Cruggleton Bay North

[NX 4770 4981]–[NX 4850 4998]

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Highlights

Three folds on the foreshore of the north side of Cruggleton Bay illustrate one of the most interesting features of the D_1 deformation in the Hawick Rocks, that of folds transected by a contemporary cleavage. Cruggleton Bay also illustrates the typical geometry of D_1 folds in the Central Belt of the Southern Uplands.

Introduction

The rocks of the Cruggleton Bay area are the typical greywackes, siltstones, and mudstones of the Hawick Rocks. Their structure was first described by Rust (1965), although this coastal section must have provided inspiration for Lapworth's (1889, Figure 3) influential cross-section of the south-west Southern Uplands. In his discussion of the deformation of the Whithorn area generally, Rust (1965) clearly regarded folds, such as those seen at Cruggleton Bay, as D_1 (his F_1), but the cleavage that crosses them in a clockwise sense he considered to be later (his F_3). Stringer and Treagus (1980, 1981) interpreted the cleavage as essentially contemporary with the folds, although having a non-axial plane (transecting) relationship to them.

The site is not as continuously exposed as adjacent parts of the coast, but it offers the best opportunity to observe the full three-dimensional relationships between D_1 folds and the clockwise transecting cleavage (Figure 2.7).

Description

The exposures of interest are seen in three anticlinal folds which protrude from the low-lying foreshore (Figure 2.8A).

Fold A [NX 4770 4981]; see (Figure 2.8)B illustrates the geometry of the non-axial planar cleavage, developed in a slightly reddened mudstone in the hinge area of a fold. The fold is a tight anticline, plunging gently about the horizontal, both to the north-east and to the south-west. The strike of the cleavage (060/70°NW) in the mudstone beds of both limbs can be seen to be up to 10° clockwise to the strike (050°) of the bedding on the limbs, and of the axial surface. But the exposures also allow a profile view of the mudstone in the hinge area; here, the cleavage shows the development of a finite neutral point (Ramsay, 1967 p. 417), with a slightly divergent cleavage fan above it (Figure 2.8)B, and a bedding-parallel fabric below. Such features are generally accepted to be the product of strain related to folding, and this example would seem to provide evidence of the contemporaneity of the non-axial plane cleavage and the folding.

Fold B [NX 4798 4982] is a more open anticline than A, plunging to the south-west. It displays alternating sandstone and mudstone beds with, in profile, classic convergent cleavage fans in the sandstones and near axial-planar cleavage in the mudstones. Because of the plunge and the flat nature of the outcrop, it is possible to walk across successive fold hinges of bedding, along the one axial surface, and it is quite clear that cleavage in both sandstones and mudstones consistently tran-sects the axial surfaces and fold hinges in a clockwise sense. This is one of the most convincing and photogenic (Figure 2.7) exposures that demonstrates this phenomenon.

Fold C [NX 4800 4992] is also an anticline demonstrably transected by the cleavage, but its principal attraction is the geometry of its hinge area, which is exposed for some twenty metres along its length. The hinge exhibits two gentle plunge culminations, as well as variation in strike of its axial surface. These features are characteristic of many of the small-scale folds of the Southern Uplands.

Interpretation

Rust (1965) in his description of the deformation history of the Whithorn area proposed that there had been four important phases (F_1–F_4). Stringer and Treagus (1980, 1981) only recognized two phases D_1 (incorporating Rust's F_1 and F_3) and D_2 (Rust's F_2 and F_4). As stated above, these divergent views rest largely on the variation in interpretation of the age of the dominant cleavage in the area, S_1 of Stringer and Treagus, S_3 of Rust. Rust (1965) observed that this cleavage transected folds of his F_1 and F_2 generations, but was axial-planar to locally developed, steeply plunging folds (see Isle of Whithorn) which he therefore regarded as of third generation (his F_3). Stringer and Treagus (1980, 1981), on the other hand, from evidence in this site and other localities, maintain that the dominant cleavage, although transecting, was essentially contemporaneous with the formation of the D_1 folds. These folds locally assume steep plunges, and there they show the axial-planar relationship of the cleavage in vertical profile view.

The arguments for the contemporary age of cleavage and folding lie in the observation that the cleavage geometry is a product of the strain variations related to the fold geometry. The most commonly observed relationship of this type is the fanning and refraction of cleavage, symmetrical to the axial surfaces of folds in profile view (see (Figure 2.6)B, Barlocco site). At Cruggleton Bay, the most persuasive relationship is that the clockwise transecting cleavage is clearly seen to have the usual detailed geometry (see (Figure 2.8)B) , around finite neutral points, seen in thickened mudstone hinges between adjacent greywacke beds. Such a relationship is taken to indicate that the cleavage pattern is a direct response to strains that developed in the tightening hinge (Ramsay, 1967, p. 417).

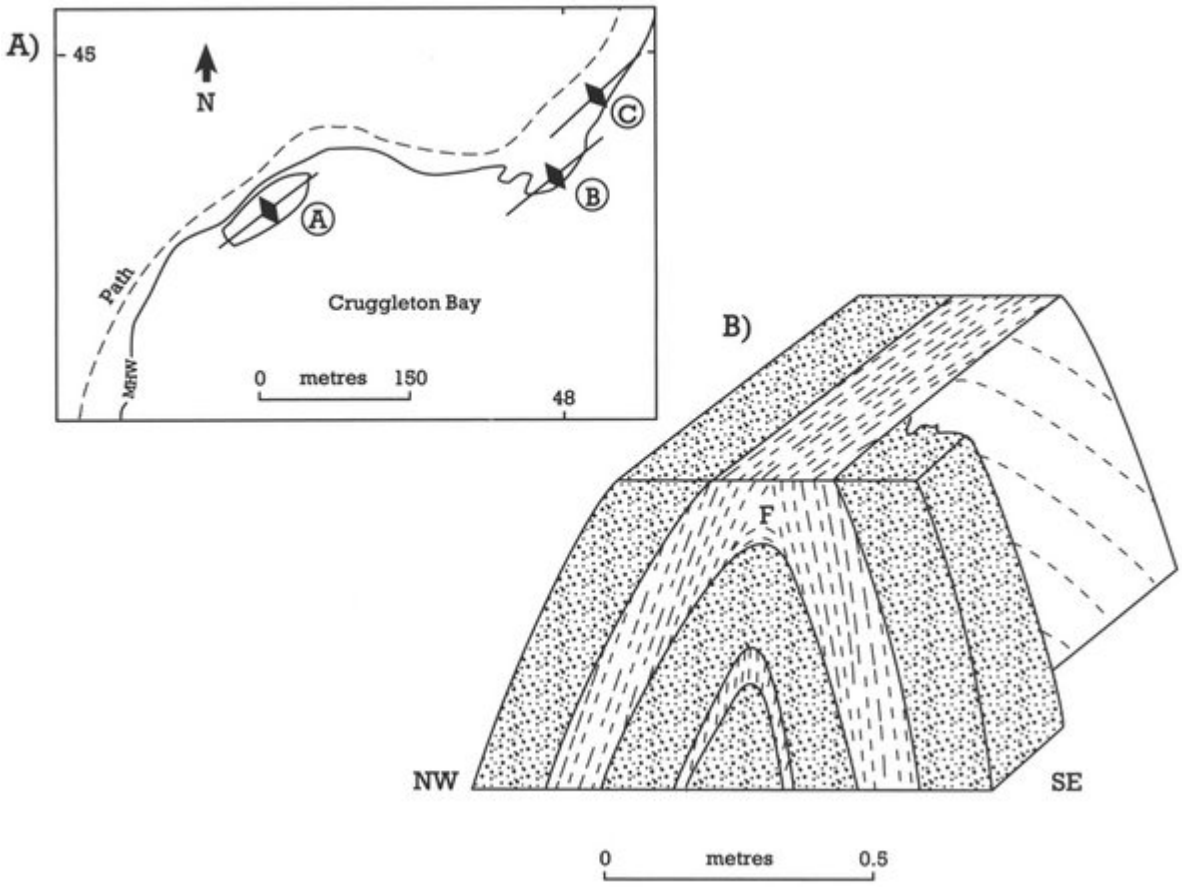
The origin of transecting cleavage, which has now been widely recognized in the Lake District and Wales (Soper *et al.,* 1987), has excited great interest, in the context of the closing of the Iapetus Ocean. Stringer and Treagus (1980, 1981) and Treagus and Treagus (1981), from observations in the Southern Uplands, have suggested that the phenomenon could result from the development of fold axial surfaces in an orientation other than the conventional one perpendicular to the bulk shortening and thus not parallel to the cleavage. The model was developed by assuming that the strain did not depart significantly from plane strain with moderate subvertical stretching, based on the limited field observations of strain parameters. In the Irish equivalent of the Southern Uplands, however, Anderson and Cameron (1979) and Murphy (1985) have recognized transection, again mostly clockwise, but associated with a distinctive, subhorizontal stretching lineation.

Transecting cleavage has been attributed to a deformation model called 'transpression' (see Sanderson and Marchini, 1984), which can be produced by superimposing simple shear on a non-rotational strain. Soper and Hutton (1984) have applied this model to the Caledonides, relating sinistral simple shear, near the Iapetus suture, to the transecting cleavage in Ireland. Similar applications of the model to terranes like the Southern Uplands and Lake District (Soper *et al.,* 1987), where reports suggest that strain is oblate (Stringer and Treagus, 1980) or plane with moderate upward stretching (Bell, 1981), require more detailed examination of strain parameters in rocks such as those at Cruggleton and Barlocco.

Conclusions

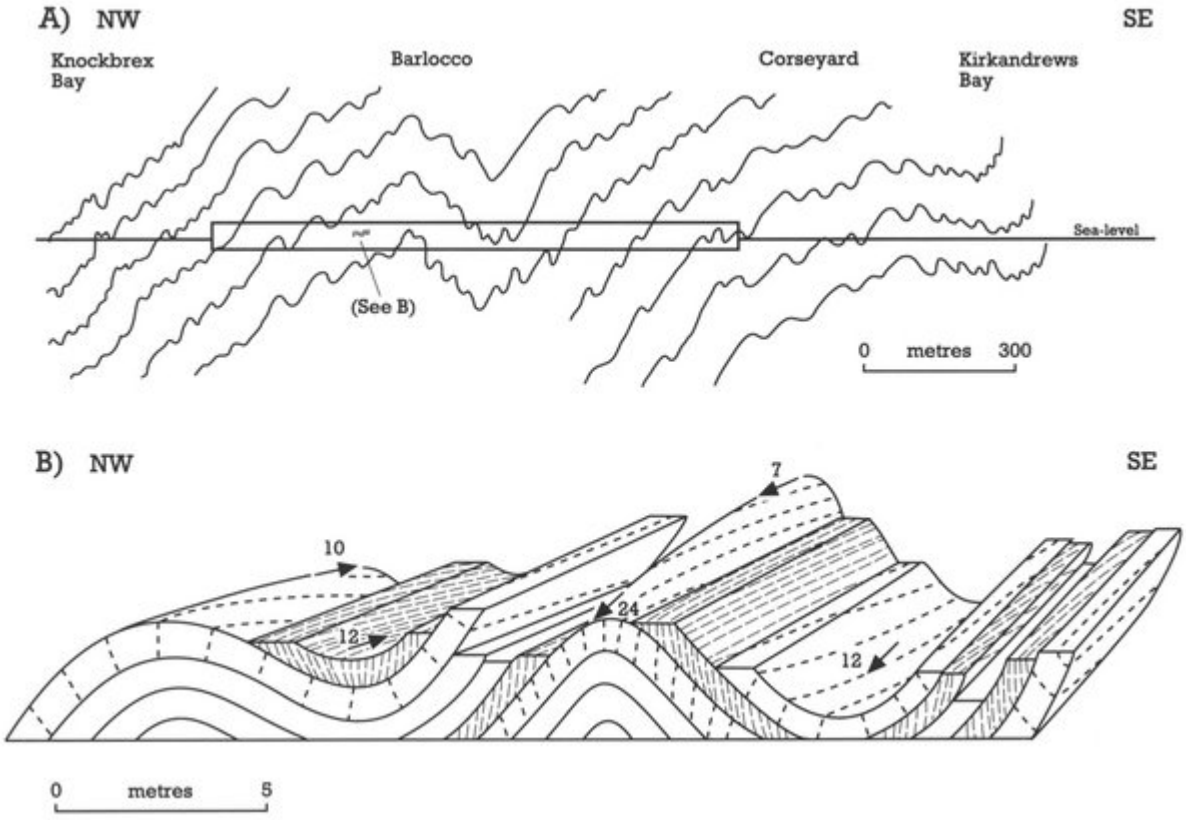
The site has been selected for inclusion in the Geological Conservation Review for its illustration of the relationship of cleavage to folding. The three-dimensional forms of a number of large folds can be seen with great clarity at this locality. The cleavage (fine, very closely spaced, parallel fractures) is orientated slightly obliquely to the trend (hinges) of the fold (it is therefore described as being non-axial planar), and yet they are contemporary. The phenomenon is important in the understanding of the movements that ended the Caledonian Orogeny in Britain, around 400 million years before the present. The non-parallelism of fold axial surfaces and cleavage suggests that when the Iapetus Ocean closed at that time, its margins were oblique to the direction of closure.

References



(Figure 2.7) Cruggleton Bay North. D_1 folds in Silurian siltstones and mudstones, plunging to the south-west, transected by non-axial plane cleavage. (Photo: P. Stringer.)

(Figure 2.8) Cruggleton Bay. (A) Location map showing position of Folds A, B, and C. (B) Schematic diagram of Fold A, drawn from field sketches, showing relationship of cleavage (dashed) to the folded greywackes (dotted). F = finite neutral point.



(Figure 2.6) (A) Diagrammatic fold profile of the Knockbrex Bay–Kirkandrews Bay coast section, with box indicating the location of the Barlocco site. Approximate position of the folds illustrated in (B) is also shown. (B) Typical fold and cleavage geometry at the Barlocco site, based on field observations at [NX 5835 4865]. Cleavage is shown: open spaced in sandstones and narrow spaced in mudstone. Plunge of fold hinges and cleavage–bedding intersections are also shown (after Stringer and Treagus, 1980, figure 2).