Thornton and Twisleton glens

[SD 694 700] and [SD 702 693]

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Introduction

Thornton and Twisleton glens have been selected as GCR sites because they provide excellent sections through the Ingleton Group of northern England. The group crops out in the Craven inliers, on the south-eastern margin of the Askrigg Block, and is best exposed in Chapel-le-Dale (Figure 9.6). It comprises turbidite sandstones and siltstones that have been isoclinally folded and subjected to low-grade regional metamorphism imparting a distinctive green colour to the strata. These arbitrary characteristics, together with an absence of macrofossils, have previously been considered to indicate that the group is Precambrian, and despite much research its true age remains enigmatic, although indirect evidence reviewed below suggests that it is probably Lower Palaeozoic.

The earliest reference to the Ingleton Group is that by Playfair (1802) who referred to the outcrop in Thornton Glen as 'schistus'. Phillips (1828) included the strata within his 'Slate Series' for which Sedgwick (1852) proposed a 'Lower Palaeozoic' age. Hughes (1867) recognized that there was a stratigraphical break, within the 'Slate Series', that separated greenish grey gritty sandstone and slate (Ingleton Group) from the overlying dark grey slates. The former were therefore in the same stratigraphical position as Sedgwick's 'green slates and porphyries' in the Lake District, for which a 'Caradoc' age had been proposed by Harkness (in Hughes, 1867; p. 354). Hughes recognized that no porphyry was present in the Ingleton succession and dropped the term from the stratigraphical name. The 'green slates' (i.e. the Ingleton Group) are shown as 'Lower Silurian' (i.e. Ordovician) on the primary geological survey and described as 'presumably on the horizon of the Volcanic Series of the Lake District' in the accompanying memoir (Dakyns *et al.,* 1890).

The contradictory evidence for this correlation with the Lake District 'Volcanic Series' caused opinions on the age of the green slates to diverge. Marr (1892) pointed out that the correlation with the volcanic rocks rested on slender foundations, being based on their greenish colour and stratigraphical relationship with the unconformably overlying 'Coniston Limestone'. Marr and W.T. Aveline (in Goodchild, 1892) and Marr (1892) suggested a correlation with some part of a Precambrian succession. Rastall (1907) reiterated this view, emphasizing that the succession consisted of true sedimentary rocks with no resemblance to the lavas, ashes and agglomerates of the Lake District, and to make this distinction clear, proposed the name Ingleton Series' for the 'pre Caradocian' rocks. He considered that the apparent conformity of the 'Caradocian' Coniston Limestone' on the 'Ingletonian' was probably deceptive, suggesting that the Ingletonian strata were much older than the Ordovician, probably of Precambrian age and equivalent to either the 'Torridonian' or 'Longmynd' groups. From his petrographical study, Rastall (1907) deduced that the Ingleton Series' was derived from an igneous and metamorphic complex, Archaean in age, which probably underlay the Pennine area of northern England at no great depth.

The discovery of a limestone neptunean dyke containing an Ashgill fauna at Horton-in-Ribblesdale led King (1932) to emphasize that the 'Ingletonian' was probably Precambrian, since there must have been sufficient time to allow for its consolidation, tilting and erosion before deposition of the Ashgill limestone. Dunham *et al.* (1953) added that King's sequence of events also had to include folding and metamorphism. Furthermore, because there were no known earth movements of sufficient intensity during the Ordovician or Cambrian, the folding must almost certainly be Precambrian. It followed that the 'Ingletonian Series' had to be Precambrian and, on lithological grounds, should be correlated with the 'Longmyndian' of Shropshire.

The sedimentology of the Ingleton Group was investigated by Leedal and Walker (1950), who used cross-bedding and graded bedding structures to demonstrate that the succession was isoclinally folded (Figure 9.6); they also deduced from contemporary slump folds, that deposition occurred on a NW-inclined palaeoslope. The authors recognized the marked contrast between these isoclinal folds and the open fold style of the overlying fossiliferous late Ordovician and Sliurian

Windermere Supergroup rocks and this led them to suggest that the 'Ingletonian' had been affected by two periods of folding; adding further weight to King's (1932) argument for a Precambrian age. The discovery of a possible organically derived toolmark in fine-grained ''Ingletonian' rocks (Rayner 1957) provided further interest but unfortunately the trace fossil was not age-diagnostic.

Geophysical investigations (Bott, 1961, 1967) revealed that the Ingleton Group forms part of a belt of magnetic basement rocks that underlies northern England. Wills (1978) named this basement domain as the Furness–Ingleborough –Norfolk Ridge. The largest magnetic anomaly on the ridge occurs on the Askrigg Block about 15 km north-east of the Ingleton Group GCR site and was investigated by a borehole at Beckermonds Scar (Wilson and Cornwell, 1982). Beneath the Dinantian cover rocks the borehole proved a turbidite succession that lithologically resembles the Ingleton Group but contains detrital magnetite, which contributes to the magnetic anomaly. One of the samples tested for microfossils yielded an acitarch assemblage considered by R. E. Turner (in Dunham and Wilson, 1985) to be of early Ordovician (Arenig) age. This biostratigraphical age, albeit only indirectly applicable to the exposed Ingleton Group rocks, is in general agreement with the late Cambrian Rb-Sr radiometric age of 505 Ma obtained on 'Ingletonian' slates from the Horton outcrop by O'Nions *et al.* (1973). These authors and Arthurton *et al.* (1988) further demonstrated that latest Ordovician (Ashgill) strata rest unconformably on the Ingleton Group at Horton-in-Ribblesdale, 10 km ESE of the GCR site.

The probable Arenig age of the Ingletonian implies it is contemporary with the Skiddaw Group and the comparable Manx Group (Cooper *et al.,* 1993). However, as these authors point out, the sedimentary characteristics, petrographical compositions and deformation history of the Ingleton Group are sufficiently different to conclude that it is unconnected to the Skiddaw Group and therefore not part of the Leinster–Lakesman Terrane that includes the latter. The two groups might therefore be separated by major, terrane-defining basement faults. The geophysical evidence, discussed above, suggests that the Ingleton Group instead formed part of a belt of magnetic basement rocks on the margins of the Midland Platform — a crustal entity which Lee (1989, pp. 59–63) envisaged as developing separately from the Leinster–Lakesman Terrane. This basement was later accreted on to the northern margin of the Eastern Avalonia microcontinental margin that formed southern Britain during the Ordovician.

Description

In the Chapel-le-Dale inlier isoclinally folded turbidite sandstones and siltstones are well exposed in Thornton (Swilla) and Twisleton glens (Figure 9.6). The rocks are readily seen in natural exposures and quarries adjacent to the popular waterfalls-walk footpath (Johnson, 1994).

Thornton Glen

The lower part of Thornton Glen exposes Carboniferous Limestone on the downthrow side of the North Craven Fault, which crosses the glen near Manor Bridge. Calcareous siltstones of Ashgill age, representing part of the Dent Group at the base of the Windermere Supergroup, are present on the upthrow side of the fault. It is unclear from this section whether the siltstones are unconformable upon the underlying Ingleton Group or are faulted against it. Cleaved Ingleton Group siltstones are exposed in a disused slate quarry on the northwestern side of the glen at Pecca Bridge; typical of fine-grained lithologies in the Ingleton Group, they contain sandy laminae indicating that the bedding is sub-vertical. A slump fold with a basal dislocation plane reveals that the beds young north-eastwards. On some bedding planes there is abundant carbonaceous detritus, individual pieces being generally elongate in shape (up to 20 x 5 mm), that is probably organic and of algal origin. The early Devonian Acadian slaty cleavage here is parallel with bedding.

The gradational boundary from the siltstone member into the overlying sandstone unit is visible adjacent to the footpath at the first viewpoint to Pecca Falls. Medium and thick beds of turbidite sandstone are interbedded in the siltstone; they gradually increase in abundance until they become dominant and form the sandstone member that crops out in Pecca Falls itself. Typically the sandstones have planar bed forms and internal sedimentological features characteristic of turbidite sandstones; these include grading (fining upwards of the grain size) and laminated tops discernible in some beds. Together with other sedimentary structures, such as irregular sole markings, they show that the sandstone succession continues to young north-eastwards towards a SE-trending synclinal axis immediately above the waterfall. Upstream, the sedimentary structures and siltstone interbeds have orientations that reveal the syncline is asymmetric, with a more steeply dipping south-west limb. The dip angle gradually increases down the sandstone succession, towards Thornton Force.

The sub-Carboniferous unconformity is spectacularly exposed in Thornton Force (Figure 9.7); it represents a time interval of about 150 million years. Sub-horizontal beds of Carboniferous Limestone form the overhang of the waterfall and rest on cleaved Ingleton Group laminated siltstone dipping 70° to the southwest. The unconformity at Thornton Force has played a fundamental part in the development of geology; the relationship was first described by Playfair (1802, pp. 217–19) in his 'Illustrations of the Huttonian Theory', which recognized that unconformites between strata dipping at different angles implied that earth movements must have occurred. The waterfalls-walk footpath continues over the Carboniferous Limestone outcrop and recrosses the unconformity on the way to Twisleton Glen.

Twisleton Glen

Ridges of Ingleton Group sandstone are exposed striking south-east across the fields near Beezleys towards Twisleton Glen, and at Beezley Falls the river Greta cuts a section through sub-vertical turbidite sandstone with siltstone interbeds. Internal sedimentological characters and sedimentary structures, similar to those seen in Thornton Glen, indicate that the succession youngs south-westwards.

At the foot of Beezley Falls, a passage from sandstone up into siltstone is well exposed. Isoclinal folds with SE-trending synclinal and anticlinal axes are displayed within the siltstone member in Baxengill Gorge. At Snow Falls, where the cleaved siltstone has been quarried for slate, two basic dykes, each about 1 m wide and 7–8 m apart, trend N–S, cutting obliquely through siltstone bedding. The dykes have not been dated but an early Ordovician age seems likely as they are cleaved, and there is no evidence for basic magmatism within the younger Ordovician and Silurian strata cropping out nearby (Leedal and Walker, 1950; Dunham *et al.,* 1953). Possibly therefore, the dykes could be related to the episode of Borrowdale Group magmatism in the Lake District.

Downstream from Snow Falls the siltstone passes upwards into turbidite sandstone and in Twisleton Glen the sandstone is deformed in an isoclinal syncline. Sedimentary structures show that the south-western limb of the isocline is overturned, with the beds dipping 70° to the south-west. The isoclinal fold brings the siltstone member, which is otherwise exposed in Baxengill Gorge and at Snow Falls, back to outcrop lower down the Twisleton Glen. A 2–3 m wide zone displaying slump folds can be seen towards the top of the siltstone near the entrance to the quarry where the cleaved siltstone has been worked for slate. South-west of the quarry, the Ingleton Group outcrop is covered by drift and the contact with Carboniferous rocks at the North Craven Fault is obscured.

Interpretation

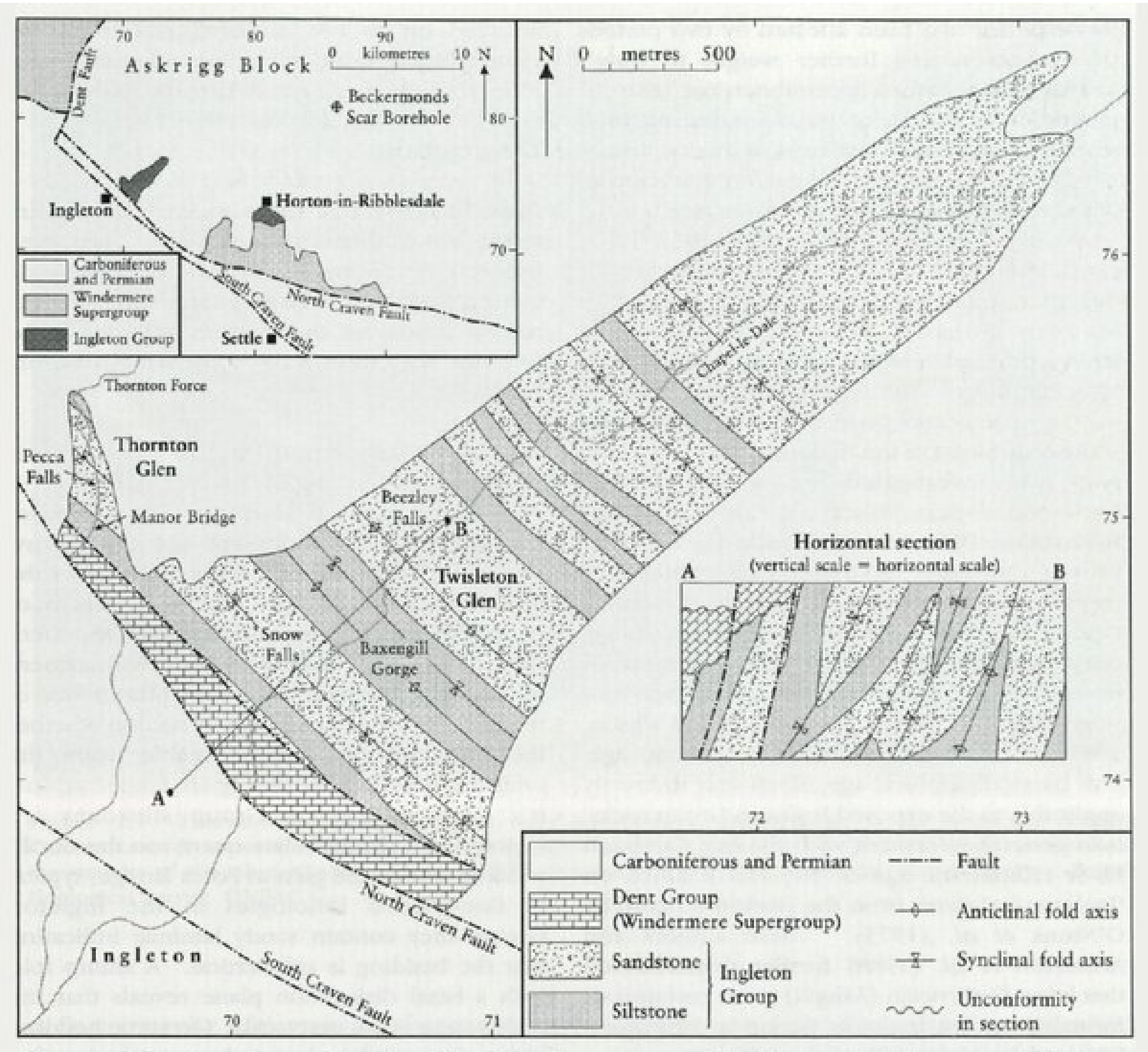
The Ingleton Group succession typifies the style of clastic turbidite sedimentation characteristic of deep-water marine environments. The sedimentary characteristics indicate that deposition probably occurred in the middle or lower parts of a turbidite fan. The probable Arenig age of the group, coupled with palaeogeographical reconstructions of southern Britain (Bevins *et al.,* 1992), further suggests that the turbidite fan developed on the northern continental margin of Eastern Avalonia, to the north of the emergent Midland Platform. This would be compatible with the NW-facing palaeoslope deduced from slump folds (Leedal and Walker, 1950) and the igneous and metamorphic clasts derived from an Archaean complex' identified in the turbidite sandstones (Rastall, 1907).

Assuming an Arenig age, it would appear that the Ingleton Group was deposited at the same time as the Skiddaw Group in the Lake District, and the Manx Group of the Isle of Man (Cooper *et al.,* 1993). However, as noted earlier, the sedimentary characteristics and petrographical compositions of the Ingleton Group are sufficiently different to conclude that it is unconnected to the Skiddaw Group. Instead, it is probable that the two groups were deposited in separate terranes, these being the Eastern Avalonian margin and the Leinster–Lakesman Terrane respectively. This may also explain the contrast in mid-Ordovician magmatism and deformation styles between the Ingleton area and the Lake District. In the former there are only a few dykes and the strata are affected by two deformations, one causing the isoclinal folds and a younger, Acadian-age event causing the open folds seen in the unconformably overlying Windermere Supergroup of the Horton-in-Ribblesdale inlier (Arthurton *et al.,* 1988). By contrast, the Skiddaw Group was subjected to uplift and extension in the mid-Ordovician, preserving the 8 km-thick Borrowdale Volcanic Group in a regional scale rift zone before Windermere Supergroup sedimentation commenced. There, the only evidence for compression is in the structures of the Acadian orogeny (Cooper *et al.,* 1993).

Conclusions

The exposures in Thornton and Twisleton glens have challenged geologists ever since the beginning of the 19th century, when Playfair (1802) used the unconformity at Thornton Force as evidence for the Huttonian Theory of earth movements, and it is clear that they will continue to do so in the future. One outstanding problem is the enigmatic absence of macrofossils from the succession, since this means that the age of the Ingleton Group — deemed to be early to mid-Ordovician (Arenig) on the basis of acritarchs from a nearby borehole — remains questionable. The sedimentary characters of the turbidite sandstones, and structures in the siltstones, allow the younging directions of the succession to be determined and are instrumental to the identification of isoclinal folds. The presence of such structures emphasizes the contrast in deformation styles between the Ingleton Group and other strata of similar age in northern England, and is critical to the understanding of the tectonic evolution of the Eastern Avalonian continental margin.

References



(Figure 9.6) Geological map of the Chapel-le-Dale Ingleton Group inlier showing the Thornton and Twisleton glens GCR site

(Figure 9.7) Thornton Force showing the sub-Carboniferous unconformity in the overhang beneath Carboniferous Limestone; weathered Ingleton Group siltstone crops out below the unconformity and around the margin of the plunge pool. (Photo: A7626, reproduced by kind permission of the Director, British Geological Survey, ©NERC.)