16 Collieston to Whinnyfold

[NK 084 337]–[NK 042 287]

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16.1 Introduction

The *c.* 7 km-long coastal section between Collieston and Whinnyfold, 20 km south of Peterhead, exposes turbiditic psammites and pelites assigned to the Collieston Formation of the Southern Highland Group, which are disposed in a series of recumbent folds. The beds show an abundance of grading from gritty bases to pelitic tops and Bouma sequences can be recognized, albeit generally incomplete. Basic sheets intrude the metasedimentary rocks, mainly as sills but locally as dykes, and a possible tuffaceous unit occurs on the north-east side of Collieston Bay. The grade of metamorphism varies from greenschist facies in the north-east to lower amphibolite facies in the south-west and the section encompasses the andalusite and cordierite isograds. The relatively low metamorphic grade and abundance of grading in the rocks enables the geometry of the early-formed fold structures to be elucidated. The beds form part of a large-scale recumbent syncline that faces eastwards and most of the exposed succession lies on its upper, inverted limb. Evidence for a second deformation episode can be found towards the south-west end of the section.

The area was mapped during the primary geological survey by J.S. Grant Wilson and the resulting one-inch Sheet 87 was published in 1885. A brief description of the metamorphic rock types and some of the structures was given in the accompanying memoir (Grant Wilson, 1886). Subsequently, the coastal section was mapped in detail by O.C. Farquhar and a comprehensive summary of the structure was given by Read and Farquhar (1956). The area was revised by the Geological Survey in 1980-81 and an account of the section was given in the excursion guide to the Geology of the Aberdeen area by Mendum (1987). This account is based upon the latter work.

Read (1955) and Read and Farquhar (1956) showed that the Collieston–Whinnyfold section is important in terms of interpreting the overall geology of the North-east Grampian Highlands. They proposed that the rocks here form the hinge-zone of their Banff Nappe, a regional east-facing recumbent anticline whose upper limb crops out in the Banffshire coast section, east of the Boyne Line (see the *Cullen to Troup Head* GCR site report). They envisaged formation of the Collieston folds by gravitational processes linked to the rise of the open Buchan Anticline farther west. However, it is now clear that the Buchan Anticline, which exposes sillimanite-grade gneissose Argyll Group rocks in its broad hinge-zone, is a late-stage structure that refolds the earlier cleavages (see the *Cairnbulg to St Combs* GCR site report). The Collieston–Whinnyfold section remains anomalous as the only area of the North-east Grampian Highlands that contains a regionally inverted succession and a structural pattern similar to that seen in Southern Highland Group rocks near the Highland Border.

16.2 Description

This GCR site consists of coastal cliffs, typically 25–30 m high but in parts reaching 45–50 m, and intertidal foreshore. As the area has been used for inshore fishing over many years the various indentations of the coast have been given names; these are partly topographical, partly historical and in places obviously personal (Figure 6.39).

The section lies oblique to the strike of the bedding and to the gentle NNE-plunging fold axes. Traversing south-west from Whinnyfold, one moves structurally down but stratigraphically up the section (Figure 6.39), (Figure 6.40). Recumbent folding on a scale of tens of metres disrupts the simple progression but south-west of Old Castle, fold amplitude and wavelength increase to several hundreds of metres. This latter section appears to be part of the hinge-zone to the large recumbent syncline. From Collieston south-westwards one appears to be traversing out of the

hinge-zone and onto the lower limb of the main east-facing syncline; the overall structure becomes more complex and the superimposed secondary deformation and folding become more dominant. Impure metalimestones and calcsilicate bands some 2.5 km south-west of Collieston, between The Smithy [NK 0262 2658] and Rockend [NK 0215 2668], are possible representatives of the Tayvallich Subgroup. The coast section is described below from north-east to south-west.

At Sandy Haven, 350 m north-east of Whinnyfold, locally brecciated and hornfelsed psammites and semipelites are cut by the red Peterhead Granite. The contact is sharp, steeply dipping and when traced southwards it is offset in places by small faults. At the south margin of the bay, large xenoliths of grey to olive-green psammite, up to 30 m wide and 100 m long, show irregular contacts with the granite. On the headland to the south-east (the Cruner) thin- to medium-bedded psammites and semipelites contain gritty bands that show flattened quartz and feldspar clasts. Some boudinage is present and a discrete S1 spaced cleavage is developed (spacing 5 mm to 13 mm).

South-west from Whinnyfold are further grey coarse- and medium-grained psammites and semipelites with interbeds of fissile cordierite-bearing pelite. In parts thicker pelitic units are present. Calcsilicate lenses are common within the turbiditic succession. Lenticular, fawn-weathering, cream, gritty quartzites with notable quartz veining form discrete units several metres thick within the turbiditic succession. The beds dip at 15° to 17° to the north-north-east and excellent grading at [NK 0809 3298] shows that the succession is inverted. Large-scale tight recumbent folds (F1) are present in Buck's Nose Bay and have a variably developed axial-planar spaced cleavage. Well-defined grading and bottom structures at the gritty psammite–pelite contacts show that the folds face to the east. Some of the folds north-east of the bay have disharmonic profiles and show discontinuities near parallel to bedding. Similar features occur farther to the south-south-west at Lady's Step [NK 0801 3274] where tight S-profile F1 folds with attenuated middle limbs are seen. In these fold-pairs, the syncline is much larger in amplitude than the corresponding anticline, which when traced westwards diminishes to zero. The fold axes are subhorizontal and trend 010°.

Cliffs on the south side of Green Craig Bay, at [NK 0684 3154], expose inverted graded beds with cuspate bottom structures trending 142°. In the pelitic units, which here form a greater proportion of the succession, grey andalusite 'slugs' and darker grey, small, rounded cordierite porphyroblasts are abundant. The stack of Green Craig itself shows recumbent F1 folds underlain by an apparent discontinuity (Read and Farquhar, 1956, plate VI, figure 1). F1 fold hinges are exposed on the foreshore at the southern edge of the bay. Fold axes here plunge very gently to the south-south-west, with the S1 axial-planar cleavage dipping at 18° to the east-south-east. However, the prominent rounded fold hinge in massive gritty psammite units figured by Read and Farquhar (1956, plate IV, figure 2) at this location folds the S1 spaced cleavage and is attributed to the secondary deformation (termed D3). Although this later fold is co-axial with F1 folds, the related axial plane dips at 26° to the west-north-west. A further sign of this later, D3 deformation is shown by the abundant folded quartz veining in more-pelitic units on the north side of the bay, which imply some 58% shortening.

At the Devil's Study [NK 0606 3091], a spectacular example of a recumbent westward-closing F1 syncline is exposed (Figure 6.41). It occurs in thick-bedded, locally gritty psammites and subsidiary interbanded cordierite-bearing schistose pelites and semipelites. A prominent S1 axial-planar spaced cleavage (spacing *c.* 5 mm) is uniformly developed across the fold profile. The lower limb is strongly attenuated and the complementary antiform in the pelitic beds below has a much smaller amplitude. The fold appears to be underlain by a discontinuity. To the south-west, towards Radel Haven, tight folds confined to individual beds are interpreted as slump folds. In addition, the gritty bases of inverted psammite units are exposed on the low foreshore. The dominant quartz and feldspar clasts show little evidence of significant superimposed strain in these thicker psammites, yet the more-elongate clasts show a strong grain alignment that plunges gently to between 340° and 020°. Grain alignment is also seen on the bases of inverted graded psammite units just north of the Devil's Study, where the resultant lineation plunges at 10° towards 007°. On the north edge of Radel Haven [NK 0584 3083], more-complete Bouma sequences contain both laminated and cross-laminated silty units.

The cliffs below Old Castle [NK 0525 3005] are composed mainly of cordierite-rich schistose semipelite and pelite with coarse andalusite present in parts. Abundant tight F1 folds plunge gently to the north, and are commonly confined to particular stratigraphical intervals. In parts a later S3 crenulation cleavage is also developed. North of the Old Castle promontory, psammites show a more closely spaced (*c.* 3 mm) S1 cleavage and in the intertidal zone the S1 cleavage is folded by minor open to close folds whose axes plunge about 25° to the north-north-east. A fine-scale spaced S3

cleavage is developed locally. F1+F3 folding is abundantly developed farther south at Portie Shore (around [NK 0415 2991]) involving the lenticular quartzite units. A weakly developed S3 spaced cleavage is widely seen on weathered surfaces in the psammites; it shows a spacing of 15–20 mm. A finely spaced crenulation cleavage in the pelitic units attests to the oncoming of penetrative D3 deformation.

Between Old Castle and Collieston, tight F1 and open to tight F3 folds are particularly abundant. An excellent example of a recumbent fold train in interbedded psammitic and pelitic units is displayed at Pottie Murlan [NK 0478 2916] (Read and Farquhar, 1956, plate IV, figure 1). The fold axes plunge at 2° to 031° and axial planes dip at 23° to the east-south-east. Although the fold profile is coherent and individual hinges are complementary to one another, closer inspection shows that there is a combination of F1 and F3 folds. Hence in some fold hinges the S1 cleavage is axial planar but in others S1 is folded and a new S3 spaced cleavage is developed. In thin section both cleavages are defined by biotite concentrations but individual biotite laths are generally aligned parallel to S3.

South-west of Pottie Murlan, thin- to medium-bedded psammites and pelitic units show tight F1 and F3 folding but are right way up overall. By Dowiestone Cave, a deformed metadolerite dyke has cuspate margins and shows cleaved biotite amphibolite marginal zones. Several other metadolerite intrusions are seen farther south in the cliffs between Aver Hill and Collieston.

At Collieston, most of the psammite–pelite succession is inverted but tight recumbent F1 folds are common giving rise to way-up reversals. The quarry face behind the car park on the east side of Tarness Haven displays a *c.* 10 m-high profile of a recumbent syncline formed in gritty, locally pebbly psammites and subsidiary semipelites and pelites. The fold faces east-south-east, has a pervasive S1 spaced cleavage, and its axis plunges at 16° to 026°. At the northern end of the quarry, similar pebbly psammites form units up to 4 m thick and contain ripped-up mud clasts derived from underlying pelitic lithologies. On the rocky slabs above St Catherine's Dub, south-east of the car park, inverted psammites with prominent gritty and pebbly bases show a strong grain-alignment lineation. The white to pink quartz clasts are notably elongate and the lineations are curved on some bedding planes and of variable intensity. The lineations plunge gently to moderately to the north-north-east. Their variability and association with a linear fabric in the matrix suggests that here they are dominantly of tectonic origin, and the overall strain patently reflects both D1 and D3 deformation events. In the psammites, minor F3 folds fold the pervasive S1 spaced cleavage and an accompanying S3 spaced cleavage is developed locally. Near the low watermark by the arch at the west side of St Catherine's Dub, tight F1 and F3 folds are abundant in gritty psammites and cordierite-bearing pelites and semipelites. F1 fold axes plunge gently to the north-north-east, co-axial with an L1 lineation, and a discordant S3 cleavage is well developed. Discordant quartz veins that post-date F1 folds and S1 cleavage are tightly folded here (F3).

A 4 m-thick discordant metadolerite sheeet with cuspate margins and small boudinaged offshoots can be traced up the east side of Tarness Haven and across the car park to the gully on the east side of St Catherine's Dub. The marginal alteration to biotite-rich foliated amphibolite is clearly seen.

Near low-water mark on the east side of Tarness Haven, weathered fine-grained, green-brown, ?chlorite-rich units are interbanded with dark-grey, thinly banded cordierite-rich pelites and semipelites over a vertical interval of 1.5 m. These units might represent tuffaceous horizons deposited in more-distal parts of the turbidite fan.

South of Collieston Harbour, coastal outcrops show psammites with excellent non-inverted grading, interbedded with pelites that contain larger cordierite porphyroblasts and some andalusite. D3 deformation generally becomes more penetrative to the south, although the earlier D1 structures are still generally apparent.

16.3 Interpretation

The Collieston to Whinnyfold section exposes beds that are assumed to represent the lower part of the Southern Highland Group on the basis of thin impure calcareous beds and quartzites, exposed at the lowest stratigraphical level to the south-west of the GCR site, which could be the sparse representatives of the Tayvallich Subgroup in this area. Read and Farquhar (1956) interpreted these calcareous and quartzose lithologies as part of the Mormond Hill Quartzite, now the Mormond Hill Quartzite Member of the dominantly semipelitic Strichen Formation. They believed that the Mormond

Hill Quartzite forms a thick lenticular unit in the core of the Buchan Anticline but the distribution of units strongly implies that there are significant lateral facies variations. Inland bedrock exposures are few on the eastern limb of the anticline, and it is difficult to correlate the stratigraphy with the better-established succession on the western limb.

The psammites and pelitic rocks of the Southern Highland Group succession are interpreted as having been deposited on a sub-marine fan by density currents in the late Neoproterozoic. The lenticular quartzose units appear to represent channel fills and might have been produced by reworking of the turbiditic units by bottom currents. Although quartz is the dominant clastic constituent of the succession, locally with a bluish opalescent tint indicative of inclusions, potash feldspar and more rarely plagioclase grains have been recorded (Read and Farquhar, 1956). The matrix consists of sericite, chlorite, altered feldspar and quartz in the low-grade rocks but as metamorphic grade increases biotite, muscovite, feldspar and quartz form a mosaic. Accessory iron-oxide minerals, tourmaline, garnet, zircon and titanite have also been recorded. Retrogression to chlorite and sericite is common locally. The pelitic rocks show more-recrystallized mica fabrics south-west of Bruce's Haven [NK 0680 3144] but cordierite porphyroblasts occur throughout much of the section. These are rounded dark-grey spots, except just south of Collieston Harbour where larger 'black slugs' are found. In thin section many are altered to pinite but as grade increases some sector-twinned cordierite is present. Andalusite is paler grey and forms elongate 'slugs'; it is first seen as pseudomorphs around Berry's Loup [NK 0745 3217] but forms coherent porphyroblasts farther south-west with laths up to 6 cm long recorded south-west of Collieston (Munro, 1986). Both cordierite and andalusite overgrow the S1 fabric and are wrapped and deformed by the S3 fabric, thus placing the peak of metamorphism between the two deformation events.

Structurally the Collieston–Whinnyfold section is important as it shows the nature of the early D1 deformation and makes an interesting comparison with that seen on the Banffshire Coast (see the *Cullen to Troup Head* GCR site report) and near the Highland Border (see the *Little Glenshee* GCR site report). In the Collieston–Whinnyfold section the F1 folds are recumbent, face eastwards and there are significant stretches of overturned strata. Oncoming of the secondary deformation (D3) is gradual but coincides approximately with the andalusite isograd. On the Banffshire coast F1 folds are largely upright and verge and face to the west and the secondary deformation comes on more sharply, again coincident with the andalusite isograd. Fold axes plunge gently northwards in both sections. Development of S1 spaced cleavage and metamorphic assemblages are also similar.

The F1 fold geometry seen in the Collieston–Whinnyfold section shows some unusual features. Fold profiles are variable along their axial planes and in numerous instances the synclines and anticlines that constitute fold-pairs have disparate amplitudes. Dislocations are also numerous both in fold stacks and beneath folded zones. This geometry suggests that either the turbiditic Southern Highland Group sequence here might not have been fully lithified at the time of deformation or that the mode of deformation was shear dominated with abundant fluids present. However, the related S1 cleavage is uniformly developed and fold axis orientations are relatively consistent, showing that deformation was tectonic and not syn-sedimentary. Although slump or soft-sediment folds seem to be present locally, they are not abundant. As this part of the sequence lies in the lower part of the Southern Highland Group, which is little younger than 600 Ma (Dempster *et al*., 2002), and the uppermost parts of the group were deposited at about 515 Ma, it seems unlikely that the succession would remain unlithified over some 80 Ma.

The lack of marker bands in the sequence makes it awkward to construct an accurate cross-section, but (Figure 6.40) shows a projected, composite, down-plunge cross-section that represents an overall structural profile of the exposed section. The orientation data for the section between Whinnyfold and Old Castle, where D3 deformation is not well developed, are shown on the stereoplot (inset to (Figure 6.39)). The fold geometry is consistent, whereas farther south-west where D3 deformation is stronger, the F1 and F3 axes show a greater spread.

Read and Farquhar envisaged the Collieston folding to have been initiated as a large recumbent fold, the Banff Nappe, which moved eastwards generating the Buchan Anticline as a 'tectonic drumlin' due to the inclusion of the resistant Mormond Hill Quartzite in the thrust succession. The folding of the Collieston turbiditic succession was attributed to 'gravity sliding' on the steep 'brow of the bulge' formed by the quartzite.

Ashcroft *et al.* (1984) and Harte *et al.* (1984) both suggested that the Collieston structure could represent a lateral equivalent of the hinge-zone below the Tay Nappe, albeit with a reduced amplitude. Certainly, the styles of folding and

metamorphic conditions resemble those found in the eastern Highland Border region, but the fold facing is to the east rather than south-east. If the Collieston–Whinnyfold rocks do belong to the lower limb of the Tay Nappe, it is interesting to speculate whether the upright F1 folding of the Banffshire coast section was indeed coeval with the recumbent F1 folding at Collieston. It seems clear that the metamorphic peak in the Dalradian rocks in general relates to orogenic events, termed D2, that are not represented by structures in the Collieston–Whinnyfold section, or elsewhere in the Buchan area. The D2 deformation occurred coeval with the intrusion of the mid Ordovician-age North-east Grampian Basic Suite at *c.* 470 Ma (Strachan *et al*., 2002). The D1 and D2 deformations were succeeded by a further deformation event and metamorphism, D3, that is represented here by the onset of reworking and enhanced metamorphic grade.

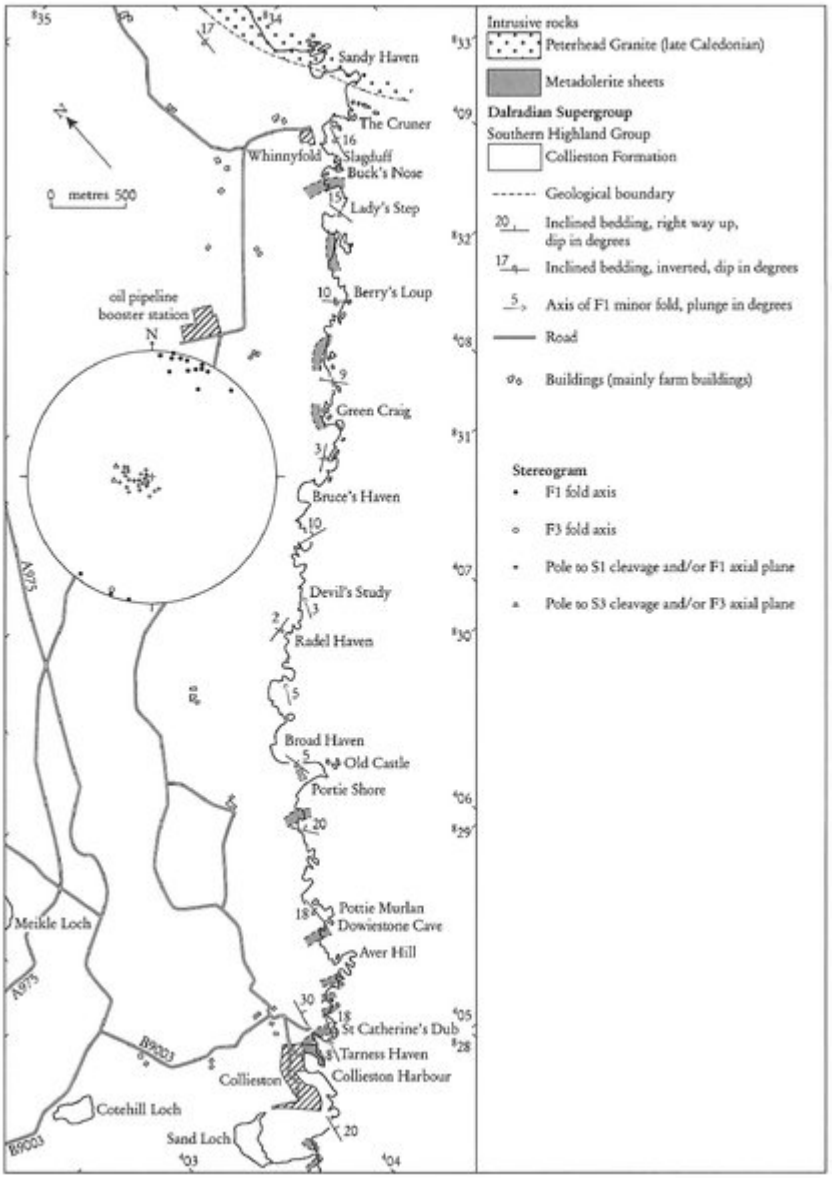
16.4 Conclusions

The well-exposed coast section between Collieston and Whinnyfold demonstrates the nature of early folding in the some of the youngest Dalradian rocks seen in the North-east Grampian Highlands. These Collieston Formation beds lie in the lower part of the Southern Highland Group and comprise turbiditic, originally sandy and muddy, psammites, semipelites and pelites. More-quartzose gritty psammites form distinctive lenticular units up to *c.* 10m thick in the turbiditic fan succession and probably represent reworked sands within channels. Grading is common and the ‘Bouma sequences’ that typify turbidite successions can easily be recognized. Groove casts, pebble alignment and rare pebble imbrication at the base of individual units imply that the density currents flowed north, and hence the offshore depositional slope appears to have been towards the north, at least in this area.

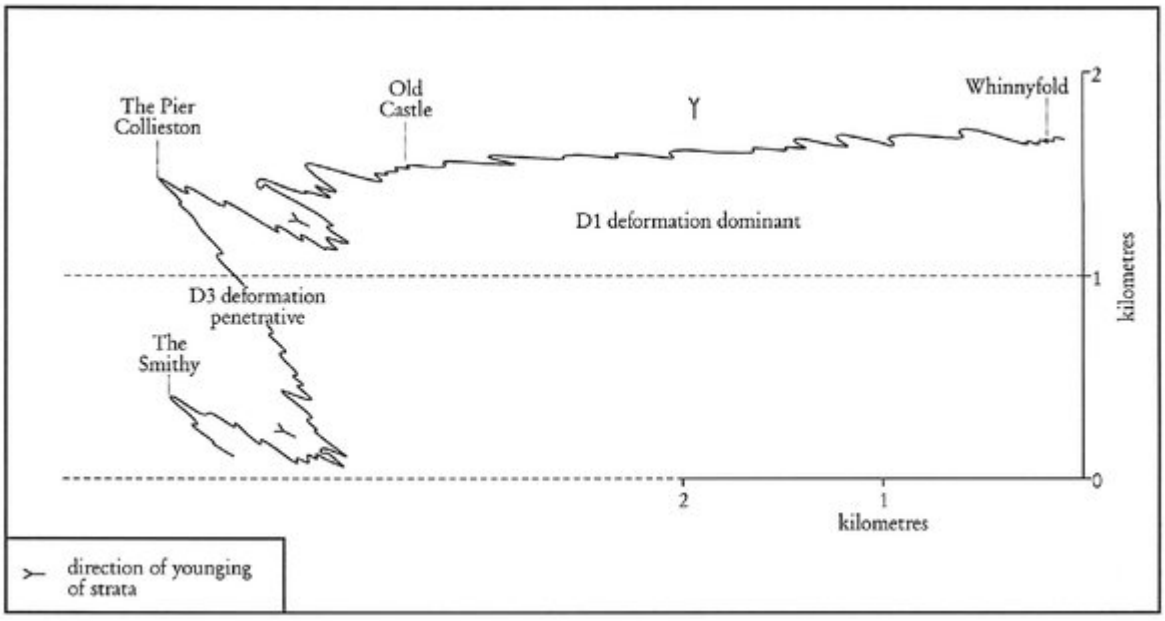
The rocks are folded into a large, composite, recumbent syncline. Numerous smaller scale anticlines and synclines have axes that plunge gently to the north and axial planes that dip gently to the north-east. The beds become younger eastwards and hence the folds face east. A penetrative spaced cleavage, defined by mica-rich seams and intervening quartz-rich microlithons, is developed in the psammites and a slaty to schistose cleavage is developed in the pelitic lithologies. Much of the succession lies on the upper, inverted limb of the main syncline, as is shown by the graded bedding. The more-pelitic rocks contain abundant cordierite, and andalusite is present in all but the lower grade north-eastern part of the section. A secondary deformation becomes progressively more important in the south-west. This has resulted in tightening of the early structures and attenuation of the cleavages. However, in many parts westward-verging minor folds fold the early cleavage and a new spaced or crenulation cleavage is developed.

The Collieston–Whinnyfold folds could represent the most north-easterly exposed extent of the Tay Nappe, although the structure here seems to have reduced amplitude. It remains an area of crucial importance in terms of regional interpretations of the Dalradian structure and sequence and lends itself to further study as well as providing an excellent teaching section.

References



(Figure 6.39) Map of the Collieston to Whinnyfold coast section showing D1 and D3 structural elements, adapted from Mendum (1987). The inset equal-area stereographic projection shows structural elements of the section between Whinnyfold and Old Castle.



(Figure 6.40) Composite cross-section of the coast section between Collieston and Whinnyfold, showing the overall fold pattern in a plane normal to the fold axes. From Mendum (1987).

(Figure 6.41) An excellent example of a recumbent, east-facing F1 fold in dominantly inverted gritty psammites of the Collieston Formation, viewed towards the north-north-east. Devil's Study, Collieston to Whinnyfold coast section. J.R. Mendum provides a scale. (Photo: BGS No. P 002878, reproduced with the permission of the Director, British Geological Survey, © NERC.)