Note

Evidence of synsedimentary tectonics in the Lower Silurian (Llandovery) strata of Brumunddalen, Ringsaker, Norway: A comment

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A critical examination is given of the material presented by Møller (1986) indicating synsedimentary tectonics in the Silurian of the Brumunddal area. Based mainly on structural and stratigraphic evidence, it is concluded that none of the three cases described is really synsedimentary tectonic deformation. In one case the deformation is synsedimentary, but unrelated to contemporary tectonics; in the other two the deformation is tectonic and post-sedimentation.

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In a recent paper in this journal, Møller (1986) suggests the occurrence of synsedimentary tectonic deformation in the lower part of the Silurian (Llandovery) in the Brumunddal area, in the northern part of the Oslo Region. Since some of the observations, as well as the conclusions, are at variance with my observations from the area, a critical discussion may be appropriate.

The area has been exposed to two strong phases of tectonic deformation. The Scandian (top Silurian-Lower Devonian) phase of the Caledonian orogeny has caused intensive folding and thrusting from N to S. The Permo-Carboniferous rifting (which may have continued into the Triassic in this area (cf. Spjeldnæs 1972)) has caused intensive faulting and regional tilting (locally about 10–20° towards ESE) mostly along N–S lines. The major fault, with a throw possibly exceeding 1000 m, is found only a few hundred metres E of the localities discussed.

Under these circumstances it is difficult to identify minor, older phases. The minimum requirement is that these phases can be identified generally over the region, and that they involve all rocks older than the deformation. The only such regionally observed break in the tectonic style is found at the Ordovician-Silurian boundary. The present author has for a long time collected data, and hopes to be able to publish convincing evidence for this later. Tectonic movements from this time have been indicated by Kiær (1901) and Spjeldnæs (1957) (folding), and Brenchley & Cocks (1982) and Stanistreet (1983) (block-faulting), in the Oslo-Asker area. In the Brumunddal area, which is closer to the orogen, signs of deformation are also to be expected.

In the Oslo Region, the effects of the Caledonian movements are seen at three different levels. The weakest, but very significant, is the long-distance effect on the sedimentation pattern. This has been described by Bjørlykke (1983), and is our best tool for dating the events in the Caledonides. The second is the existence of weak tectonic movements about the Ordovician-Silurian boundary in the Oslo-Asker area. They are seen as weak tilting or buckling of the beds, resulting in drastic changes in sedimentation, such as local erosion, channelling, coarse conglomerates, and facies patterns linearly related to the structures.

The third level, which included actual deformation of the rocks, is seen in connection with the Scandic phase of the Caledonian movements. By their very nature, such compressional tectonics will lead to profound changes in the stratigraphy. In most cases a considerable tilting of the beds will result in angular disconformities, and the compression will result in a thickening of the sequence leading to a regression and a considerable break in the stratigraphic record. In most cases the top of the deformed beds will be removed by erosion. Very little of this is seen in the lower Silurian in Brumunddal. Møller (1986) mentions that the sequence is incomplete, but that is not evident from Fig. 2, which shows a peculiar mixture of time- and rock stratigraphy.

The biggest hiatus occurs between the Ordovician Mjøs Limestone and the lower Silurian 'Helgøy Quartzite'. The basal Silurian beds are developed in three lithologically different facies in the Mjøsa Districts, and in two of them, the lower beds (in contact with the Ordovician) are non-fossiliferous. In one of them, there is a good dating (to the Idwian by brachiopods) from the topmost beds, but in Brumunddal, where the beds are fossiliferous all through, there is no precise dating (due to lack of faunal studies, and because of the special character of the fauna, cf. Spjeldnæs 1982). The sediments (which are well described by Møller) indicate shallow water, and deposition in a short time interval only. There are no faunal or other indications that the deposition of the 'Helgøy Quartzite' in Brumunddal continued into the Fronian, as shown in Møller's Fig. 2.

Above the 'Helgøy Quartzite' there is another important hiatus, below the Rytteråker Formation. In some localities in the Mjøsa district, this hiatus can be shown to be double, by the presence of 0–0.3 m of sediments with *Borealis borealis*. This species forms thick coquinal banks in the lower part of the Rytteråker Formation in the type area (Ringerike), and the thin beds preserved are interpreted to be erosional remains of much thicker beds. Since the specimens of *B. borealis* are cut by erosion both at the upper and lower contacts, the corrosion was at least in part intrastratal/diagenetic.

The bulk of the Rytteråker Formation in Brumunddal is developed as a nodular limestone, with a rich but undescribed fauna dominated by corals, brachiopods and echinoderms. The age of the top of the Rytteråker Formation is older in the Mjøsa district—where the overlying Ek Formation includes the *turriculatus*-zone (Howe 1982)—than in the type area. This zone is correlated with the upper part of the Rytteråker Formation in Ringerike (Worsley 1982, p. 15).

The supposed phase of deformation described by Møller is reported from three localities, and in all of them the deformation is restricted to one horizon, not affecting the underlying beds. The beds are of different age (lower part of the 'Helgøy Quartzite' in loc. 1, upper part of it in loc. 2, and at the boundary between the Rytteråker and Ek Formations in loc. 3).

Locality 1 consists of a complete fold, as illustrated by Skjeseth (1963, Fig. 33). The core of the syncline consists of Rytteråker Formation (nodular limestone) and the anticline of Mjøs Limestone. The 'Helgøy Quartzite' is exposed three times. The spectacular sedimentary structures in the lower part of the formation were suggested to be load casts by Skjeseth (1963), but a modern interpretation would be fluidization structures, in a rapidly sedimented sand. The more complex structures described by Møller (Figs. 3–5) are found in the southernmost section, in the slope above river level. These sedimentary structures are not seen in the middle section in locality 1 (they may have been squeezed out tectonically, but there is no good observational evidence for this), and they are also not found in locality 2, or in the three others, not so well exposed sections of the 'Helgøy Quartzite' in Brumunddalen.

The complex structure (Møller's figs. 3–5) is interpreted (by the present author) as due to slumping with some deformation by later, Caledonian folding. The beds were probably not cemented when the slumping took place, but they had some cohesion, due to clay content. Similar structures are not uncommon in rapidly sedimented, impure, unconsolidated sands in the Quaternary of Norway.

It is not clear how Møller has envisaged the actual tectonic influence on the formation of these structures. They cannot have been formed by sliding on a tectonically formed slope, since the beds above and below are parallel. Mechanical push from an advancing thrust sheet is improbable because such structure in soft sediments would have been restricted to the immediate front of the sheet, and have a very small preservation potential. No thrust sheets are seen in the immediate neighbourhood.

In *locality 2*, (cf. Møller's Fig. 6) the deformation is obvious, brittle and extensional. Most of the fragments in the breccia are angular, and the shape of some of them suggest that they are broken along a jointing pattern. This indicates the following sequence of events: complete cementation—jointing due to tectonic pressure—brecciation along the joints, in extensional fissures. Since jointing seldom takes place at the surface of sediments, it seems more likely that the breccias were formed later at depth, and not synsedimentary, as suggested by Møller.

Two tests could be made to solve this problem. The presence and direction of the solution surfaces in the fragments of the breccia may be important. The solution surfaces which are common in the 'Helgøy Quartzite' are mostly parallel to bedding, and probably due to Caledonian tectonic pressure, or Permo-Triassic overburden, or both. Tilted solution surfaces (and joints) would indicate that the brecciation was later. It would also be of interest to study the direction of tectonic deformation in this locality by means of tectonic striation to see if the deformation showed Caledonian or Permian directions, or both. In Brumunddal there are some extensional fissures, filled with sediments and rock fragments, finally cemented with calcite. They are irregular in detail, but have a general N-S trend, and are by the present author associated with the rifting phase, being extensional, and cutting through all sediments in the area.

Even if the precise age of the brecciation cannot be determined in this locality, it seems unlikely that it is synsedimentary. The beds in which they are found are probably slightly younger than those from locality 1, and the deformation pattern is strikingly different.

In *locality 3*, just across the river from locality 2, the presumed synsedimentary deformation is at the contact between the Rytteråker and Ek formations. Due to the differences in competence between the limestone and the soft graptolite shale, there is a strong deformation at the contact, and—as described by Møller—a marked contrast in style of deformation. There is also no doubt that there were two phases of deformation, one which was partly plastic, and a later one which was brittle. It is quite common in the Oslo Region to find two major phases of deformation, and they are usually interpreted as the Caledonian, and the Permian ones. Since the rifting took place in several stages, the later phase often appears multiple, as seen by Møller (1986, p. 14). There is no good evidence for a different explanation in this case. The fact that the early deformation was more plastic than usual can be easily explained by thin overburden over the Rytteråker Formation (the Ek and Mariendal Formations are about 200 m or less) before it was hit by the Caledonian deformation.

The contact between the Rytteråker and Ek Formations has been intensely tectonized, and especially the top of the limestone has been much altered. The evidence for an original erosional disconformity, with lag conglomerate, is not quite convincing. The rounded rock fragments shown in Møller's fig. 12 are now surrounded by solution surfaces, and their original shape is unknown. Because of the tectonization it is very difficult to see if an erosional disconformity was originally present or if the apparent break is due to later deformation.

This is without relevance for the age determination of deformation, which in any case seems to have taken place well below the surface. In the Oslo Region, the Rytteråker formation is part of an upwards shallowing sequence (cf. Worsley 1982, p. 13), which is followed by an abrupt deepening. It is in keeping with Bjørlykke's (1983) model that the deepening started earlier in the north, where the base of the Ek Formation belongs in the *turriculatus* zone, than in the type area, where the base of the Vik Formation is supposed to be in the *crispus* zone. It is quite possible that the top of the Rytteråker Formation was exposed locally to erosion, but this is not in itself an indication of synsedimentary deformation.

In conclusion, none of the three localities can be taken to indicate synsedimentary tectonic deformation. In locality 1, the spectacular sedimentary structures can be best explained by slumping and pore-water escape, and in the two others, the obvious and complicated tectonics show all signs of being formed later at considerable depth below the surface.

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