6 Duke’s Pass

[NN 499 030]–[NN 523 043]

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6.1 Introduction

The Duke’s Pass is followed by the A821 road between Aberfoyle and the west end of Loch Achray. Ground extending either side of this corridor provides numerous, readily accessible exposures of metasedimentary rocks belonging to the Southern Highland Group, which comprise the GCR site (Figure 4.18). The GCR site is particularly important in revealing the nature of the earliest phase of deformation, free of the effects of the main second deformation event, and the way in which the second deformation modified the earlier structures.

The Aberfoyle district was important in early work on the Dalradian, yielding the now well-known names of some of the key lithostratigraphical units in the Southern Highland Group, especially the Aberfoyle Slates and Ben Ledi Grits. A resurvey by the British Geological Survey of 1:50 000 Sheet 38E (Aberfoyle, 2004) has delineated other lithostratigraphical units and has determined that faults related to the Loch Tay Fault system are responsible for the mismatch of structures and outcrop pattern across the Duke’s Pass.

The area is of major importance in determining the 3-D structure of this segment of the Highland Border region. The high degree of deformation was recognized during the original mapping by the Geological Survey in the late 19th Century (original unpublished manuscript released as Cunningham-Craig, 2000), although its precise nature and significance for the tectonic evolution of the Grampian Terrane was not recognized until the latter half of the twentieth century. Henderson (1938) was the first to demonstrate the way-up of the beds from sedimentary structures and showed that the Aberfoyle Slates occupy the core of the ‘Aberfoyle Anticline’. Anderson (1947a) maintained that this structure extends along the Highland Border from West Water in the Edzell district, Angus, to the Isle of Arran in the south-east. Subsequently, Shackleton (1958), in his seminal paper on the structure of the Dalradian rocks of the Highland Border, demonstrated that the structures observed on either side of the Aberfoyle Slates are downward-facing. The slaty metamudstones thus occupy the core of a downward-facing anticline, constituting the inverted nose of the Tay Nappe. Mendum and Fettes (1985) showed that at least two other major early folds, complementary to the Aberfoyle Anticline, occupy ground to the north of the latter structure and lie structurally beneath it. This renders the hinge-zone of the Tay Nappe much more complex than envisaged by Shackleton. The Aberfoyle Anticline is thus just one of a number of early structures in the hinge-zone of the nappe. The northern half of the GCR site is affected by a second deformation and local, minor development of later cleavages, which become more intense northwards.

6.2 Description

The GCR site lies entirely within the Highland Border Steep Belt, the domain of steeply, generally north-west- to north-dipping strata that occupy the ground south of the Highland Border Downbend (Stephenson et al., 2013a, fig. 7). It also lies to the north-west of the Loch Tay Fault Zone, which in this area trends south-west from the north-west side of Meall Ear [NN 530 027], passing immediately south-east of Creag Gownan [NN 533 025] and the lower slopes of Craigmore [NN 510 021] (Figure 4.18).

Within the GCR site, the Southern Highland Group is dominated by metasandstones. Although most of these were originally wackes, carrying abundant matrix, many were quartz-rich arenites. The very local nature of lithological variation within the metasandstones limits the potential for lithological subdivision. However, mapping by the British Geological Survey has delineated three discrete metasandstone units on the western side of the Duke’s Pass Fault (Figure 4.18).

Graded bedding is very commonly developed and other sedimentary structures, which help to constrain the way up, include scours, load structures and, very rarely, ripple marks. Rip-up clasts, now metamudstone, are abundant locally and can reach several tens of centimetres in size. The way-up criteria are critical to the understanding of the structure of the Duke's Pass area (see below).

The bulk of the metasandstones are assigned to the Ben Ledi Grit Formation. In this unit they vary from massive, very thick, gritty to locally pebbly coarse metasandstones to thin-bedded, fine-grained units with metasiltstone and locally metamudstone interbeds. The coarser grained lithologies dominate. Excellent examples of the coarse-grained lithologies are exposed on the low hillside around [NN 518 031], where they occupy a fold hinge (see below). Here, basal scours contain gravel lag deposits and loading structures are common where very coarse material has been deposited on finer grained units.

To the west of the Duke's Pass and north of the Aberfoyle slate quarries, metasandstones are assigned to the Creag Innich Sandstone Formation. They are grey, coarse-grained, quartz-rich, medium- to thick-bedded rocks that crop out extensively in the high ground, particularly around Creag a Mhadaidh [NN 513 036]. This formation lies below the Ben Ledi Grit Formation, but appears to be laterally discontinuous on a regional scale (Thomas *et al.*, in press). The metasandstones in this formation are generally cleaner, with less fine-grained matrix, than those of the Ben Ledi Grit Formation.

To the north of the Creag Innich Sandstone, metasandstones are assigned to the Ledard Burn Member, a generally finer grained unit within the Ben Ledi Grit Formation. This unit comprises medium-bedded, fine-grained metasandstones with metasiltstone interbeds; thin gritty units are present at the bases of some upward-fining packets of sandstone.

Metasiltstone and metamudstone are common as interbeds and laminae in many of the metasandstones. They also occur in much thicker units, the most notable of which forms the Aberfoyle Slate Formation west of the Duke's Pass Fault, which is well exposed in the abandoned Aberfoyle Slate Quarries [NN 505 032]. This unit is dominated by grey and greenish or purplish grey metasiltstones with darker laminae of metamudstone. Bedding is commonly picked out by discontinuous thin wisps of quartzose material. Way-up is rarely determinable in these rocks, but very locally the thin quartzose laminae contain discernible cross-lamination and have small-scale scours at their bases, indicating the direction of younging. The Aberfoyle Slate Formation contains the oldest Southern Highland Group rocks within the GCR site, these rocks being correlated traditionally with the Pitlochry Schist of Perthshire. They were worked extensively for slate in the Aberfoyle quarries in the 19th century before extraction become uneconomic in the face of competition from lighter and higher quality Welsh slate.

The metasiltstones of the Aberfoyle Slate Formation pass southwards into pale, quartzose metasandstones that are correlated, on the basis of recent BGS mapping, with the Creag Innich Sandstone Formation to the north. The metasandstones pass southwards, in turn, into the more-impure metasandstones, metasiltstones and subordinate metamudstones of the Ben Ledi Grit Formation, the outcrop of which continues to the Highland Boundary Fault at the southern margin of the GCR site.

East of the Duke's Pass, within the Achray Forest, a unit of metamudstone within the Ben Ledi Grit Formation is bounded to the east by the Loch Tay Fault and to the west by smaller faults (Figure 4.18). The metamudstones are black, grey, green or maroon in colour and are strongly cleaved. In the ground immediately west of and within the Loch Tay Fault Zone (200–300 m west of Meall Ear, [NN 530 027]), metamudstones are black, rich in pyrite and contain cherty laminae. These lithologies are similar to those seen in the Leny Quarry [NN 619 101], north-west of Callander (see the *Keltie Water* GCR site report), but differ significantly from those exposed in the Aberfoyle slate quarries. Thinner units of metasiltstone and metamudstone, such as that trending eastwards about 500 m north of Aberfoyle, occur throughout the general mass of Ben Ledi Grit to the east of the Duke's Pass Fault and are generally similar lithologically to those described above. Hence, contrary to previous interpretations (Shackleton, 1958; Mendum and Fettes, 1985), the fine-grained rocks to the east of the Duke's Pass Fault are not lithostratigraphical correlatives of those seen in the Aberfoyle Slate Quarries. The corollary is that there has been considerable displacement across the Duke's Pass Fault, resulting in the juxtaposition of different lithostratigraphical units and different structural levels (see below).

Bedding in the metamudstones, very rarely observed, is picked out by very thin silty laminae or by subtle variations in hardness that indicate a more siliceous layer. Metre- to decimetre-scale folding in these rocks is well observed in exposures on a forest track west of Creag Gownan, at [NN 520 024]. Very fine-scale graded bedding in silty laminae shows that the rocks are inverted and that the folds and first cleavage face downwards.

The southern part of the GCR site, south of Hill Cottage [NN 515 031], contains exposures that reveal the nature and geometry of the D1 deformation, free from the effects of subsequent deformation events, most particularly D2. Outcrops of thick-bedded, very coarse wacke metasandstone on the eastern flanks of Craigmore [NN 510 021] lie in large-scale F1 fold closures, as indicated by locally variable and moderate easterly dips and by high-angle intersections between bedding and cleavage. The dominant S1 cleavage is widely spaced (*c*. 0.5–1.0 cm) and anastomosing in the coarse-grained lithologies, becoming more finely spaced where the grain size is less. This cleavage is the S1p cleavage of the *Little Glen Shee*, *Craig a'Barns* and *Rotmell* GCR sites.

The exposures on the low hills immediately east of Hill Cottage lie within an antiform, the core of which contains very coarse metasandstones with locally developed gravel lags filling scours in bed tops. Graded bedding is well developed in these rocks, showing unequivocally that the fold is a syncline facing downwards on the first cleavage. The dominantly strongly oblique relationship between bedding and first cleavage displayed in the coarse metasandstones shows that most exposures lie within or close to fold hinges throughout the area. The F1 folds are tight to isoclinal and are generally on the decimetre scale or larger (Figure 4.19).

Moving north-westwards from the Highland Boundary Fault in this area, D2 structures are first seen in the coarse metasandstones of the Creag Innich Sandstone Formation to the north of Hill Cottage on the western side of the Duke's Pass and are clearly observed in exposures above the A821 road in the area around [NN 518 040]. D2 structures occur only as cleavages within the Duke's Pass GCR site, but these are widely enough spaced to appear as stacks of F2 minor folds of the S1 spaced cleavage (cf. Booth, 1984; Harte *et al.*, 1987). Large F2 folds of bedding are not observed. Where it is more intense, the S2 cleavage is in general nearly parallel to the steep north-dipping bedding. Towards its southern limit, it is commonly more oblique to bedding, dipping generally at shallower angles to the north. In the northern part of the GCR site, the S2 cleavage is more intensely developed and becomes the dominant fabric, manifest as a strongly planar spaced cleavage, particularly in the finer grained lithologies. D2 structures and their effects on S1 are particularly well observed at the northern limit of the GCR site at Craig Noran [NN 504 066], just north of the Achray Hotel. Here, graded bedding in a thin, coarse-grained unit beneath a massive, thick gritty metasandstone unit shows that the beds are inverted. The S1 cleavage is nearly normal to the coarse-grained, thick bed and is clearly deformed by D2, the latter resulting in a locally developed, widely spaced crenulation cleavage. The near-parallelism between S2 and bedding is readily apparent.

Effects of the D4 deformation related to the formation of the Highland Border Downbend, as seen elsewhere along the Highland Border (e.g. at the *Craig a'Barns* GCR site), are developed only very locally within the northern part of this GCR site. For example, a shallow and northerly dipping crenulation cleavage is developed in metamudstones in a small exposure by the A821 road at about [NN 516 051].

6.3 Interpretation

The overall lithological character and the bedforms of the coarse- to very coarse-grained metasedimentary rocks in the Duke's Pass area indicate that they were deposited by turbidity currents and debris flows within major channels of a fan system on a continental margin. They are, therefore, just part of the much more-extensive, extremely dynamic, depositional system manifested by the Southern Highland Group throughout the Dalradian outcrop of Scotland and Ireland (Burt, 2002). In such an environment it is likely that the finer grained rocks represent off-channel or overbank deposits. However, the locally developed, black, cherty, sulphidic metamudstones near Meall Ear [NN 530 027] suggest that more-euxinic, pelagic or isolated basinal sedimentation occurred at times. This might have reflected a major geographical shift in the depositional system as much as a major deepening of the depositional basin.

Faulting is an important feature of the Duke's Pass area, which contains the southern end of the Loch Tay Fault system. The Loch Tay Fault is known to have experienced several kilometres of oblique, sinistral strike-slip movement (Treagus,

1991). This precludes any close correlation of lithostratigraphical units across it in the Aberfoyle area, despite apparent lithological similarities. This problem applies equally to the related Duke's Pass Fault and other parallel faults within the area. Notable effects of the Duke's Pass Fault include the apparent displacement of the incoming of D2 deformation, which is farther to the north-east and in a different lithostratigraphical unit on the eastern side, implying a significant change in structural level across the fault (Figure 4.18).

The structures reveal that the Duke's Pass area is occupied by a major F1 fold system. The original interpretation of a single synformal closure centred on the Aberfoyle Slate Formation is likely to be an over-simplification. Evidence for extensive long fold limbs is lacking and fold hinges are commonly observed, either directly or via the changes in bedding/cleavage relationships. Mendum and Fettes (1985) have already shown that the Highland Border Steep Belt in this area is occupied by regional-scale F1 nappe structures that lie structurally beneath the Aberfoyle Anticline. The structural evidence in the Duke's Pass area, outwith the effects of D2, indicates the presence of a complex F1 fold hinge-zone, which is most easily interpreted as the front of a major nappe structure of which the Aberfoyle Anticline is part. The style and degree of deformation in the metasedimentary rocks suggest that the southern part of the Duke's Pass GCR site, south-east of the Duke's Pass Fault, is occupied by the upper and outer structural parts of this nappe front.

Based on the younging and structural evidence in the Duke's Pass area, D2 structures only begin to appear at deeper structural levels within the F1 nappe system. Hence, the absence of D2 effects in the southernmost part of the GCR site suggests that these rocks were originally at higher structural levels and allows the original geometry of the major F1 fold structures to be discerned. The field evidence indicates that the F1 nappe and fold structures were recumbent when formed; their current attitude in the south of the GCR site resulted essentially from rotation around the late Highland Border Downbend and subsequent compression during D4.

Observations on the effects of D2 deformation on S1 cleavages in particular, made in the *Duke's Pass* and *Bealach nam Bo* GCR sites, strongly suggest that D2 deformation was dominated by *NW-directed* simple-shearing accompanied by flattening (Mendum and Fettes, 1985; Mendum and Thomas, 1997). This interpretation differs fundamentally from those of other workers who interpreted the Tay Nappe and related structures as resulting from the combined effects of D1 and *SE-directed* D2 deformation, the latter dominated by simple-shearing (Harris and Bradbury, 1977; Krabbendam *et al.*, 1997). Thus, the evidence from the Duke's Pass area, combined with that from other GCR sites in this paper (*Little Glen Shee*, *Craig a'Barns*, *Rotmell*, *Garron Point to Muchalls*), is critical to the debate on the nature of the early orogenic events that affected the south-eastern part of the Grampian Terrane as a whole (see discussion by Stephenson et al., 2013a).

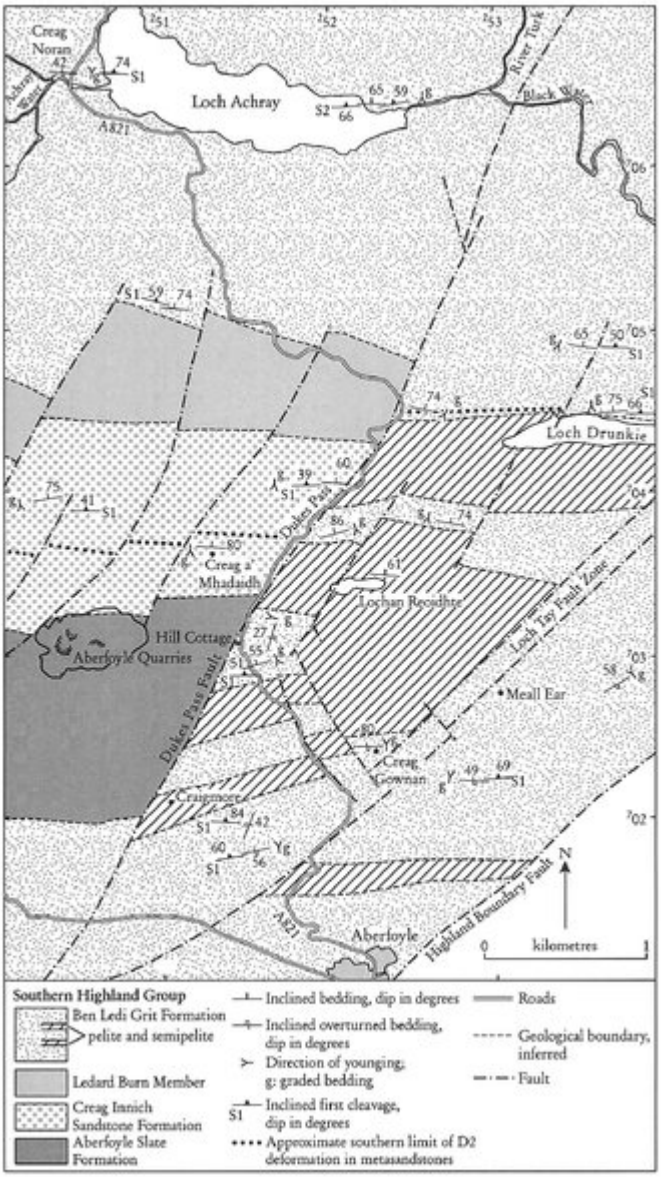
6.4 Conclusions

The Duke's Pass between Aberfoyle and Loch Achray provides outstanding and readily accessible exposures of Southern Highland Group metasedimentary rocks. These exposures not only reveal the nature of the processes that deposited the original sediments, but also the effects of the subsequent, mainly Ordovician deformation. The coarse metasandstones were deposited by sediment-laden currents (turbidity currents) and debris flows within major channel systems in a marine fan delta complex on a continental margin.

The rocks were deformed several times. The dominant early structures were flat-lying, kilometre-scale folds, of which the Aberfoyle Anticline is the best known. The true nature and orientation of the early structures are revealed in the southern part of this GCR site, because there they are unaffected by the second deformation, which is observed in the northern part of the site. There, the relationship between the first and second phases of deformation can be readily discerned; the second structures are largely parallel to the original bedding and their main effect was to deform the first cleavage.

The structural evidence indicates that the rocks in the southern part of the site occupied the upper and outer part of the uppermost of the major nappes in the region, probably close to the nappe front. The present steep orientation of the bedding and downward facing of the folds arose from refolding of the rocks around the Highland Border Downbend, a major late fold that re-orientated the nose of the nappe structures.

References



(Figure 4.18) Map of the area around the Duke's Pass, Aberfoyle. Based upon mapping by the British Geological Survey, 1996–1998.

(Figure 4.19) Typical F1 fold in metasandstone of the Creag Innich Sandstone Formation at [NN 5144 0344] on the Duke's Pass, Aberfoyle. The coarse-grained base of a gritty metasandstone unit lies above the hammer head, passing down into finer grained rock towards the end of the handle. The rocks are inverted and the fold is downward facing. Hammer shaft is 36 cm long. (Photo: C.W. Thomas. BGS No. P 643897.)