John's Road and Agate Point

[NT 9528 6411]–[NT 9547 6410]

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Highlights

The plunge variations at John's Road are extraordinary, by the standards of any slate-belt folding, and are certainly the best exposed and most dramatic yet described in the 'non-metamorphic' Caledonides. The plunge variations occur in a zone some 300 m wide, but the regional context is not known.

Introduction

This site is located in the Llandovery rocks of the Central Belt (Figure 2.1) in the poorly described Berwickshire coastal section. Originally reported in the Geological Survey Sheet Memoir (Geikie, 1863), they have subsequently attracted the detailed description by Dearman *et al.* (1962). The regional setting of this coast section appears to be broadly similar to that of the Hawick Rocks in the Scottish south-west coastal sections (see below).

Unfossiliferous Silurian greywacke siltstone and cleaved shale generally dip steeply to the northwest and young in the same direction, but in detail are affected by folds, of a variety of scales, with gentle plunge and south-east vergence.

Dearman *et al.* (1962) described a zone on this coast, some 250 m wide across strike, in which the regional fold pattern alters to one in which fold plunge changes not only to vertical and steeply downward-facing (as in the Isle of Whithorn), but also to gently plunging, downward-facing attitudes. Agate Point and John's Road are the two principal localities which Dearman *et al.* (1962) described within this zone.

Description

In the 4 km coastal exposures, between Eyemouth and Burnmouth, the rocks show the typical structural features of this belt of the Southern Uplands, with steep or north-west-dipping and north-west-younging sequences, interrupted by folds with wavelengths of between 5 m and 20 m. These folds are open to tight, south-east-verging, with gentle plunges to the south-west or northeast, and are upward-facing on subvertical axial surfaces. In the Eyemouth area, immediately north-west of the site, fold plunges of 20–40°SW are characteristic, with variations up to 50°SW and 20°NE. About 100 m north of John's Road, plunge values to the south-west begin to increase; no obvious planes of movement are associated with this change. The plunge variations continue in a zone of some 300 m with a return to more usual plunges to the south of Agate Point. The zone may, in fact, extend beyond this point, but no data are available in the rather inaccessible cliff section to Burnmouth. Two localities have been selected in this zone, described in detail by Dearman *et al.* (1962), because they provide the best exposures of the full plunge variation.

Agate Point [NT 9541 6411]

This area, some 25 m by 50 m, illustrates the typical plunge behaviour of the folds; the folds (Figure 2.4) can be followed on to the islands to the north-east of the site. The map is based on Figure 3 in Dearman *et al.* (1962). Four greywacke units were mapped around the axial surfaces of four folds (1–4 on map). The folds are tight, with limb dips about the vertical, striking NNE or NE. Sedimentary structures provide clear evidence of the direction of younging, as indicated.

Plunge varies within the site, from 20° upward facing, to 28° downward facing. Fold 1 shows the most marked and rapid variation from 70°NE (downward-facing), through the vertical to 50°SW (upward-facing) over some 15 m. To the north-east, this fold can be traced to beds where hinges plunge as low as 20°SW. Folds 2, 3 and 4 all show similar variations, from vertical to 45°NE (downward-facing). Discontinuities occur on the fold limbs (see map) and may well have been essential, as zones of high shear strain, to the mechanism whereby the steep plunges were achieved.

John's Road [NT 9536 6414]

This locality is one rib of rock, some 40 m by 10 m, in a broader zone of plunge variation. The exposure illustrates, particularly well, plunge variation in three dimensions. The exposure is well documented in Dearman *et al.* (1962, Figure 5; see (Figure 2.5), this volume). The greywacke–shale sequence here is folded into a prominently displayed anticline–syncline pair, which plunges steeply south-west. Successive fold hinges, of this fold pair, can be followed to the north-east where they rapidly pass through the vertical and assume low plunges (30° and less) towards the north-east. These folds can be shown, from the younging evidence, to be downward-facing and provide a most dramatic illustration of the plunge variation. Again, discontinuities can be observed on fold limbs and these, together with beds of disrupted material, may provide evidence of the origin of the plunge variation.

In both localities, the shale beds are affected by a weakly developed cleavage, which is NE–SW-trending and broadly parallel to the axial surfaces of the folds. No mineral fabric, or other exceptional textural features of finite strain, have been observed in the field, which might be used to explain the exceptional fold plunge variation.

Interpretation

The interest of this site lies not only in the unusual range of plunge variation, but in the short distance over which it occurs. Within the Southern Uplands, the features exhibited in the site are unique; comparable examples have not been described. Somewhat similar features have been reported by Stringer and Treagus (1980, 1981) and the Isle of Whithorn site described in this volume; in these instances, however, the plunge variation is neither as extreme, nor is it seen to occur over such short distances.

Dearman *et al.* (1962) attribute the plunge variation to refolding, claiming that 'it can be demonstrated that folds, with a NE–SW axial trend, have been refolded about NW–SE axes and that the two show a common axial plane' (p. 275). In discussion of the paper by Dearman *et al.* (1962), Westoll (p. 283) comments, that such a phenomenon might be a consequence of 'a single continuous movement picture' resulting from the directions of expulsion of intergranular water. Other speakers comment on the lack of superimposed minor structures and the possible contribution of wet-sediment deformation (pp. 284–5). Stringer and Treagus (1980 pp. 328–9), in their discussion of plunge variations seen in a somewhat similar zone in the south-west Southern Uplands, appeal to heterogeneous strain both within the zone and of the zone itself relative to the rocks outside, and to the physical rotation of packets of folds bounded by shear planes.

There has been widespread interest in reports of strongly curvilinear and 'sheath' or 'eyed' folds in recent years. These reports (Roberts and Sanderson, 1974; Cobbold and Quinquis, 1980) have been based on observations in the field of modelled folds where strong extensional strains are observed. However, there is no evidence of such strong extensional strains, or indeed, of any unusual strain pattern in the rocks where these phenomena are reported from the Southern Uplands.

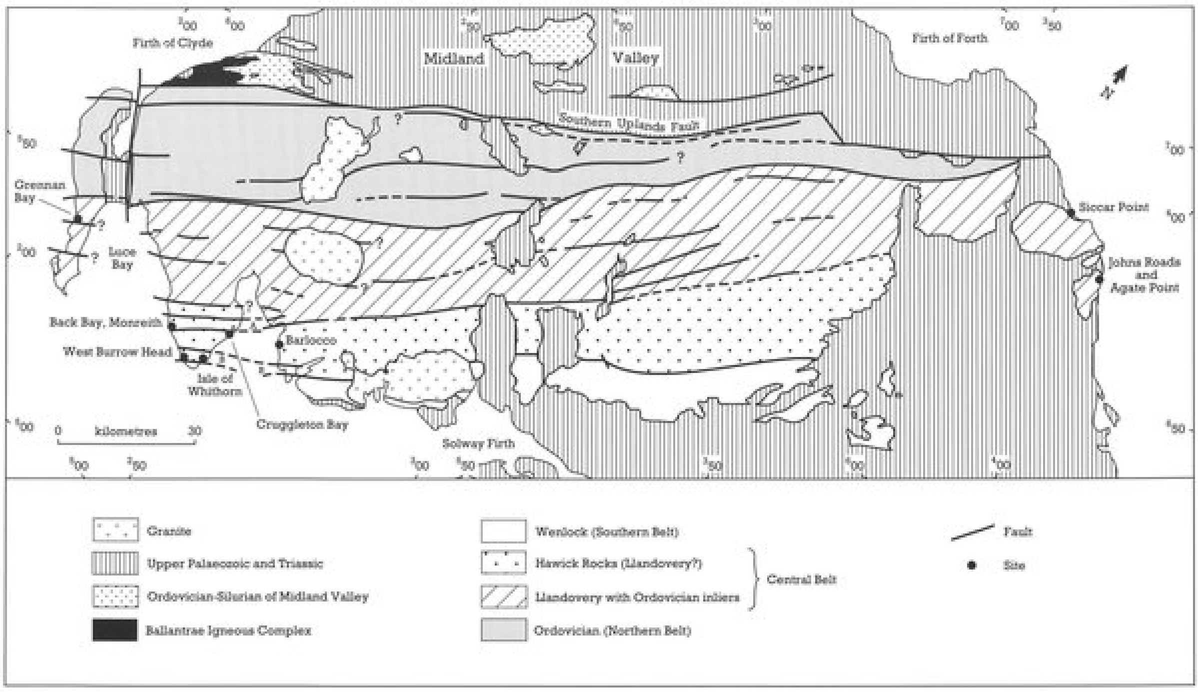
The rocks of this site do exhibit two features which may be important in future research. Some sequences are noticeably disturbed and individual beds cannot be traced far along strike. This may be due to bedding-plane movements during folding and, certainly, there are also discordant zones along which there is similar disturbance. However, it is possible that the fold plunge variation might be partly attributed to the existence of soft-sediment folding (cf. Webb and Cooper, 1988, describing similar situations in the Lake District), which pre-dated the tectonic folding and with which the local chaotic bedding might be associated. Irregularity of bedding leads to discontinuous beds which furthers variation in plunge.

In the part it has to play in discussion of the accretionary prism model that has been advocated for the Southern Uplands (see Chapter 1), this site may be important in two respects. Firstly, this zone of unusual plunge variation, like that to the southwest, may be indicative of local strain gradients associated with thrusting (Stringer and Treagus, 1980) and secondly, it may be significant in the clear association cited by authors of wet-sediment movement within the accretionary prism setting (Kemp, 1987; Knipe and Needham, 1986).

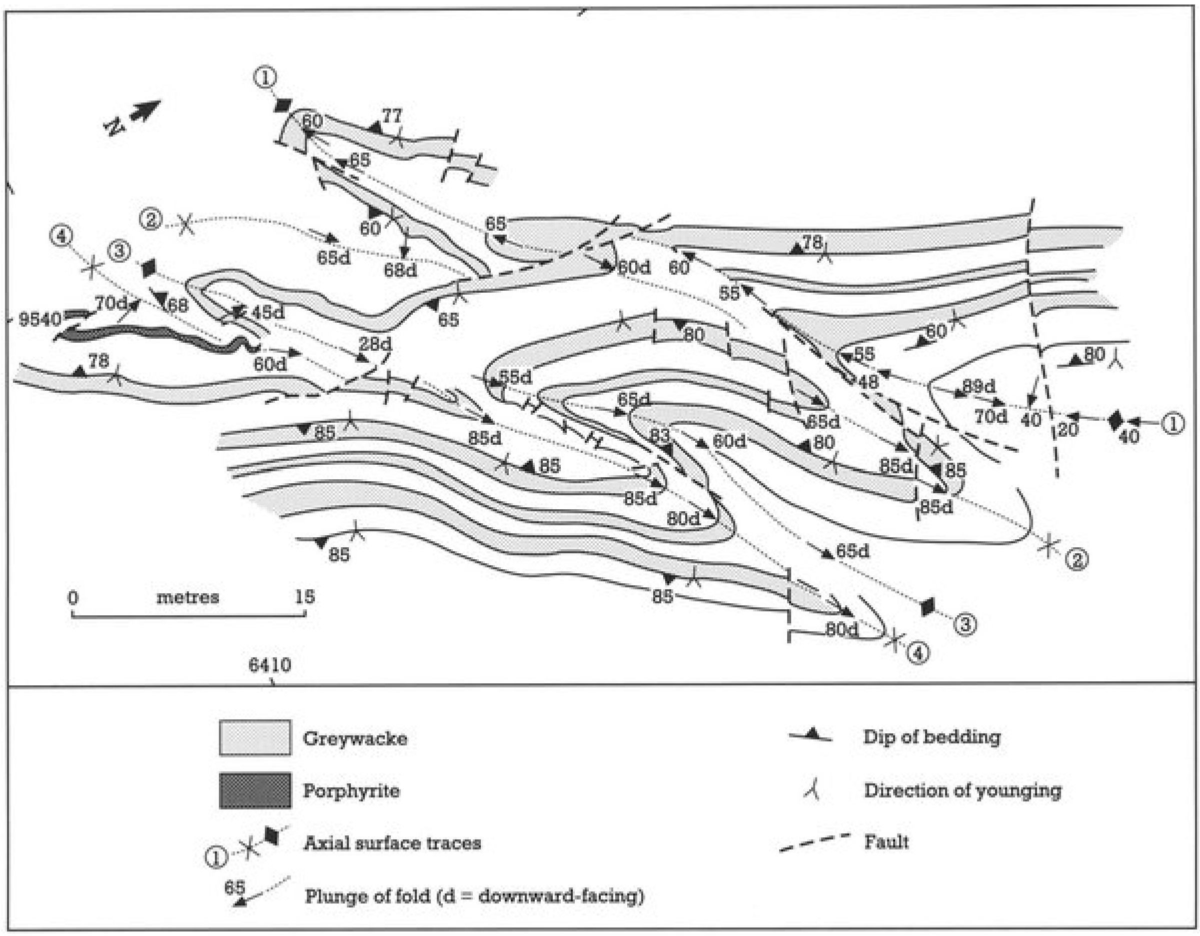
Conclusions

This site is included, primarily, for its particularly clear exposures of local zones of unusual complex folding. These contortions were perhaps produced by the intense compressive stress that was generated during the Caledonian mountain-building episode (orogeny). In general, fold structures elsewhere have a fairly regular form, but at this locality the hinges of the folds are strongly curved, sometimes by as much as 165°. This is exceptional not only in the Southern Uplands but in the Caledonian Orogenic Belt as a whole. These zones are important in understanding the evolution of the large-scale structure of the Southern Uplands, as indicating the presence either of local strain gradients associated with thrusting or horizons which suffered wet-sediment deformation, the latter associated with the accretionary prism which, prior to the orogeny, existed on the northern side of the Iapetus Ocean.

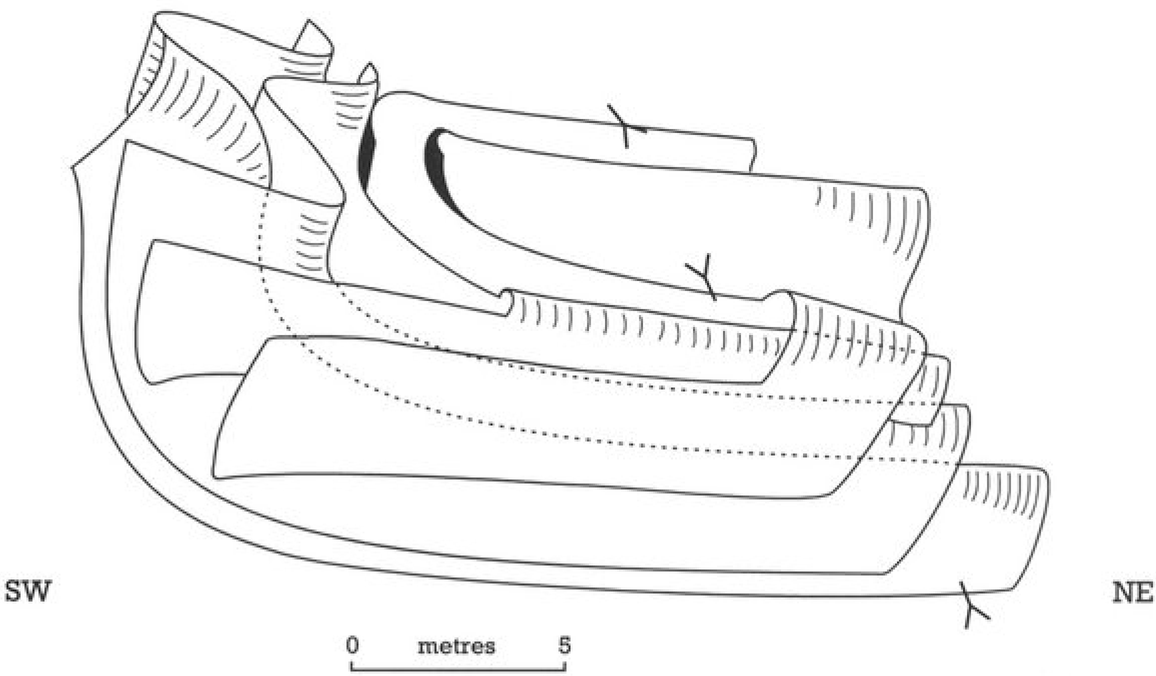
References



(Figure 2.1) Geological map of the Southern Uplands, showing the distribution of the three main belts, some of the steep faults that bound these belts, and subsidiary tracts. The positions of the sites discussed are also shown. A and B, in the south-west, show the zones of D_2 folding and steep D_1 plunge respectively, as discussed in the text.



(Figure 2.4) Geological map of Agate Point (after Dearman et al., 1962).



(Figure 2.5) Diagrammatic representation of the folds at John's Road (after Dearman et al., 1962).