Note

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

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With a brief preliminary note (Møller 1986) I tried to draw attention to some structures in the Lower Silurian strata of Brumunddalen, which in my view represent evidence of synsedimentary tectonics. I was therefore pleased to get a prompt response through Spjeldnæs' comment (Spjeldnæs 1987). In his contribution he challenged my interpretation and claimed that the evidence presented in my paper did not prove the existence of synsedimentary tectonics. Having considered his arguments thoroughly, however, I would like to note that although being aware of uncertainties in my interpretation I do not think it has been convincingly disproved. The discussed problem will probably not be solved before supplementary data are collected within the scope of a comprehensive study.

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In the following, brief replies are given to Spjeldnæs' main arguments. As he states, it is difficult to discriminate minor Llandovery tectonics from the Scandian or Permian main events of deformation. The chronological discrimination, however, is in this case given by the fact that the deformation structures were formed in soft or weakly lithified sediments near the surface.

Our disagreement concerning *locality 1* (Møller 1986) is based on several misunderstandings. The observed structures are not restricted to the lower part of the Helgøya Quartzite. Its entire thickness in this locality is 5.5 to 7 m. Almost the entire section is exposed, and the structures are found from bottom to top of the exposed section on one limb of the antiform mentioned by Spjeldnæs (1987) (Møller's Fig. 3). *Localities 1* and *2* are thus not situated on different stratigraphic levels as Spjeldnæs assumes. Furthermore, there is not sufficient biostratigraphic data to draw any detailed conclusion concerning the relative age of the different structures.

The sediment cannot have had any significant cohesion due to clay content, because the sand only contains negligible amounts of clay in the deformed beds. The sediment is therefore supposed to have been weakly cemented prior to slumping, because the bedding is preserved in the slump units (Møller 1986).

Spjeldnæs considers rapid sedimentation as the triggering factor for the slumping. However, the mentioned coherent behaviour in spite of the absence of a significant clay content indicates that diagenesis had advanced to some extent when slumping took place, and points to low rates of net sedimentation. It is thus difficult to explain the slumps as a result of fluidization of the sediment, whereas there are no difficulties in explaining them by tectonic triggering.

I agree with Spjeldnæs (1987) that 'mechanical push from an advancing thrust sheet' cannot be taken into consideration; this was not proposed at all. However, slumping triggered by seismic shocks is a well known phenomenon and may take place on submarine slopes of a few degrees, dependent on the shear strength of the sediment (Stow 1986). The slopes might then be so slight that angular unconformities with the neighbouring beds cannot be recognized due to the overprint by Scandian deformation.

Quartzite breccias in *locality 2* (Møller 1986) are explained by Spjeldnæs (1987) by a later tectonic brecciation along a jointing pattern after lithification of the beds. This appears comprehensible, as the sediment shows *in situ* brecciation and the fragments are angular. However, at several horizons rounded clasts without pressure dissolution rims occur, and even clasts of bioclastic limestone are involved. Such limestones are interbedded with the respective level of the Helgøya Quartzite, but the limestone clasts are not arranged along certain horizons within the breccia, nor do they lie within fault planes. Thus, minor sediment transport may have occurred after brecciation.

Pressure dissolution seams are not always parallel to bedding, but generally develop along inhomogeneity planes. They do this also in rotated fragments, thus receiving their 'rotated' orientation after brecciation. However, internal dissolution seams in the clasts are rare, whereas seams commonly dissect the matrix and bend around clasts or separate clasts from each other.

The number of exposed breccia-filled fissures is too small and their directions too variable to identify a statistically significant Caledonian or Permian trend, as proposed by Spjeldnæs. Furthermore, the fissures are strata-bound and do not continue into over- or underlying beds. The latter appear to be undisturbed. Deformation of poorly consolidated sediment will – on a minor scale – not necessarily follow regional trends, but will be controlled predominantly by the differential competence of the sediment.

As noted above, the breccia is situated within the stratigraphic range of the slumping structures (*locality 1*) and the 'strikingly different deformation pattern' (Spjeldnæs 1987) can be thought to reflect local differences in consolidation, seismic movements, and possibly topography.

Concerning the boundary between the Rytteråker and Ek Formations in *locality 3*, I assigned the major deformation structures to the Scandian event. Synsedimentary tectonics are solely assumed to be responsible for the rapid basin subsidence, causing the facies change at the boundary between the Rytteråker and Ek Formations as well as associated erosion and brecciation.

Conclusions

The arguments given by Spjeldnæs do not represent suitable criteria with which to satisfactorily dismiss the hypothesis of synsedimentary tectonics being responsible for the described deformation structures. The problem has to be approached by more detailed field and petrographic studies and possibly by observations in modern sediments as a base for actualistic comparisons.

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References

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