SILURIAN TIDAL SEDIMENTS FROM THE BASE OF THE RINGERIKE FORMATION, OSLO REGION, NORWAY

By

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Abstract. Sedimentary structures from the base of the Ringerike Formation are interpreted as having been formed by tidal currents because of their resemblance to structures found in modern tidal deposits. Fossils of undoubted marine origin have been transported into an estuary by tidal currents and are interbedded with unfossiliferous red mudstones. The estuary probably progressed from the N or NW towards the S or SE, and the border between stage 9 (marine Ludlow) and 10 (red beds) may be an anisochronous one.

Introduction

The structures described in this paper are found just S and SE of the Kolsås hill, some 5 km from the centre of Oslo. They are found in the basal part of the Ringerike Formation and just above the marine limestones of the Lower or Middle Ludlow. The sediments, interpreted here as being tidal, were first discovered in a ditch in the middle of a shallow depression between the Kolsås hill and a much lower hill, consisting of marine limestones running WSW–ENE.*

The geology of the area is shown on the map by HOLTEDAHL and DONS (1952) and has been described by DONS (1957). The detailed stratigraphy of the Ringerike Formation has not been described in this area. In the type area (Ringerike), it has been dealt with by KIÆR (1908, 1911), and more recently by STÖRMER (1954) and WHITAKER (1964). The Ringerike Formation consists mainly of evenly bedded siltstones and mudstones. The lower part is rich in sedimentary structures, and occasional fossil horizons are also found. The lower part

* Designations such as Kolsås sediments, Kolsås beds, etc. as used in this article must not be confused with the sediments of the Permian Kolsås formation to be described in the next number of this journal (DONS and GYÖRY 1967).

is rich in red mudstones, while at higher levels grey and greenish-grey micaceous siltstones and sandstones are dominant.

It has been assumed that beds of the Ringerike Formation, like the 'Old Red' facies in general, were deposited in fresh or brackish water. This is based mainly on observations of the marine fauna of the beds below, which is gradually impoverished towards the contact to the Ringerike Formation, and also on the increasing amount of shallow water- or subaerial-structures and the increasing amount of clastic material present. Some marine organisms, however, do penetrate into the red mudstones, and the boron content of the lower mudstones does not differ significantly from that in the marine shales lower in the Silurian (SPJELDNÆS 1962). The fauna of the lower part of the Ringerike Formation consists mainly of eurypterids and agnaths (anaspids and cephalaspids), and the same fauna is also found in the marine beds just below it. However, it should be mentioned, that the vertebrates and eurypterid remains in the marine part of the section are found mostly in thin dark shale horizons, which might represent incursions of brackish water. HÖEG and KIÆR (1926) described a similar transitional zone lower in the Ringerike sequence (zone 9d) and reported supposedly marine plants (*Chaetocladus*) and eurypterids from beds resembling the grey, vertebrate- and eurypterid-bearing shales below the Ringerike Formation. In the case described by HÖEG and KIÆR (1926) and at the base of the Ringerike Formation, and in the type section and at Kolsås, there is a gradual impoverishment in the marine fauna from the rather pure limestones below to the more argillaceous beds above. In the beds mentioned by Höeg and Kiær, the transitional beds are abruptly overlain by normal marine limestones, but in the others it is followed by the Ringerike Formation. It is hard to determine whether the changes in fauna which accompany these lithological changes are due to the increasing amount of clastics, which made the environment unsuitable for the sessile benthos found in the limestones, or whether they are due to changes in salinity, or both. The problem of the palaeosalinity of the Ringerike Formation must therefore remain unsolved at present.

The Ringerike Formation is more than 1,000 m thick in the type area, and this exceeds that of the combined Cambro-Silurian sequence below. This indicates that there was a great influx of clastic material combined with a rapid sinking of the Oslo Region at the end of the Silurian.

The base of the Ringerike sandstone probably belongs to the Middle and Upper Ludlow (STÖRMER 1954). In the Holmestrand District (Jelöya), fossils of basal Downtonian age are found in the upper part of the sandstone (KIÆR 1931). It is possible that this part of the formation is not isochronous with that in the type area.

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Description of the rocks

The section found S and SE of Kolsås is shown diagrammatically in Fig. 5. The basal part of the section consists of thick, bedded, more or less pure limestones, which are referred to stage 9. Their detailed stratigraphy is rather complicated, and they were deposited mainly in shallow water as evidenced by mud-cracks and ripple marks. They have a rich marine fauna.

In the small valley between the ridge formed by these limestones and the Kolsås hill, the transitional beds between the marine limestones and the Ringerike Formation are exposed. They consist mainly of red mudstones. In the lowest part, exposed in a ditch and a small rivulet, there are several calcareous bands. These range from 1 to 35 mm in thickness, are very irregular and often form thin, elongate, curved lenses. In some cases, the calcareous bands have been deformed, supposedly as loadcasts, and in other cases they have been broken up by mud-cracks and transformed into an intraformational conglomerate. There are some burrows, most of them about 2–4 mm in diameter, which are perpendicular to the bedding or at steep angles to it. They often penetrate several consecutive laminations.

The calcareous laminae or beds are often distinctly graded and contain fossil rather than consolidated limestone fragments. Most of the fragments are of arthropods (trilobites and large ostracods) and echinoderms. Some fragments of brachiopods and mollusks are also found. There are also a number of phosphatic fragments, some of which belong to phosphatic brachiopods. Unfortunately, most of them cannot be readily identified. None show bone structure, but some might be fragments of crustaceans and others of anaspids. More complete fossils include especially beyrichiid ostracods, some small brachio-

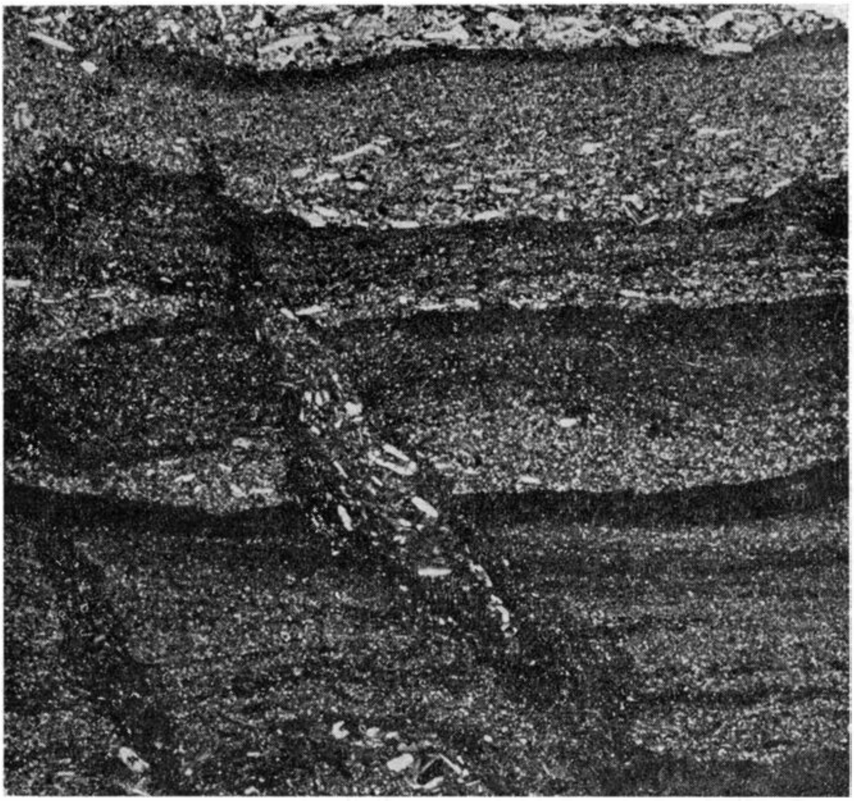

Fig. 1. Photograph of a thin section of the calcareous beds at the base of the Ringerike Formation at Kolsås, showing graded bedding of fossil fragments, lamination, and two oblique burrows. Approx. × 11.

pods, and parts of colonies of a tabulate coral. Because of a slight recrystallization, the rock does not break along the fossils, and the ostracods have only been observed in thin sections.

The size of the fossils is generally less than 1 mm, which is the size of the larger particles at the bases of the thick graded beds. The only exceptions found are the corals mentioned above and some echinoderm fragments. The latter may reach 3 mm in diameter, and the former may be over 1 cm long, and 3–4 mm in diameter. The empty coral colony probably consisted of at least 60–75% open pores, and the echinoderm would also be highly porous. This would result in a high

Fig. 2. Photograph of a thin section of the calcareous beds at the base of the Ringerike Formation at Koìsås, showing graded bedding of the fragmentary fossils. Note the large echinoderm fragment at the lower right and close to it the section of a coral with mud-filled interspaces. Approx. × 11.

buoyancy, thus giving the fragments a 'hydraulic diameter' much smaller than the actual one.

The larger size of these fragments could also have been due to the fact that the organisms lived closer to the area of deposition. This is not probable in this case, because they are found throughout a graded bed, indicating that the transport distance did not influence the size of the fragments. Both the echinoderms and corals are usually stenohaline, and, if the beds are regarded as estuarine (see below), their deviating size is probably due more to higher buoyancy than to length of transport. The coral might also have had an unusual ecology. It is the last marine organism (strictly speaking, with calcareous skeleton) to disappear in the gradual transition between the marine limestone and the Ringerike Formation in the type area and in the localities NE of Kolsås. The coral fragments were described by KIÆR (1908) as *Amplexopora* or *Monticulipora* sp., and they certainly have the same diameter and external aspect as the trepostome bryozoans mentioned under these names by Kiær from other localities in stage 9. However, thin sections show that the wall structure is more like that in the favositid corals, and there is also, in contrast to the trepostome bryozoans, no mature and immature part in the colonies. The coral differs from *Coenites* in lacking the restricted apertures and mural spores; no septae or septal spines have been observed. The coral fragments are also found in the mud between the calcareous beds and are not associated with other clastics of comparable size.

It is remarkable that, even in the specimens which occur in the rather coarse-grained parts of the calcareous beds, the interior of the coral is generally completely filled with red mudstone. The specimens are well washed and very little mud has been trapped in the interstices between the calcareous fragments. This may indicate that the coral really lived in the red mud, which must have been a rather unusual environment for a coral because of both the rapid clay sedimentation and the possible abnormal salinity.

Even if there may be some doubt about the ecology of the coral, it is highly unlikely that the other fossils, in particular the echinoderms, originated in a brackish-water environment. They were probably transported into the environment from a normal marine one. Because of the irregularities of the bedding and the limited exposure, it was not possible to determine the direction of transport.

Towards the top of this lower member of the Ringerike Formation, the calcareous laminae become thinner, fewer in number, and have more red mudstone between them. Cross-lamination, also found lower down, is more common near the top. The member with calcareous beds and laminae is overlain by a thick, red mudstone. The actual thickness is not known because of intervening Permian faults in all sections. Towards the top, the mudstone has an increasing number of

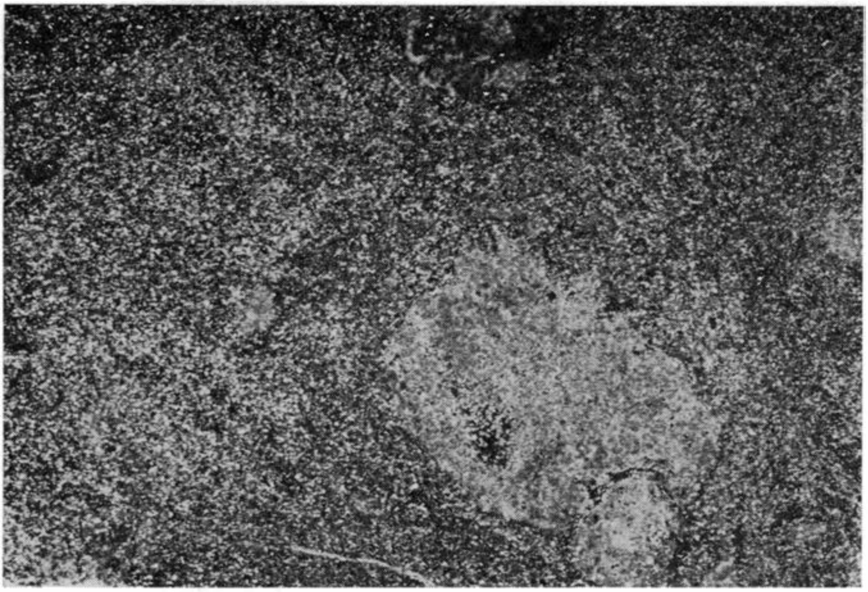

Fig. 3. Photograph of a thin section of the calcareous mudstone with marl lenses at the top of the basal beds of the Ringerike Formation at Kolsås. Approx. × 8.

small carbonate lenses which are from less than 1 mm to more than 4 cm long, irregularly shaped, flattened, and consist of an impure micrite with diffuse border to the mudstone (Fig. 3). The number of calcareous lenses increases towards the top, and locally the mudstone approaches a nodular limestone. No fossils have been found in these beds in spite of long and intense search.

The transition between the mudstones and the typical Ringerike sandstone above is rather an abrupt one. At least in one locality a carbonate conglomerate is developed (Hauger station on the Kolsås tram line). This conglomerate (Fig. 4) rests with a distinct erosional disconformity on the mudstones. The pebbles in the conglomerate are not well sorted and range from well-rounded to angular. Most consist of the limestone lenses from the upper part of the mudstone and fragments of carbonate-cemented mudstone. Both the matrix and the pebbles seem to be devoid of fossils. The only trace found was a small fragment showing what might have been echinoderm structure. It was found within one of the pebbles. The smaller pebbles often show

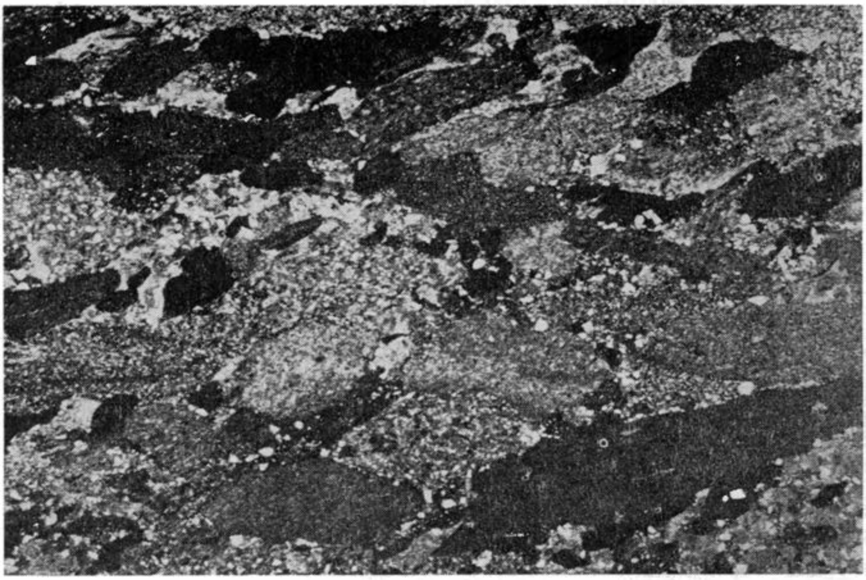

Fig. 4. Photograph of a thin section of the conglomerate at the top of the red mudstone at Hauger. The imbrication of the flat fragments indicates a current direction from left to right in the Figure. Approx. × 8.

a marked imbrication (Fig. 4), which may indicate deposition in a fluviatile environment. The largest pebble observed was 16 cm long, but the majority are much smaller and 1–2 cm is the usual size. This conglomerate was evidently formed by local erosion of the upper part of the mudstone. This is also indicated by the smaller thickness of the beds with carbonate lenses in this locality, compared with others where the conglomerate is absent.

Above the conglomerate is the typical Ringerike sandstone which is essentially a grey-green micaceous siltstone with subordinate sandstone and reddish mudstone. Many sedimentary structures are present, especially in the lower part, such as ripple-marks, mud-cracks, mud-flake conglomerates, tracks, load-casts, and others (see WHITAKER 1964).

In the Late Silurian, the Oslo Region was a rapidly sinking basin in which carbonate sedimentation gave way to a clastic one. Because of the great number of sedimentary structures indicating shallow-water or subaerial conditions, it is generally assumed that after the sinking a regression took place, and the Ringerike Formation was deposited in fresh or brackish water, possibly in lagoons or tidal flats. The marine beds below the Ringerike Formation, however, were also deposited in very shallow water, and the very rapidly sinking basins are found in other parts along the margin of the Fenno-Scandian shield. In Scania, Bornholm, in northern Poland, and in the other areas of the South Baltic, the thickness of the beds markedly increases in the Ludlow, and, in Scania, the topmost beds preserved are also red-beds (the Öved-Ramsåsa Formation). These rapidly sinking basins may be tectonically connected and related to the Caledonian orogenic movements. The Ringerike Formation may therefore partly have been a marine one or at least deposited close to sea level.

The fossils in the carbonate beds at the base of the Ringerike Formation at Kolsås were at first thought to be derived from the erosion of limestones older than the red mudstones, but a closer examination reveals that they were deposited as clastic particles and as whole shells. This indicates that when these beds were deposited there must have been nearby areas with normal marine conditions where the animals lived. The shells must then have been transported inland, or at least in a direction against the main transport of clastic material.

The only means by which this can be done extensively under the conditions described here is by tidal currents. If this was the case, then the carbonate beds could have been formed in an estuary inside the main coastline where the tidal currents transported marine sediments in along the bottom, while fresh water was floating on top (see Fig. 5).

Comparison with other tidal deposits

A number of the features found in the Kolsås beds are similar to those found in the Rhine estuary at or near Harlingvliet in Holland (OOMKENS and TERWINDT 1960, DE RIDDER 1960, NOORTHOORN VAN DER KRUYFF and LAGAAIJ 1960). Oomkens and Terwindt have shown that in the outer part of the estuary the sand is dominately of marine origin and is carried in by tidal currents. The sediments in this zone have a striking similarity to those from Kolsås except that if the Kolsås sediments consist mainly of carbonate, whereas the ones from Harlingsvliet also have a considerable amount of clastic quartz and other detrital minerals. Further inshore in the Rhine delta, there is a zone of mainly mud with little sand. This, supposedly, is because the river, having been slowed down by the tidal current, cannot normally transport coarser material. According to OOMKENS and TERWINDT (1960), large quantities of river-transported sand are found only at an innermost zone about 44 km from the actual coastline.

The intransported sand in the mouth of the estuary at Harlingsvliet was identified as being marine mainly because of the presence of remains of an undoubted marine fauna (Foraminifera, bryozoans, and others). Because of the higher buoyancy, they have been transported along with the sand grains despite the fact that they are larger than them.

The conditions from the Harlingsvliet seem to fit very well with those from Kolsås even though the grain-sizes in the Kolsås sediments are somewhat less than those found in the Rhine estuary. This close resemblance gives a strong indication that the Kolsås beds were also formed in an estuary under tidal conditions.

Fossil tidal sediments have been described from a number of localities, and most of the details have been summarized by PANNENKOEK (1960). However, he did not mention the intransport of marine fossils but did outline the structure of the beds, with regular, graded laminations, often in connection with cross-bedding, load-casts, and other structures. Compared with the other recent and fossil estuarine beds described, the Kolsås beds are fine-grained and on a small scale. This may indicate that the Kolsås beds were deposited in a small estuary, or that either the tidal forces were comparatively weak or that they came from the marginal part of the tidal channel. The structures observed fit best with those described by OOMKENS and TERWINDT (1960 pp. 708–709) from the marginal part of the tidal channel, but, until the basal beds of the Ringerike Formation have been studied in detail in more localities, it will be difficult to estimate the size and structure of the Kolsås estuary.

The fact that the three zones defined by OOMKENS and TERWINDT, (1960) are found above one another in Kolsås (see Fig. 5) indicates that the Kolsås estuary moved seawards. This is in agreement with the generally accepted picture of the geological development of the region.

A similar estuarine sequence has been described by LAGAAIJ and KOPSTEIN (1964) from the Rhône delta, but in this case the sea level first rose and then became stable. In this case also, the sediments seem to be rather similar to those at Kolsås. The almost complete

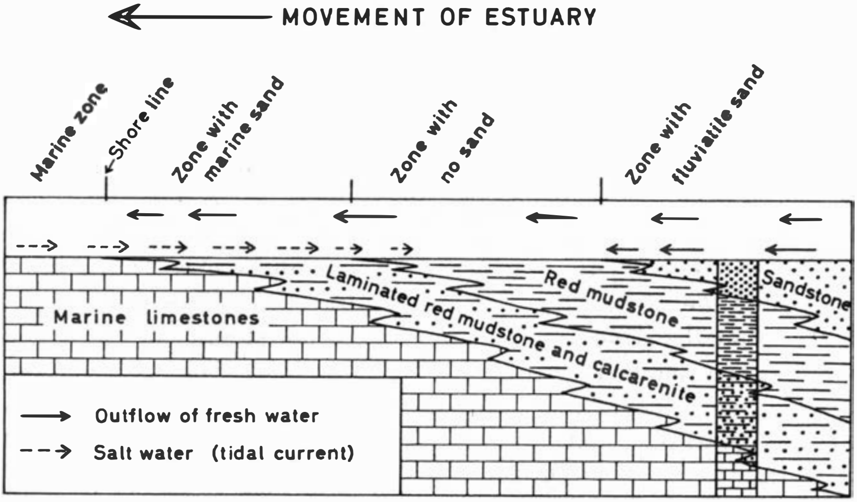

Fig. 5. Diagrammatic Figure illustrating the author's interpretation of the formation of the estuarine beds at the base of the Ringerike Formation at Kolsås. The column indicates the position of the Kolsås section.

absence of autochthonous fauna in the beds at Kolsås is remarkable. Normally, such beds would have been burrowed intensively, and they would have been transformed into bioturbites. In the actual case, only a few burrows are found to indicate the presence of at least some infauna. This might be due to an impoverished fauna because of the variable salinity. LAGAAIJ and KOPSTEIN (1964 p. 223) indicated that the very rapid rate of sedimentation (40 cm/year) in these sediments precluded the presence of most of the infauna, and all fossils found in these beds must be regarded as allochthonous.

Stratigraphic Remarks

The diagrammatic Figure demonstrating the conditions of deposition of the Kolsås beds (Fig. 5) indicates that the marine limestones and the Ringerike Formation coexisted for some time, with the limestones being deposited in the sea and the Ringerike Formation in the estuary and delta which spread gradually over the marine limestones. Generally, the limestones are referred to stage 9 and the Ringerike formation to stage 10. Since the stages are chronostratigraphical units, this can therefore only be valid in the type area (Ringerike). According to

Whitaker (written communication), the transport of sediment in the Ringerike Formation came from the N and NW, and the estuary therefore probably spreads towards the S and SE. At Kolsås, which is 26 km SE of Ringerike, it is therefore possible that the upper part of the limestone corresponds to the basal part of the Ringerike Formation in the type area, and that the base of the formation at Kolsås is somewhat younger than at Ringerike.

The difference in time might be very small because of the rapid sedimentation of the estuarine beds, but HENNINGSMOEN (1954) has shown that the stratigraphy of the marine limestones can be worked out in great detail. It is therefore possible that one or more zones of marine fossils (beyrichiid ostracods) might be found at Kolsås than in the typical development in Ringerike.

In the Holmestrand District, the contact between the marine limestones and the Ringerike formation is not exposed, but here the possibility of a time lag is even better than at Kolsås. Jelöya is 70 km SSE of Ringerike. The basal Downtonian fossils found at Jelöya (KIÆR 1931) are generally assumed to occur at the top of a very thick sandstone sequence. This may be so, but they might also occur not far above marine limestones contemporaneous with a considerable part of the Ringsaker Formation in the type area. A core drilling through the sandstone in the Holmestrand area may shed new light on this.

In the area farther south, in the Skien–Langesund district, both the marine limestones and the Ringerike sandstone are too metamorphosed (Permian contact metamorphism) to permit a detailed stratigraphic interpretation.

If the interpretation of the Kolsås beds as due to tidal currents is accepted, it may be taken as an indication of the presence of the moon, or rather a moon, in the late Silurian. The beds at Kolsås seem to indicate that the tidal forces were roughly equal to or somewhat weaker than those today, but the material is not at all sufficient for a quantitative estimate. Considering the strong local differences in the tides and that the gravitational force of the sun is about 47 per cent of that of the moon, the present observations cannot be taken as conclusive evidence for the presence of a moon at the time of the formation of these sediments. Even in the absence of a moon, the solar tides may have been strong enough to account for the structures reported here.

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