Siccar Point to Hawk's Heugh, Scottish Borders

[NT 813 710]–[NT 790 714]

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Introduction

Accorded SSSI status in 1961, the Siccar Point unconformity (known as 'Hutton's unconformity') is an internationally famous place of geological pilgrimage. It is of great historical importance in the development of the science of geology. Although James Hutton had previously observed unconformities in Arran (see North Newton Shore GCR site report, this chapter) and Jedburgh (see (Figure 4.2), Chapter 4), the unconformity at Siccar Point is the most spectacular. It was here in 1788 that Hutton, accompanied by James Hall and John Playfair, was the first person to appreciate the significance of unconformities in the geological record (Hutton, 1795). He used the locality to demonstrate the cycle of deposition, folding, erosion and further deposition that the unconformity represents. He understood the implication of unconformities in the evidence that they provided for the enormity of geological time and the antiquity of the earth, in contrast to the biblical teaching of the creation of the Earth (Repcheck, 2003). All three of 'Hutton's unconformities' have been proposed as Global Geosites on the basis of their historical importance in the development of geology (Cleat *et al.,* 2001). A casting of the Siccar Point unconformity is housed in the American Museum of Natural History, New York.

Field guides to Siccar Point were provided by Craig (1960, 1986) and Greig and Davies (1978). Greig (1988) and Balin (1993) gave detailed accounts, from which the following description is largely derived. The geology of Siccar Point is placed into a wider context of the geology of the area between Redheugh and the Hawk's Heugh SSSI to the west (Figure 3.37), including the superb cliff sections of Upper Old Red Sandstone in Pease Bay (Craig, 1960; Greig and Davies, 1978; Fyfe, 1985; Clarkson, 1986; Greig, 1988; Salter, 1992; Bolin, 1993). The 4 km coast section from Siccar Point westwards to Hawk's Heugh and Cove Harbour provides a unique, magnificently exposed transect through the succession of Upper Devonian to Lower Carboniferous rocks and merits protected status in its entirety. The uppermost part of the transect lies within the Cove GCR site and is described in the GCR volume on Lower Carboniferous stratigraphy (Cossey *et* al., 2004)

Description

Siccar Point

Siccar Point (Figure 3.38) is a coastal promontory of gently dipping Upper Devonian (Upper Old Red Sandstone) beds resting discordantly on folded, vertical, Lower Palaeozoic strata. The latter are turbiditic, dark grey, fine-grained wacke sandstones and interbedded finely laminated, fissile mudstones of the Gala Group, of early Silurian (Llandovery Series) age. The sandstone beds are up to 0.4 m thick and the mudstones are up to 0.15 m. The beds are locally contorted by tight folds and cut by closely spaced, parallel fractures produced by intense compressive stresses during the Caledonian Orogeny. In the south-east of the outcrop, the beds dip to the north-west at almost 90°, but a synclinal axis results in dips to the south-east of about 60° in the north-west of the site. They are truncated by the sharp, angular unconformity, which is overlain by Upper Devonian strata comprising reddish brown conglomerates and sandstones of the Redheugh Mudstone Formation of the Stratheden Group (Figure 3.39). These beds were deposited in the Oldhamstocks Basin (Lagios, 1983), which was possibly a sub-basin of the Scottish Border Basin. The beds are undeformed, with only a gentle inclination produced during the later, here less intense Variscan Orogeny. Siccar Point is the only well-exposed example of this unconformity in the Southern Uplands and clearly demonstrates the contrasting effects of the Caledonian and Variscan orogenies in this part of Scotland.

The Stratheden Group comprises the Redheugh Mudstone Formation and the overlying Greenheugh Sandstone Formation (Browne *et al.,* 2002). At Siccar Point, the Redheugh Mudstone Formation comprises a basal conglomerate (the Siccar Point Conglomerate Member) overlain by argillaceous sandstones fining upwards generally into red, sandy mudstones with mainly thin intercalated sandstones. The basal conglomerate is locally up to 6 m thick at Siccar Point, but is absent higher up on the south-eastern side of Siccar Cove. It is present at Hirst Rocks [NT 830 705] to the east and at one locality in Tower Burn south of Pease Bay to the west, but elsewhere the lowest Old Red Sandstone rocks are red-brown sandstones (Greig, 1988).

The unconformity surface at Siccar Point is very irregular because of differential rates of pre-Late Devonian weathering and erosion of individual beds in the Silurian succession. On the north side of the point, the overlying conglomerate forms an area of wave-cut slope about 100 m long and up to 20 m wide. The conglomerate dips seawards (north-west) between 15° and 20°. The surface on which the conglomerate rests is in detail very uneven, some of the beds of wacke sandstone standing up more sharply and prominently than others. The overlapping of the beds of conglomerate against the wacke sandstone surface is well displayed on centimetre- to metre-scale, with at least 3–10 m of palaeorelief on the unconformity surface. Relief of 10 m is observable towards the western margin of the main outcrop at Siccar Point. Similar relief is also seen in the faulted, 60 m-high cliff face forming the eastern limit of the exposure, where the unconformity in part of this excellent 125 m-long view has a scalloped surface (Balin, 1993).

The conglomerates were deposited preferentially in hollows on the original land surface (Greig, 1988). Beds of crumbly red mudstone and siltstone with ribs of sandstone rest on the unconformity above the small inlier of Silurian in Tower Burn [NT 758 702]. In Pease Burn, red sandstones dipping at 35° to the north rest unconformably on Silurian rocks. West of Siccar Point, the cliffs of Silurian rocks are capped by conglomerates that are up to 3 m thick in depressions in the palaeosurface. The unconformity descends to the beach south-east of Kirk Rigging, striking ENE on the shore, where there is little basal conglomerate. To the south-east of Siccar Point, a set of NE-trending faults downthrows the conglomerate to the south-east to sea level in the bay. Near high-water mark in the corner of the bay is a small Silurian inlier overlain by 5 m of conglomerate and 6 m of red, pebbly sandstones. Further faulting leads to exposure of higher sandstones on the shore in front of the landslip-scarred Manly Brae [NT 8130 7075], where the unconformity can be seen. Further exposures of the unconformity, but with little palaeorelief, occur at the east end of Redheugh Shore on the beach south of Hirst Rocks [NT 8265 7030] and in a small outlier in the cliffs above.

The conglomerates are poorly sorted and framework-supported with a matrix of red, medium- to coarse-grained sandstone. The angular, generally tabular clasts are of grey, wacke sandstone of pebble- to boulder-grade up to 0.56 m, with a few vein quartz pebbles up to 0.07 m (Balin, 1993). Greig (1988) noted strong imbrication indicating transport by south- to SE-flowing palaeocurrents. Individual beds are sheet-like and range from about 0.9 m to 2 m in thickness, with apparently planar tops and bases, except where adjacent to basement channel margins. Weak normal and reverse grading are present locally. The sandstones that overlie the conglomerates, and locally lie within them, are horizontally laminated and trough cross-bedded. The laminated beds are up to 1.6 m thick and comprise centimetre-scale laminae with scattered cobbles. The trough cross-bedded sandstones comprise sets up to 0.5 m high and over 1 m wide, commonly stacked into multi-storey units. Palaeocurrents are mainly to the south-west, as also inferred from most of the pebble imbrication in the conglomerate. There are also a few tabular sheets of cross-bedded sandstone about 0.15 m thick with low-angle foresets.

The Siccar Point Conglomerate Member passes up into the main, mudrock-dominated part of the Redheugh Mudstone Formation. The formation is about 200 m thick and comprises red-brown, sandy mudstones interbedded with mainly thin, red-brown, pale yellowish grey, green, purple and cream sandstones that become more numerous and massive upwards. One bed contains calcareous concretions up to 1 m in diameter (Greig, 1988). The proportion of mudstone to sandstone Is of the order 3:1 at Meikle Poo Craig [NT 822 708] 1.5 km east of Siccar Point. Fossil fish remains indicating a Famennian age include *Bothriolepis hicklingi* found in loose blocks at Redheugh, Siccar Point and Greenheugh Point, and fragments of *Grossilepis brandi, Bothriolepis* sp. and *Holoptychius* sp. from Hazeldean Burn [NT 8138 7019] (Miles, 1968).

Pease Bay

Pease Bay, 2 km west of Siccar Point (Figure 3.37) is a sandy bay dramatically rimmed by cliffs of Upper Old Red Sandstone strata that dip 25°–35° to the north (Clarkson, 1986). At its eastern end, Greenheugh Point [NT 800 711], the transition between the Redheugh Mudstone Formation and overlying Greenheugh Sandstone Formation is exposed. The latter comprises mainly medium- to coarse-grained sandstones and thin, red, mudstone and siltstone interbeds. About 70 m of the formation is present at Greenheugh Point, with a further 25 m at Red Rock [NT 791 711] on the west side of Pease Bay. Salter (1992) and Balin (1993) gave detailed sedimentological accounts of the beds. The sandstones are mainly red-brown, but with some pale yellow and pale green beds. Fragments of *Bothriolepis* have been found in the lower sandstones and scales of *Holoptychius nobilissimus* have been found in abundance (Dineley, 1999d). A large fallen block crowded with intact specimens of *Bothriolepis* was recorded by Clarkson (1986), the fish probably washed out of a river channel during flooding and stranded in a drying pool.

Red, medium- to coarse-grained, cross-bedded sandstones at Red Rock have silty mudstone interbeds containing yellowish green ribs and coarse sandy layers. In the corner of the bay 150 m to the north, the highest mudstone is exposed on the shore and is succeeded by red sandstones forming the high cliff at the Deil's Hole. These dip 17° to the north and comprise alternating parallel-bedded and cross-bedded sandstone bodies with well-rounded grains. The basal beds of the sandstone are trough cross-bedded, the troughs trending south. Above, both fluvial and aeolian facies (Figure 3.40) have been identified (Salter, 1992).

Hawk's Heugh [NT 790 714]

About 240 m north of Red Rock [NT 7910 7134] three E–W-striking faults, seen particularly well in the cliff, throw down to the north, bringing in the Kinnesswood Formation (the Cockburnspath Formation of Balin, 1993). This formation is exposed in an extensive wave-cut platform and high cliff at Hawk's Heugh and is characterized by the presence of calcrete. Accorded protected status because of the occurrence of *Remigolepis,* the only British example of this fish (Dineley, 1999d), the site provides superb exposures of this calcrete-rich topmost part of the Upper Old Red Sandstone. Strongly cross-bedded sandstones at the base of the section contain an abundance of veins and layers of bright red and purple-brown, iron-stained carbonate nodules, the latter commonly aligned along the horizontal bedding planes. Above, grey beds appear locally in the red beds and there is an increasing upwards abundance of carbonate in the form of red-brown, iron-stained irregular lenses and layers of nodules that form prominent ridges trending seawards across the wave-cut platform. Vertical, cylindrical concretions also occur. The sandstones are predominantly red, particularly in the lower part of the formation; many of the higher beds are greyish white with red flecks of ferroan dolomite. The sandstones occur in trough cross-bedded, tabular cross-bedded and massive bodies. Intraformational calcrete-clast conglomerates are interbedded in the succession and thin, red-white mottled, locally micaceous, argillaceous interbeds occur sporadically (Balin, 1993).

The Hawk's Heugh SSSI is described in the companion GCR volume on fossil fishes (Dineley and Metcalf, 1999). *Remigolepis* was found in a loose block of intraformational conglomerate similar to a bed in the cliff above about 6 m below the top of the Kinnesswood Formation. *Holoptychius* and *Bothriolepis* are also recorded from the bed.

The top of the Kinnesswood Formation is in Eastern Hole [NT 7900 7157], the bay to the north of Hawk's Heugh. It was placed at the top of a prominent deep-red, 0.9 m-thick calcrete with cream chert veins and lenses by Salter (1992), and 1–1.5 m above it by Greig (1988) and Balin (1993), at the top of a bed of trough cross-bedded sandstone of Old Red Sandstone facies that overlies the calcrete. Above this, yellow and dark green, plant-bearing mudstones and ferroan dolostones (cementstones) of the Ballagan Formation make their first appearance. Described as a sandstone by Greig (1988), the calcrete is a silty mudstone with coarse, ferroan, dolomite crystals (Andrews *et al.,* 1991). A cementstone with layers of conglomerate containing yellow, angular dolomite clasts and fish fragments (the Eastern Hole Conglomerate) lies about 13 m above.

Interpretation

James Hutton was probably the first natural philosopher to recognize and understand the significance of the relationships between rocks separated by an angular unconformity. He understood the long time-period represented by the unconformity and also, to a degree, the events that led to the formation of the observed features. The first of the uncOnfortnities he studied was at North Newton Shore on Arran in 1786 (see GCR site report, this chapter), followed by the one at Inchbonny, Jedburgh (formerly known as Aller's now a RIGS site; (Figure 4.2), Chapter 4). Hutton and John

Playfair were obviously struck by the significance of the exposure at Siccar Point — 'the mind seemed to grow giddy by looking so far into the abyss of time' (Playfair, 1805).

The planar-bedded conglomerates and interbedded sandstones above the unconformity at Siccar Point were interpreted by Balin (1993) as sheet-flood deposits, formed mainly by ephemeral floods, which created pulses of sediment-charged water that spread out from the mouth of a channel. Localized thickening of the conglomerate beds results from the infilling and draping of the uneven basement topography at the unconformity surface. Balin (1993) considered that the coarse grain-size of all the Late Devonian lithofacies at Siccar Point was consistent with deposition by high-velocity, high-gradient flows. Framework-supported gravels are laid down by high-energy water flow that prevents, or partially prevents, deposition of sand from suspension. This fact, together with the clast imbrication and the framework-supported structure of the conglomerates, suggests deposition from traction currents or as flash-flood sheets. Reduced-flow regime allowed sand to settle in the spaces in the gravels and deposition of the plane-bedded sandstone lithofacies (Balm, 1993).

The generally impermeable bedrock contributed to the high velocity of the flood discharges. Also important was the bedrock topography, the steep-sided gully at the western side of Siccar Point, for example, being responsible for the local SE-directed imbrication (Balin, 1993). Pipe-like burrows, about 1 cm wide and 10 cm long, in the planar-bedded sandstones at Hirst Rocks suggest periods of lower flow-energy and non-deposition. The conglomerates form part of an upward-fining succession, suggesting that uplift of the source area ceased. With complete draping of the palaeotopography and burial of remnant highs, floodplain mud- and silt-dominated deposition became established and the remainder of the Redheugh Mudstone Formation was laid down widely in the Scottish Border Basin.

The Greenheugh Sandstone Formation has been interpreted as entirely fluvial by Bann (1993) and as mixed fluvial and aeolian by Salter (1992). The basal part of the formation at Greenheugh Point was interpreted by Salter (1992) as the deposits of shallow, braided streams and overbank sheet-flooding across a broad, flat alluvial-plain. Balin (1993) noted that the absence of vegetation resulted in easily eroded channel banks, facilitating the migration of stream channels. Silts were deposited in ephemeral lakes on the floodplain at the terminations of some channels. Minor aeolian reworking of exposed fluvial bar forms also occurred. The sandstone-dominated succession at Red Rock was interpreted by Salter as the product of deposition in ephemeral, shallow channels that became the sites of aeolian deflation during periods of increased aridity. Salter also suggested that stabilized aeolian dune-fields formed during times of maximum aridity; resulting in aeolian bedforms up to 2 m high at Red Rock (Figure 3.40). Balin (1993) favoured an entirely fluvial origin, but noted that the textures of some grains (Fyfe, 1985) suggest that they may have been involved in a phase of aeolian transport. The presence of pin-stripe lamination and the alternation of laminae with marked contrast in grain size is regarded as characteristic of aeolian deposition.

Calcrete palaeosol development in the upper part of the Upper Old Red Sandstone (the Kinnesswood Formation) is seen throughout the Midland Valley of Scotland and Southern Uplands. The carbonate concretions at Hawk's Heugh are interpreted as pedogenic calcrete, their formation along foresets, bedding planes and desiccation cracks being aided by increased groundwater permeability. The vertical, cylindrical concretions are interpreted by Balin (1993) as rhizocretions formed around plant roots. The 0.9 m-thick calcrete close below the top of the Kinnesswood Formation contains horizontal, cream-coloured chert lenses, indicating a mature stage of palaeosol development (Stage 4 of Leeder, 1975; Stage VI of Machette, 1985), and a period of formation of up to 1.5 million years (Salter, 1992). Low sedimentation rates and a semi-arid climate are requisite for calcrete formation, although the climate may have been less arid than during deposition of the Greenheugh Sandstone Formation. The prolonged period of tectonic stability during formation of the mature calcrete near the top of the Kinnesswood Formation preceded a major change in palaeogeography when coastal floodplain deposition of the Ballagan Formation was introduced. Eustatic sea-level rise at the start of the Carboniferous Period, a wetter climate and tectonic factors may all have contributed to the change.

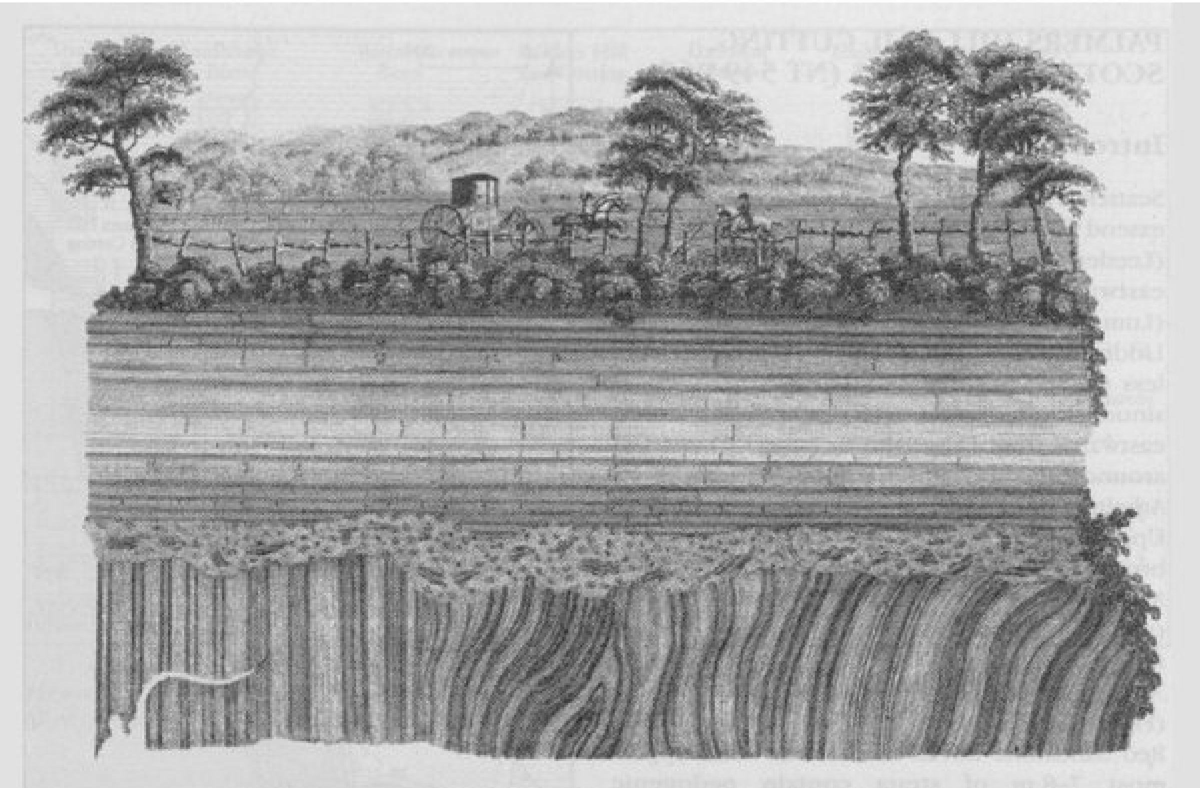
The fish from Pease Bay (*Bothriolepis* and *Holoptychius*)point to a Famennian age for the Greenheugh Sandstone Formation (Dineley, 1999d). *Remigolepis* from the Kinnesswood Formation at Hawk's Heugh occurs elsewhere in the world in strata ranging from Frasnian to Early Carboniferous in age. The position of the Devonian-Carboniferous boundary at the Hawk's Heugh GCR site is not clear. The base of the Eastern Hole Conglomerate and the basal cementstone beds have variously and arbitrarily been taken as the boundary in the past, but late Tournaisian (CM Zone) spores have been recovered from the lowermost cementstones (Andrews *et al.,* 1991). The Devonian-Carboniferous boundary may therefore lie at a level lower than its previous, arbitrary position, within or near the base of the Kinnesswood Formation (Browne *et al.,* 1999).

Conclusions

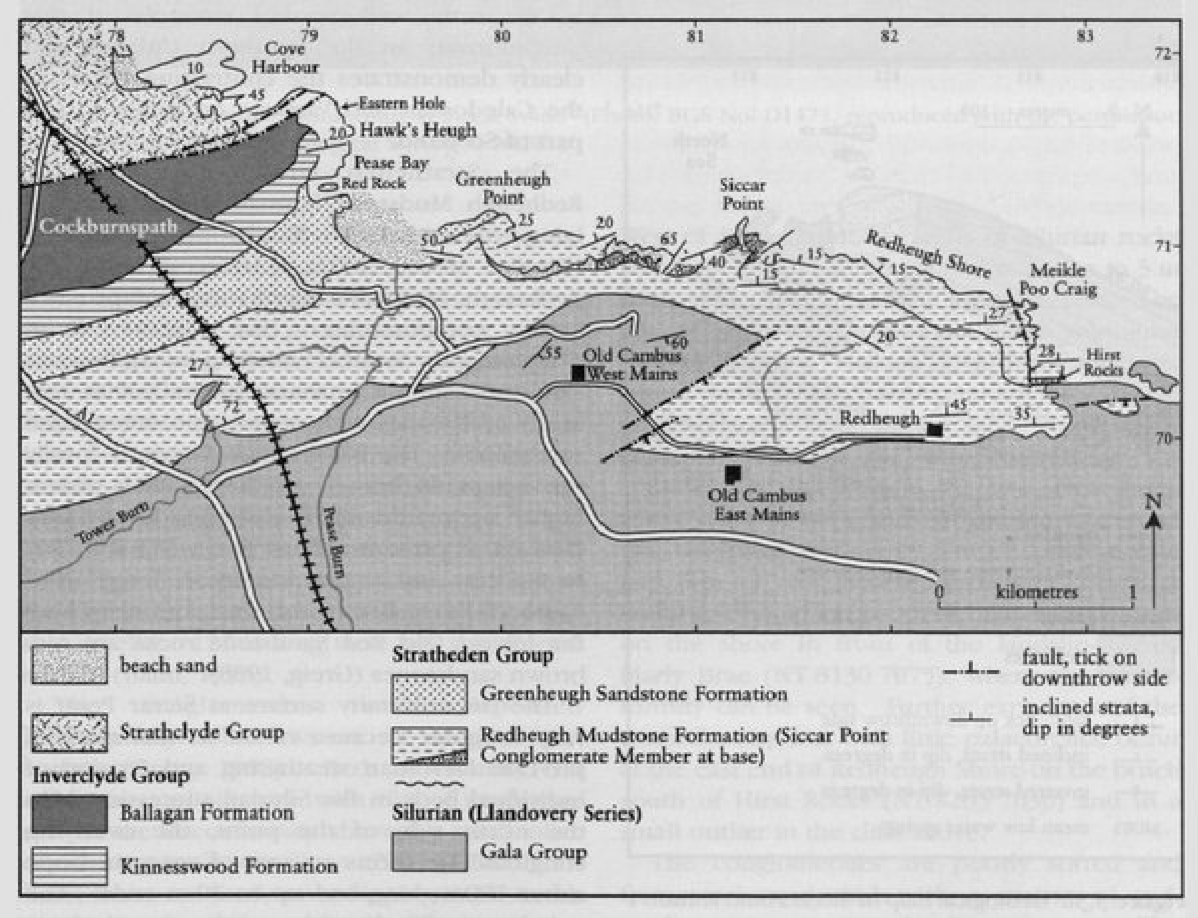
Siccar Point is a world-renowned site forever associated with James Hutton, in particular, but also with Sir James Hall and Professor John Playfair. It is arguably the most important SSSI in Scotland and a place of international geological pilgrimage. In addition to its main, historical, importance, it is also important in providing excellent exposures of the Silurian and Late Devonian sedimentary rocks that lie below and above Hutton's unconformity respectively. The unconformity is beautifully displayed in three dimensions at Siccar Point, providing one of the best exposures of an angular unconformity in Scotland.

The coastline from Siccar Point westwards through Pease Bay to the Hawk's Heugh fossil fishes GCR site and the Cove Lower Carboniferous Stratigraphy GCR site presents a magnificently exposed, complete transect of the entire Late Devonian (Famennian) succession and the transition into the overlying strata of Early Carboniferous (Courceyan) age. Both river and wind-borne sediments are beautifully displayed in the cliffs and foreshore and the beds have yielded important fish remains, including the only occurrence of *Remigolepis* at Hawk's Heugh and complete specimens of *Bothriolepis* from Pease Bay. The whole section is frequently visited by students and professional geologists. It is an important teaching resource in terms of the sedimentary and contemporaneous pedogenic structures displayed, and the depositional environments they represent. There is also the potential for future fossil fish discoveries, and the section between the two existing GCR sites at Siccar Point and Cove is eminently worthy of protected status.

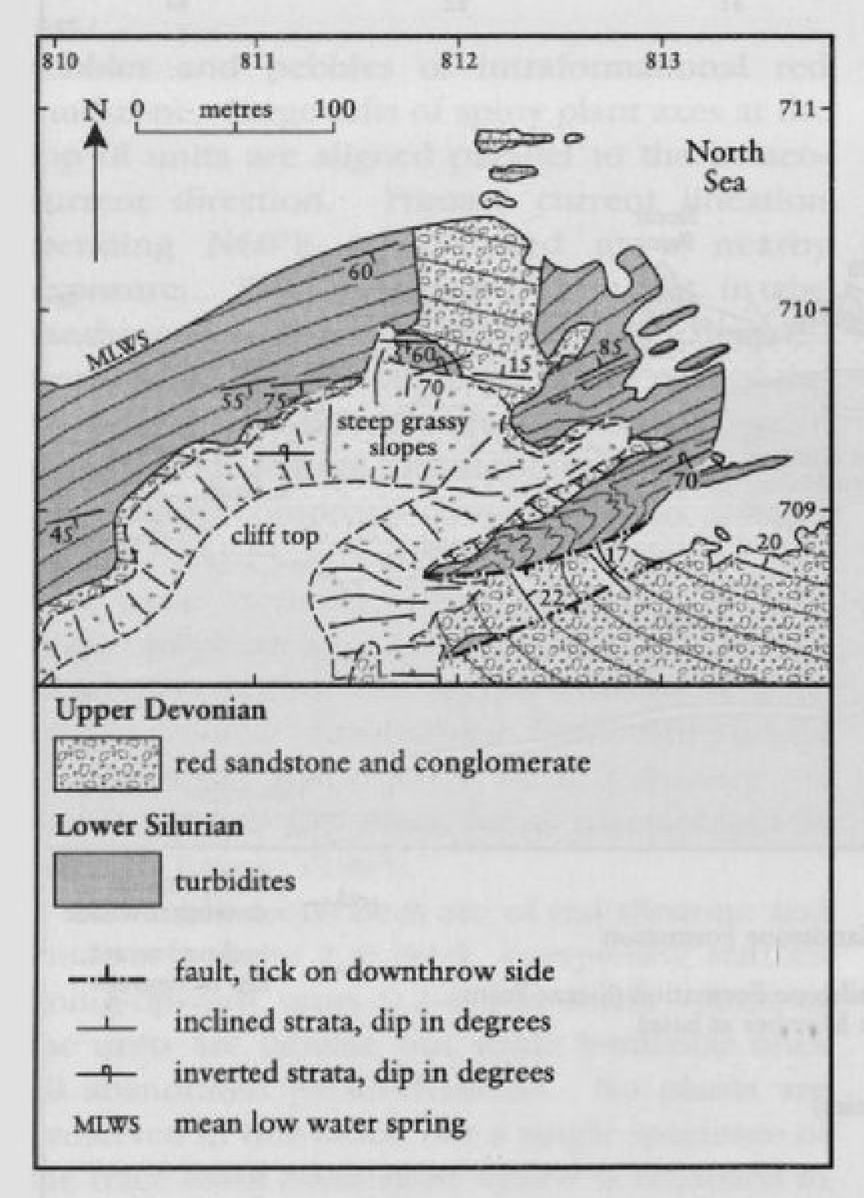
References



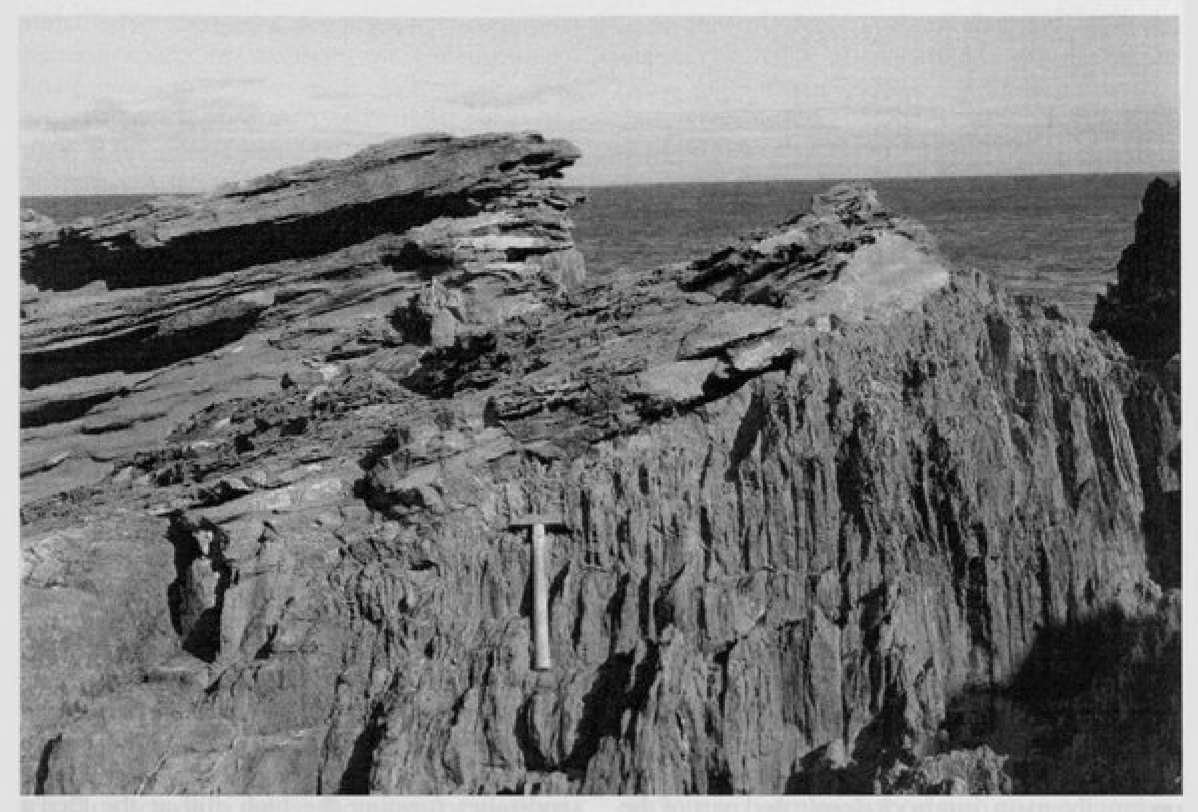
(Figure 4.2) Engraving after a drawing of the unconformity at Jedburgh [NT 652 198] by John Clerk of Eldin (1787), used for Plate III of the Theory of the Earth, Volume 1, by James Hutton (1795). Vertical Silurian greywackes and shales are unconformably overlain by Upper Old Red Sandstone basal breccia and overlying sandstones. From Craig et al. (1978), reproduced by permission of Sir R.M. Clerk Bt.



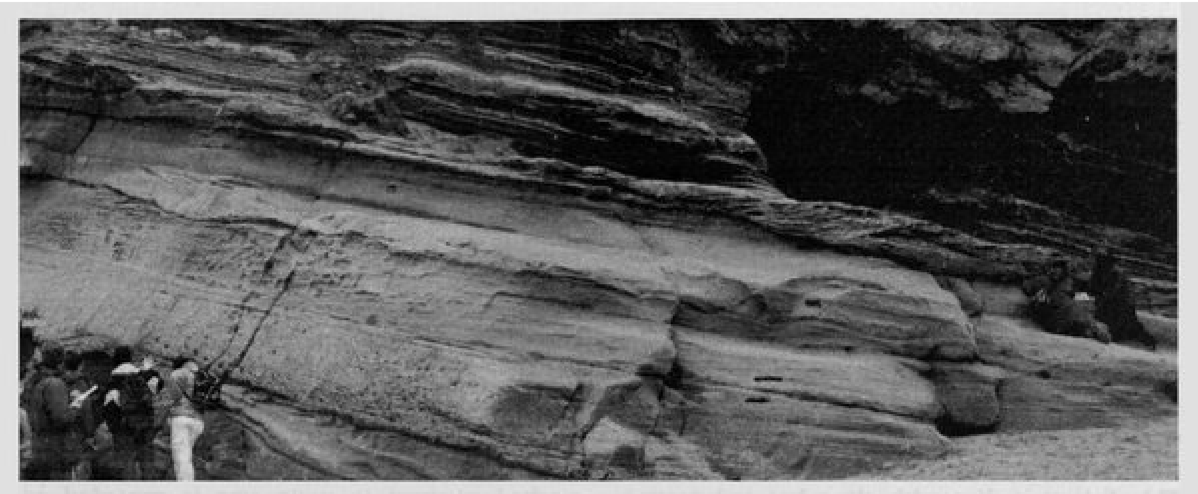
(Figure 3.37) Geological map of the area around Siccar Point, from Cove Harbour to Hirst Rocks. After British Geological Survey 1:50 000 Sheet 34 (Scotland), Eyemouth (1982).



(Figure 3.38) Geological map of Siccar Point: Hutton's Unconformity. After Greig (1988).



(Figure 3.39) Hutton's Unconformity at Siccar Point. (Photo: BGS No. D1471, reproduced with the permission of the Director, British Geological Survey, © NERC.)



(Figure 3.40) Interbedded fluvial and aeolian sandstones at Red Rock, Pease Bay. The aeolian sandstones show sandflow and wind ripple lamination, the fluvial sandstones are sheet-flood deposits (Photo: B.P.J. Williams).