Helwith Bridge

[SD 803 700]

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Highlights

The site provides continuous exposure across an anticline affecting Lower Palaeozoic rocks. This fold shows the ESE trend of the Caledonian structures, in some of the easternmost exposures in Britain. The exposures also exhibit the slight anticlockwise transection of the folds by cleavage. Both the ESE trend and the transection sense are considered to be important evidence for the geometry of the southern margin of Iapetus and of its movement during closure.

Introduction

Twenty kilometres south-east of the Lake District, the Lower Palaeozoic rocks outcrop as a 15 km^2 inlier surrounded by Carboniferous strata. The principal inlier, centred on Horton-in-Ribblesdale, between Austwick and Malham (see (Figure 3.1)), contains Arenig Series (Ingleton Group) and Ashgill Series (Coniston Limestone Formation) rocks, but is predominantly composed of later, Silurian turbidites and siltstones. The stratigraphy and structure of the inlier has recently been revised and reviewed by Arthurton *et al.* (1988), building on previous structural work by King and Wilcockson (1934).

The dominant structure is the ESE–WNW-trending Studrigg–Studfold Syncline, which preserves Ludlow Series rocks in its core, in the envelope of Wenlock formations. This fold is flanked by the Crummock Anticline to the north and the Austwick Anticline to the south, with a wavelength of some 3 km. Smaller-scale folds, with wavelengths of up to 300 m, open to upright style and plunges up to 25° to the ESE, are seen in most formations but particularly within the Horton Formation of Ludlow age (Arthurton *et al.,* 1988), partly equivalent to the Horton Flags of King and Wilcockson (1934) and the Horton Formation of McCabe (1972) and McCabe and Waugh (1983). The lithology is laminated, micaceous, somewhat calcareous, sandy siltstones, which generally exhibit a well-developed, spaced cleavage. The formation correlates with the Upper Coldwell Beds, below the Coniston Grit Formation of the Lake District. King and Wilcockson (1934, Plate 1 and Figure 7) mapped the folds in the area of the site, between the Arcow Wood and Combs Quarries, showing the 100–300 m wavelength, the open style, axial trend to 120° and plunge up to 20° to the ESE.

The anticline that has been selected here is the anticline shown by King and Wilcockson (1934, Plate 1:[SD 803 700]) south-east of the Foredale Lime Quarry. This fold is exceptionally well exposed in three dimensions, with the hinge plunging subpar-allel to the hillside.

Description

The principal exposure is in the hinge region of the anticline, which is seen almost completely in a 40 m-wide exposure on the hillside [SD 8035 7002]–[SD 8027 7008]. However, isolated exposures, to the south-east and east of the exposed hinge, give a more complete picture of the extreme limb dips, which reach 130/35°NE on the north limb and 087/35°S on the south limb. In the north of the site, bedding turns into the adjacent syncline.

The attitude and geometry of the fold are best illustrated by a profile section across the hinge region. The one illustrated was taken about two-thirds up the exposure [SD 8032 7006] and the data are presented here in a stereogram (Figure 3.20). The data in this and similar sections show the fold to be almost perfectly cylindrical, open in style, with axial plane (constructed) 119/88°N and plunge 18/118°.

The cleavage can be measured almost anywhere in the exposure and is approximately axial-planar, being subvertical and trending ESE. However, even by eye, an impression can be gained that the cleavage does, in fact, transect the

hinge region in an anticlockwise sense. Precise measurement, across the hinge region reveals a very slight fanning, with very steep dips towards the south on the north limb, but subvertical on the south limb (Figure 3.20). More importantly, however, the non-axial planar relationship of the cleavage is confirmed by strikes up to 10° anticlockwise of the constructed axial plane and by more gentle intersection lineations (which are well developed on both cleavage and bedding) on the south limb (for example, 12/108°) than on the north limb (for example, 20/110°). (Figure 3.20) clearly illustrates how the anticlockwise strike of the cleavage from the axial plane and fold hinge produces this relationship.

Interpretation

The relationships described have been measured recently by Soper *et al.* (1987) in their analysis of the fold and cleavage swing across north-west England. The site was chosen to exemplify two features of the easternmost exposures available; firstly, that the swing in strike reaches ESE, secondly, that in contrast to the clockwise transec-tion usually seen in the western and central Lake District, it is here distinctly anticlockwise.

The first of these features is clear from the bedding and cleavage data presented (Figure 3.20) and should be compared with that at Shap Fell and Tebay. This trend appears to be common to all the rocks in the inlier, according to the data of King and Wilcockson (1934) and Arthurton *et al.* (1988 and accompanying map sheet 60 of 1:50 000 BGS Series). The latter authors comment (p. 97) that the folds decrease in wavelength and amplitude to the north-west. The 20° plunge of the fold also appears to be typical of that in the inlier, although variation to 8° occurs both locally and regionally. In the Shap area, Moseley (1968) claims that the 5° easterly plunge is due to post-Carboniferous tilting. At Horton, the unconformable Carboniferous is virtually horizontal, so it would appear that the dominantly north-easterly plunge of the western Lake District is re-established here.

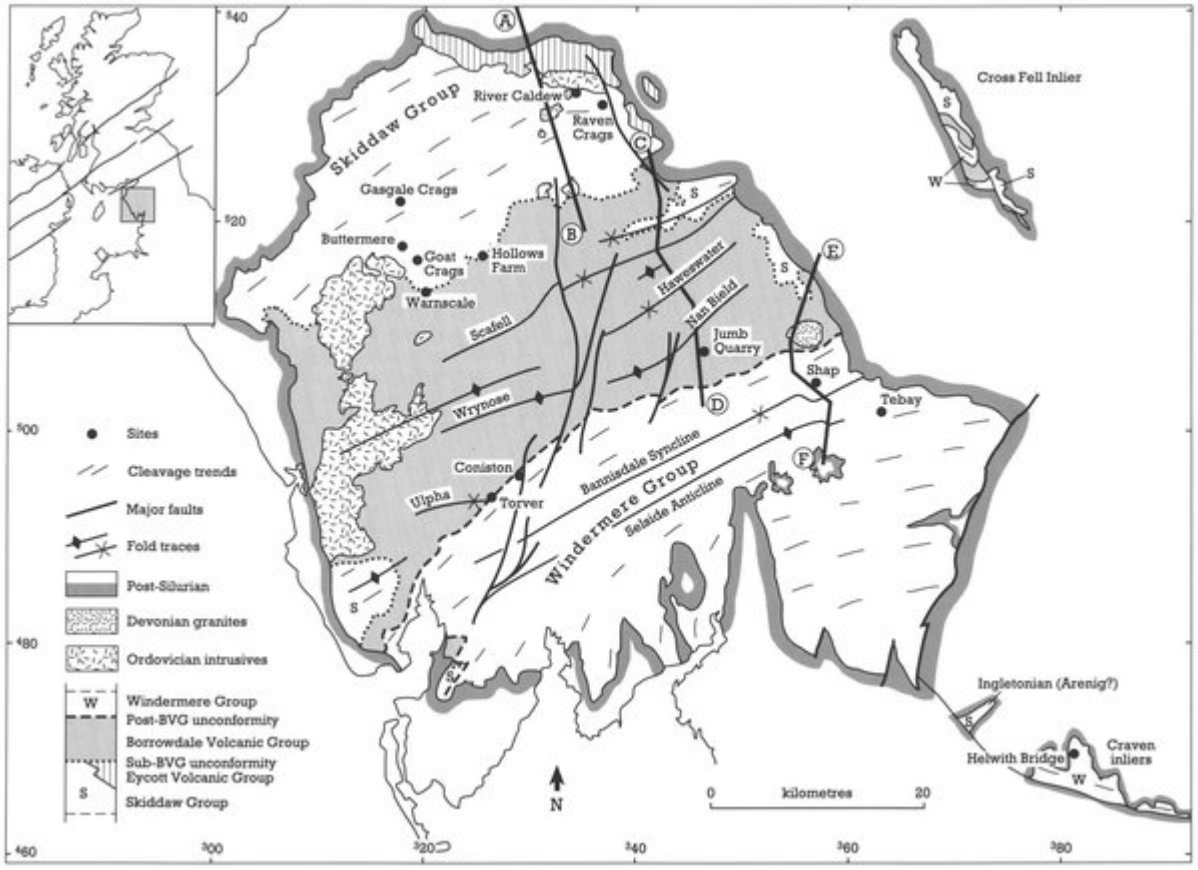
The anticlockwise transection of the axial planes by the cleavage is subtle, but measurable. The strike difference between the two subvertical planes is about 8° and produces plunge angle variations of up to 15° for intersection lineations. As explained in the Introduction to this chapter, a clockwise non-axial plane relationship has been increasingly recognized in the Southern Uplands, the Lake District and Wales. It is generally ascribed to be the result of sinistrally oblique compression which affected most of the British Caledonides during the final closure of Iapetus.

The reader is referred to Soper *et al.* (1987) for details, but the interest and importance of the Horton transection is that the change from a clockwise to this anticlockwise sense coincides with the swing in regional strike. This swing is interpreted as reflecting the detailed geometry of Caledonian structures on the southern flank of Iapetus. There they were moulded around the Precambrian Midland Massif during transpressive N–S closure of the ocean. On a regional scale this swing is related to the 'third arm' of the Caledonides, which runs from the North Sea into the German–Polish Caledonides (Tornquist's Sea Convergence Zone — see Figure 2, in Soper *et al.,* 1987). Thus, the change in transection sense described and discussed above is suggested to be a direct reflection of the contact strain around this Midland indenter and is therefore an important element in the understanding of both the geometry of the southern margin of Iapetus and its closure.

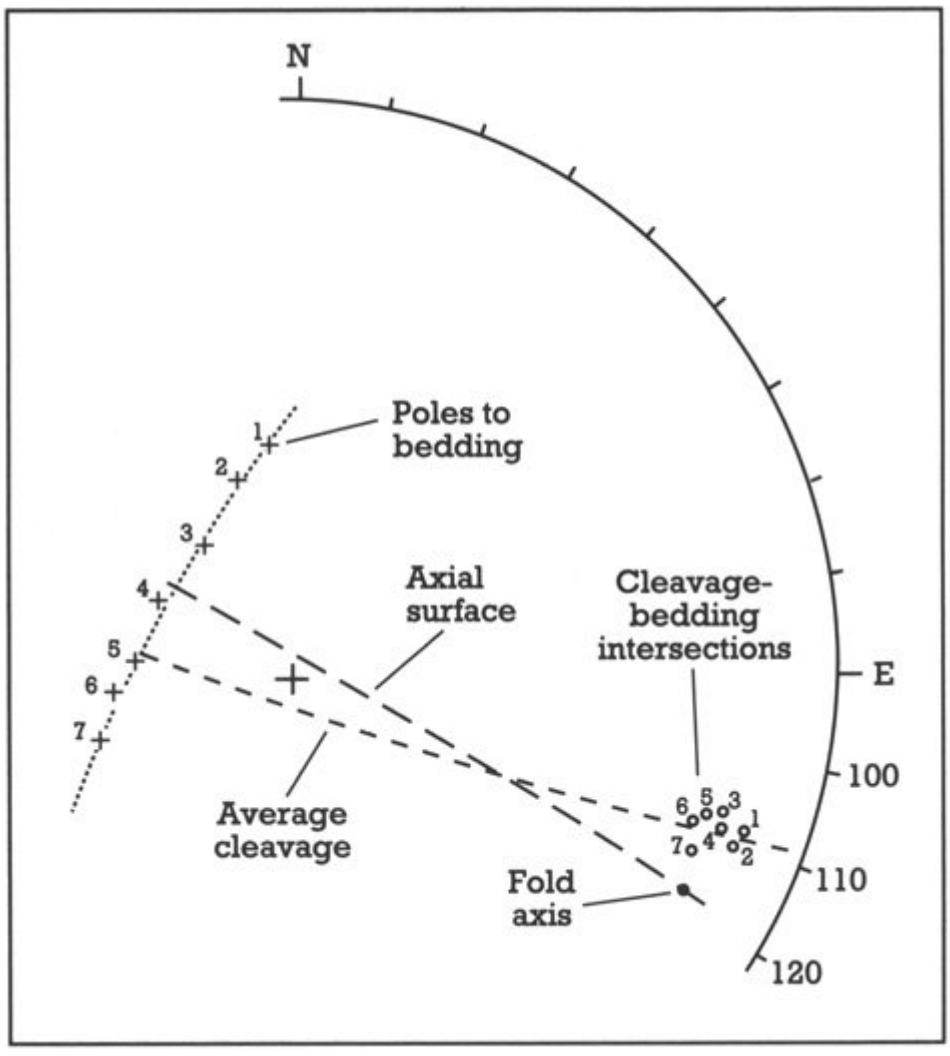
Conclusions

This site is important, not only as an example of the swing in Caledonian structure to ESE in the eastern Lake District, but it is also an example of the change in the east of the orientation of cleavage (fine, parallel fractures) relative to the ESE trend of the folds. This 'anticlockwise transec-tion' of the folds by the cleavage is significant. Both features have been used recently to demonstrate the progressive swing in the trends of Caledonian structures around the Midland Platform. Soper *et al.* (1987) thought that the trend of the folds was modified by the solid mass of the English Midlands, against which the Lake District was forced when the latter collided with the northern (Scottish–American) continent as the Iapetus Ocean closed, in the final stages of mountain-building (orogeny).

References



(Figure 3.1) Geological map of the Lake District, and Cross Fell and Craven Inliers, showing lithostratigraphical groups, and major folds and faults of Caledonian age (adapted from Moseley, 1972; Branney and Soper, 1988).



(Figure 3.20) Stereographic representation of data from Helwith Bridge. Poles to bedding (crosses) numbered across the anticline with corresponding numbers at bedding–cleavage intersections (open circles).