# Some Features of Tectonic Deformation of Old Red Sandstone Sediments on Hitra, West Central Norway

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Roberts, D. 1981: Some features of tectonic deformation of Old Red Sandstone sediments on Hitra, West Central Norway. *Norges geol. Unders. 370*, 45–48.

Minor tectonic structures affecting Downtonian Old Red Sandstone sediments on Hitra include folds parasitic to a major syncline, and an associated axial surface spaced cleavage. The cleavage is most prominent in mudstones, and appears to represent dissolution foliae; no neocrystallization has been detected. In these rocks carbonate nodular concretions show evidence of mechanical rotation from bedding-parallelism towards the plane of the cleavage. Younger structures are represented by crenulations and kink bands.

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Parorogenic tectonic deformation of the Old Red Sandstone (ORS) deposits of southern Norway first became widely known following Vogt's (1928) synthesis of late Caledonian crustal events throughout the North Atlantic region. Since that time, workers in the several ORS basins have recognised a variable degree of deformation of the intermontane molasse sediments, generally in the form of open folding and faulting (e.g. Holtedahl 1960, Holmsen 1963, Nilsen 1968, Siedlecka & Siedlecki 1972, Roberts 1974) but also reflected in thrusting (Nilsen 1968, Høisæther 1971), local pebble stretching in conglomerates (Nilsen 1968, Indrevær & Steel 1975) and in one area cleavage development with very low grade metamorphic recrystallization (Roberts 1974a).

The Downtonian (and possibly also Ludlovian?) to Lower Devonian sediments on Hitra have been a subject of modern stratigraphical and sedimentological study by Siedlecka & Siedlecki (1972). The sedimentary succession is divided into 5 informal members, A to E, which together constitute the Hitra Formation. Alternating sandstones and mudstones compose members B and D, but otherwise the formation is characterized by conglomerates and sandstones with a basal breccia (Siedlecka & Siedlecki 1972). These authors described the major structure affecting the apparently unmetamorphosed sediments; an asymmetrical open syncline of NE–SW to ENE–WSW trend with generally southeastward-dipping axial plane, which is transected by both longitudinal and transverse to oblique fault sets.

An assessment of the strain state of the Hitra sediments from Siedlecka & Siedlecki's descriptions was not possible since no minor tectonic structures relatable to the major syncline had been reported. Observations by the present author in 1977 showed, however, that mesoscopic folds are present locally in favourable multilayered pelite–arenite lithologies and that a prominent cleavage is developed in mudstones in the southeasternmost parts of the ORS outcrop (for locations, the reader is referred to Fig. 1 in Siedlecka & Siedlecki 1972, p. 2).

In the coastal tract east from Furuholmen, and especially in the small bay Bosvikvågen (1:50,000 map-sheet 'Hemne'), dark grey mudstones of member

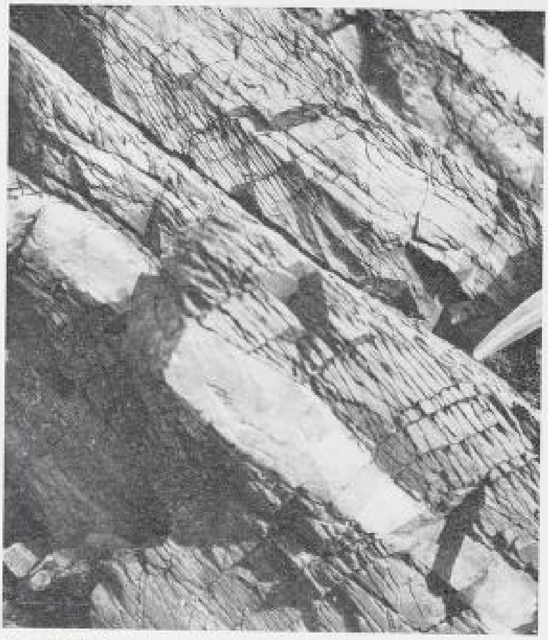

*Fig. 1.* Cleavage development in mudstones of alternating pelite–arenite sequence, member D, Hitra Formation, Bosvikvågen. Photo taken looking northeast approximately normal to the bedding/cleavage intersection lineation: part of hammer-head as scale.

D exhibit a conspicuous spaced cleavage (Fig. 1). Bedding/cleavage disposition and low-angle WSW-plunging intersection lineations indicate a close relationship to the major syncline. Minor parasitic folds are rare here. Some thicker sandstone units display a coarse fracture cleavage.

Curiously, the cleavage has not developed equally pervasively in all mudstone beds; in some pelites it is difficult to trace, or may be almost absent. The reason for these variations is not known. They cannot be ascribed solely to varying degrees of strain, but may associate with slightly differing mudstone mineralogies; for example, a higher ratio of quartz and calcite to phyllosilicates may facilitate dissolution processes and thus promote cleavage development. Even the most prominent cleavage is not a truly penetrative structure but rather a series of subparallel, slightly sinuous and anastomosing, closely spaced fracture surfaces separating domains of non-cleaved mudstone. Microscopic examination of the cleavage is extremely difficult as the rock splits so readily along these very surfaces. The examples that have been observed to date show the cleavage surfaces as dark seams of insoluble residues, largely clay minerals and oxides, the foliae apparently representing dissolution zones. No new mineral growth has been observed. Inter-cleavage domains reveal clastic quartz, feldspar, muscovite, sericite, chlorite and some carbonate as the main mineral constituents, with a crude preferred orientation of phyllosilicates paralleling the primary lamination and probably representing a compactional fabric. This latter seems a reasonable assumption in view of the likelihood that some 2–2.5 km of Devonian sediments may once have overlain the Hitra Formation in this coastal district of Norway (Siedlecka 1975).

An interesting feature of these mudstones is the presence of carbonate concretions and nodules. Siedlecka & Siedlecki described them as ellipsoidal or subdiscoidal and lying parallel to bedding. Siedlecka (1977) grouped the con-

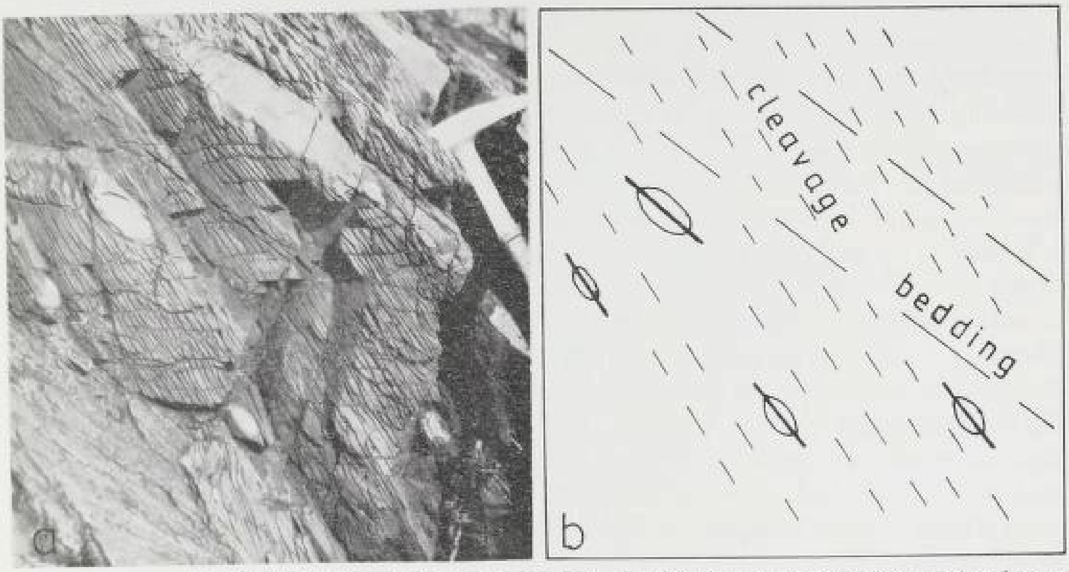


*Fig. 2.* (a) Carbonate nodular concretions in member D mudstones showing varying degrees of rotation from initial bedding-parallel orientation towards subparallelism with cleavage. (b) Tracing from (a) to help clarify the bedding/cleavage/nodule ellipse relationships. A heavy line is drawn through the long axis of each nodule. Bosvikvågen. Looking east-northeast on joint surface at right-angles to bedding/cleavage intersection.

cretions into two types: one which developed prior to the completion of sediment compaction, and another group which post-date this compaction. Where the cleavage is better developed it is clear that the nodular concretions have suffered a mechanical rotation, with final attitudes disposed at varying angles between bedding and cleavage (Fig. 2), the smaller concretions showing the greater propensity for tectonic rotation. In the present case it would be dangerous to attempt any finite-strain analysis in view of the apparently wide range of initial to post-compactional shape exhibited by these bodies, and also because of problems inherent in determining the amount of compactional strain suffered by these rocks. It can be noted, though, that some 20–30% transverse shortening across the ORS basin is indicated by the macroscopic folding of the Hitra Formation sediments, based on simple stratal rotation or unfolding.

Folds parasitic to and coaxial with the Hitra syncline are better developed on the southeastern limb of the major fold. At Selnes an incipient spaced cleavage is axial planar to close to tight mesoscopic folds in alternating mudstones and silty sandstones which Siedlecka & Siedlecki (1972) found difficult to place in their ORS stratigraphy. Microscopically, this cleavage is identical to that in member D; and the generally stronger deformation here is probably associated with strike-parallel, dip-slip faulting. In this area, traces of a later, N-dipping, incipient crenulation cleavage are detectable, and from here westwards towards Bosvikvågen there are NNW–SSE-trending kink bands with consistent westerly downstep in many mudstone horizons. A pilot TEM study of a cleaved member D mudstone has revealed micro-kink bands affecting clastic micas without any indications of recrystallization of phyllosilicates along the kink planes (S. White & B. A. Sturt, pers. comm. 1980).

The age of the fold-deformation affecting the ORS sediments on Hitra is generally considered as Svalbardian (early Upper Devonian), following Vogt (1928), although there are no precise stratigraphical constraints on this tectonism in this region of Norway. It follows that the cleavage would also be of the same age. Faulting in these coastal districts would appear to have been polyphasal (cf. Roberts 1974b, Siedlecka 1975) — initially syndepositional, then Svalbardian, but also with important dislocatory movements in Mesozoic (Oftedahl 1975) and Tertiary time. The syndepositional character of the faulting in western Norway in ORS time is well documented with strike-slip as well as normal dip-slip components (e.g. Bryhni 1964, Nilsen 1968, Steel 1976). Thrusting of ORS rocks in some areas in late Devonian time has probably been facilitated by a reversal of the slip vector along the earlier normal faults bounding the ORS basins (Steel et al. 1978). The age of the post-cleavage minor structures is open to speculation; any time from Svalbardian to Tertiary may be conjectured. As the kink bands denote downstep to the west, a relationship to either Permo–Jurassic rifting or the Tertiary uplift of Fennoscandian is quite within reason.

*Acknowledgements.* – Professor B. A. Sturt and Dr. Anna Siedlecka are thanked for their comments on a first draft of the manuscript to this note.

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