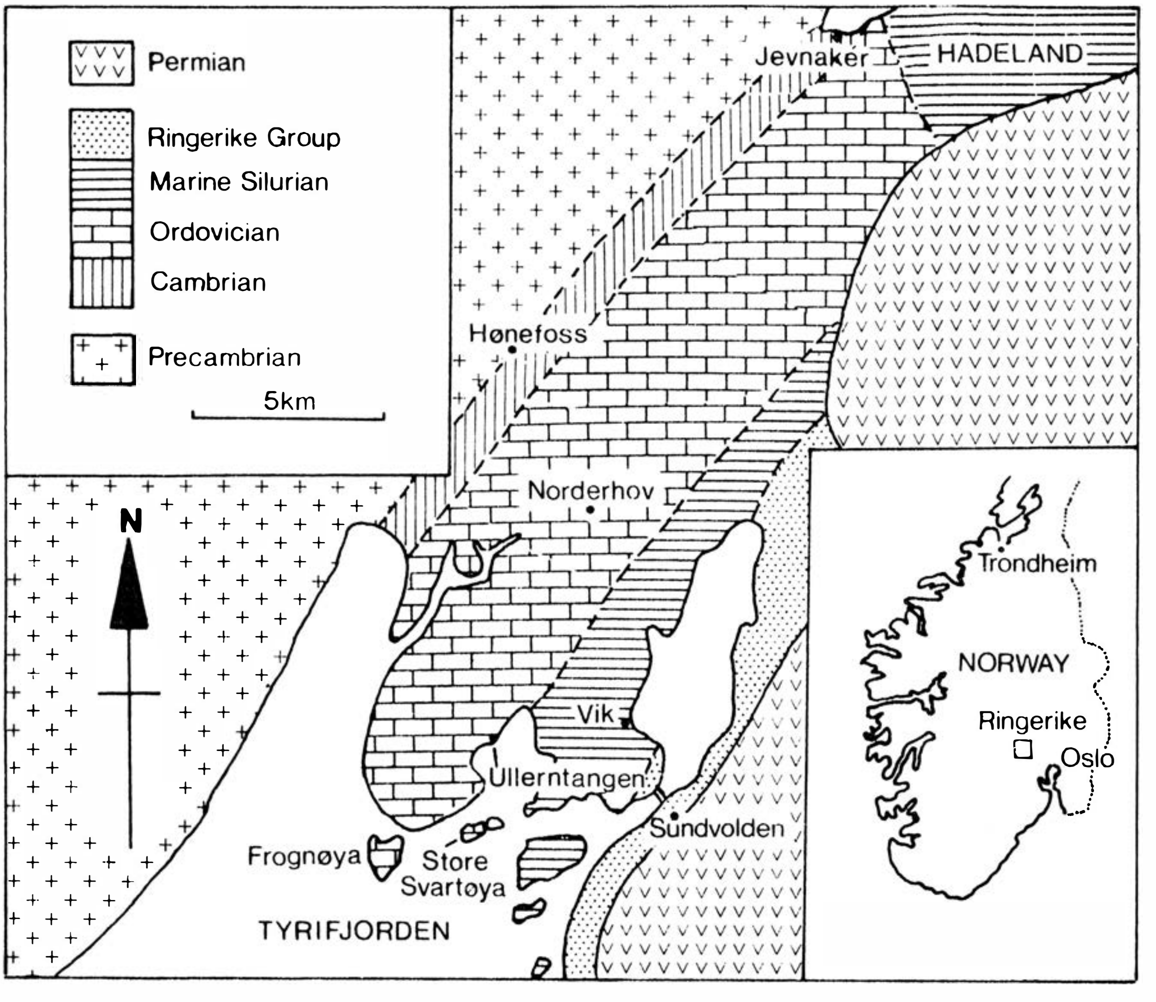

Figure 1. Simplified geological map of Ringerike (from Owen 1979).

the uppermost Ordovician. Only the upper Caradoc and Ashgill formations have been described in any detail to date (Kiær 1897; Hanken 1974, 1979; Owen 1979) although Størmer (1953) outlined the Middle Ordovician sequence and the whole succession is currently being mapped in terms of a modern lithostratigraphy (Owen and Harper in prep.).

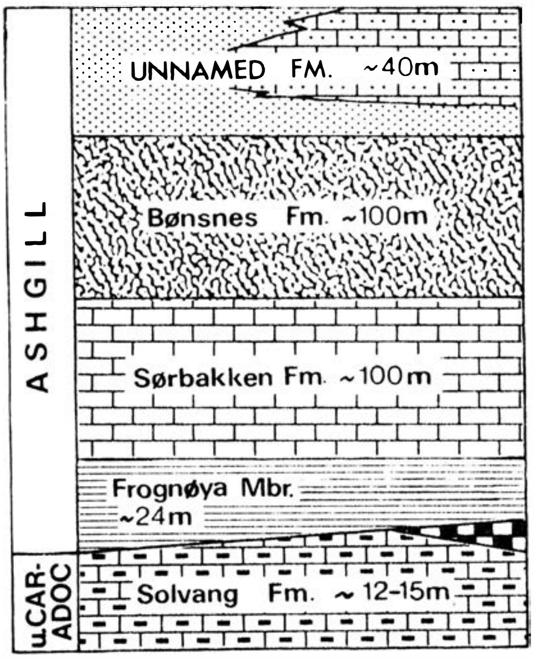

Figure 2. Summary of the Upper Ordovician succession in Ringerike.

The Ashgill succession is approximately 270 m thick (Fig. 2) and is dominated by shelf limestones although the lowest Ashgill is marked by the development of shales (the Frognøya Member of the Venstøp Formation). Latest Ashgill regression and transgression episodes resulted in the development of siliciclastic horizons as well as a very shallow water carbonate facies. Various elements of the Ashgill faunas of Ringerike have been described. The trilobites were described by Owen (1980, 1981) and the brachiopods are being revised by Harper (in prep.) following studies by Holtedahl (1916) and Öpik (1933) on the Strophomenida. Some taxonomic attention has also been given to the bivalves (Toni 1979), cephalopods (Strand 1933; Sweet 1958), gastropods and monoplacophorans (Koken 1925, Yochelson 1977), bryozoans (Brood 1980), conodonts (Hamar 1966), corals (Bassler 1950; Hanken 1979a; Kiær 1899, 1903, 1929; Neumann 1969, 1975; Scheffen 1933), ostracods (Henningsmoen 1954) and algae (Kiær 1920). In addition, Kaljo *et al.* (1963) have compared the late Ashgill corals and stromatoporoids of the Oslo Region (including Ringerike) with those of Estonia.

The route from Sundvolden passes over the causeway at the south end of Steinsfjord from where the boat will depart for Frognøya (Fig. 1). The red sandstones and shales on the beach and on the stretch of road beyond are described by Whittaker (1977) and show non-marine redbeds of the

Ringerike Group (Ludlow).

STOP 1 FROGNØYA (NM 65205825) (Fig. 3)

The section on the north-west coast of this island contains the stratotypes for the Høgberg Member of the Solvang Formation, the Frognøya Member of the Venstøp Formation and the base of the Sørbakken Formation in a cliff some 35 m high. The gentle northeastward dip of the succession enables the complete 65 m of this section to be examined at or about beach-level around the northwest promontory.

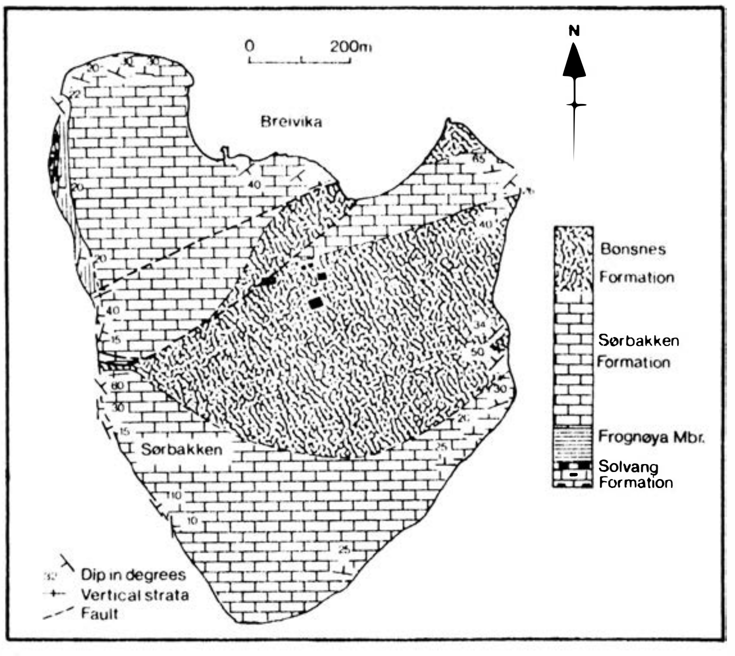

Figure 3. Geological map of Frognøya (from Owen 1979).

Solvang Formation 7.5 m of the Solvang Formation is exposed here. Abundant calices of the cystoid *Echinosphaerites* occur at about fjord-level in the lowest exposed part of 4.6 m of nodular and massive limestone. These beds also contain a 14 cm zone of imbricated nodules indicating dislocation parallel to bedding. The upper 2.9 m of the formation is composed of planar limestones and shales (The Høgberg Member) and a lens (now quarried out) in the lower part of this has yielded a very diverse trilobite fauna dominated by *Tretaspis kiæri*, *Phillipsinella preclara* and *Lonchodomas* aff.

pennatus (Bruton 1976; Owen & Bruton 1980). These and other elements of the fauna also occur elsewhere in the member but are rare and are interpreted as representing the final phase in the progressive immigration of a carbonate facies fauna into the central Oslo Region. The distinctiveness of this fauna led some earlier workers to suggest an hiatus at equivalent levels elsewhere in the region. The recent recognition, however, of a marked faunal shift associated with the diachronous base of the overlying Venstøp Formation makes such an hypothesis unnecessary (Bruton and Owen 1979).

Venstøp Formation The Frognøya Member of the Venstøp Formation comprises friable dark shales with thin beds of limestone and laminated siltstone. The bases of some of the latter horizons show sole markings. The trace fossil Chondrites is seen on some bedding planes. The fauna shows low diversity, although in the upper part the trilobites Tretaspis anderssoni and Flexicalymene trinucleina? and the brachiopod Chonetoidea iduna are abundant. Other trilobites include:
Tretaspis hisingeri, Remopleurides spp., Stenopareia aff. glaber, Cybeloides (Paracybeloides) aff. girvanensis, Calymene (s.l.) aff. holtedahli, Calyptaulax norvegicus, Toxochasmops aff. extensa, Primaspis (P.) bucculenta.

Other elements of the fauna include bivalves, small gastropods, inarticulate brachiopods, the articulate brachiopod Gunnarella and linearis Zone graptolites (including Dicellograptus cf. johnstrupi), some in full relief.

Sørbakken Formation 34 m of micritic limestones and calcareous shales of the Sørbakken Formation are exposed along the north-west coast of Frognøya. These beds contain a diverse fauna dominated by trilobites and brachiopods but also gastropods, nautiloids, bryozoans and rare graptolites. The trilobite fauna is similar to that of the underlying unit although species of Toxochasmops and Cybeloides are absent, the Remopleurides is close to R. aff. dalecarlicus Warburg and Illaenus (Parillaenus) cf. roemeri and Holotrachelus cf. punctillosus appear. The brachiopod fauna is more diverse than that of the Venstøp Formation and includes species of Gunnarella, Dalmanella, Triplesia, Oxoplecia, Eoplectodonta and Cyclospira.

The uppermost part of the Sørbakken Formation can be examined along the central part of the west coast of Frognøya. The cliff line between here and the Solvang Formation outcrop shows the effect of faulting and thrusting. The uppermost beds of the Sørbakken Formation are somehwat darker limestones than those seen on the north-west promontory and locally contain a trilobite fauna dominated by Tretaspis anderssoni, Stenopareia aff. glaber, Illaenus (Parillaenus) cf. roemeri and Isotelus frognoensis. The base of the overlying Bønsnes Formation is marked by the development of dark, platy limestones packed with fragments of the calcareous alga Palaeoporella. Elsewhere on Frognøya the Palaeoporella-bearing strata are overlain by limestone containing silicified corals.

STOP 2 STORE SVARTØYA (NM 67855835) The highest Ordovician unit in Ringerike, so far unnamed (Fig. 2), is about 40 m thick and reflects a complex pattern of depositional environments (Fig. 4). The only complete section is exposed here on Store Svartøya where the upper 13 m of the Bønsnes Formation, all the unnamed Formation, and the lower 18 m of the Silurian Sælabonn Formation are exposed. The upward change in lithology from the shaly Bønsnes Formation to sandstones of the unnamed Formation is gradual (Kiær 1897). The sandstone sequence is about 15 m thick and thickens northwards. The boundary between the sandstone unit and the overlying limestone is erosional with development of a basal sandstone conglomerate. The clasts are angular to subrounded and contain the same faunal elements as the underlying sandstone, indicating that they have been derived locally.

The overlying strata are dominated by crinoidal biosparites with occasional small unbedded mounds. The mounds attain their greatest size here and on Lille Svartøya where their visible height may be more than 3 m; in the Ullerntangen area they are generally much less. The lateral change from the bedded crinoidal biosparite to the

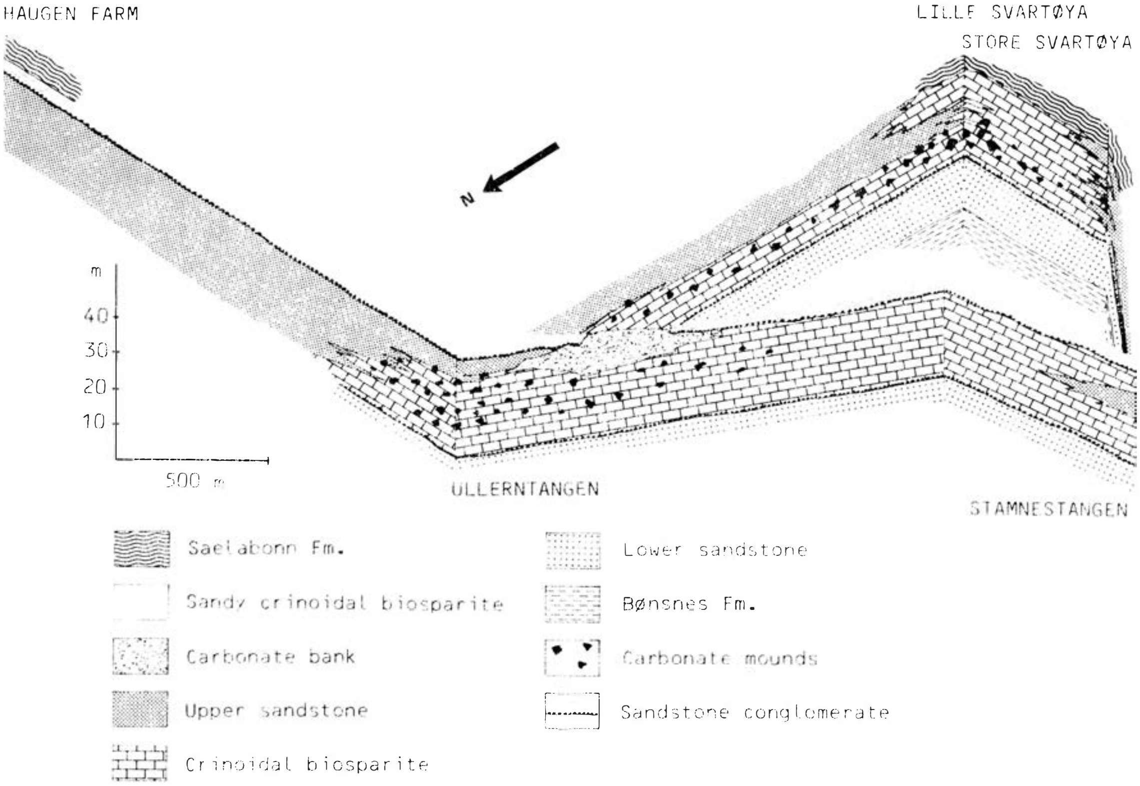

Figure 4. Fence diagram showing the lithofacies distribution within unnamed Formation at the top of the Ordovician in the central Ringerike area.

unstratified limestone of the mounds is fairly abrupt, but marly intercalations can be followed into some of the mounds with only slight deflection indicating that they did not protrude very much above the contemporary sea-floor. The lithology of the mounds includes discontinuous argillaceous intercalations and pockets of argillaceous limestone with scattered colonies of tabulate corals and sheet-like stromatoporoids.

Dislodged blocks with a typical mound biota are fairly common in the intermound facies close to the mounds. They are of variable size, the largest being more than one metre in diameter. The presence of these blocks indicates cementation penecontemporaneous with mound growth. The crinoidal biosparites have yielded a single trilobite specimen, an extremely large cephalon of Eobronteus aff. laticauda. The Ordovician-Silurian boundary in Ringerike is only exposed here on Store Svartøya. It is marked by a karst surface with north-south trending runnels infilled with Silurian shale/siltstone. Further north the hiatus is developed as a fairly smooth surface cutting straight through fossil fragments and oolites. Investigation of the brachiopods in the basal Silurian deposits seems to indicate that the lowermost part of the Rhudannian is missing in Ringerike and with a significant hiatus between the Ordovician and Silurian (Thomsen 1982).

STOP 3 ULLERNTANGEN (NM 68506100) (Fig. 1) On the southern part of Ullerntangen the small argillaceous mounds are overlain by an extensive carbonate bank which is at least 350 m long and 100 m wide. Kiær (1897) regarded this structure as a large reef, but Hanken (1974) reinterpreted it as an extensive carbonate bank because it lacks a framework and has a very high percentage of transported fauna (Fig. 5). The bank is very fossiliferous and

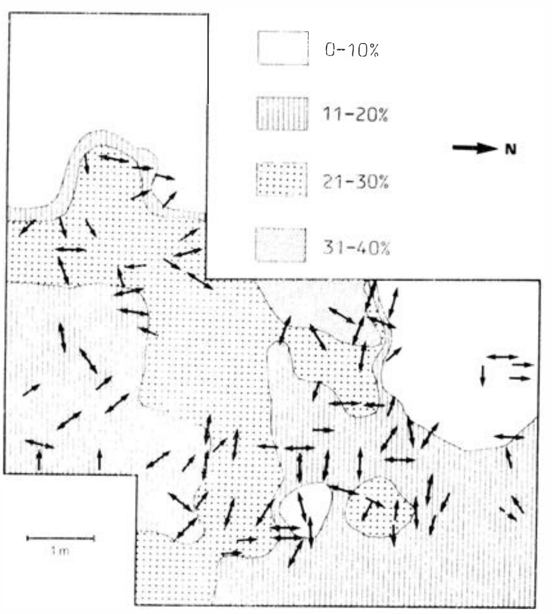

Figure 5. Slightly oblique section through a part of the surface of the carbonate mound at Ullerntangen showing the percentage of the surface occupied by corals and stromatoporoids. Arrows indicate the growth direction of coral colonies and stromatoporoid coenostea; (a double arrow has been used in cases where way up is uncertain). Highly variable growth directions indicate that most of the organisms are not _in situ_.

is dominated by the stromatoporoid _Pachystylostroma_ sp., the colonial rugose corals _Palaeophyllum insertum_, _Cyathophylloides_ sp., _Tryplasma_ sp. and the tabulate corals _Saffordophyllum kiaeri_, _Rhabdotetradium frutex_, _Lyopora incerta_, _Reuschia_ sp., _Catenipora_ sp., _Proheliolites_ sp. and _Plasmopora_ sp. Locally isolated parches of cystoids and inarticulate brachiopods of the family Trimerellidae are found in great numbers.

The matrix of the carbonate bank consists of microspar with abundant skeletal fragments. Point counts of thin sections have shown that the skeletal components comprise up to 40-50%. The skeletal sand is mostly composed of echinoderm, brachiopod, and bryozoan debris and the calcareous algae Vermiporella sp., Girvanella sp. and Hedstroemia sp.

The carbonate bank at Ullerntangen is of highly variable thickness because of extensive erosion prior to deposition of an overlying sandy crinoidal biosparite facies. Fissures up to 5-6 m deep have steep, sometimes vertical to overhanging sidewalls indicating subaerial erosion of the already lithified bank.

Most fossils with large primary cavities (e.g. corals and cephalopods) have collapsed after deposition on the carbonate bank. In some cases the whole fossil is affected while in others only certain zones in the fossils are broken, the intervening parts not being affected (Fig. 6). With the aid of cathodoluminescence microscopy,

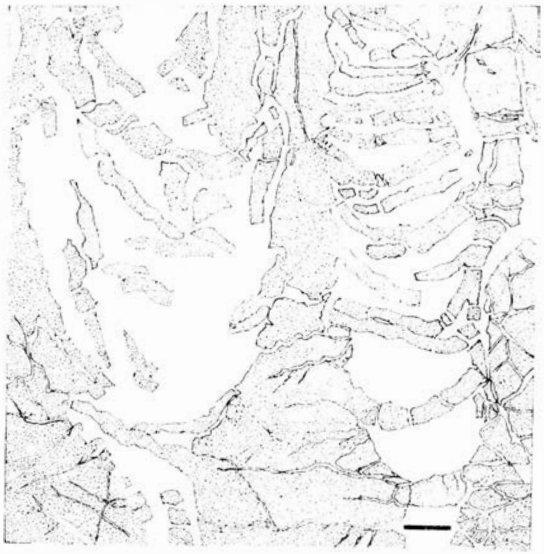

Figure 6. Drawing of longitudinal section through the colonial rugose coral Tryplasma sp. The coralite wall is transected by numerous cracks and the tabulae are fragmented. Stippled, coral; white, secondary sparry infilling. Carbonate bank, Ullerntangen. Scalebar - 1 mm.

the presence of several distinct calcite generations in the fractured fossils can be demonstrated (Fig. 7). The first calcite generation is an isopachyous rim of small, non-luminescent, equant crystals of calcite which are never found on the broken surfaces. However, the broken surfaces of the fossils are directly imbedded in a thin veneer of brightly luminescent second generation calcite cement. The small cracks in the walls of the fossils are also infilled with second generation calcite. These observations indicate that the fracturing took place subsequent to deposition of the first generation calcite, but prior to deposition of the second. The extensive fracturing is probably a result of the early emergence of the partly cemented carbonate bank. Emergence would be accompanied by stress set up by loss of the support provided by hydrostatic pressure.

The rocks in the upper part of the unnamed formation commonly have a somewhat dark appearance due to a high content of solid hydrocarbons; a fact which was pointed out by Kjerulf (1862). In the carbonate bank on Ullerntangen the hydrocarbons are restricted to primary cavities in fossils or in thin cracks. Fig. 7 shows the relationship between the hydrocarbons and the deposition of different cement generations. The hydrocarbons, probably derived from the Alum shale (Middle Cambrian—Lower Ordovician), have filled late diagenetic cracks and the remaining cavities in fossils after

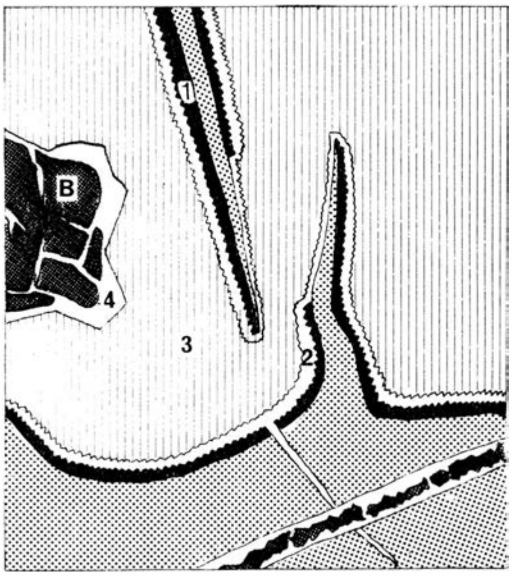

Figure 7. Relationships of cement generations and solid bitumen (B) in a coral (stippled) as revealed by cathodoluminescence microscopy. The numbers refer to the different cement generations. There are two different generations of cracks; the last is infilled with both solid bitumen and secondary calcite of the 4th generation.

deposition of the third calcite generation. During a later diagenetic stage the originally fluid hydrocarbons have lost their most volatile constituents and the remaining part has gradually turned to solid bitumen. This transition has been accompanied by a reduction in volume so that the solid bitumen shows numerous cracks from the later stage of this conversion. The cracks are later filled with a fourth generation of sparry calcite.

The carbonate bank passes northwards into a sandstone facies which contains a rich fauna close to the bank (the faunal diversity diminishes northwards). The fauna is dominated by transported disarticulated brachiopods including species of Plaesiomys, Schizophorella, Hirnantia, Katastrophomena, Sowerbyella and Hypsiptycha. The brachiopods commonly show signs of bioerosion. Other elements of the fauna include the solitary rugose coral Ullernelasma svartoeei and the gastropods Phragmolites sp., Tropidodiscus sp., Clathrospira sp., Loxoplocus (Lophospira) sp. and Globonema sp. A species list of the bryozoans is given by Brood (1980).

Sandstone pseudomorphs of aragonite fossils are highly characteristic of the uppermost Ordovician sediments in the central Ringerike area (Hanken 1979). Moulds of gastropods and cephalopods have been filled with well sorted clastic sand giving a fairly good cast in sandstone of the original organism. The fossil moulds are thought to have been formed by selective dissolution of aragonite shell by groundwater during early emergence of the semiconsolidated sediment.