Excursion 18 Dunkeld and Little Glen Shee

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Purpose: To examine a cross-section through the Tay Nappe; to see evidence for three phases of deformation, which produced large-to small-scale folds; to examine Dalradian metamorphosed sedimentary rocks of the Birnam Slate and Grit Formation and the Dunkeld Grit Formation (Southern Highland Group).

Logistics: This is a one day excursion. For advice on shooting and forestry activities, contact the Factor, Murthley and Strath Braan Estate, Murthley near Dunkeld for Birnam Hill, contact Landsdown Estates for Little Glen Shee and the Factor at Atholl Estate Office, Blair Atholl for Craig a' Barns area.

Maps: OS 1:50,000 Sheet 52 Pitlochry to Crieff; OS 1:25,000 Sheet 379 Dunkeld, Aberfeldy & Glen Almond; BGS 1:50,000 Sheet 55E Pitlochry; locality map (Figure 18.1).

A regional late-stage, asymmetric monoform, the Highland Border Down-bend, folds the lower inverted limb and parts of the hinge zone of the Tay Nappe from flat lying in the north (the inverted Perthshire Flat Belt) to steeply dipping in the south (the Highland Border Steep Belt). As a result, a traverse from the Highland Border NW to the hinge of the downbend (Figure 18.2) provides a vertical section from higher to lower levels of the nappe (Rose & Harris, 2000) and illustrates the increasing complexity of deformation and grade of metamorphism at lower structural levels.

The metamorphosed sedimentary rocks (Birnam Slate and Grit Formation and Dunkeld Grit Formation) in this part of the Tay Nappe were originally interbedded grit, sand and mud and are part of the Southern Highland Group, the second youngest group in the Dalradian Supergroup. The thickest slate unit, formerly the 'Birnam Slates', separates the 'Dunkeld Grits' to the north from the older 'Birnam Grits' to the south. The commonly gritty metasandstones show normal grading and are interpreted as turbidite deposits that accumulated as part of an extensive submarine fan system.

The structural history of this part of the Grampian Highlands can be considered in terms of three principal phases of deformation and cleavage formation (termed D_1, D_2 and D_4 in the overall regional scheme). The first two were associated with prograde metamorphism and the emplacement of the Tay Nappe. A third phase (D_3) is recognised farther to the NW but not in this area. The fourth phase (D_4) is related to retrograde metamorphism linked to regional uplift of the Tay Nappe and formation of the Highland Border Downbend. D_1 resulted in the formation of large-scale folds of bedding (F_1), associated with a spaced pressure-solution cleavage in the metasandstones and a slaty cleavage in the finer grained metamudstone and metasiltstone beds (S_1). At high levels of the nappe, now seen only on the steep limb of the downbend, these folds are preserved as downward-facing structures with steeply NW-dipping axial planes (Localities 18.1 and 18.2). Unrolling the downbend by 120° about its hinge restores the F_1 folds to recumbent structures with gently dipping axial planes. Detailed fabric studies provide evidence for modification of the F_1 folds in a rotational strain field, related to the more-intense D_2 deformation seen at deeper levels of the nappe (see Locality 18.3 and Rose & Harris, 2000).

In the Dunkeld area there is no major downward-facing synform comparable with the Aberfoyle Antiform of Shackleton (1957) to the SW; the overall succession youngs to the NW from the Highland Boundary Fault to the downbend hinge. However, there is ample evidence for the development of a complex series of large-scale F_1 folds of bedding in the Sma' Glen– Glen Almond area north of Crieff, and in the Ben Vane–Ben Ledi area. They possibly lie in a wide hinge zone of the Tay Nappe. D_2 deformation resulted in intense small-scale folding (F_2) and attenuation of S_1 and more rarely of bedding. D_2 is also associated with a strong horizontal planar fabric (S_2) and a N–S stretching lineation (L_2), but is developed only at intermediate and low structural levels of the nappe (Locality 18.3). Curved inclusion trails in garnet show that D_2 deformation was coeval with the main metamorphism. Shear criteria (see Locality 18.5) have been interpreted to show that D_2 involved a component of SE-directed simple shear. However, the models of Harris *et al*. (1976) and Bradbury *et al*. (1979), which invoke bedding-parallel, south-directed simple shear to generate the F_2 folds, are an oversimplification, as F_2 refolds of bedding are also seen.

An alternative version of this excursion has been published by Treagus (2009). Some localities are also described in the Geological Conservation Review (GCR) of the Dalradian of Scotland (Tanner *et al*., 2013).

Locality 18.1 [NN 9792 3453] (Little) Glen Shee: high-level F_1 folds

This locality is best approached from the A9 just north of Perth [NO 0925 2925]. From the A9 follow the B8063 for 8 km towards Glen Almond and Crieff. At a sharp left-hand bend near Drumharrow Cottages [NO 0220 3080], take a single-track minor road on the right signposted to Glen Shee. The track up the glen is reached after 5 km, at a hairpin bend in the road [NN 9870 3410]. Parking is available to the south of the fording point of the Shochie Burn, close to the wooden footbridge [NN 9880 3404]. To reach the exposure, follow the good track west past Little Glenshee farm steading, and at a large boulder by the track painted (now faint) with 'No dogs' [NN 9792 3447], turn right up the side of the valley. The exposure [NN 9792 3453] is a 50 m-long, west-facing low cliff about 50 m up the bracken and heather-covered slope.

This locality is in the 'Birnam Grits', on the steep limb of the Highland Border Downbend and on the inverted limb of the Tay Nappe. The exposure consists of folds of interbedded pale-greenish grey metasiltstones and graded metasandstones in which ripple cross-laminations are sparsely preserved. The folds are associated with a fanning, spaced pressure-solution cleavage in the sandy layers and a slaty cleavage in the more-micaceous lithologies, and verge NW (Plate S.1, (Figure 18.3)). The grading is picked out by the refraction of cleavage towards the fold axial plane with decreasing grain size (Plate 18.1). Younging directions, determined from normal grading and possible cross-bedding, show that the beds are inverted and that the folds are downward facing. Note that the pressure-solution cleavage fans are asymmetric about the fold axial planes, with the cleavage on the southern limbs of synforms generally closer to the fold axial plane than that on the northern limbs. On the southern limbs of synforms, original bedding laminations between the cleavage planes are commonly orientated at up to 80° oblique to the gross bedding (Figure 18.3), and within some sandy beds the pressure-solution cleavage is folded. This may relate to variations in the local shear strain during F_1 fold formation or to subsequent modification by the D_2 deformation.

Locality 18.2 [NO 0404 4040] Birnam Hill Quarry: high-level F_1 fold

From Glen Shee, take the road to Bankfoot and follow the B867 (the old A9) north towards Dunkeld. At 300 m before the junction with the new A9, park on the left-hand side of the road where a public footpath goes under the railway [NO 0410 4045]. To reach the exposure follow the track under the railway, walking around the gate, and after 50 m take the footpath on the left signposted to Birnam Hill. After another 50 m [NO 0403 4049], turn right up an overgrown track, partly followed by a stream, which leads to the small disused quarry, and a fine viewpoint over the Tay valley (limited in summer), illustrating the regional context.

South of Newtyle Hill, on the NE side of the Tay valley, the southernmost Dalradian outcrop is unconformably overlain by Lower Devonian strata, the Highland Boundary Fault running just to the south. The F_1 folds on Newtyle and Birnam hills all verge NW, and thus no synformal F_1 nappe closure is exposed here. The quarries worked the various slate units and the largest of these on Newtyle Hill lies in an antiformal F_1 closure. The complementary synform is cut out by a fault at the base of the 'Birnam

Slates' above. North of Dunkeld, the craggy ridge of Craig a' Barns is coincident with the hinge of the Highland Border Downbend. F_2 folding, which strongly affects the deeper levels of the nappe to the north of Birnam, is limited to areas up to 1.5 km SE of the downbend.

In the small quarry, an antiformal closure of 'Birnam Grits' is exposed, again on the steep limb of the downbend and the inverted limb of the Tay Nappe. The younger 'Birnam Slates' are exposed in the larger quarry to the north [NO 0378 4052]. The beds consist of coarse, matrix-rich, graded gritty metasandstones and greenish- and bluish-grey slaty metamudstones with large pyrite cubes. Younging, derived from observations of normal grading, shows that the beds are inverted and the fold is downward facing. The gritty metasandstones are feldspar rich with abundant chlorite and blue quartz; lithic clasts include granitoids, deformed quartzites and altered basic metavolcanic rocks. The assemblage

suggests derivation from a volcanic terrain with exposed high-grade metamorphic basement. The fold is associated with fanning, spaced pressure-solution and slaty cleavages as at Locality 18.1.

Locality 18.3 [NO 0078 4178] River Braan at The Hermitage: intense F_2 folding at intermediate levels

From Birnam Hill drive north and join the A9. Pass Little Dunkeld and take the turning on the left [NO 0138 4230], signposted to The Hermitage, and park in one of the two large car parks. Take the path south-westwards by the river to Ossian's Hall (National Trust), and at the first right-angle bend upstream from Ossian's Hall examine the large flat exposure in the Dunkeld Grit Formation [NO 0078 4178] on the north bank. **These rocks become dangerously slippery in wet weather**, and flood conditions can severely restrict the area of exposure. This locality is also situated on the steep limb of the Highland Border Downbend, now only 800 m SE of its hinge. The metamorphic grade is higher than at Birnam Hill — cleaved metasiltstones are phyllitic with a high percentage of muscovite. D_2 deformation is well developed locally and tight folding of the first pressure-solution cleavage (S_1) can be seen. Thick composite sandy (psammitic) units are interbedded with mixed sandy and muddy (pelitic) units but convincing graded bedding has not been found, so that the structural facing cannot be demonstrated. A traverse across the flat surface illustrates the relationship between F_1 and F_2 (Figure 18.4). In parts bedding is difficult to discern.

Locality 18.3a lies at the NE end of the rock pavement below a low vertical face. S_1, a 0.5–1.0cm-spaced striping in metasandstone, changes its orientation relative to bedding across the exposure, indicating the presence of an F_1 synform. F_2 folds of S_1 consistently verge towards the NW and have steep axial planes, generally orientated close to bedding (Plate 18.2). Bedding is rather obscure but can be detected by the absence of S_1 striping in more-pelitic beds. The pelitic beds also carry a crenulation cleavage that dips at around 45° to the NW and is probably related to the downbend here. Locality 18.3b is along the strike of the F_1 fold axial plane from Locality 18.3a. The F_1 synformal closure can be seen but here it has a core of metasiltstone. In this area there are several examples of F_2 folds that show strong attenuation of F_1 fold limbs and the development of a second pressure-solution striping (S_2 cleavage) in their hinge regions. Between Localities 18.3b and 18.3c the bedding and S_1 cleavage are generally steep and their relative orientations are consistent with an F_1 synformal closure to the NW. At Locality 18.3c, S_1 has a shallow dip and is cut by a steep second pressure-solution cleavage (S_2), giving the rock a 'lozenge' appearance (Plate 18.3). In the centre of the lozenge zone, bedding also has a shallower dip, suggesting the presence of an F_2 fold of bedding and cleavage (Figure 18.3). This suggests that locally the F_1 fold stack was refolded by F_2. If time is available, it is possible to walk westwards up the river for just over a kilometre to the local beauty spot of the Rumbling Bridge waterfall; good examples of lozenge-shaped 'microlithons' between the S_1 and S_2 cleavage planes (as in (Plate 18.3)), refolded folds and rodding lineation can be seen here at the top of the falls [NN 9963 4120]. Alternatively, a short drive from Little Dunkeld along the A822 leads to the same place.

Locality 18.4 [NO 018 438] Craig a' Barns: hinge zone of Highland Border Downbend

From The Hermitage, take the A9 eastwards and turn left into Dunkeld [NO 0255 4210]. Drive through the town and turn right towards Blairgowrie on the A923. 150 m up the hill, take the second turn on the left after a sharp bend and join the forestry track leading to Craig a' Barns [NO 0250 4330]. 500 m up the track, turn left at a crossroads [NO 0242 4372] into a car park [NO 0230 4372]. From the NW corner of the car park take the track to the west and after 100 m branch to the right up a small path which leads through the dense woods at the foot of the prominent crags. After 1 km, just beyond a small waterfall [NO 0180 4378], turn sharp right up a poorly defined path that climbs steeply, following a small burn on its west side (Figure 18.5).

When the slope eases, turn right off this path to cross the small burn and reach a terrace between upper and lower cliffs at Locality 18.4a. The cliff section above the terrace (a favoured climbing venue, known as Upper Cave Crag) is dominated by pelitic lithologies at its NW end and psammitic lithologies at its SE end, all in the Dunkeld Grit Formation. The increase in grain size of the micas and the occurrence of rare chloritised garnets in the metasiltstones indicate that the peak metamorphic grade was higher on Craig a' Barns than in the River Braan. D_2 deformation is more intensely developed, with many F_2 folds of bedding and S_1 cleavage. The composite S_1/S_2 foliation has a steep sheet dip and is

folded by many open to tight F_4 folds, which verge NW towards the downbend hinge, here only about 200 m away. From a distance, F_4 folds can be picked out by folded, foliation-parallel quartz segregations in the pelitic rocks. Many hook-shaped interference patterns occur, where F_2 folds are folded around F_4 folds in mixed metasandstone–metasiltstone units. F_4 folds in the more-pelitic lithologies are associated with a locally prominent crenulation cleavage (S_4) that dips about 45° to the NW.

From Locality 18.4a, return along the path to the point where it rejoins the main path [NO 0158 4390]. Turn right up the small gently sloping valley (glacial meltwater spillway) with a series of craggy exposures on the NE slope. The first few crags are rather inaccessible due to the thick vegetation but the sheet dip of the foliation can be seen from the path to be about 45° to the SE. This is in the hinge zone of the Highland Border Downbend.

After a short gap in the exposure, more-accessible crags are reached at Locality 18.4b, where the sheet dip of the composite S_1/S_2 foliation and regional bedding is subhorizontal. A thick, massive metasandstone bed can be traced along the side of the valley and is folded by minor F_4 monoclines that verge SE towards the downbend hinge. The F_2 fabric is more easily studied here than at Locality 18.4a, as F_4 folding is less intense. Metre-scale F_2 folds of S_1 and bedding are common and verge towards the NW. On the horizontal long limbs of F_4 folds, F_2 axial planes are flat lying. The S_1 cleavage planes and the penetrative S_2 schistosity in the more-pelitic units commonly carry a N–S-trending lineation, defined by the preferred orientation of mica, which is folded around F_2 folds. This lineation is inferred to have been initiated during D_1 but modified on the limbs of F_2 folds, effectively to record the D_2 extension direction. The presence of asymmetrically boudinaged quartz veins suggests that a component of SE-directed shear strain was associated with the modification of F_2 folds.

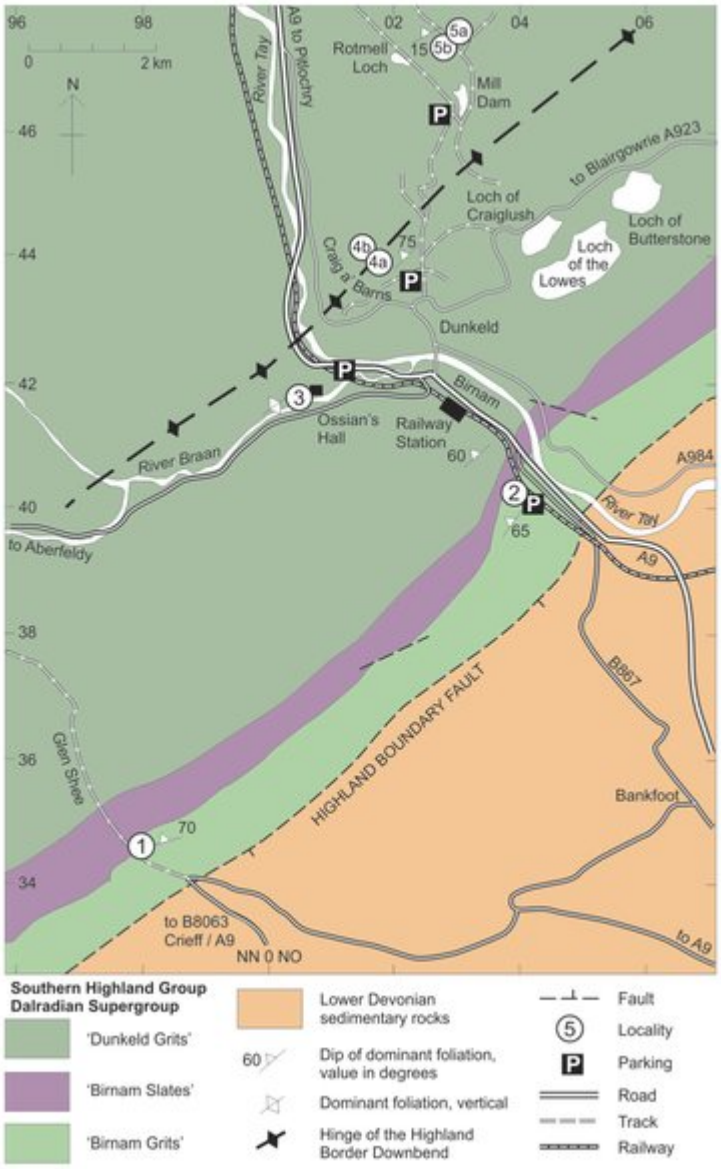
Locality 18.5 [NO 0280 4760] to [NO 0290 4742] Deuchary Hill: Perthshire Flat Belt

Return to the crossroads to the east of the car park [NO 0240 4370], and continue north along the track for 3.5 km, passing Upper Hatton, Birkenburn and the Glack. Parking is available at the south end of the small Mill Dam lake [NO 0310 4620]. Cross the dam and follow the path north along the lake side. Bear left at the fork after a small bridge [NO 0312 4722] and continue to the 100 m-long, NW–SE cliff section, Locality 18.5a, just beyond a stile at [NO 0290 4745] (Figure 18.1).

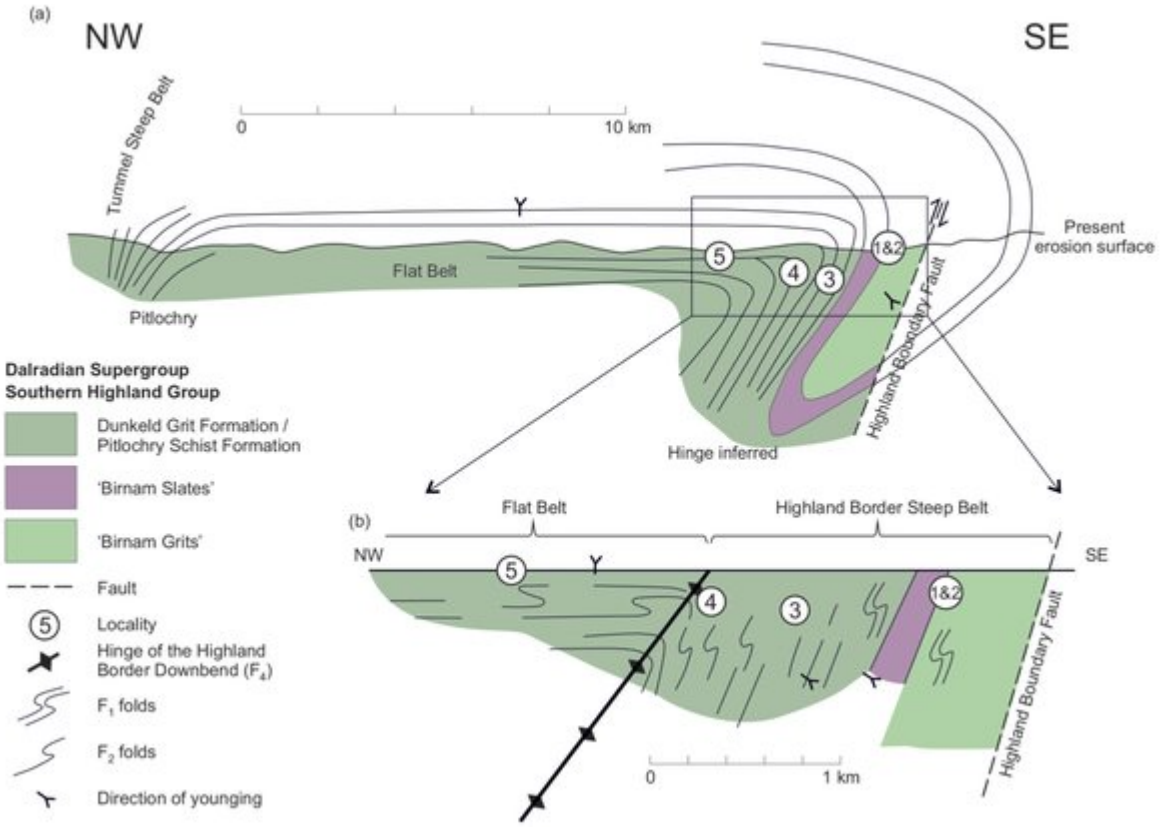
The metasiltstones here are garnet-mica schists [NO 0280 4760], the rocks being well to the north of the garnet isograd. The sheet dip of the composite S_1/S_2 foliation is about 20° to the north and there are a few small F_4 monoclines, which verge to the south (Plate 18.4). A spaced S_4 crenulation cleavage associated with these folds is developed locally in metasiltstones. The main linear and planar features of D_2 are similar to those seen at Craig a' Barns. At the south end of the exposure, a clean face shows an excellent example of an F_2 fold of a lenticular metasandstone bed; many more examples can be seen along the exposure. The garnets in the metasiltstones are asymmetrically wrapped by the penetrative S_2 fabric, are elongated at about 45° to the foliation and contain chlorite-filled cracks, which consistently dip to the south. Combined with asymmetrically boudinaged quartz veins, these features suggest a south-directed shear component in the overall D_2 strain.

Return across the stile to the NE-trending cliff section overlooking the Mill Dam, which is Locality 18.5b [NO 0290 4742]. The view from the top of this cliff can be used to illustrate the scale of the Tay Nappe. The Highland Border Steep Belt at Birnam Hill and Craig a' Barns can be seen just to the south, whereas the dark Ben Eagach ridge, 18 km to the NW, lies in the Loch Tummel Steep Belt, which marks the general NW limit of the regionally inverted rocks of the Perthshire Flat Belt. To the NW of the Loch Tummel Steep Belt, structures commonly face up to the NW. This cliff exposure is approximately normal to that at Locality 18.5a, and so offers a three-dimensional view of the F_2 structures. At the NE end, numerous eye-shaped closures of the first, S_1 pressure-solution cleavage are a result of the curvilinear nature of the F_2 fold hinges. In the upper, SE part of the crag, examples of F_4 folds can be seen refolding F_2 folds.

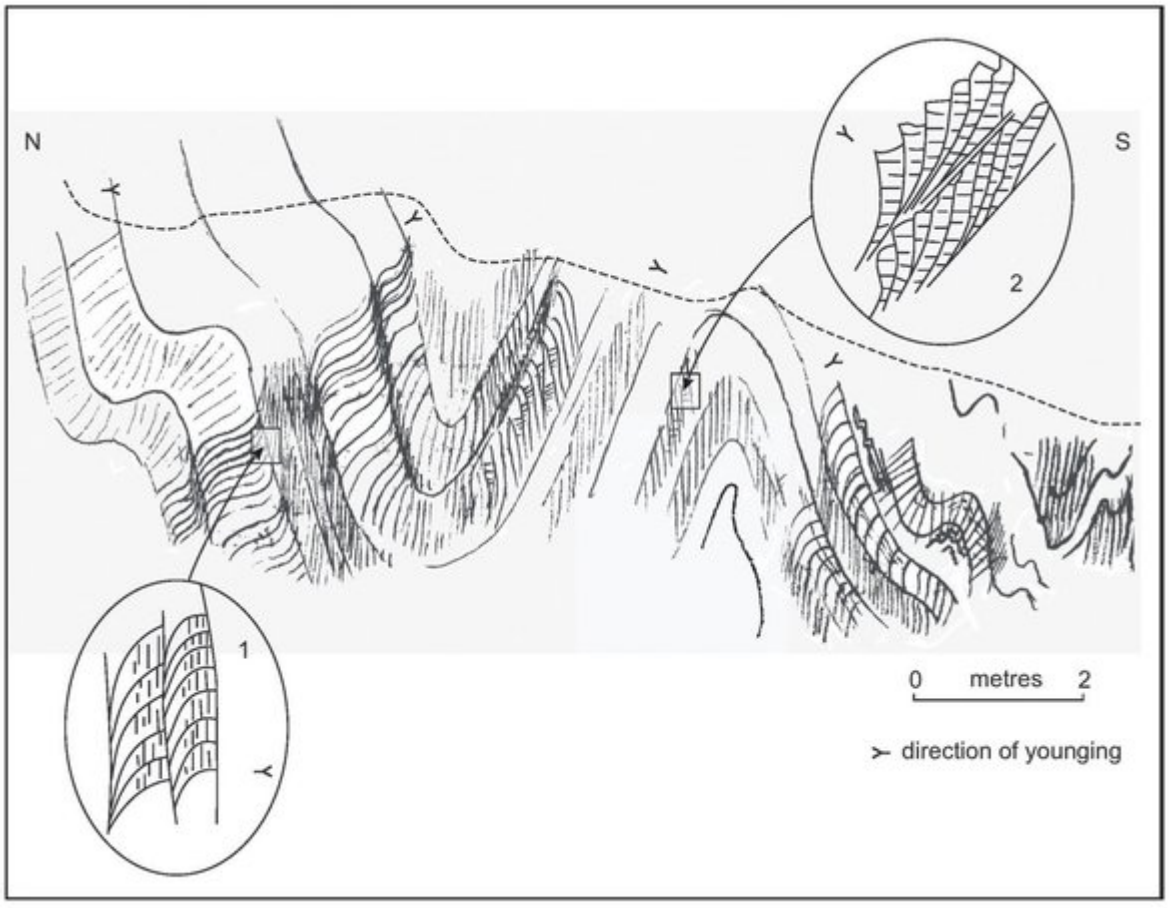
References



(Figure 18.1) Geological map of the Highland Border area around Dunkeld and Little Glen Shee, showing localities for Excursion 18.

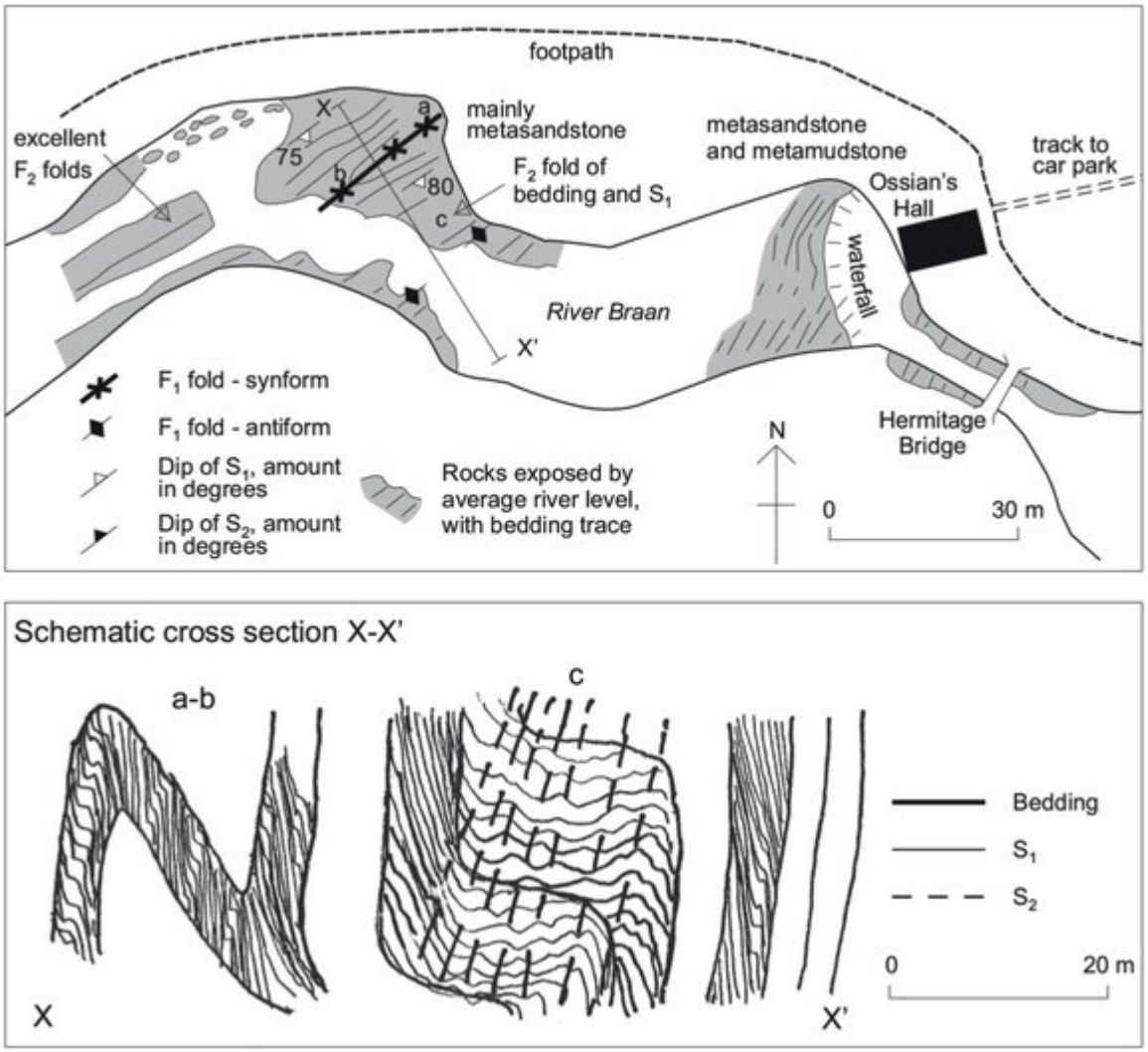


(Figure 18.2) (a) Schematic cross-section through the Tay Nappe from Pitlochry to Dunkeld, showing relative positions of localities for Excursion 18; (b) Detailed geology in relation to major features of the structure. Adapted from a drawing by Philip Rose in Tanner et al. (2013, fig. 24).



(Figure 18.3) Details of downward-facing F1 folds close to the downbent hinge zone of the Tay Nappe at Little Glen Shee, Locality 18.1, (Plate S.1). Fanning of the S cleavage around minor folds and its refraction reflecting the original grain size are clearly shown. Insets show generalised detail of relations between gross bedding, the S spaced cleavage and re-orientated bedding lamination. Adapted from Tanner et al. (2013, fig. 25).

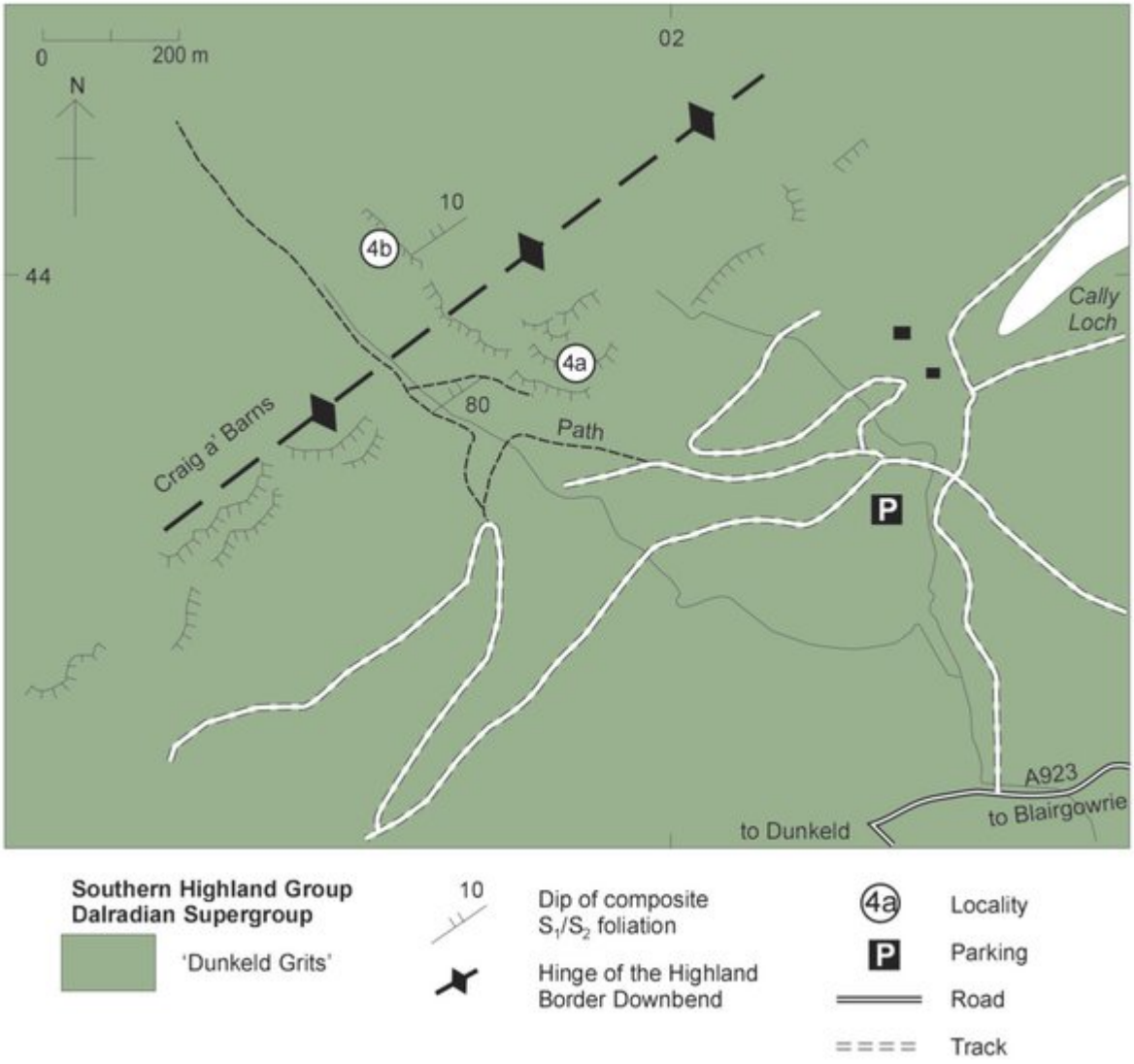
(Plate 18.1) Locality 18.1. Refraction of S_1 spaced pressure-solution cleavage on the steep NW limb of a synform (far left on (Plate S.1) and (Figure 18.3)), Little Glen Shee. The cleavage fans around the minor folds and is at a higher angle to the bedding in the coarser grained beds. The curvature indicates grading towards finer grain size, and hence younging, to the left. Thus the folds in (Plate S.1) are downward facing.



(Figure 18.4) Detailed geological map and cross-section, showing relationships between D1 and D2 structures at The Hermitage, Locality 18.3.

(Plate 18.2) Locality 18.3a. Characteristic F_2 folds of spaced S_1 cleavage in metasandstone at The Hermitage.

(Plate 18.3) Locality 18.3c. Lozenge-shaped microlithons' formed by S_2 spaced pressure-solution cleavage (top left to bottom right) cutting a folded earlier, S_1 spaced cleavage in metasandstone, The Hermitage.



(Figure 18.5) Route map and major structures at Craig a' Barns, Locality 18.4.

(Plate 18.4) Locality 18.5a SE-verging F_4 minor folds of composite S_1/S_2 foliation in schistose metasiltstone in the Flat Belt, NW of the Highland Border Downbend, Deuchary Hill.