THE SILURIAN/ORDOVICIAN BORDER IN THE OSLO DISTRICT

BY

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Abstract. It is suggested that the Ordovician/Silurian boundary should be placed at the base of the beds with *Climacograptus scalaris normalis* and that Southern Wales should be regarded as the type area. An angular unconformity is described from the Oslo District, just below the Ordovician/Silurian border. The stratigraphy of the uppermost Ordovician and the basal Silurian is described and it is concluded that the orogeny started in 5a, reached a maximum in 5b, and faded out in 6 (Upper Llandovery).

Introduction

This paper is a preliminary report on the author's work, and it is presented here because the final results will not be completed for several years. The results were presented at the Second Nordic Geologic Winter Meeting in Oslo 1956 (SPJELDNÆS 1956).

The names of localities mentioned in the text, and the general geological structure are clearly shown on the map in HOLTEDAHL & DONS (1957).

In the Oslo District, the transition between the Ordovician and the Silurian has been described especially by KIÆR (1908), but details are given also by BRØGGER (1887). KIÆR's paper (1902) on the development of the uppermost Ordovician in the Asker District (to the West) is also important in this connection.

I am deeply indebted to Prof. O. Holtedahl, Prof. L. Størmer, Dr. G. Henningsmoen and Geologist H. Major for valuable discussions in connection with this paper.

The Ordovician-Silurian Border

The Ordovician-Silurian border has been placed at different levels by Scandinavian stratigraphers. KIÆR, in his first papers (1897, 1902) tried to escape the problem by making a new system, «Mittelsilur» between the Ordovician («Untersilur») and the Silurian («Obersilur). Later (1908) he placed the border between stages 5b and 6a. Later on again he placed the border below 5b, and above 5a. Most other Scandinavian stratigraphers have also used this border (5a/5b). This border is based on the supposed large break between the Dalmanitina-beds and the Tretaspis beds. This break is undoubtly present in Sweden, but in Norway, the break between stage 5b (corresponding to the Dalmanitina-beds in Sweden) and 6a is much more important. It must also be stressed that the border can not be placed at the position which is most convenient in each area. In order to be useful it must be isochronous in all areas. (Cf. SPJELDNÆS 1956). It is therefore necessary to select a type area, and correlate all the others with this area, even if the resulting border will be an inconvenient one in most areas. It is natural to use South Wales as the type are, because the oldest descriptions of Silurian are from that area. This has also been indicated by JONES (1949), and is also accepted long time ago by all British stratigraphers. Most Scandinavian stratigraphers also use this principle now.

The long-distance correlations are mainly done with the aid of graptolites in the Silurian, and WÆRN (1948) and DAVIES (1929) have showed a perfect agreement in the development of the graptolites in Great Britain and Scandinavia in the lowest Silurian. The find of a specimen of the lowest variety of *Climacograptus scalaris normalis* from the lowest part of zone 6aα at Ormøya in the Oslo District, therefore indicates that the border between the Ordovician and the Silurian in the Oslo District should be drawn between stages 5b and 6a. The same low variety indicate the very base of the Silurian in Britain (cf. DAVIES 1929). It is, therefore, probable that the border used here is contemporaneous with the British one. It is also a very convenient one, being a faunistic as well as lithological break of first order. In other parts of Scandinavian this break is not clearly defined, and it might be difficult to place the border exactly in some sections.

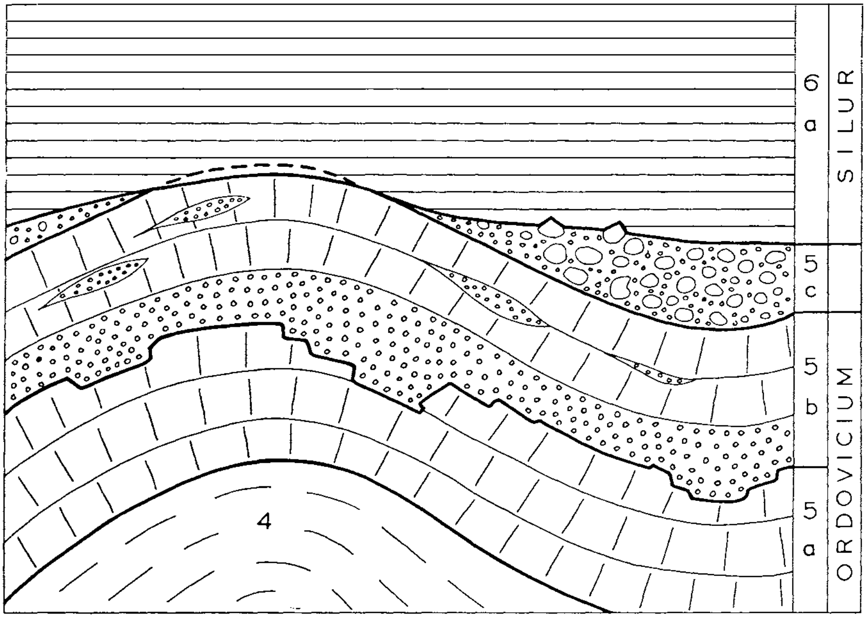

Fig. 1. Diagram showing the formation of the 5c conglomerate and the conglomerates in 5b. In the Oslo District there is generally no thick conglomerate beds at the base of 5b, but they are common in Asker.

The contact between the Ordovician and Silurian in the Oslo District is by most authors regarded to be conformable. KIÆR (1902) showed, however, in an ingenious way that stage 5b was folded below stage 6a. His maps of the facies in 5a and 5b showed that the areas with same facies were elongated, and parallel to the present strike of the beds, even when the compression of the later folding was compensated for. This shows that there must be an angular unconformity between 5b and 6a, even if he was not able to find it in the field.

The author succeeded in finding two localities in the Oslo District, in which the angular unconformity is clearly shown (see below). At the end of 5b-time, the beds were slightly folded in gentle syn- and anticlines, the latter reaching above the sea. The synclines between them were filled with coarse conglomerate, differing in groundmass from the common intraformational conglomerates in 5b. On this partly leveled surface the Silurian beds were deposited. Because of this structure, the angular unconformity is only observed in the flanks of the old (5b) anticlines, which often are distorted by later (Caledonian) folding, and Permian faulting (cf. text fig. 1). This is probably the reason why the unconformity has not been discovered earlier. It is worth mentioning that there are at least three types of conglomerates in connection with stage 5b. First at the base, often with erosional contact against 5a (in some localities in Asker, it seems as if the whole 5a is eroded away, and 5b rests upon 4d). This contact in some localities resembles an angular unconformity, but a closer examination always shows that the sections in question are in the slope of erosion channels in the older beds. The second type of conglomerate is the intraformational conglomerates, which are abundant in most localities, and which are most common in the upper part of the stage.

The third type of conglomerate is the filling of the synlines formed between 5b and 6a. In most localities it showns lithological differences from the other conglomerates.

LOCALITIES.

Alnabru. This locality is in the eastern end of a quarry just West of the railway and North of the main road (Strømsveien) at Alnabru. In the southern slope of the anticline (forming a prominent ridge in the landscape), the conglomerate is exposed. The angular unconformity between the base and the top is clearly demonstrated, towards the top of the anticline it thins out rapidly, and increases also in coarseness towards the syncline. The large, angular boulders might be more than one meter in diameter, and the matrix in the upper part of the conglomerate is formed by the Silurian shale. This indicates that the Silurian was deposited on a surface covered with large, loose boulders. This seems also to be the explanation why the nodular limestone band at the base of the shale is broken by one of the large protruding boulders. It probably reached above the bottom when the nodules were formed. No Permian faulting found in the section can explain the structure mentioned above.

Along the same anticline, there are several sections through the Ordovician/Silurian border, but in all these the massive limestone of 5b is followed by about ½ m of nodular limestone, and then dark,

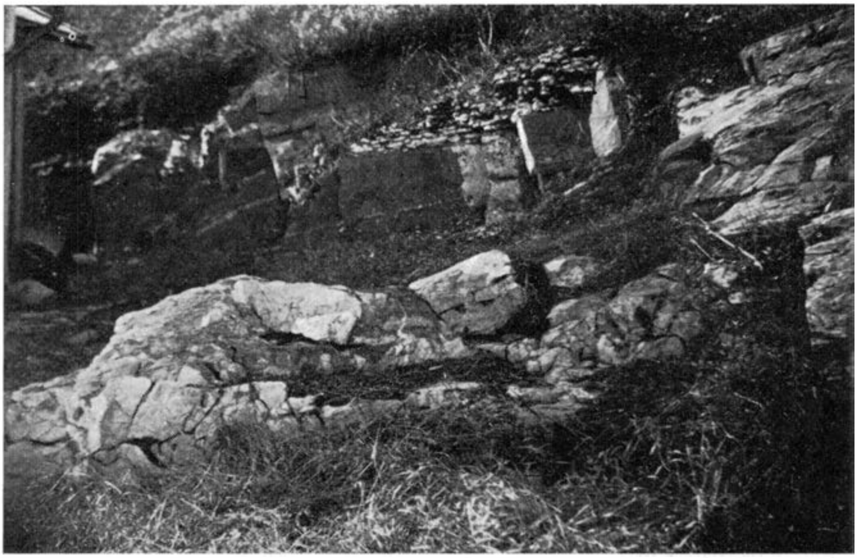

Fig. 2. The angular unconformity between 5b and 6a at the south-eastern end of Hovedøya. The conglomerate (5c) in the foreground, in the background the brownish calcareous sandstone (5c) with nodular limestone (6a) on top. Only some few meters to the right, the conglomerate has wedged out, and the sandstone is resting directly on 5b.

somewhat silty shales with some irregular siltstone bands. No trace of conglomerate is found, but the contact between the Silurian and the Ordovician indicates an unconformity, because the top of the limestone is distinctly eroded, and small-scale carst phenomena are quite common.

As mentioned above, the upper part of 5b consists of massive, partly oolithic limestones with few fossils. The lower part, the intraformational conglomerates and the border to 5a is not exposed.

Hovedøya. (Textfig. 2.) In this locality the contact between the Ordovician and the Silurian is exposed along the southern shore of the island, and shows very well the variations in the transitional beds. The locality was briefly mentioned by the author (SPJELDNÆS 1957), and a figure was given of the easternmost part of the section, where the angular unconformity is well developed. It is quite like that

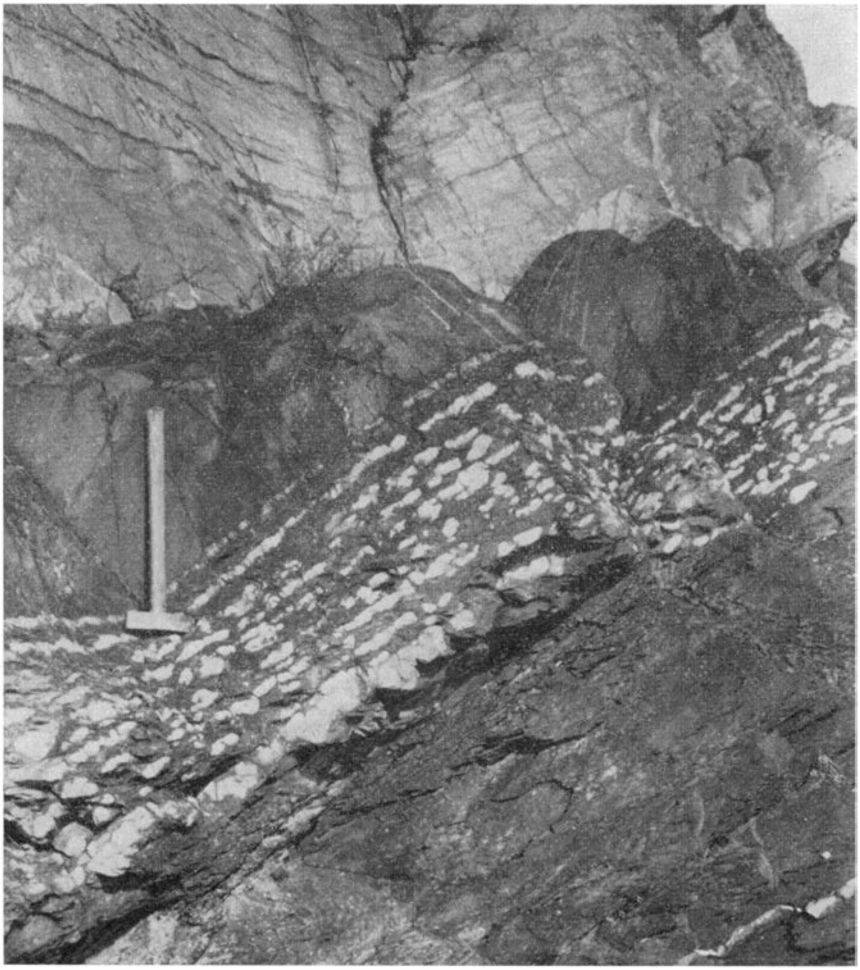

Fig. 3. The contacts 5b/5c/6a at the southern side of Hovedøya. The beds are inverted, so that the limestone seen on top is 5b, then with an interval of erosion 5c, and then with another interval the nodular limestone of 6a, followed by the sandy shale.

found at Alnabru, but in this case the conglomerate is not directly overlayered by the nodular limestone and shale. A thin bed (1–½ m) of brownish weathering calcareous sandstone is found in between. The matrix of the conglomerate is also the same sandstone. The

Fig. 4. The coarse conglomerate in 5c at the south-western end of Hovedøya. The largest boulder on the picture is 1 ½ m long. The beds are inverted, and the conglomerate is filling a small valley in 5b.

conglomerate itself is only exposed in a cliff at the shore, and only some few meters higher up along the flank of the anticline, the nodular limestone is resting directly on the massive limestone of 5b with erosion contact.

To the West the beds are inverted, so that the massive limestone is found above the Silurian. No conglomerate is found, except on the westernmost end of the island. The sequence is first massive limestone, then (with erosion-contact) the brown, calcareous sandstone, and then, possibly also with an unconformity, the nodular limestone, which form the base of the Silurian (textfig. 3). The surface of the 5b limestone is generally very even, but small irregularities occur in some places.

At the westernmost end of the island, the brownish sandstone grades into a coarse-grained limestone-conglomerate, which forms a channel in 5b. The boulders in the conglomerate are of variable size, most of them are small, but in some lenses they are very large, up to 1,5 m in diameter. They are angular, and consist mainly of different types of massive limestones from 5b. Most of the limestone boulders seem to be derived from the sides of the erosion cannel, but other types are also found, some of which are met with in 5b in other localities (textfig. 4).

Especially in the finegrained beds of the conglomerate, many fossils are found. They seem to be of the same type as those found in 5b, but the fauna is not yet studied in detail. Any great difference from the fauna in 5b can not be expected, because of the small difference in time and the similarity in facies. Members of the fauna in the lowest Silurian is probably absent because of the striking difference in facies (limestone with no or little clay, and dark, lime-free silty shales). Among the fossils found in these beds are *Graptodichtya proava* (EICHWALD), which is common in the upper part of 5b, and also is found in the upper part of the Dalmanitina Beds in Sweden, and in the Porkuni Beds in Esthonia.

STRATIGRAPHY.

The stratigraphy of the uppermost Ordovician and the lowest Silurian in the Oslo District has been studied especially by BRØGGER (1887) and KIÆR (1908). Much more studies are, however, necessary in order to get an opinion of the stratigraphy and sediment petrology of this district.

Just as in Asker (cf. KIÆR 1902), the facies is very variable both in 5a and especially in 5b. Generally it seems as if the sediments as a rule are coarser and more calcareous in the Oslo District, and the range of different types of sediments is not so wide as in Asker.

In most localities the transition between 5a and 5b is gradual, without a conglomerate. Just above the base of 5b, a peculiar bed is found. It is about ½ m thick, and consists of sandy limestone with a crumbled bedding, indicating a formation by subaqueous slides. This thin horizon is, however, remarkably persistent, and seems always to occur in the same stratigraphical position (textfig. 5). The origin of the bed is therefore unknown. In the higher parts of 5b there are generally conglomerates. In some localities there are only very few beds of conglomerate, and in others they form the larger part of the sequence.

All the conglomerates are of the same type; they occur as lenses,

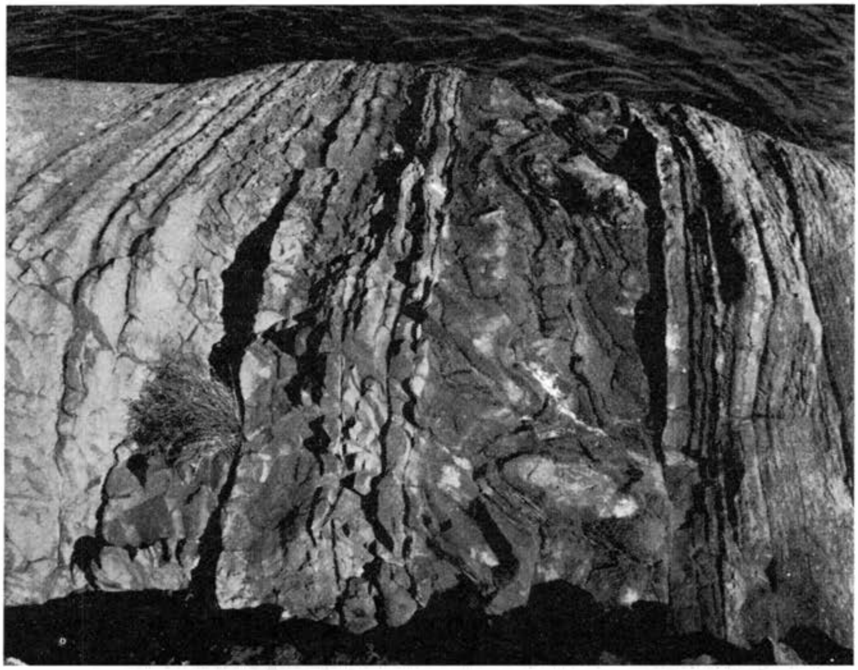

Fig. 5. Sandy limestone bed with disturbed bedding, from the lower part of 5b, at the eastern end of Rambergøya. The bed is 60 cm thick in this locality.

generally with cross-bedding (textfig. 6). The boulders are well rounded, of uniform size, and consist of limestones and rolled fossils, mainly corals. Most of the fossils found as boulders are from 5a; in fact the guide fossil for this zone, *Sarcinula organum* is very common. Algal limestones with *Rhabdoporella* and *Vermiporella* are also common. This is remarkable, because these fossils, which are very common in 5a in Asker are not found in 5a in the Oslo district. The well rounded boulders also indicate a long transport of the material.

The matrix of the conglomerate, and the beds in between the conglomerates consist generally of sandy limestones, which often are so rich in sand that they should be classified as calcareous sandstones.

The sand in this rock is unusual, as some of the grains, smaller than 0,3 mm, are angular, and the larger ones (½–4 mm) are very well rounded; in fact most of them are nearly perfectly sphaerical.

Fig. 6. Conglomerate beds in the upper part of 5b, at the southern side of Rambergøya. Note the slight unconformity in the foreground to the left. The beds are inverted, so that the upper beds are to the right.

The larger grains have also a «frosted» surface, and might be eolian. In some localities, especially at Bjerkøya in Asker, the beds show well developed crossbedding, resembling that of dune sands. One argument against the interpretation of these rocks as eolian sediments is that the smaller quarts grains do not seem to be eolian in origin (angular, and without frosted surface), and that the velocity of wind necessary to move quarts grains of this size (½–4 mm) through the air is too high to be a constant feature under normal conditions. A detailed study of the origin of these sediments is outside the scope of this paper, and the features are only mentioned to give an impression of the type of sediment found.

All the rocks, even those very rich in quarts have calcareous cement, and oolithes are common. Fossils are not common, except as boulders in the conglomerate, and in finegrained beds where the supposed eolian grains are not found.

Above the typical 5b the unconformity is found, and even in the localities where it can not be seen to be angular, the top is eroded. The beds between 5b and the typical Silurian (6a) are rather characteristic, and because of the important border between them, a new term, 5c, is introduced for these beds. They are defined as the beds resting with erosional contact on 5b, forming the wedges of sediment between 5b and 6a. It represents a very short time interval, and it is difficult to refer it to the Ordovician or Silurian. It is formed after or during the folding, appearently conformable with the Silurian, and disconformably above the Ordovician (5b). On the other hand, it has the same facies as the Ordovician, and differs strongly in lithology from the Silurian. The paleontological dating of the beds are based on the find of graptolites in the lowest part of 6a, and this graptolite indicate the very base of the Silurian. 5c is therefore with a query included in the Ordovician. The angular disconformity is then not exactly at the border between the Ordovician and Silurian, but just below it, in the topmost Ordovician.

The basal beds of the Silurian are generally developed as a thin (½ m) nodular limestone, followed by sandy shales with siltstone bands from 2–15 cm thick. The siltstone bands often show graded bedding, which might be due to turbidity currents, possibly from the flanks of the Ordovician anticlines toward the bottom of the synclines.

The thickness of the beds in the Lower Silurian is variable, and considerable differences in facies are found in different localities. KIÆR (1908) described some of the sections in detail, and divided the beds into zones, 6aα, 6aβ, 6bα, 6bβ, 6cα, 6cβ. There are no sharp faunistic and lithological limits between these zones; the content of carbonate increase towards the top, and the fauna is also much richer in the upper zones than in the lower.

A detailed study of KIÆR's sections shows that his zone 6aβ is only found on the northernmost islands in the Bunnefjord, and in these localities the typical 6aα is missing. This is developed only in the southern islands in the Bunnefjord, Malmøya and Ormøya.

A comparison of the faunas in 6aβ and 6bα indicates that these zones are identical, and that the terminology has to be slightly revised. 6a is reserved for the thick siltstone-shale beds found only on the southern islands. It is not subdivided; further studies of the graptolites might give good subzones. 6bα is used for the fossiliferous shales with some few siltstone beds, and some nodular limestone beds in the upper part.

The difference in facies in 6a–b might be explained in two ways. Either the Silurian sea transgressed northwards, and reached the northern islands later than the southern ones. Or the sections on the southern island are more in the middle of synclines where the beds are thicker, either due to contemporaneous folding, or because the 5b-anticlines were still topographical ridges.

The features in the areas to the north and west seem to indicate a transgression, but it might also be a combination of both.

In the mainland in Oslo (Alnabru) the development is exactly similar to that in Hovedøya, and in Asker the beds described as 6aα and 6aβ by KIÆR (1908) have the same fauna as 6b in the Bunnefjord area. This might also be interpreted as a calcareous facies of 6a, but this is not supported by any paleontological data.

North of Oslo, in a railway section between Gulleråsen and Gråkammen, 6b is resting directly on the eroded surface of 5b.

In the Ringerike district, KIÆR (1908) also described beds as belonging to zones 6aα and 6aβ and also 6b and 6c. Even in the beds designated 6a, one finds fossils which are guide fossils for 6c in the

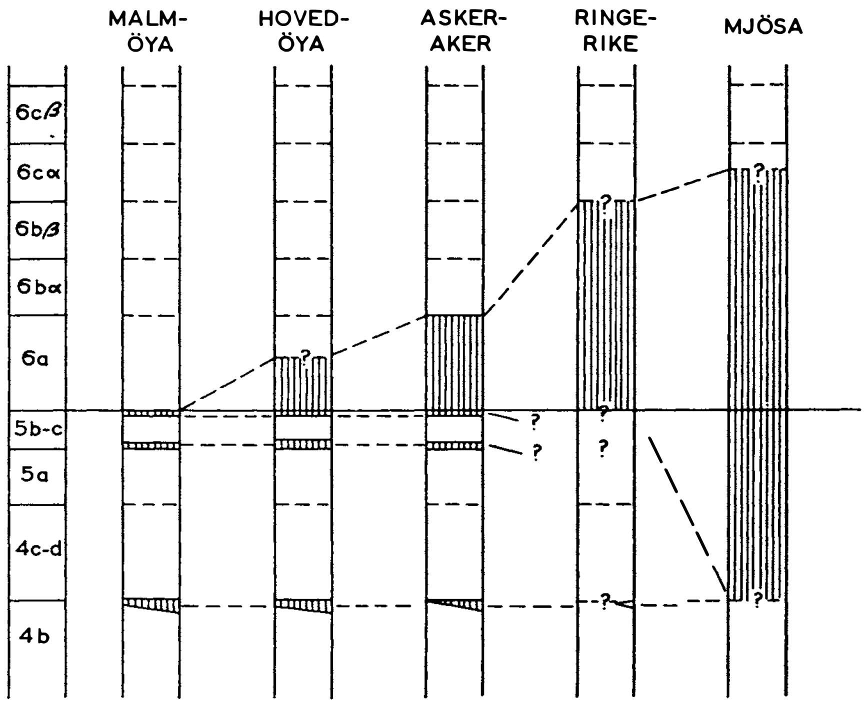

Fig. 7. Diagram showing the development of the Upper Ordovician and Lower Silurian in parts of the Oslo Region.

Oslo–Asker districts (*Rhinopora malmoeensis* and Stropheodontids). This indicates that the zones 6a and possibly also 6b are missing in Ringerike.

In Hadeland a thick, unfossiliferous sandstone is resting on 5a, and the oldest fossils found above it belong to 6c (cf. MAJOR 1946). In the Mjøsa district, the oldest Silurian belong to 6c, and is resting on the Middle Ordovician Mjøsa Limestone (textfig. 7).

This seem to indicate that the base of the Silurian is younger towards the north, and that the most complete sequence is found in the south-east (Malmøya).

No names are given to the lithostratigraphical units at present; — much detailed studies still have to be made in this area.

TIME AND STRENGTH OF FOLDING.

The presence of an angular unconformity just below the Ordovician-Silurian border in the Oslo district was obscured by the presence of two phases of folding, with the same direction, one in the uppermost Ordovician and one post-Silurian. Because the two foldings were in the same direction, it is difficult to estimate the relative strength of the two orogenies.

It has repeatedly been noticed that the Ordovician beds are stronger folded than the Silurian ones in the Oslo Region, but this is generally ascribed to the fact that the Ordovician beds mainly consist of shales which are more easily folded than the more competent, massive limestones in the Silurian. The latter are supposed to show a «Schuppen» — structure. The presence of the angular unconformity described here offers an alternative explanation; that the Ordovician beds were folded before the deposition of the Silurian.

The angular disconformity is generally very slight, 10–20° at most. This seems to indicate that the folding was very slight, and in this case it could not explain the difference in folding between the Ordovician and Silurian.

It is, however, probable that the folding took place both before and after the unconformity was formed. In the Oslo Region the beds were folded during rather rapid sedimentation, and unconformities will not be found, because each step in the folding is immediately compensated by sedimentation and erosion. Even if, theoretically, numerous angular unconformities are present, they are all too small to be detected. Only when the sedimentation is stopped, such as at the top of 5b, there will be time enough for developing a visible angular unconformity.

The coarse sediments, and the irregular development of the facies both in 5a and 5b (cf. KIÆR 1902, figs. p. 48–50) indicate that the folding started already in 5a, reached a maximum in the top of 5b, and continued also in 6. The numerous beds with graded bedding in 6a and the base of 6b also indicate that the folding continued up to this time, and in 6c at Sælabonn in Ringerike, there are signs of subaqueous slides.

It is therefore possible that the Ordovician-Silurian folding was

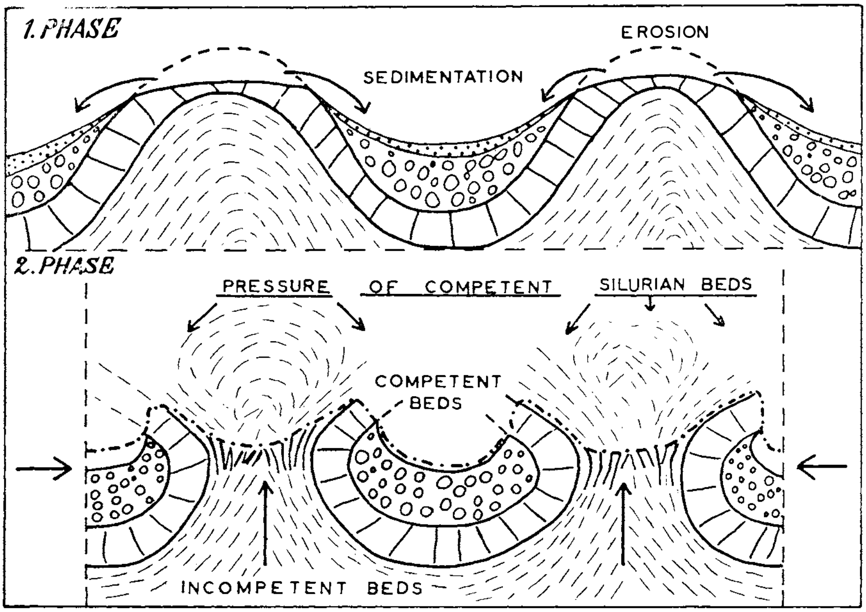

Fig. 8. Diagramatic figure illustrating the author's theory of the formation of the overfolded anticlines in the Bundefjord district by two phases of folding. For explanation see the text.

considerably larger than it appears from the size of the angular unconformity. It is also an interesting question if the directions of the two phases of folding were exactly the same, or if they differed slightly. This latter possibility might explain some of the irregularities of the folding in the Oslo Region. It is, however, outside the scope of this paper to deal with that problem.

The special style of folding found in the Bunnefjord area, (cf. BRØGGER 1887) might be explained by the double folding. In this area all the anticlines are overfolded, either to the southern side, or to both sides. The anticlines consist of Ordovician shales, and the partly closed synclines of Silurian beds, and the massive calcareous beds of 5b. The sections mentioned from Hovedøya indicate that the anticlines were formed already in the Ordovician, and that their tops vere eroded before the deposition of the Silurian. The synclines were filled with sediments, generally very competent beds.

When the post-Silurian folding started, the area consisted of bands of competent beds (former synclines) and incompetent ones (former anticlines). By the folding, the soft beds in the anticlines were squeezed up, and folded over the more competent beds in the synclines (textfig. 8). This is an example of one of the feature in the folding in the Oslo district which is difficult to explain if it is supposed that there was only one phase of folding, but is easily explained by the presence of two phases of folding.

It is also interesting to note that the phase of folding continued for a long time, in contrast to the statements given by STILLE (1924, 1950). Features similar to those in the Oslo district shown by folding during sedimentations are described by KREJCI-GRAF (1950). It seems, therefore, to be established that the phases of folding were not very short, abrupt events, but that they developed slowly, through millions of years.

In the usual terminology of orogenic phases, this folding should be termed the Taconic. This folding is supposed to be found at the border between the Ordovician and Silurian. In the Oslo Region this is almost correct, but in Wales (Llandovery district, cf. JONES 1925) there are three phases in the lowest Silurian, and in central Scandinavia, it is deeper in the Ordovician (in Northern Sweden KULLING (1933) reports *Holorhynchus giganteus* and other 5b fossils from above the Voitja conglomerate, which possibly marks the folding).

This indicates that the orogenies at least in some cases are not contemporaneous in all areas, even if their maxima seem to fall within a rather short period. This period is, however, of the order of size as the Ashgillian or Llandoverian.

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