Grennan Bay

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Highlights

This site exposes one of the 'inners' of Moffat Shales within the Llandovery greywackes of the Central Belt. Here the contacts between the two units are unusually well displayed. The Moffat Shale inliers have played a central role in the debate over the structure and geological history of the Southern Uplands, for more than a century.

Introduction

The Central Belt of the Southern Uplands, like the Northern and Southern Belts, comprises essentially steeply dipping and dominantly north-west-younging greywackes. In addition to the south-east-younging sequence of the three belts (Ordovician, Llandovery, and Wenlock in the main), the greywackes within the Central Belt also exhibit a sequence of blocks decreasing in age to the south-east — see 'Introduction' to this chapter, (Figure 2.2)C and Leggett *et al.* (1979). Craig and Walton (1959) and Walton (1961) proposed that these blocks must be separated by steep strike faults with downthrows on their south-eastern sides (Figure 2.2B). The evidence for these faults comes largely from the presence, within the poorly fossiliferous greywackes (of generally Late Llandovery age), of the graptolitic Moffat Shales, (Harden, Birkhill, and Glenkiln Shales, of Llandeilo to Llandovery age). The juxtaposition of Moffat Shale slices above, and to the north-west of, the greywackes in the Grennan Bay site requires faults with substantial throws. Lapworth (1889) and Peach and Horne (1899) in the earliest interpretation of the Moffat Shale strips within the greywacke, saw them as anticlinal inliers of the Ordovician, although they fully appreciated their faulted nature (Figure 2.2)A. This site is important in its bearing on the structural relationships between the Moffat Shale 'inners' and the younger Llandovery greywackes of the Central Belt. At its southern margin, this site exposes a gradational contact between the Moffat Shales and these greywackes to their north. The northern half of the site consists of a 100 m-thick slice of Moffat Shales, with fault contacts with the greywackes to their north and south (Figure 2.15). The latter fault is an example of one of the steep 'thrusts' which, in the accretionary interpretation of the Southern Uplands, would be consequent to the north-westerly subduction of the Iapetus Ocean crust.

The area of the Rhinns of Galloway in which the Grennan Bay site lies, had not been studied since the original Geological Survey mapping (Peach and Horne, 1899). However, it has recently been the subject of resurvey by J. A. McCurry (Barnes *et al.,* 1987), who provided much of the background information for the present description.

Description

The stratigraphy at Grennan Bay, together with post-cleavage lamprophyre dykes and faults, is demonstrated at eight localities within the site (a–h; (Figure 2.15)); these are discussed in detail below. The structure is illustrated by the cross-section in (Figure 2.15).

1. The southern boundary between the Moffat Shales and the greywackes displays transitional lithologies between the grey/black Birkhill Shales (Llandovery) and the grey shale and siltstone lithologies in the greywackes (late Llandovery) to the north. This provides an ideal contrast with the two boundaries (d and g) further north, which are clearly faulted and where these transitional lithologies are absent. Dips are subvertical at the contact, and there is north-west younging in both the transitional lithologies and in the greywackes.
2. The southern unit of greywackes consists of 1 to 3 m-thick greywackes with subordinate grey siltstone and mudstone at the north-west margins of graded units. The beds dip steeply to the south-east, apparently unaffected by D_1 folds;

they are inverted and thus young consistently to the north-west.

3. The northern twenty metres of the greywacke is affected by a faulted syncline, some 10 m across, clearly seen on the eastern wall of a later NNE-trending fault which also cuts the boundary with the Moffat Shales. The southern limb of this syncline is interrupted by a steep, narrow fault zone. The movement on this fault may well be contemporary with that on the Moffat Shale margins, mentioned below. No complementary anticline is seen before the Moffat Shales junction (d) is reached, although unequivocal south-easterly-younging was not found in the greywacke at the junction.
4. The greywacke at the southern junction with the Moffat Shales block is, therefore, assumed to be right way-up, dipping some 60°SE. The first metre of the Moffat Shales, north of the immediate junction, is strongly disturbed by a fault zone, the effects of which extend for a further three to five metres into the Moffat Shales to the north. Within this first metre, lenses of greywacke, up to a metre in length, occur in sheared black shale and the Moffat Shales beyond are broken by anastomosing fracture planes. The actual junction with the Moffat Shales is generally sharp and planar (dipping steeply to the south-east), but in detail it is often undulating. Some striations are subvertical within the fault zone, but there is no other obvious indication of direction, or amount of movement. Some movement disturbs, and thus post-dates, the S_1 cleavage. The simple structure of the greywackes (c) and the position of the Moffat Shales (a) and (e), suggest that movement on this fault (assuming it to be subvertical) was down on its south-east side.
5. The Hartfell Shales have yielded Caradoc graptolites (*C. wilsoni–D. clingani*) and the Birkhill Shales have yielded a Lower Llandovery fauna (*M convolutes* biozone). The Moffat Shales are well bedded, away from the faulted margins, but do not readily reveal their 'way-up'. They are interrupted by several zones, a few metres wide, of D_1 folding. These folds, with a wavelength of 0.5–1 m, generally plunge at gentle angles to the north-east, but also exhibit plunges up to 50°NE and 80°SW. The vergence of the folds, in the central outcrops, appears to be neutral, or to the south-east, and this supports the fragmentary evidence of northwesterly younging (assuming that the folds face up). It is possible that the south-east part of the slice of Moffat Shales could be on the southern, south-east-younging, limb of an anticline (as in the cross-sections of Peach and Horne and in (Figure 2.15) herein) interrupted by the southern fault (at point d) and separated from the succeeding greywackes; this is supported by the observation (McCurry, pers. comm.) that the southernmost Moffat Shales contain common bentonites, suggesting they represent the youngest part of the Birkhill Shales. Strike-parallel faults (of unknown displacement) are certainly present within the Moffat Shales slice, making the reconstruction of fold geometry more difficult. The S_1 cleavage is only locally developed in the Moffat Shales in the axial zones of the D_1 folds; it appears to be subaxial planar.
6. Towards the northern end of the main outcrop of Moffat Shales is a zone of grey mudstone/ shale, some 10 m wide, which is presumed to be part of the upper Hartfell 'Barren Mudstone'; the northern junction with the Moffat Shales appears to be a sedimentary and conformable junction younging northwards, but the southern junction is probably a fault. Since the southerly junction is followed by a syncline in the Moffat Shales, the outcrop of the Barren Mudstone may well be anticlinal with a thinned and faulted southern limb, as shown in (Figure 2.15).
7. The junction of the Moffat Shales with the greywackes to the north is, again, clearly a fault zone. The actual junction was only seen in one place (but this is dependent on the movements of material on the foreshore), over a distance of 1 m, where it is a sharp plane, steeply dipping to the south-east, between black shale and platy grey siltstone. The Moffat Shales are broken by fractures, and bedding is lost within a zone some 3 m-wide to the south of the junction. To the north, thin beds of greywacke display excellent lensoid structure in a matrix of platy siltstone and grey shale for several metres; D_1 folds have been disrupted. Again, subvertical striations provide a suggestion of the movement direction. If the movement direction is sub-vertical then the stratigraphical separation would require displacement down on its north-west side.
8. The greywacke beds to the north of the fault zone are 0.5–2 m thick, dipping steeply to the south-east. Within ten metres of the fault zone they are inverted and show uniform north-west younging.

The Moffat Shales Inliers' are of great importance in studies of the Caledonian structural history of the Southern Uplands. They are not simple anticlinal inliers as envisaged initially by Lapworth (1889), but have come to be seen, from the work of Walton (1961), Toghill (1970), and, most recently, Webb (1983), as the expression of D_1 fold pairs modified by faulting, particularly on their SE-facing short limbs. Their stratigraphical and structural relationships suggest that each is marked by one, or more, powerful faults down-throwing to the south-east (thrusts' if dipping to the north-west), such that Moffat Shales in the Central Belt are repeatedly brought down to the surface. More importantly, such faults, cumulatively, are believed to more than counteract the effect of the steep north-westerly sheet-dip of the Lower Palaeozoic rocks of the

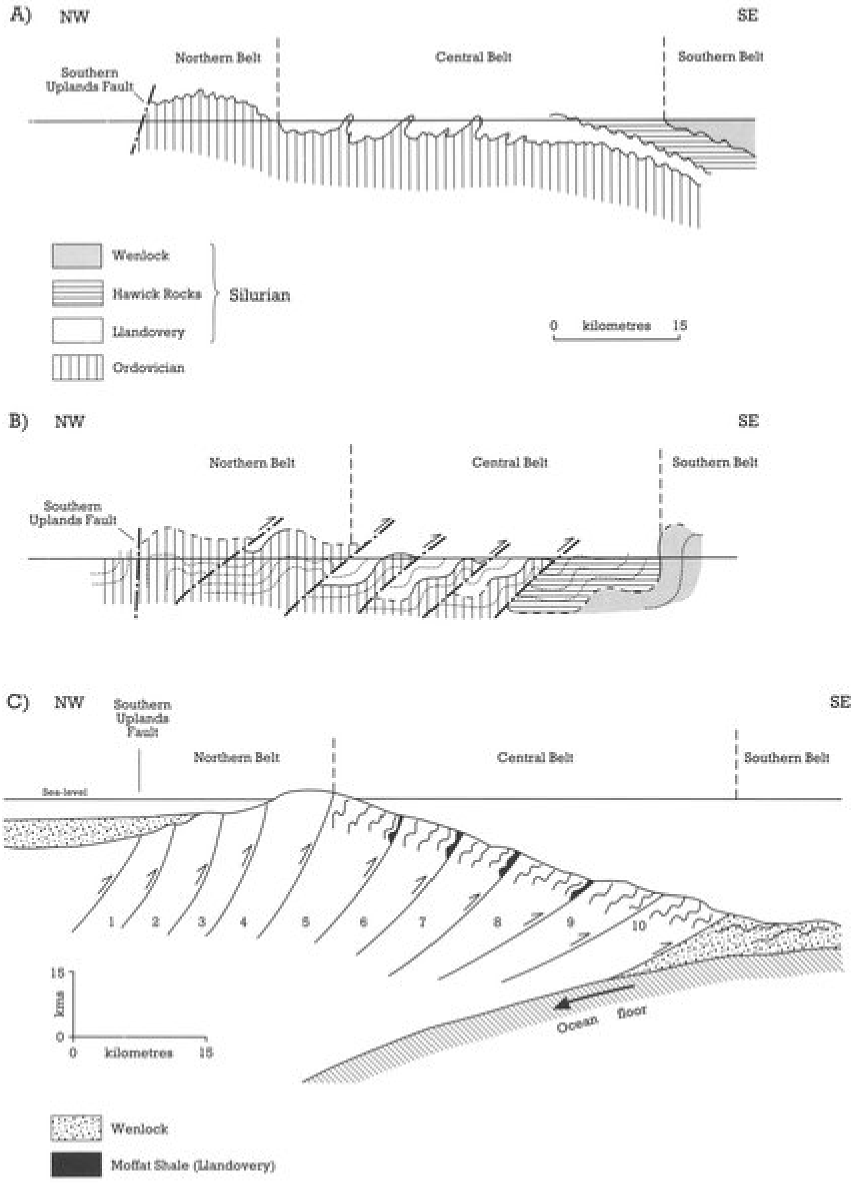
Southern Uplands, so that successively younger rocks are encountered in a south-easterly direction. These faults have further come to be seen as the effect of an oceanic plate being subducted, in a north-westerly direction, beneath an oceanic trench, causing the sediments to be sliced and accreted on to the forearc prism to the north-west (Figure 2.2C and Leggett *et al.,* 1979, 1983).

The Grennan Bay site offers clean, almost continuous exposure across three junctions in two inliers. It is superior, in this respect, to any of the exposures of the inliers that have been described already (for instance, Toghill, 1970; Fyfe and Weir, 1976). Although the displacement on the bounding faults are yet to be proved and the internal structure and stratigraphy of the Moffat Shales has not been mapped in detail, the potential for future study at this site is very great (it is currently being studied by J. McCurry, Aberdeen). What the site clearly demonstrates is that here, at least, the outcrop of the Moffat Shales is a consequence of combination of north-west younging, tight folding and complex faulting. It strongly suggests that a D_1 fold pair is present and that the faults are closely related to the D_1 folds and subparallel to the axial surfaces and S_1 cleavage associated with those folds. These folds are interpreted as examples of the south-easterly verging fold pairs that characterize the Southern Uplands, but here the incompetent Moffat Shales have acted as a detachment horizon for at least one substantial (and now vertical) fault, in part contemporaneous with the folding and/or cleavage. In the accretionary model this relationship would be interpreted to demonstrate the continuity of the north-west under-thrusting of the oceanic crust, producing initially south-easterly-verging flat-lying folds which were subsequently detached at Moffat Shales horizons; thrusts and folds were then rotated to their present attitude during accretion. The S_1 cleavage should be the last imprint of the Iapetus closure, and may well have been associated with later strike-dip movement on the thrust planes. In detail, the S_1 cleavage appears to be disturbed by the faulting, but it is thought that this reflects a continuing history of movement that has taken place in the fault zones. Although one fault, on the southern margin of this inlier, certainly has a powerful downward displacement to the southeast (a steep normal fault), another fault at the northern margin must have a substantial downward displacement to the north-west. More work needs to be done, in particular to determine the sense of shear on the fault planes and fault zones.

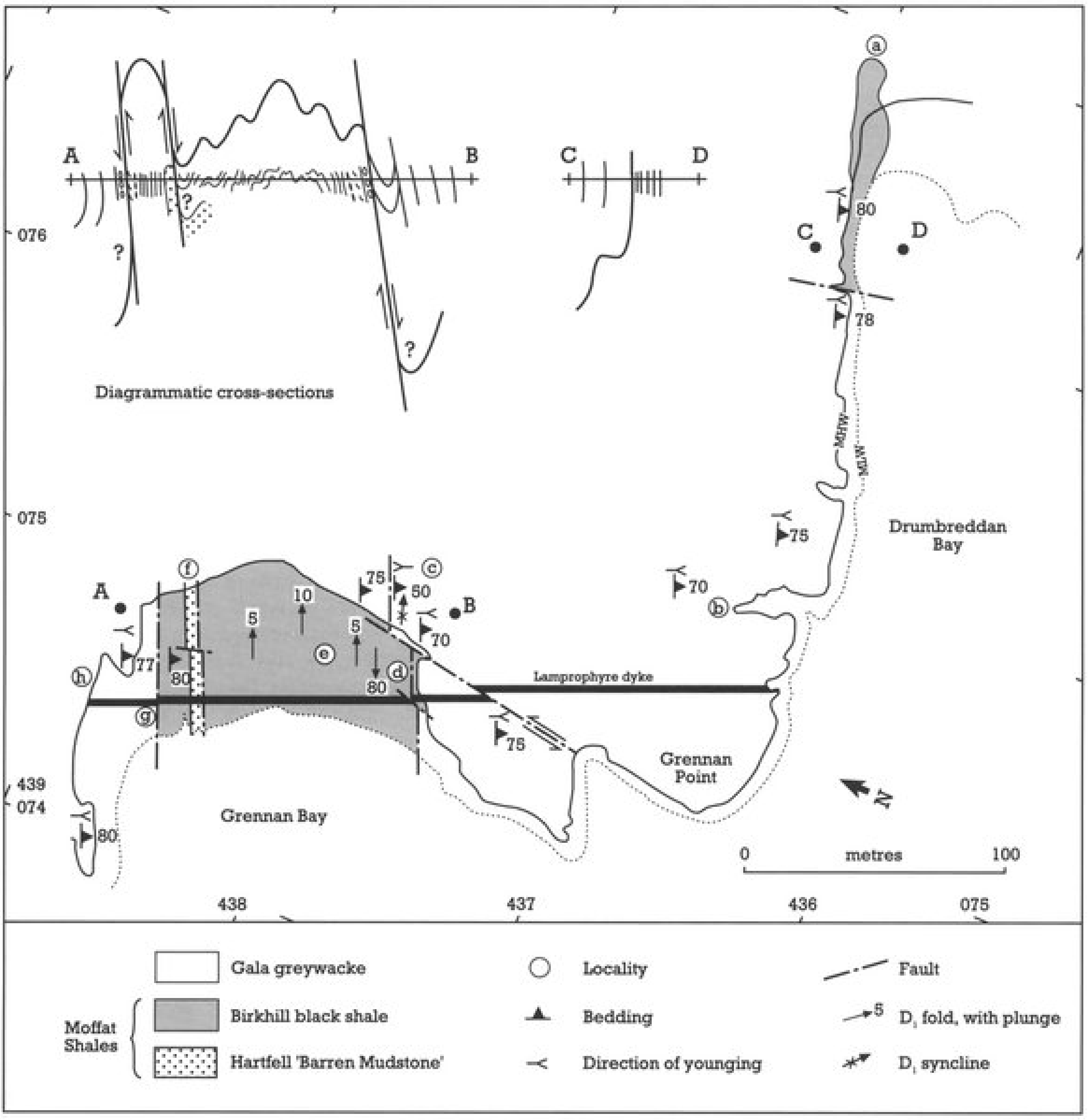
Conclusions

This locality affords outstanding opportunities to study sections in one of the Moffat Shales Inliers' of the Southern Uplands, with faulted and unfaulted contacts between the Upper Ordovician to lowermost Silurian Moffat Shales and the surrounding Lower Silurian greywackes. These inliers (that is, areas of older rocks surrounded by younger ones) are now regarded as first-generation (D_1) folds, formed during the early stages of Caledonian mountain building and modified by later faulting. Both the folding and faulting are thought to result from the descent of ocean crust beneath the continent (subduction) on the north-west margin of the Iapetus Ocean: a situation similar to that seen today just east of Japan where the Pacific oceanic plate plunges beneath the Asian continental plate. When this happened in the Southern Uplands during late Silurian to early Devonian times the rocks and sediments were added (accreted) on to the continental margin in a sliced (faulted) wedge or prism.

References



(Figure 2.2) Cross-sections of the Southern Uplands. (A) After Lapworth (1889); (B) after Walton (1961); (C) reconstructed profile of the accretionary prism, in Wenlock times. The tracts 1–10 are of decreasing age south-eastward, within each tract rocks young to the north-west. The style of the D_1 folding is shown schematically in the Llandovery and Hawick Rocks of the Central Belt (after Leggett et al., 1979).



(Figure 2.15) Geological map and cross-sections (inset) of the Grennan Bay site (after J. A. McCurry, unpublished).