

To me the major problems are the production of the sheets themselves and their fabric, and the development of the lineation on them rather than their folds, etc.; once the sheets are present in the sequence their particular deformation features seem to follow from the regional deformation.

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Tectonic ripples and associated minor structures in the Silurian rocks of Denbighshire

SIR,—We are grateful to Dr Nicholson for his interest in our paper (*Geol. Mag.* **107**, 51–60). In the absence of photographs illustrating the megascopic features of the calcite-quartz bodies in the Silurian rocks of the Llangollen area (described by Wedd *et al.* 1927; Nettle, 1964, and himself, 1966), we have examined a number of localities there. Whilst there is a superficial resemblance between the structures associated with these bodies and certain examples of some of our structures, we cannot agree, for the reasons outlined below, that there is any real similarity, in either appearance or origin.

The calcite veins in the Llangollen area, for example at Moel y Faen Quarry, occur along high-angle joints which are members of a conspicuous set of master joints, locally parallel to the highly inclined bedding. In some cases, as Nicholson himself states (1966, p. 118), the veins are not parallel to the bedding. In contrast, our tectonic ripple horizons invariably correspond to the generally low-angle bedding of the Denbigh area.

The presence of calcite, we believe, is not a prerequisite for the formation of tectonic ripples. Indeed, as we pointed out (p. 58) there is no evidence that the carbonate seen, for example, at Gorsedd Brân (Loc. F) predated the initiation of the shearing movements responsible for them, any more than did the chlorite-quartz association at Creigiau Quarry (Loc. B). Furthermore we cannot agree that calcite has been present at all our tectonic ripple horizons, or that when present it played the same role as in the Llangollen structures. The choice of the Gorsedd Brân specimen for a photomicrograph was governed by its obvious photogenic qualities in illustrating the shape and dimensions of the tectonic ripples. Since the publication of our paper four further localities have been recorded in North Wales and our attention has been drawn to the occurrence of tectonic ripples in Ordovician and Silurian rocks of the Lake District (R. B. Rickards, *in litt.*) and elsewhere in Britain and Continental Europe. In the majority of cases the characteristic appearance is of 'positive' and 'negative' ripples separated only by mylonitic crush rock. Removal of this mylonite gives rise to the gap referred to by Dr Nicholson.

More significantly, tectonic ripples and the associated structures are all developed

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essentially in the country rock, although this may now include layers of chlorite-quartz, goethite or calcite separating a number of micro-horizons of rippling. The Llangollen structures, in marked contrast, are in essence small folds in vein (calcite) material. They appear to us to have a general resemblance to normal, slickensided deformed veins seen through much of the stratigraphical column.

In detail, the contrast is even greater. The structures present in the mudstone adjacent to the vein, at Moel y Faen Quarry for example, appear to be a lineation resulting from the bedding/cleavage intersection and emphasized by subsequent weathering, which is quite clearly not the case with the tectonic ripples (Warren *et al.* Table 1). Furthermore, slickensides in the Llangollen area occur in the vein material and are subparallel to the above lineation, whilst those of the Denbigh area are on rock surfaces and lie at right angles to the ripple axes: this, despite the fact that in both areas the regional structure is similar with predominant E-W bedding, cleavage and fold axes.

As Dr Nicholson agrees, mullions do not appear to have been recorded previously, and their intimate association with the ripples and slickensides provides further evidence of the dissimilarity between the various structures in the two areas. Although mullions are recorded from only a few localities, there would appear to be an inverse relationship between them and the tectonic ripples: our two photographs (Plate 2) illustrate the 'end-members'.

Finally, although we do not wish at this stage to enter into arguments on the origin and dating of either his or our structures, we must make one point clear. Despite Dr Nicholson's assertions to the contrary, we reaffirm that, as stated in the summary of our paper, the tectonic ripple horizons are part, albeit a late phase, of the main deformation of the Denbighshire Silurian. We see no reason for changing our proposed (p. 60) sequence of tectonic events.

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