10 Garron Point to Muchalls

[NO 894 877]–[NO 907 921]

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10.1 Introduction

The east coast of the Grampian Highlands, north of Stonehaven, provides a continuously exposed and largely accessible section through Southern Highland Group metasedimentary rocks (Figure 4.32). The outcrops reveal in outstanding detail, the characteristics of the original sedimentary rocks and their response to metamorphism and deformation. In particular, there is a continuous section across the Tay Nappe, from the Flat Belt, across the Highland Border Downbend, into the Highland Border Steep Belt and the downward-facing complex hinge-zone of the nappe, which is truncated here by the Highland Boundary Fault (Figure 4.33). In addition, distinctive metamorphic mineral assemblages are developed within the pelitic rocks, which differ from those of the ‘Buchan’ metamorphism to the north, and the ‘Barrovian’ metamorphism to the west.

The importance of this coast section has long been recognized. Although the study of the metamorphic mineral assemblages has been an important feature (e.g. Williamson, 1953; Harte and Hudson, 1979), it is the study of the structure that has been particularly important and highly relevant to the regional Dalradian structure. Anderson (1942, 1947a) was the first to describe and interpret the geological structure of the coast, relating this to the structure he observed in the River North Esk. And Stringer (1957) identified the four main phases of deformation, which he traced from the coast along the Highland Border to the south-west. However, it was Shackleton (1958) who recognized the monoformal Highland Border Downbend, and was able to show, by combining way-up evidence in the metasedimentary rocks with the geometrical relationships between first cleavage and bedding, that the first fold structures in the Highland Border Steep Belt are downward-facing. In other words, he showed that the sequence was already inverted prior to folding around the Highland Border Downbend. This inversion was attributed to the emplacement of an early nappe, equivalent to the Tay Nappe of Perthshire. However, the recognition of a right-way-up succession in the Tarfside district to the west led Harte (1979) to propose that the coast section may not lie on the inverted limb of the Tay Nappe, but on the right-way-up limb of an underlying ‘Tarfside Nappe’. This interpretation was supported by Booth (1984), who also concluded that the coast section lies on a right-way-up fold limb. But more-recent work by the British Geological Survey during the remapping of 1:50 000 Sheet 67 (Stonehaven, 1999) indicated that this interpretation is difficult to substantiate. Younging evidence in outcrops to the north of the Highland Border Downbend shows that the rocks are generally inverted, which is more consistent with the traditional interpretation that the coast section lies in the lower, inverted limb of the Tay Nappe.

10.2 Description

The GCR site extends for some 5 km from the southern end of Skatie Shore at Garron Point [NO 894 877], to Ritchie Shore [NO 907 921], some 300 m south-east of Muchalls. The coast is dominated by steep cliffs, locally up to 30 m or more in height, above a rock platform that is exposed at mid to low tides.

The metasedimentary rocks are very well bedded. Bedding is generally planar, although beds do wedge out locally. Graded bedding is abundant and is seen particularly well in the south of the site, where the metamorphic grade is lower. The succession is dominated by metasandstone (psammite), with metasiltstone (semipelite) and metamudstone (pelite) common in many places. The metasandstones vary from fine-grained, thinly bedded units to massive, very coarse-grained and sometimes pebbly or microconglomeratic units in excess of 2 m in thickness. To the north of the Highland Border Downbend, calcsilicate-bearing layers commonly occur in the centre of metasandstone beds. These are

thought likely to be of diagenetic origin, but now contain garnet, amphibole and plagioclase. Units containing volcanic debris, informally known as ‘green beds’ and a notable feature of the Southern Highland Group elsewhere, are conspicuously absent from the coast section, exacerbating correlation problems.

The structure of the coast section is complex. Four major phases of deformation are developed between Garron Point and Findon Ness [NO 944 974], to the north of the GCR site, and three of these are readily observed within the site. The site is divided into two structural domains by the Highland Border Downbend (Figure 4.32) and (Figure 4.33). This major structure cuts the coast at Castle Rock of Muchalls [NO 899 907], where it is very sharply defined, much more so than in many other areas of the Highland Border region. The coast to the north of the downbend is occupied generally by relatively shallow-dipping strata of the Flat Belt. To the south of the downbend, strata dip steeply, generally to the north-north-west, in the Highland Border Steep Belt.

D1 structures dominate the southern part of the GCR site along Skatie Shore and Perthumie Bay, and this early phase of deformation appears to be generally more intense than in some other areas where lithostratigraphically equivalent rocks are exposed (e.g. in the Aberfoyle district; see the *Duke’s Pass* GCR site report). It is manifested most obviously as coarsely spaced, anastomising cleavages (S1) in gritty metasandstone beds. Tight to isoclinal F1 folds can be shown to be present on the basis of changes in younging direction, but hinges are very rarely seen. The best example is exposed below mid tide on the rock platform in the southern part of Perthumie Bay. In this example, the S1 cleavage is seen to fan around the hinge. On the basis of the facing of the S1 cleavages observed in the southern part of the site, it is clear that the F1 fold system is not cylindrical, and F1 fold plunges are markedly variable.

D2 structures probably occur throughout the GCR site, but are only readily observable north of Perthumie Bay. In addition, it appears that the D2 deformation is not pervasive. D2 is manifested by complex minor structures that deform the first cleavage in the metasandstones in a very characteristic manner, giving rise to what is most easily described as a very coarse crenulation cleavage. The minor F2 folds formed within this cleavage have axial planes that are approximately parallel to the bedding and have markedly curvilinear hinges. F2 folds to the south of the Highland Border Downbend plunge generally to the south-west. To the north of the downbend they plunge to the north. Larger F2 folds of bedding are developed more commonly in the northern part of the coast section, where they are tight to isoclinal in form. The D2 deformation is probably heavily partitioned into the pelitic rocks, but the fine-grained and recrystallized nature of these lithologies obscures the D1-D2 relationships that are so readily observed in the coarse-grained metasandstones. D2 deformation is generally considered to just pre-date or be synchronous with the peak of metamorphism.

The D3 deformation is not well developed within the GCR site; unequivocal D3 structures are best observed in the Portlethen area about 6 km to the north of Muchalls. Folds just north of Red Man [NO 892 888], ascribed by Booth to D3 (Booth, 1984; see also Harte *et al.*, 1987, locality 6), are thought more likely to have resulted from D1 deformation. Locally developed cleavages of obscure origin might be due to D3 effects, but their relationships to other cleavages are commonly ambiguous and they could well have arisen from local strain partitioning.

The D4 deformation is complex and probably occurred over a protracted period, involving early extension, followed by compression. The observable effects of this phase of deformation are focussed on the Highland Border Downbend. F4 folds are overturned towards the downbend from both the south and the north. They are open to close, parallel fold structures that become more intense towards the downbend. In the Steep Belt, F4 folds are centimetre- to ten metre-scale structures. In the Flat Belt, F4 folds range in scale from small, centimetre-sized structures to large folds on the scale of tens of metres. These larger structures produce local steep zones that form the short limbs of the folds. Crenulation cleavages are best developed in pelitic beds and in laminae within the hinge regions of the folds. F4 folds plunge at shallow angles mainly to the south-west and, less frequently, to the north-east. F4 axial planes dip at shallow angles to the north-west.

Faults and dislocations are a common feature of the coast section. In general, they appear to become more common towards the Highland Border Downbend from the south and are common in the Flat Belt towards Muchalls, where they result in a complex, incised coastline. In broad terms, they can be divided into low-angle and high-angle sets.

The low-angle faults were probably related to D4 compression after the formation of the Highland Border Downbend, probably originating as thrust structures during or after the development of F4 folds. Good examples of low-angle faults are observed in Hall Bay [NO 898 899]. One at the northern end of Hall Bay is clearly a thrust, having a thin gouge along the fault plane. Low-angle discontinuities are displaced by a steep fault in the section east of Craigview [NO 9050 9127], about 1 km south of Muchalls. This suggests that the steep faults post-date the low-angle faults.

Two sets of steep faults are identified. A dominant set trending north-west is responsible for the deeply incised coastline north of the Highland Border Downbend, particularly around Doonie Point [NO 903 910] and on the promontory at Grim Haven, south of Muchalls. These faults generally dip steeply to the north-east or south-west and the available field evidence indicates that they are normal faults. The other conjugate set trends north-east and dips steeply to the south-east or north-west, but these faults are relatively uncommon compared to the NW-trending set. They are roughly parallel to the regional strike and the Highland Boundary Fault and might be related to the formation of the Highland Border Downbend.

The metamorphism within the coast section is characterized by a rapid increase in grade northwards from the Highland Boundary Fault. This is manifested by the development of distinctive mineral assemblages in the pelitic rocks, most notably chloritoid + biotite and andalusite, the latter in place of the kyanite that is characteristic of the classic Barrovian assemblages of the Angus glens to the south-west. The presence of chloritoid and andalusite led Harte (1975) to define the ‘Stonehavian’ metamorphic assemblage sequence, which is intermediate between the relatively high-pressure Barrovian and high-temperature Buchan sequences (Harte and Hudson, 1979). Biotite + chlorite-bearing pelitic rocks at Skatie Shore become garnet-bearing in the northern part of Perthumie Bay. Chloritoid appears first in the northern part of Red Man in highly aluminous pelites (Harte and Hudson, 1979). The main appearance of chloritoid results from the discontinuous reaction between garnet and chlorite to yield chloritoid + biotite, this being the chloritoid isograd in the Stonehavian sequence. Staurolite first appears just to the north of Red Man [NO 892 888], initially resulting from reaction between chloritoid and chlorite to produce staurolite + biotite and then from the terminal breakdown of chloritoid to give staurolite + garnet + biotite. Andalusite is the stable aluminosilicate polymorph throughout the site. The staurolite + biotite assemblages coupled with the presence of andalusite indicate peak metamorphic pressures of no more than about 3 kbar at temperatures in excess of 500°C (Spear, 1993).

10.3 Interpretation

There are no precise constraints on the age of the metasedimentary rocks within this GCR site. All are assigned to the Glen Lethnot Grit Formation, in the upper part of the Southern Highland Group. This formation is now generally considered to be broadly equivalent in its lithological character and lithostratigraphical level to the Ben Ledi Grit Formation of the Aberfoyle–Callander area, a correlation first suggested by Anderson (1942). However, the lack of significant marker horizons at this site precludes precise correlation. Although metasiltstones and metamudstones are common locally, metasandstones dominate. Their general sedimentological characteristics indicate deposition within a submarine fan system on a continental margin, generally by turbidity currents; mass-flow mechanisms are thought to have been responsible for the deposition of massive, very thick single units of coarse, gritty rocks.

The metasedimentary rocks were strongly deformed during the Grampian Event of the Caledonian Orogeny and three of the four main phases of deformation generally recognizable in the Dalradian are developed within the GCR site. The pre-D2 way-up of the section is critical to the interpretation of the overall structural setting. Although Harte (1979) proposed, by analogy with the Tarfside succession inland, that the coast section might lie in the right-way-up limb of a nappe lying below the Tay Nappe, all the available younging evidence in the Flat Belt indicates that the rocks are generally inverted. This, coupled with the downward-facing nature of the F1 folds in the Steep Belt, indicates that the rocks are more-readily interpreted as lying within the inverted limb of an early nappe structure most simply correlated with the Tay Nappe.

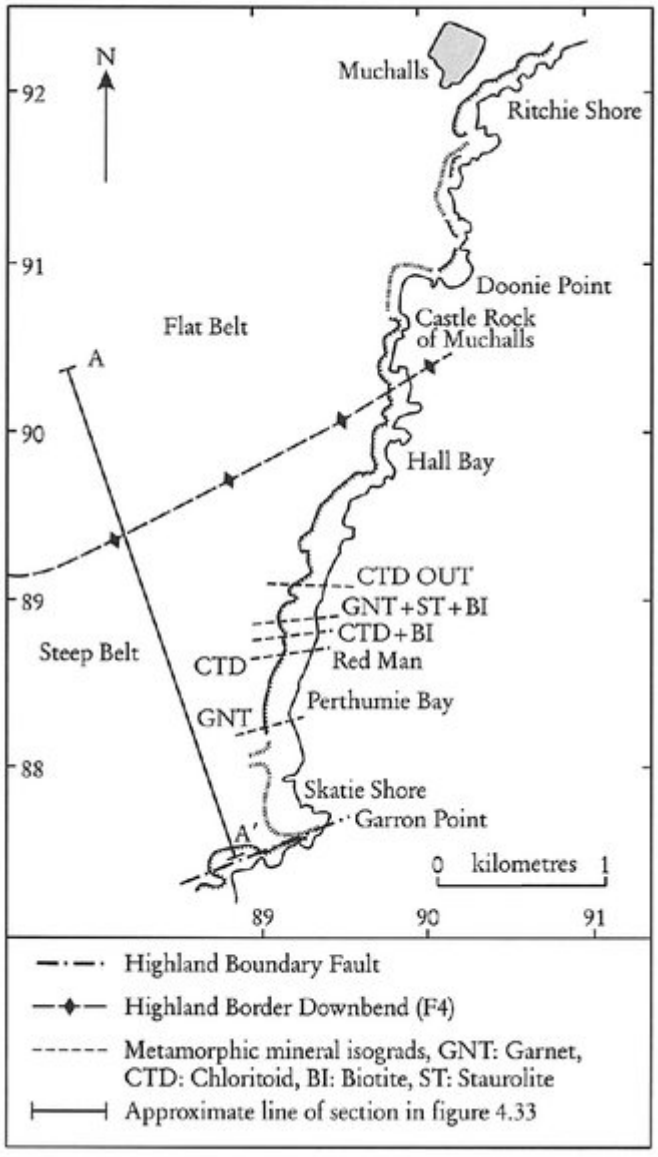
10.4 Conclusions

The coast between Garron Point and Muchalls contains outstanding exposures of Southern Highland Group metasedimentary strata in an area of the Highland Border region that is otherwise poorly exposed. The site is of national and international importance for the continuous section that it exhibits across the downbent complex hinge-zone of the Tay Nappe, the most intensively studied and, arguably, the most important structure in the Grampian Highlands. The effects of three deformation events (D1, D2 and D4) can be readily discerned and the site contains some of the first localities in the world at which downward-facing geological structures (e.g. synformal anticlines) were deduced from their smaller scale component structures by Robert Shackleton in 1958. The recognition of the facing of the early structures led to a radical re-interpretation of the structure of the south-eastern part of the Dalradian as a whole.

Metamorphism accompanying the deformation resulted in the generation of mineral assemblages in the pelitic rocks that are a distinctive feature of the area around the GCR site and indicate rapidly increasing metamorphic grade northwards from the Highland Boundary Fault. Metamorphic conditions were intermediate between those of the high-temperature Buchan Zones to the north and those of the high-pressure Barrovian Zones to the south-west.

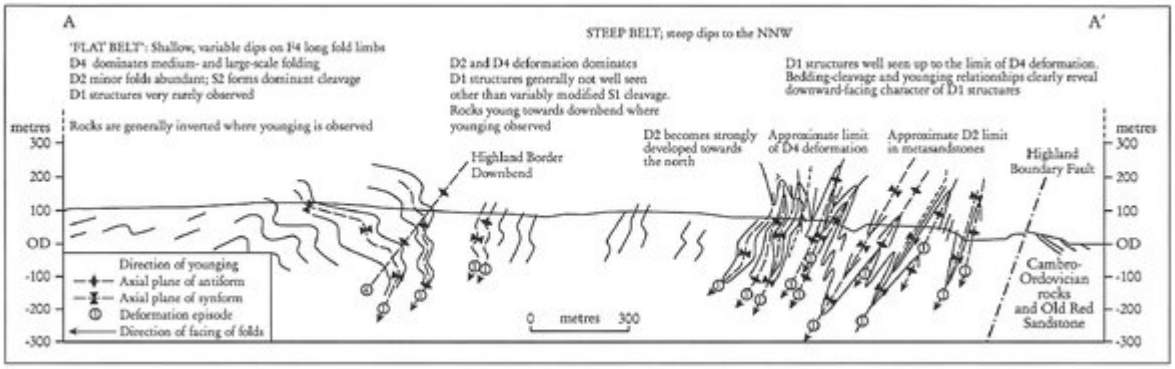
The ready accessibility of the outcrops, the excellent exposure and the nature of the lithologies make this an excellent site within which to demonstrate and teach structural geology and the temporal links between deformation and metamorphism within a classic orogenic belt.

References



(Figure 4.32) Location of the coast section in Southern Highland Group rocks from Garron Point to Muchalls, north of Stonehaven, showing the principal structural and metamorphic features. After BGS 1:50 000 Sheet 67 (Stonehaven,

1999), with approximate locations of metamorphic mineral isograds based on Harte et al. (1987, figure 2a).



(Figure 4.33) Partly schematic structural cross-section of the coast north of Garron Point, Stonehaven, showing the contrast in dip of bedding in the Flat and Steep belts, the principle F1 and F4 folds and the limits of D2 and D4 deformation in metasandstones. Structures observed on the coast have been projected onto the line A–A′ shown on (Figure 4.27). Section is true scale (no vertical exaggeration). After BGS 1:50 000 Sheet 67 (Stonehaven, 1999).