Storm-influenced marine sandstones in the Ordovician Lower Hovin Group, Nord-Trøndelag

ANTONY T. BULLER & SVERRE O. JOHNSEN

Buller, A. T. & Johnsen, S. O.: Storm-influenced marine sandstones in the Ordovician Lower Hovin Group, Nord-Trøndelag. *Norsk Geologisk Tidsskrift,* Vol. 62, pp. 211–217 Oslo. 1982. ISSN 0029-196X.

Sandstones containing wave ripple forms, hummocky surfaces, traces of hummocky cross stratification, graded sandstone-siltstone couplets and sole markings have been discovered in an outcrop of Ordovician metasediments of the Lower Hovin Group (Flornes area, Nord-Trøndelag). These sedimentary structures are indicative of sand transportation and deposition under the influence of coastal storms. The site of deposition may have been in an offshore zone, perhaps towards maximum storm wave base. This interpretation is in accordance with the overall stratigraphic sequence as the sandstones are situated between discontinuous limestones of presumed shallow water origin and overlying thin-bedded turbidites.

A. T. Buller & S. O. Johnsen, Petroleum Geology Division, Geologisk Institutt, N-7034 Trondheim-NTH, Norway.

The Trondheim region of central Norway contains representatives of a thick pile of Ordovician to Lower Silurian metasedimentary and volcanic rocks of the Upper and Lower Hovin Groups. Many of these were thought to have been accumulated in a back-arc or marginal geosynclinal basin, or in some form of similar geotectonic setting (Gale & Roberts 1974, Roberts & Gale 1978, Bruton & Bockelie 1980, Ryan & Williams 1980). The metasediments are dominated by sequences of sandstone-shale alternations with conglomerates and limestones.

In the Nord-Trøndelag region the sandstone-shale alternations are generally attributed to sedimentation in a turbiditic environment (e.g. Siedlecka 1967, Roberts 1968), and this has been corroborated by the identification of deep-water trace fossils (Roberts 1969). The conglomerates represent parorogenic movements, and the limestones may have been formed in shallow waters close to volcanic islands (Gale & Roberts 1974). These limestones mainly crop out in the western parts of the depositional basin, particularly in the Stjørdal district (Fig. 1).

Here, the Middle Arenig to Lower Ordovician rocks of the *Lower* Hovin Group are believed to consist, almost exclusively, of deep-water flysch-type sandstones and shales, together with the presumed shallow-water limestones. From an environmental point of view, the 'missing link' should thus be a transition zone of intermediate depth extending from the shallow carbonates to the deep waters of the flysch trough. The discovery of Lower Hovin outcrops containing sedimentary structures indicative of offshore sandstones and shales (i.e. wave ripples and traces of hummocky cross stratification) may help to fill this gap as they are stratigraphically situated between the limestones and the overlying turbidites (Fig. 1).

This note contains a brief documentation of these sedimentary structures and an interpretation of their environment of deposition. The outcrops in question are located approximately 7 kms to the west of Flornes (Fig. 1). They extend for some 500 m or so parallel to the northern side of the main E 75 road. The rocks are dominated by inverted and steeply dipping sandstone beds with thin intervening shales and shale partings. The sandstones are metamorphosed, the shales are cleaved, and the association is occasionally shot through by quartz veins. To the east, the outcrops are more tectonised and the sediments are visibly folded.

It must be stressed that these tectonically-influenced rocks are most unlikely candidates for sedimentological investigation. With the exception of rippled bedding planes (Fig. 2), the rocks are generally unyielding for the clear recognition of sedimentary structures and the fine detail of bedding relationships in the field. These restraints necessitated the collection of a few large samples which were carried back to the laboratory for slabbing and polishing. The study progressed by the calibration of structures revealed by slabbing with limited field observations.

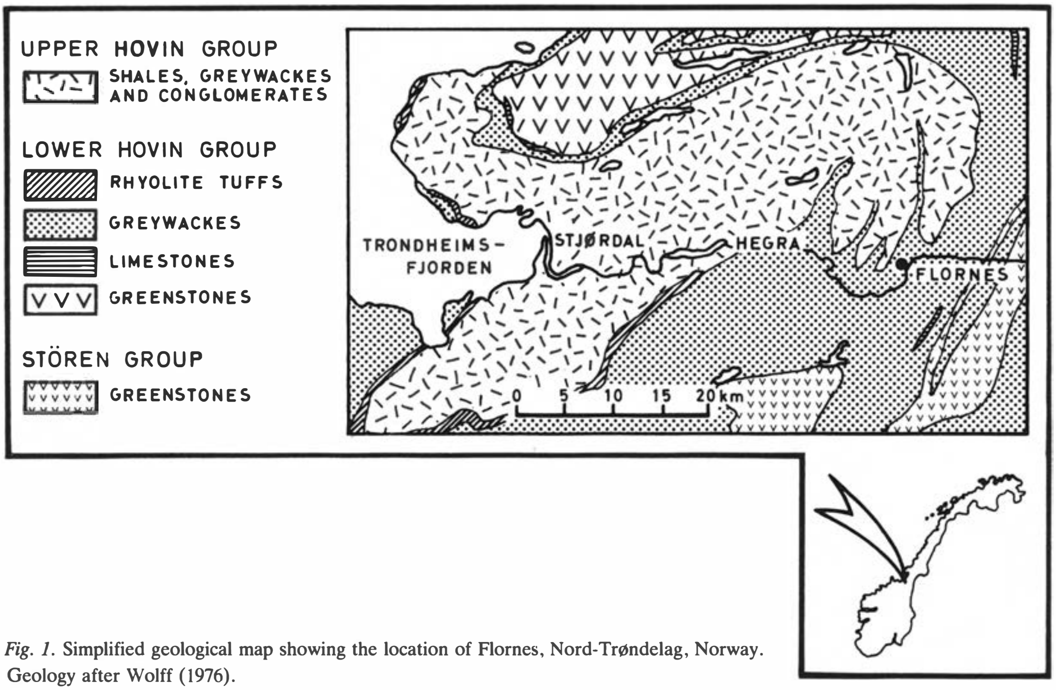

Fig. 1. Simplified geological map showing the location of Flornes, Nord-Trøndelag, Norway. Geology after Wolff (1976).

These structures could only be seen in the *sandstones*: cleavage eliminated all traces of structures which may have originally been present in the shales.

The ripple-marked bedding planes

On closer examination, the ripple marks seen on inverted bedding planes (Fig. 2) were found to

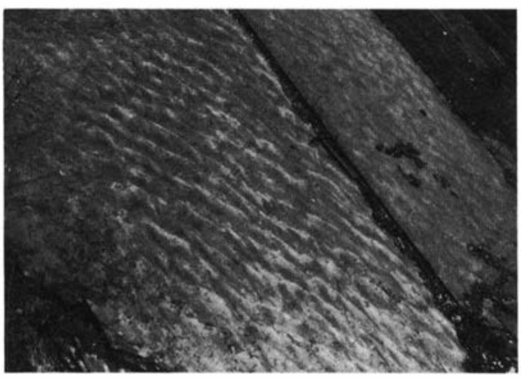

Fig. 2. Steeply dipping, inverted bedding planes showing ripple marks. (Strike 045^g; dip 50^g.)

consist of paper-thin schistose shales. As muds cannot be rippled in this way, it was considered that these might be *pseudo*-ripples formed by the intersection of bedding planes with micro-faulting on cleavage planes (see Hills 1963, his Figs. 11-16). But this is not the case.

By carefully stripping off the paper shales, layer by layer, thin, rippled, very fine sandstone streaks (mm-scale) were found in the very heart of the enveloping shaly laminae. The shales have clearly assumed this ripple morphology during compaction. Thus the shale 'ripples' are compaction features reflecting the unseen presence of thin rippled sandstones.

Sedimentary structures in thin sandstone beds and streaks

Under a binocular microscope, the sandstone streaks were seen to be composite in form. They consist of (mm-scale) couplets of very fine sandstone capped by clayey siltstone laminae. The tops of the sandstones usually grade into the siltstone. Each of the couplets is subject to rather symmetrical pinching and swelling which imparts to them a gentle undulatory and weakly lenticu-

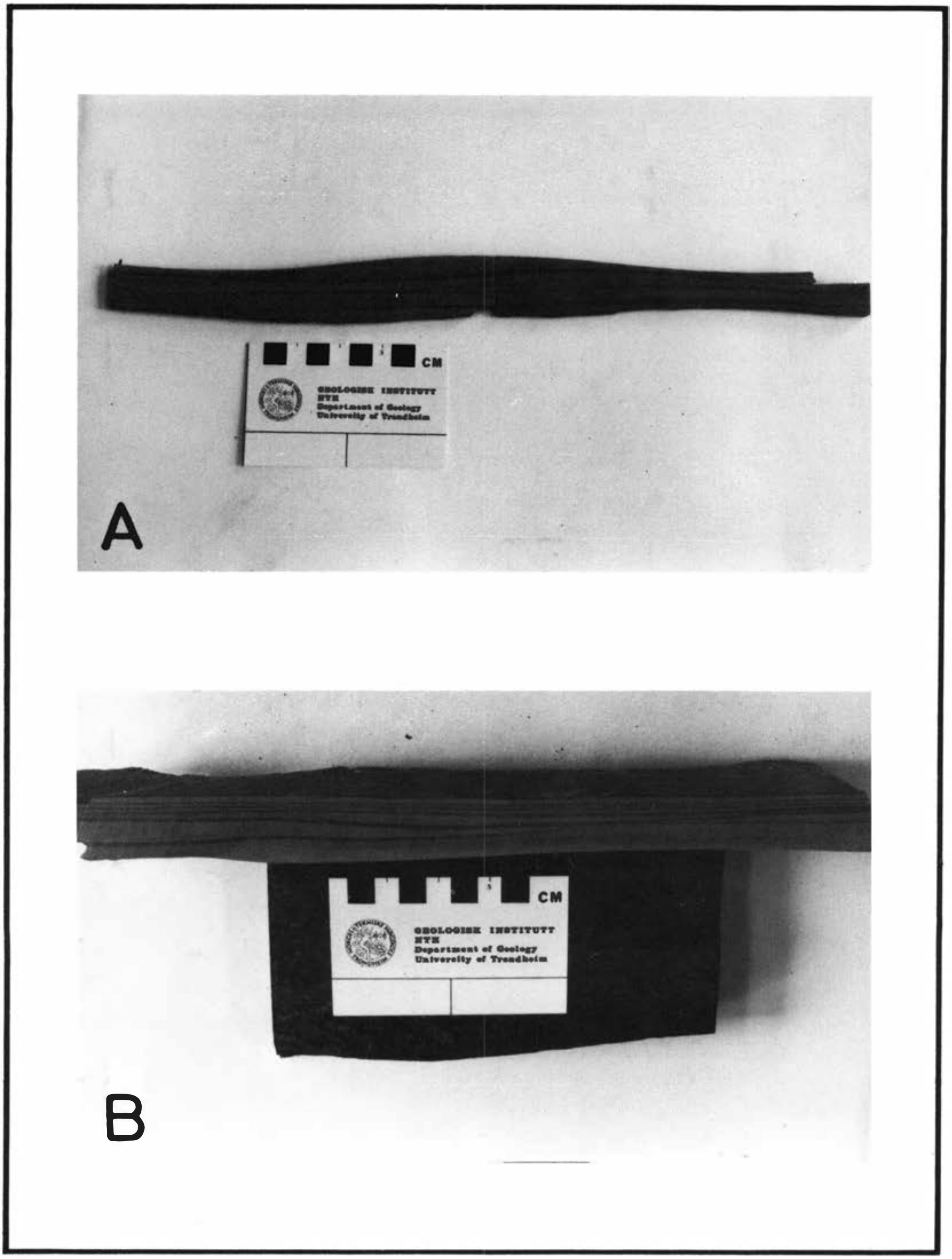

Fig. 3. A. Slabbed section of a composite, thin-bedded sandstone containing four sandstone-siltstone couplets. Note the rather symmetrical pinching and swelling of each couplet, and the systematic offsetting of 'nodes' and 'antinodes'. The surface of this composite bed (not illustrated) is distinctly hummocky. – B. Slabbed section of a composite thin-bedded sandstone showing the couplet thicknesses decreasing upwards. The base of this composite bed (not illustrated) contains sole markings (see Fig. 4).

Fig. 4. The directional sole markings (largely tool marks), seen here in shaly laminae, have been impressed downwards from the base of an overlying thin-bedded sandstone. The lineations from upper right to lower left are cleavage traces; the dark blebs are pyrite crystals.

lar appearance in section. The couplets are stacked in such a way that their 'nodes' and 'antinodes' are slightly offset. Swells and pinches are very weakly aligned, and it is this alignment which is mimicked in the paper shales to give the rippled surfaces. Internally the sandstone layers are either structureless, or contain weak laminations. The latter may be horizontal to sub-horizontal, gently curved or form-concordant, or very slightly asymptotic (usually less than 5°).

Thicker sandstone beds of cm–dm scale are also composites and, although of a larger scale, they contain features similar to those described for the sandstone streaks (Fig. 3A). There are, however, some significant differences. The lower and upper bounding surfaces of the beds contain an even weaker alignment of pinches and swells, and this results in the development of distinctive hummocky surfaces with smooth mounds and swales. Some beds contain finely oriented sole markings on contacts with the underlying shales (Fig. 4). The thicknesses of graded sandstone-siltstone couplets tend to vary considerably, and some of them thin upwards, thus imparting an overall fining-upward appearance (Fig. 3B). Laminations are (again) largely form-concordant, yet it is easy to be misled because the siltstones contain linear and refracted cleavage traces which look exactly like micro-crosslaminations.

Sedimentary structures in thicker sandstone beds

Composite beds of dm-scale consist of virtually amalgamated couplets of plane laminated fine-grained sandstone with thin shaly tops. The lamination is sometimes accentuated by the presence of flat-lying mud clasts. In section they may either have a wavy appearance, a gently undulating appearance, or they may be rather flat. Apart from the waviness, individual couplets bear some of the hallmarks of mass flows; that is, plane laminated sandstones whose tops are mildly gradational into very thin siltstones and shales. They may be distinguished from turbidites, however, because they do not consist of distinctive sandstoneshale interbeds.

Details of the internal stratification of the thickest fine- to medium-grained sandstones are difficult to see in the field, and the scale of these beds (dm–m) precludes any form of realistic sampling and subsequent slabbing. Nevertheless, a few of them do contain traces of structures which are believed to be similar in appearance to the hummocky cross stratified sandstones illustrated and described by Harms (1975), Hamblin & Walker (1979), Walker (1979) and Wright & Walker (1981).

The essential features are gently undulating sets of stratification which intersect each other at rather low angles (Fig. 5A). Lamination is typically form-concordant with the bounding surfaces of the hummocks and swales. The bases of the beds are mildly undulating; the tops of the beds are hummocky (Fig. 5B). (The difficult nature of the outcrop does not permit a more sophisticated or detailed description.)

Environmental interpretation

The environmental interpretation for all of these sandstones rests on a number of key observations. First, the ripple forms are always rather symmetrical (Figs. 2 & 3A), and this (as a first approximation) suggests some form of ripple moulding by wave action. Second, many of the sandstones are weakly graded and this suggests that sedimentation out of suspension predominated over sedimentation from traction currents. Third, typical angle-of-repose wave cross-stratification or lamination is absent, and this indicates that once the beds had been emplaced, they were not reworked by wave action. Fourth, the occurrence of oriented sole markings on some bed

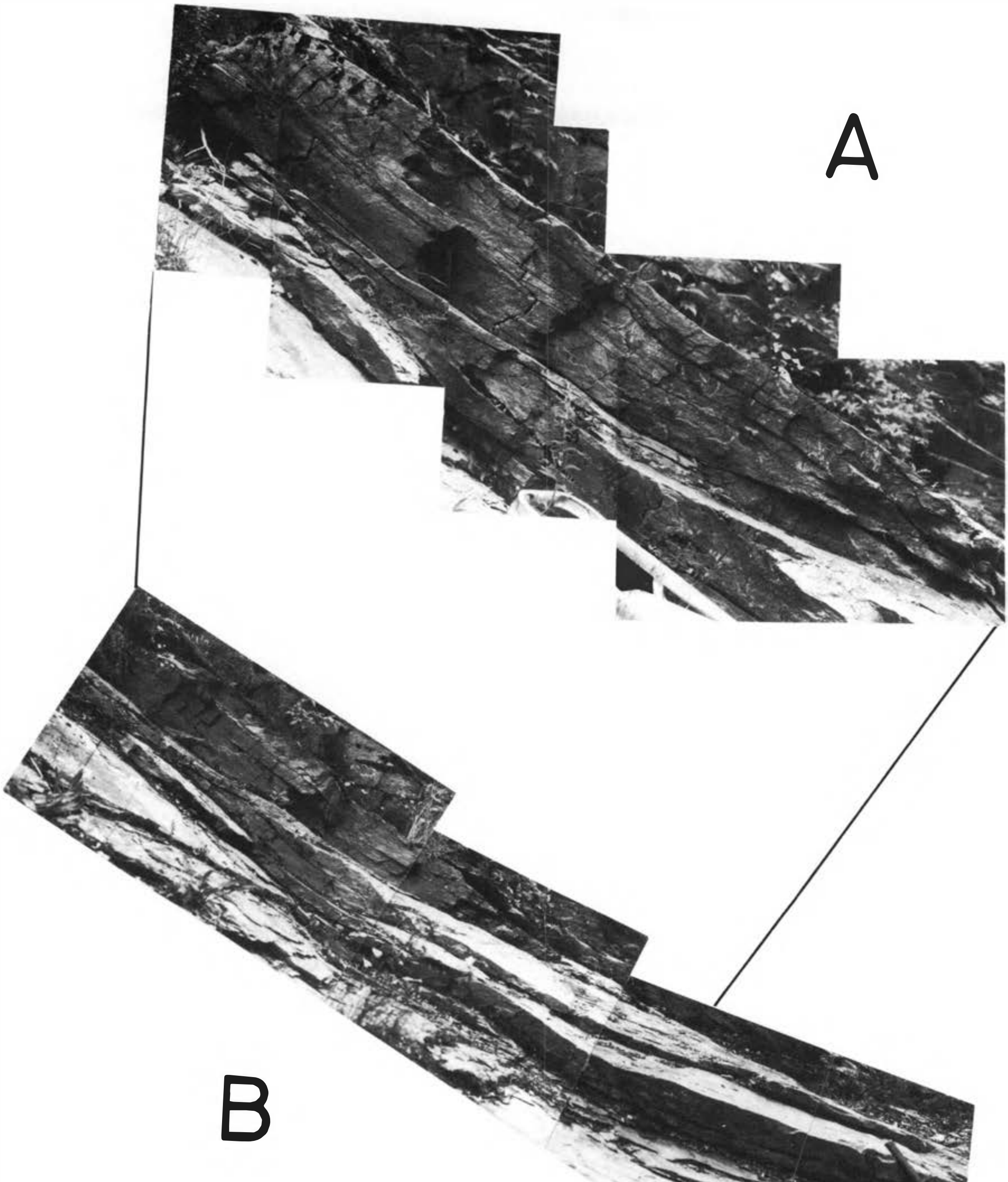

Fig. 5. Two photomosaics from the same locality showing hummocky cross stratification. Mosaic A, photographed in 1981, shows a detail of the low angle, curved intersection between two undulating sets of cross stratification. Mosaic B, photographed in 1982 (after the removal of unstable blocks to prevent rock-fall onto the adjacent road), shows the hummocky form of the *upper* bed. *Note* that the steeply dipping beds are inverted. The scale is provided by the hammer shown in the lower right-hand corner of B.

bases (Fig. 4) suggests the scouring action of density currents. And fifth, some of the beds contain structures which are normally attributed to mass flows. In short, there seems to have been some type of genetic influence (or influences) at work which combined the activities of waves and density currents to produce this hybrid association.

The styles of ripple morphology and the internal characteristics of the mm-scale sand streaks are very similar to those illustrated by de Raaf et al. (1977) for their $M_1$1 (swell and pinch) and $M_2$1 (incipient lenses) wave formed ripple lithotypes. Their interpretation for these is that they represent storm-emplaced fine sand layers which settled out of suspension (cf. Reineck & Singh 1972). The ripple forms may have been moulded at the same time as, or just after, deposition by wave activity related to the same storm. This activity did not, however, persist long enough (in our examples) to rework the storm-sand layers into forms containing typical wave cross lamination.

For the thicker sandstones (cm to cm–dm scales) the same genetic forces are believed to have been operative, only the storm-induced flow power must have been greater in order to transport greater volumes of sediment. The composite fining-upward appearance of some of the beds (e.g. Fig. 3B) may indicate deposition from decaying, pulsed, storm flows (cf. Brenchley et al. 1979, their Fig. 14d) which permitted 'fines' to increasingly drape thinner and thinner sand layers.

The dm-scale composite sandstones are similar to those described by Goldring & Bridges (1973; their Fig. 9B – without bioturbated tops). Their tentative conclusion regarding sheet sandstones of this type invokes the effects of storm-generated bottom currents.

The generation of hummocky cross-stratification (as seen in some of the dm-m scale sandstones, Fig. 5) is also thought to be dependent on storm influences (e.g. Wright & Walker 1981). It is argued that one of the effects of storms is the piling up of water along a coastline. This potential energy is then released by the generation of seaward-directed return flows which are sometimes capable of entraining sand and developing into relatively long travelling density currents. The internal structure and morphological characteristics of deposits derived from such density currents depend on the depths of water at the sites of final deposition. For example, thin-bedded turbidites may develop if deposition takes place in quiet waters below maximum storm wave base (e.g. Hamblin & Walker 1979). Hummocky cross-stratification may form if deposition occurs above maximum storm wave base, but below fair-weather wave base (see Walker 1979, his Fig. 15, p. 86). In this case the moulding of the hummocks and swales is thought to occur *immediately* after deposition from the density current suspension. The moulding is caused by storm waves touching bottom. The combined result of these two, almost simultaneous, processes is a hybrid structure, half mass flow, half wave formed. Finally, if deposition occurs above fair-weather wave base, at least the tops of hummocky cross-stratified beds will be reworked into typical wave cross stratification.

In the case of the Lower Hovin Group hummocky cross-stratified beds, the lack of any conventional cross stratification typical of wave action suggests that these were deposited between storm and fair-weather wave bases.

Conclusions

All the available evidence (i.e. wave ripple forms, hummocky surfaces, traces of hummocky cross stratification, graded sandstone-siltstone couplets, sole markings, and the lack of typical wave cross-stratification) leads to the following conclusions:

(1) that the Lower Hovin Group sandstones in question were deposited in a *relatively* shallow marine environment of deposition; and
(2) that they were emplaced under the influences of storm-induced density currents, with many of them being moulded into rather symmetrical ripple and wave forms (hummocks and swales) by storm waves touching bottom.

The depositional site was clearly below fair-weather wave base and above storm wave base. Such a site may be designated as offshore, perhaps towards a shelf or slope edge. The association of some relatively unmodified mass flows, together with the wave moulded or wave influenced sands, suggests that the depositional site was rather close to the *maximum* storm wave base. The absence of recognisable burrows and bioturbation may also lend weight to this idea (bearing in mind that the finer sediments are cleaved, and this may have destroyed all evidence of animal activity).

This environmental setting fits sensibly into the existing stratigraphic sequence in that the sandstone association is underlain by discontinuous limestones of presumed shallow water origin, and is overlain by thin-bedded turbidites.

Acknowledgement. – The authors are indebted to the late Prof. Chr. Oftedahl for pointing out the rippled surfaces during a field excursion.

Manuscript received August 1982,
revised October 1982

References

Brenchley, P. J. Newall, G. & Stanistreet, I. G. 1979: A storm surge origin for sandstone beds in an epicontinental platform sequence, Ordovician, Norway. *Sediment. Geol. 22,* 185–217.

Bruton, D. L. & Bockelie, J. F. 1980: Geology and palaeontology of the Hølonda area, western Norway – a fragment of North America? *In* Wones, D. R. (ed.), The Caledonides in the U.S.A. I.G.C.P. project 27: Caledonide Orogen 1979 meeting, Blacksburg, Virginia. *Dept. Geol. Sci. Va. Poly. Inst. & State Univ., memoir no. 2,* 1980, 41–47.

De Raaf, J. F. M., Boersma, J. R. & Van Gelder, A. 1977: Wave-generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland. *Sedimentology 24,* 451–483.

Gale, G. H. & Roberts, D. 1974: Trace element geochemistry of Norwegian Lower Palaeozoic basic volcanics and its tectonic implications. *Earth Planet. Sci. Letters 22,* 380–390.

Goldring, R. & Bridges, P. 1973: Sublittoral sheet sandstones. *J. Sediment. Petrol. 43,* 736–747.

Hamblin, A. P. & Walker, R. G. 1979: Storm-dominated shallow marine deposits: the Fernie-Kootenay (Jurassic) transition, southern Rocky Mountains. *Can. J. Earth Sci. 16,* 1673–1690.

Harms, J. C. 1975: Stratification and sequences in prograding shoreline deposits. *In* Harms, J. C., Spearing, D. R., Southard, J. B. & Walker, R. G., *Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences,* Lecture notes for S.E.P.M. short course no. 2, 81–102, Dallas, Texas.

Hills, E. S. 1963: *Elements of Structural Geology.* Science Paperbacks & Methuen & Co. Ltd., 483 pp.

Reineck, H-E. & Singh, I. B. 1972: Genesis of laminated sands and graded rhythmites in storm-sand layers of shelf mud. *Sedimentology 18,* 123–128.

Roberts, D. 1968: Tectonic features of an area NE of Hegra, Nord-Trøndelag, and their regional significance-preliminary notes. *Nor. geol. unders. 225,* 10–20.

Roberts, D. 1969: Trace fossils from the Hovin Groups, Nord-Trøndelag, and their bathymetric significance. *Nor. geol. unders. 258,* 228–236.

Roberts, D. & Gale, G. H. 1978: The Caledonian-Appalachian Iapetus Ocean. *In* Tarling, D. H. (ed.): *Evolution of the Earth's Crust.* Academic Press, London, New York, 255–342.

Ryan, P. D. & Williams, D. M. 1980: A revised interpretation of the Ordovician stratigraphy of Sør-Trøndelag, and its implications for the evolution of the Scandinavian Caledonides. *In* Wones, D. R. (ed.), The Caledonides in the U.S.A. I.G.C.P. project 27: Caledonide Orogen 1979 meeting, Blacksburg, Virginia. *Dept. Geol. Sci. Va. Poly. Inst. & State Univ., memoir no. 2,* 1980, 99–105.

Siedlecka, A. 1967: Geology of the eastern part of the Meråker area. *Nor. geol. unders. 245,* 22–58.

Walker, R. G. 1979: Facies models 7. Shallow marine sands. *In* Walker, R. G. (ed.), Facies Models. *Geoscience Canada, Reprint Series 1, Geol. Assoc. Canada,* 75–89.

Wolff, F. Chr. 1976: Geologisk kart over Norge, berggrunnskart Trondheim 1:250 000. *Nor. geol. unders.*

Wright, M. E. & Walker, R. G. 1981. Cardium Formation (U. Cretaceous) at Seebe, Alberta – storm-transported sandstones and conglomerates in shallow marine depositional environments below fair-weather wave base. *Can. J. Earth. Sci. 18,* 795–809.