British Lower Carboniferous Stratigraphy

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Chapter 5

Stainmore Basin and Askrigg Block

P.J. Cossey and A.E. Adams

INTRODUCTION

The Askrigg Block and Stainmore Basin area is bounded to the west by the Dent Fault and to the south by the Craven Fault System. The Alston Block lies to the north and Lower Carboniferous strata disappear beneath Upper Carboniferous and Permian cover to the east (Figure 5.1). Included in this chapter is the westwards extension of the Stainmore Basin to Ravenstonedale and Shap. Also included is the transition zone of the Craven Fault System between the Askrigg Block and the Craven Basin, where shelf-margin features such as reefs are developed (Figure 5.2).

Throughout this entire area the outcrop is dominated by Lower Carboniferous strata. Lower Palaeozoic rocks are exposed in inliers along the line of the North Craven Fault (Figure 5.2) and Upper Carboniferous strata are seen in some outliers, particularly in the eastern part of Stainmore (Figure 5.1). Exposure is fairly good for an inland area, with working and disused quarries, dale sides and stream sections providing a good basis for studying at least the carbonate rock geology. Sandstones and

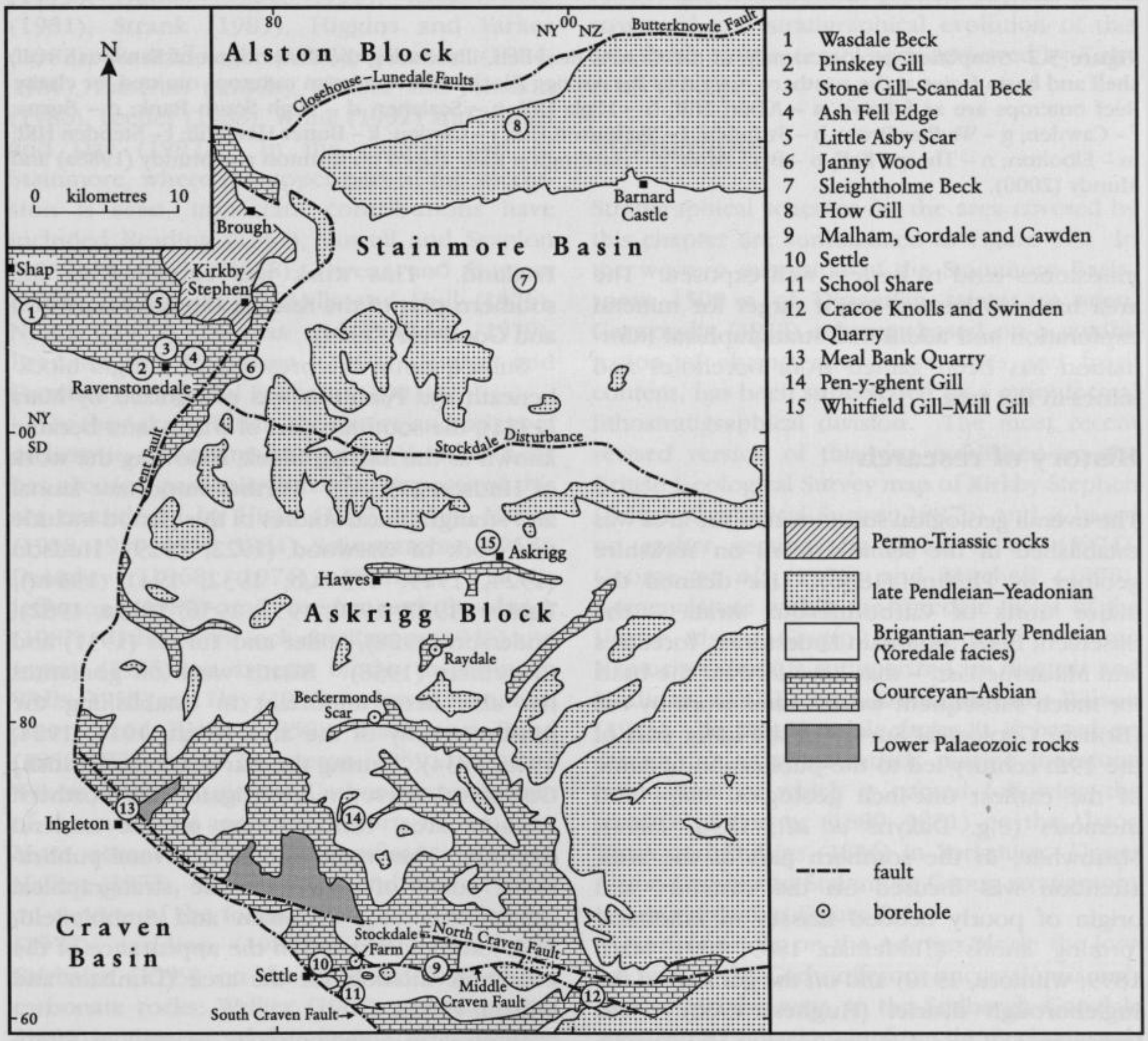


Figure 5.1 Geological map of the Askrigg Block and Stainmore Basin illustrating the distribution of Carboniferous outcrops and the locations of GCR sites described in the text. Note that outside the area delineated by the bounding faults, only the geology of the Ravenstonedale area is shown, and that within this area igneous rocks are omitted. After Dunham and Wilson (1985).

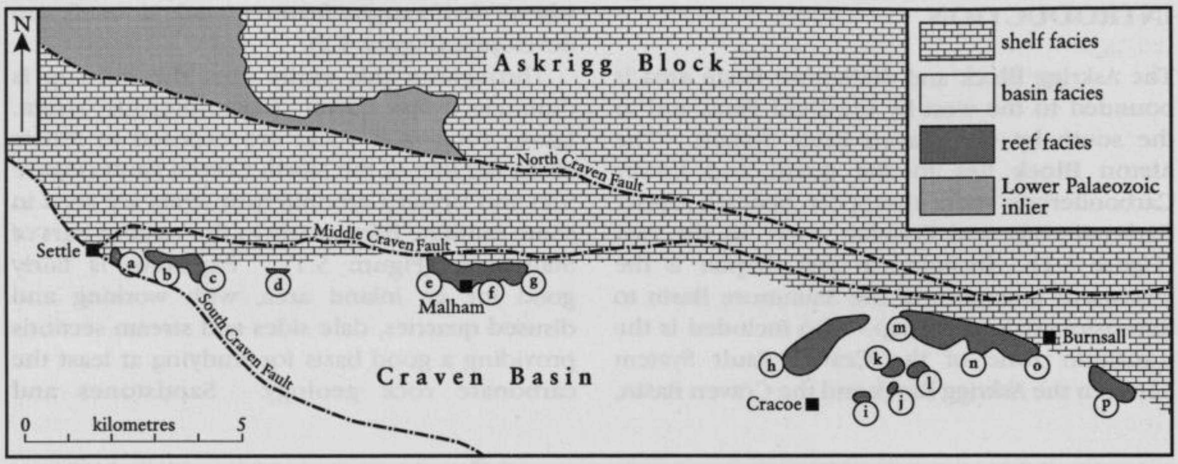


Figure 5.2 Simplified geological map of the Craven Reef-Belt, illustrating the distribution of Dinantian reef, shelf and basin facies at the southern margin of the Askrigg Block, with Namurian outcrops omitted for clarity. Reef outcrops are as follows: a – Albert Hill; b – High Hill; c – Scaleber; d – High South Bank; e – Burns; f – Cawden; g – Wedber Brow; h – Swinden; i – Skelterton Hill; j – Carden; k – Butter Haw Hill; l – Stebden Hill; m – Elbolton; n – Thorpe Kail; o – Byra Bank; p – Hartlington Kail. Based on Brunton and Mundy (1988a) and Mundy (2000).

mudstones tend to be less well exposed. The area has also been a major target for mineral exploration and additional stratigraphical information has been gained from boreholes and mines in the area.

History of research

The overall geological succession of the area was established in the seminal work on Yorkshire geology by Phillips (1836). He defined the major units of Carboniferous strata – the Basement Beds, Mountain Limestones, Yoredales and Millstone Grit – that have formed the basis for much subsequent work. Later work by the [British] Geological Survey in the latter part of the 19th century led to the publication of some of the earliest one-inch geological maps and memoirs (e.g. Dakyns *et al.*, 1890, 1891). Meanwhile, in the southern part of the area, attention was focused on the structure and origin of poorly bedded masses of limestone forming 'knolls' (Tiddeman, 1889, 1891; Marr, 1899; Wilmore, 1910) and on the geology of the Ingleborough district (Hughes, 1908). The importance of fossils in the division and correlation of the Lower Carboniferous succession was appreciated by Garwood (1913, 1916) who used the section in Ravenstonedale as a 'standard' to which he compared other sections in north-west England. This work was extended to the southern part of the Askrigg Block by Garwood and Goodyear (1924).

Subsequently, the presence of a 'rigid block' beneath the Pennines was recognized by Marr (1921), the southern part of which later became known as the Askrigg Block, following the work of Hudson (1938a). Further important faunal and stratigraphical studies of this period include the work of Garwood (1922, 1929), Hudson (1924, 1929, 1930a,b, 1932, 1941, 1944a), Turner (1927, 1950, 1955, 1956, 1959a, 1962), Anderson (1928), Miller and Turner (1931) and Carruthers (1938). Bisat's work on goniatites has also been important in establishing the biostratigraphy of the area (Bisat, 1914, 1924, 1928, 1934). During the war years the [British] Geological Survey re-investigated the northern Pennine area, concentrating on the mineral deposits. This work resulted in several publications, some of which include stratigraphical information (e.g. Dunham and Stubblefield, 1945) and culminated in the appearance of the economic memoir for the area (Dunham and Wilson, 1985).

Interest in sedimentology as well as stratigraphy led to an expansion in research during the 1950s, which has continued to the present day. This work can be conveniently considered under three regional headings: the Stainmore

Basin, the main part of the Askrigg Block, and the transition zone between the Askrigg Block and the Craven Basin.

In the Stainmore Basin, attention has been focused on the area between Shap and Kirkby Stephen, where a thick succession of Dinantian strata can be seen. Faunal, stratigraphical and palaeoenvironmental studies on these dominantly carbonate rocks include Capewell (1955), Rowley (1969), Ashton (1970), Johnson and Marshall (1971), Rose *et al.* (1973), Johnson and Nudds (1975), Burgess and Mitchell (1976), Mitchell (1978), Nudds and Taylor (1978), Holliday *et al.* (1979), Varker and Higgins (1979), Nudds (1981, 1993), Ramsbottom (1981), Strank (1981), Higgins and Varker (1982), Barraclough (1983), Kimber (1984, 1987), Bancroft (1986b), Kimber and Johnson (1986), Leeder (1988), White (1992) and Nudds and Day (1997). In the eastern part of Stainmore, where the upper part of the succession is seen, important contributions have included Reading (1957), Rowell and Scanlon (1957a,b), Wells (1958), Owens and Burgess (1965), Elliot (1975), Mills and Hull (1976), Nudds (1977), Burgess and Holliday (1979), Brenner and Martinsen (1990), Hodge and Dunham (1991) and Fairbairn (2001).

On the Askrigg Block, the nature and origin of cyclicity in carbonates and in the Yoredale beds has aroused particular interest. Aspects of this are considered by Hicks (1957, 1959), Moore (1958, 1959, 1960, 1984), Schwarzacher (1958), Doughty (1968, 1974), Waltham (1971), Jefferson (1980) and Leeder and Strudwick (1987). Other work includes Rayner (1946) and Joysey (1955) on aspects of the macrofauna; Wells (1955) and Hey (1956) on lower Namurian cherts; and Black (1950), Black and Bond (1952), Wilson and Thompson (1959, 1965) and Wilson (1960a,b) on the Carboniferous System of the southern and eastern parts of the area. More recent studies of significance include Hallett (1970), Strank (1981) and White (1992) on aspects of the foraminiferal faunas; Cousins (1977), Izzidien (1984), Scott (1984) and Fairbairn (1999) on the sedimentology of the carbonate rocks; Walker (1967) and Martinsen (1993) on aspects of the clastic sedimentology; the Settle Memoir of Arthurton *et al.* (1988); Burgess (1986) on the stratigraphy of the Sedbergh area; and Brandon *et al.* (1995) on the biostratigraphy and correlation of lower Namurian successions across the Askrigg Block into the neighbouring Craven and Stainmore basins. Two boreholes, at Raydale (Dunham, 1974) and Beckermonds Scar (Wilson and Cornwell, 1982), have penetrated to the base of the Carboniferous succession on the Askrigg Block.

Along the transition zone between the Askrigg Block and the Craven Basin the origin of the knoll reefs has continued to provide the major interest. Important studies include those of Bond (1950a,b), Black (1954, 1958) and Mundy (1980a, 1994, 2000). Reviews of the geology of the whole of the area covered in this chapter include Kendall and Wroot (1924), Rayner (1953) and Ramsbottom (1974). Aspects of the structural and stratigraphical evolution of this area have most recently been reviewed by Kirby *et al.* (2000).

Stratigraphy

Stratigraphical schemes for the area covered by this chapter are summarized in Figure 5.3. In the western extension of the Stainmore Basin, some 1500 m of Dinantian strata are seen. Garwood's (1913) scheme, based on a combination of characteristic rock types and fossil content, has been superseded by a more formal lithostratigraphical division. The most recent revised version of this was published on the British Geological Survey map of Kirkby Stephen (British Geological Survey, 1997b) and is based on earlier versions by Taylor *et al.* (1971), George *et al.* (1976) and Mitchell (1978). Nomenclature within the Yoredale facies of the Upper Alston Group and in the overlying Namurian strata is summarized by Burgess and Holliday (1979) and Dunham and Wilson (1985). In the Yoredale facies it is based on recognition of characteristic marine limestone units, each of which is named following the practice of Forster (1809, 1821) on the Alston Block and Phillips (1836) in Yorkshire. Upper Alston Group and Stainmore Group stratigraphy is summarized in Figure 5.4.

Farther south, on the Askrigg Block, the lowest part of the Carboniferous succession is only exposed in the west, in the Sedbergh–Garsdale area, but it is also known from the Beckermonds Scar and Raydale boreholes. The stratigraphical divisions from these areas, described by Wilson and Cornwell (1982) and Burgess (1986), have been applied to the Askrigg Block part of the

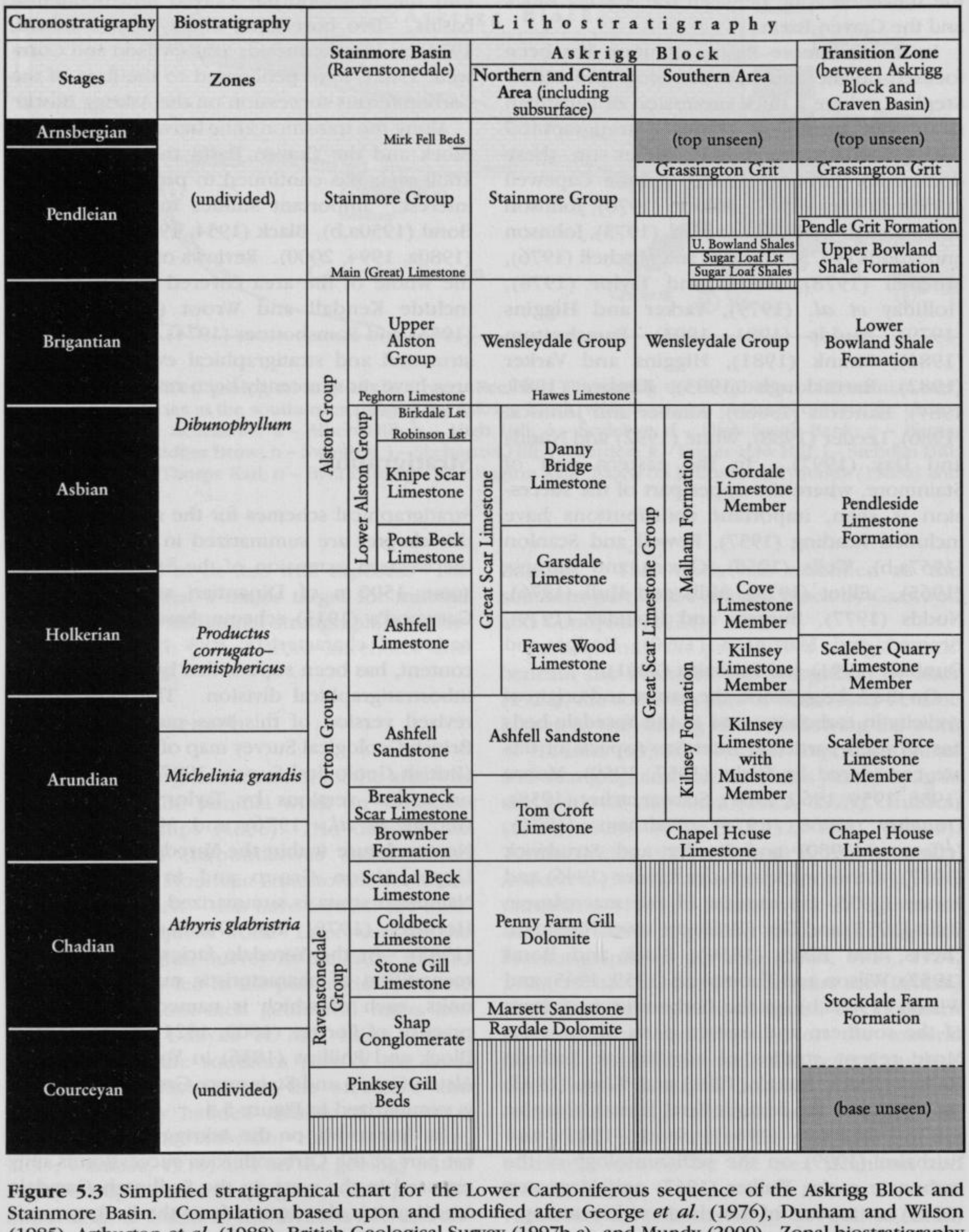


Figure 5.3 Simplified stratigraphical chart for the Lower Carboniferous sequence of the Askrigg Block and Stainmore Basin. Compilation based upon and modified after George *et al.* (1976), Dunham and Wilson (1985), Arthurton *et al.* (1988), British Geological Survey (1997b,c), and Mundy (2000). Zonal biostratigraphy (Chadian–Brigantian only) after Garwood (1913). For further details of the Wensleydale Group, Upper Alston Group and Stainmore Group successions, see Figure 5.4. Areas of vertical ruling indicate non-sequences. Not to scale.

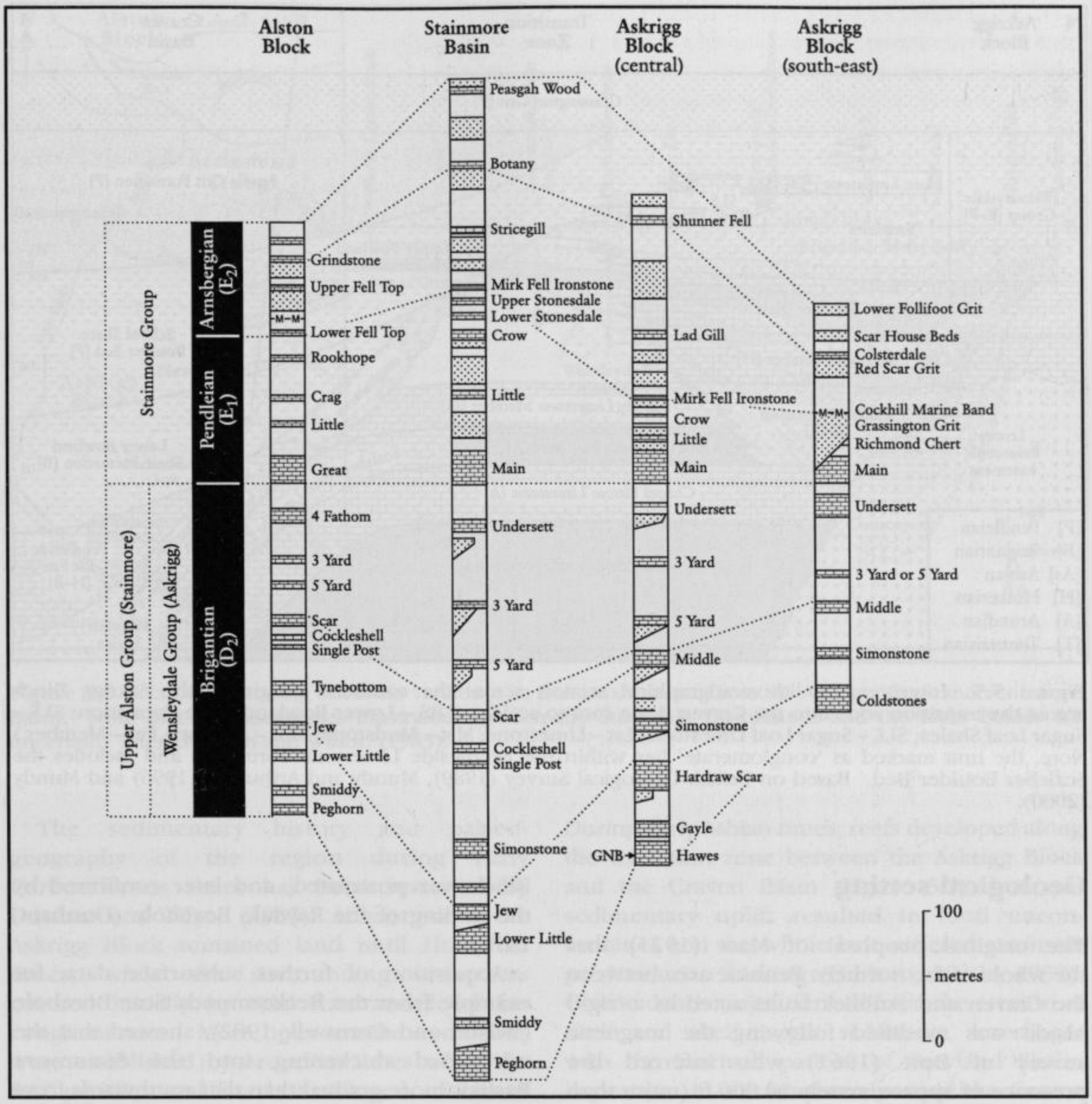


Figure 5.4 The stratigraphy of selective Upper Alston Group and Stainmore Group successions from the Alston Block, Stainmore Basin and Askrigg Block. Note that all units with a brickwork ornament are 'Limestones' unless otherwise specified. (GNB – Girvanella Nodular Bed.) Based on Ramsbottom (1974) and Ramsbottom *et al.* (1978).

Kirkby Stephen area (British Geological Survey, 1997b) and to the Hawes area (British Geological Survey, 1997c) and are shown in Figure 5.3. In the southern part of the block, Ramsbottom (1974) and George *et al.* (1976) set up a new stratigraphy based on the Horton area (Figure 5.4), but Arthurton *et al.* (1988) revised this for the Settle area, particularly in the light of new borehole information (Figure 5.3). They also changed the status of the Wensleydale Formation to a group, the individually named Yoredale limestones becoming formations.

The stratigraphy of the Craven Reef-Belt at the southern margin of the Askrigg Block is complex, because of local facies variations. Local stratigraphical names in use are discussed in the appropriate site descriptions. The relationship between shelf and basin units in the Settle area described by Arthurton *et al.* (1988) is shown in Figure 5.5 and details of stratigraphical schemes for the Craven Basin are discussed in Chapter 6.

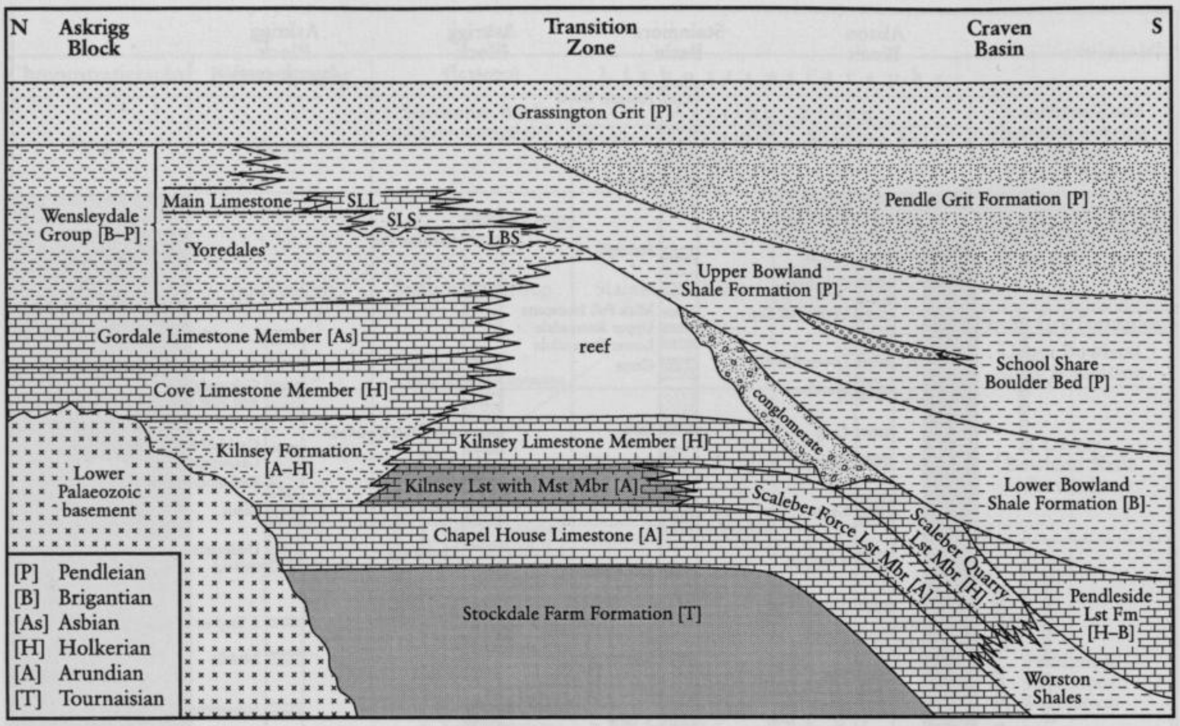


Figure 5.5 Interpretative lithostratigraphical section across the southern margin of the Askrigg Block across the transition zone into the Craven Basin (not to scale). (LBS – Lower Bowland Shale Formation; SLS – Sugar Loaf Shales; SLL – Sugar Loaf Limestone; Lst – Limestone; Mst – Mudstone; Mbr – Member; Fm – Member.) Note, the unit marked as 'conglomerate' lies within the Pendleside Limestone Formation and includes the Scaleber Boulder Bed. Based on British Geological Survey (1989), Mundy and Arthurton (1996) and Mundy (2000).

Geological setting

The original proposal of Marr (1921) that the whole of the northern Pennine area between the Craven and Stublick faults acted as a 'rigid block' was modified following the magnetic survey of Bott (1961) who inferred the presence of approximately 10 000 ft (more than 3000 m) of Lower Carboniferous and possible Devonian rocks beneath the Stainmore area, contrasting with the few hundred metres known from the Alston Block to the north and the Askrigg Block to the south. Bott (1961) suggested that the Closehouse–Lunedale–Butterknowle Fault System was the southern boundary of the Alston Block, and further work (Bott, 1967; Johnson, 1967) confirmed the presence of the Stainmore Basin between the two blocks which also extends westwards to Ravenstonedale and Shap. The line of the Stockdale Disturbance (Figure 5.6) was suggested to mark the position of the southern margin of the basin. Futhermore, the presence of the Wensleydale Granite beneath the Askrigg Block was postulated, and later confirmed by the drilling of the Raydale Borehole (Dunham, 1974).

Acquisition of further subsurface data, for example from the Beckermonds Scar Borehole (Wilson and Cornwell, 1982), showed that the northward thickening into the Stainmore Basin is more gradual than that southwards from the Alston Block, although the Stockdale Disturbance marks a line where the rate of thickness increase accelerates (Figure 5.6). The realization that the Askrigg Block was a northerly dipping 'tilt-block' during Dinantian times and that the Stainmore Basin was a 'half-graben', similar to those recognized in other areas, led to some suggested changes in the nomenclature for these structural units (Grayson and Oldham, 1987), but these have not, on the whole, been adopted. The inferred pattern of thickness variations in Dinantian successions across the Askrigg Block and Stainmore Basin is shown in Figure 5.6. A more detailed evaluation of basin evolution in this area is considered by Collier (1991).

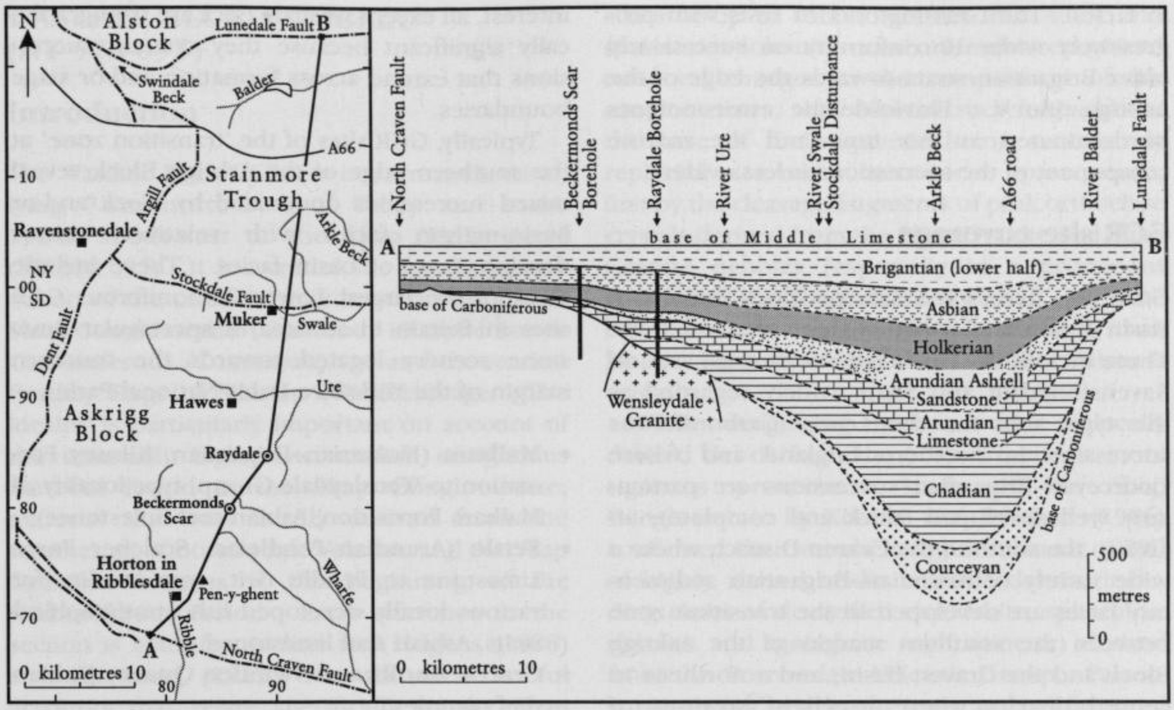


Figure 5.6 Section illustrating thickness variations in Dinantian strata across the Askrigg Block and Stainmore Basin. Note that the thicknesses illustrated between the Stockdale Disturbance and the River Balder are uncertain. After Dunham and Wilson (1985).

The sedimentary history and palaeogeography of the region during Early Carboniferous times has been reviewed by Dunham and Wilson (1985). At least part of the Askrigg Block remained land until Holkerian times, while the surrounding area was covered initially by tidal flats and local fan conglomerates. More open marine conditions were established by Arundian times when the first prolific coral faunas developed. Strata at Ravenstonedale are all indicative of fairly shallow-water conditions. To what extent a deeper-water basinal facies (*sensu stricto*) might be represented in the thick subsurface successions to the east has yet to be established. In the latter part of Arundian times, the Ashfell Sandstone, a fluvio-deltaic sand-body sourced from the east or north-east, interrupted carbonate deposition. Shallow marine carbonate deposition continued throughout Holkerian and Asbian times, although there is evidence for subaerial exposure at regular intervals.

Along the southern margin of the block there is a complex relationship between faulting and sedimentation (Kirby *et al.*, 2000; Mundy, 2000). During early Asbian times, reefs developed along the transition zone between the Askrigg Block and the Craven Basin (Figure 5.2), but synsedimentary uplift resulted in local unconformities and the whole belt suffered extensive pre-Namurian faulting (Hudson, 1930a, 1932). Coarse debris units, derived from the erosion of shelf and shelf-margin sediments, interfinger with the 'normal' pattern of Bowland Shales deposition in the northern part of the Craven Basin (Dixon and Hudson, 1931; Black, 1957).

At the end of Asbian times, carbonate deposition across much of the area finally gave way to the mixed carbonate and siliclastic deposits of Yoredale facies, which developed in 11 broadly shallowing-upward cycles during Brigantian and early Namurian times. Moore (1958, 1959, 1960) interpreted the Yoredale facies as the product of shifting deltas building out onto a shallow subsiding shelf. Mechanisms for the generation of the cyclicity are reviewed by Leeder and Strudwick (1987). Cherts are a significant part of upper Yoredale cycles in Swaledale and their origin was discussed by Wells (1955) and Hey (1956). Towards the top of the Pendleian Stage there is a marked change in facies. The Grassington Grit rests with progressively wider unconformity on successively older Brigantian strata towards the edge of the Askrigg Block. Fluvio-deltaic environments predominated at this time and the marine component of the successions is less evident.

GCR site coverage

GCR sites across the Askrigg Block–Stainmore Basin region are located in three separate areas. These include an area to the north-west around Ravenstonedale and Shap, widely regarded as the type area for the Lower Carboniferous succession in northern England and where Courceyan–Brigantian successions are particularly well developed (thick and complete); an area to the south in the Craven District, where a wide variety of Arundian–Brigantian sedimentary facies are developed in the transition zone between the southern margin of the Askrigg Block and the Craven Basin; and a northern to central district where excellent sections of Brigantian–Arnsbergian Yoredale successions are known. A diverse array of ancient sedimentary environments are represented by the successions at the selected localities, and more than half of these include stratotype sections of either regional or international significance.

Sites in the Ravenstonedale–Shap district towards the western end of the Stainmore Basin include the following:

- **Wasdale Beck** (Courceyan, Shap Conglomerate, alluvial-fan deposits);
- **Pinskey Gill** (Courceyan, type locality for the Pinskey Gill Beds, marginal marine facies);
- **Stone Gill–Scandal Beck** (Chadian–Arundian, type locality for the Stone Gill Limestone, Coldbeck Limestone, Scandal Beck Limestone and Breakyneck Scar Limestone, marginal marine to open marine facies);
- **Ash Fell Edge** (Arundian–Holkerian stage boundary, Ashfell Sandstone–Ashfell Limestone, deltaic to open marine facies);
- **Little Asby Scar** (regional stratotype for the Asbian Stage at the base of the Potts Beck Limestone, open marine facies);
- **Janny Wood** (regional stratotype for the Brigantian Stage at the base of the Peghorn Limestone, Yoredale facies).

While most of these sites include features of intrinsic sedimentological or palaeontological interest, all except Wasdale Beck are stratigraphically significant because they contain successions that extend across formation and/or stage boundaries.

Typically, GCR sites of the 'transition zone' at the southern edge of the Askrigg Block reveal mixed successions dominated by block and/or basin-margin facies with relatively minor developments of basin facies. These include three of the largest Lower Carboniferous GCR sites in Britain in an area of spectacular limestone scenery located towards the southern margin of the Yorkshire Dales National Park:

- **Malham** (Holkerian–Brigantian, Kilnsey Formation to Wensleydale Group, type locality of Malham Formation, Asbian reef limestones);
- **Settle** (Arundian–Pendleian, Scaleber Force Limestone to Pendle Grit, type locality for various locally developed lithostratigraphical units, Asbian reef limestones);
- **Cracoe Knolls and Swinden Quarry** (Asbian reef complex).

The value of these sites as an educational resource is considerable. Further sites of particular stratigraphical and sedimentological interest in this area are

- **Meal Bank Quarry** (unusual Asbian shelf limestone–coal association);
- **School Share** (non-sequence at the Dinantian–Namurian boundary associated with a carbonate debris bed at the base of the Upper Bowland Shales).

In northern and central areas, Lower Carboniferous successions are typically of Yoredale facies and are dominated either by carbonate rocks or by a carbonate–clastic deposit mix.

Carbonate-dominated successions:

- **Pen-y-ghent Gill** (Brigantian, lower Wensleydale Group, Hawes Limestone to Hardraw Scar Limestone, Girvanella Nodular Bed, marine facies).

Mixed carbonate–siliciclastic successions:

- **Whitfield Gill–Mill Gill** (Brigantian, Wensleydale Group, deltaic and marine facies);
- **Sleightholme Beck** (Pendleian, Great Limestone Cyclothem, deltaic, marine and barrier-island facies);
- **How Gill** (Arnsbergian, Botany Limestone, deltaic and marine facies).

WASDALE BECK, CUMBRIA (NY 578 095)

Introduction

The Wasdale Beck GCR site is a stream section, lying 7 km north-west of Tebay and some 150 m south-west of the Shap Wells Hotel (NY 578 095). It is a critical site for the examination of the unconformity between the fluvial Shap Conglomerate (Garwood, 1913) of Lower Carboniferous (Courceyan) age and the marine Brathay Flags of Silurian (Wenlock) age. The locality is particularly important on account of the unusually high concentration of igneous material found in the Shap Conglomerate; material that was locally derived from the weathering of Borrowdale Volcanic and the Shap Granite outcrops at the beginning of the Carboniferous Period. Early reference to the section is made by Aveline and Hughes (1888) and Garwood (1913), but the most useful accounts that relate specifically to the Shap Conglomerate are provided by Capewell (1955) and Kimber and Johnson (1986).

Description

The Brathay Flags are best exposed at a prominent waterfall at the south-western end of the site. Here the unit comprises dark, pyritic and laminated siltstones, dips steeply to the south-east and has a distinctive Caledonide (north-east–south-west) trend (Shipp, 1992). Northwards (downstream) the unit is unconformably overlain by the gently dipping beds of the Shap Conglomerate (= the 'Basement Series' of Capewell, 1955), which are best exposed in small cliff sections on the right bank of the beck as it approaches the Shap Wells Hotel. The two units are separated by an irregular unconformity surface (Aveline and Hughes, 1888).

Above the unconformity the Shap Conglomerate comprises a heterogeneous mix (< 10 m thick) of vari-coloured (reddish-brown to green) clastic sedimentary rocks dominated by conglomerate, but with minor developments of sandstone, siltstone and mudstone. This part of the succession was referred to by Capewell (1955) as the 'Lower Conglomerate Group', the lowest of three subdivisions he recognized in the Shap Conglomerate. Capewell (1955) described these basal conglomerates as having angular clasts of up to cobble size set in a sandy and sometimes dolomitic matrix. He also recognized temporal changes in the composition of the conglomerates, with Silurian rock fragments at the base of the sequence being successively replaced as a major constituent up sequence, first by the cleavage fragments of pink orthoclase crystals derived from the Shap Granite and Shap Granite pebbles (especially in a prominent conglomerate unit currently well exposed 0.5–3 m above the unconformity surface), then by silicified clasts of Borrowdale Volcanic origin.

While recognizing the occurrence of locally derived debris from the Shap Granite, a more rigorous provenance study of the Shap Conglomerate by Kimber and Johnson (1986) confirmed the overwhelming dominance (92%) of highly altered acidic volcanic debris (including clasts of devitrified rhyodacite, spherulitic rhyolite and ignimbrite with minette) derived from the Borrowdale Volcanic Group. Palaeocurrent work here by the same authors favoured a south-westerly to SSW provenance for this material.

Interpretation

The angular unconformity between the Brathay Flags and the Shap Conglomerate formed at the end of Early Palaeozoic times during the Caledonian orogenic episode when much of northern Britain was transformed into a mountainous land area. During this orogenic episode, which began in the late Silurian Period and continued into the Devonian Period, the Lower Palaeozoic rocks of the Lake District (including the Brathay Flags) were deformed, metamorphosed and uplifted within an emerging landmass that was subsequently intruded by granites (e.g. the Shap Granite) and exposed to the effects of subaerial weathering. The Shap Conglomerate formed as an erosional by-product of this weathering process at the beginning of the Carboniferous Period, and the inclusion within it of material derived from the Shap Granite (early Devonian) bears testimony to the unroofing of this granite at this time (see Shilston and Harpum, 1964; Taylor *et al.*, 1971; Shipp, 1992).

The Shap Conglomerate formed as a post-orogenic subaerial piedmont fan complex that developed on the eastern margin of the Lake District massif between Ullswater and

Ravenstonedale during early Dinantian times (Capewell, 1955; Ashton, 1970; Johnson and Marshall, 1971). Although basal to the Carboniferous succession at Wasdale Beck, a similar continental red-bed facies mapped as Shap Conglomerate overlies the earliest Carboniferous deposits of the Pinskey Gill Beds at Ravenstonedale to the south (see Figure 5.3 and **Pinskey Gill** GCR site report, this chapter). However, Capewell (1955) considered the conglomerates at Wasdale Beck as the direct lateral equivalents of the Pinskey Gill Beds (which are dated as Courceyan in age on miospore and conodont evidence; see Johnson and Marshall, 1971; Holliday *et al.*, 1979; Varker and Higgins, 1979; and Pinskey Gill GCR site report) and older than the Shap Conglomerate of the Ravenstonedale area.

Regional variations in sequence thickness and the presence of early diagenetic cements led Capewell (1955) to conclude that the conglomerates at Wasdale Beck were alluvial-fan deposits that formed in an erosional hollow in the underlying Silurian bedrock and, possibly subaqueously, in the same 'saline body of water' (lagoon?) as the Pinskey Gill Beds. A depositional setting for the Shap Conglomerate close to the margin of the Stainmore Basin was envisaged by Barraclough (1983). A more refined view was taken by Kimber and Johnson (1986) who considered the Shap Conglomerate as the product of an early Carboniferous valley-confined braided river system that flowed to the north or NNE draining an elevated landmass of considerable topographical expression (the Lake District massif) which may have been densely vegetated.

Conclusions

The unconformity between the marine Brathay Flags of Silurian age and the fluvial Shap Conglomerate of Lower Carboniferous age reveals important evidence of a significant mountain-building episode (the Caledonian Orogeny) which took place at the end of the Silurian Period. Its association with the overlying fluvial Shap Conglomerate provides critical evidence of the unroofing of the Shap Granite during early Carboniferous times. Together these features make Wasdale Beck an outstanding site for educational purposes and in particular for the understanding of basic geological principles.

PINSKEY GILL, CUMBRIA (NY 699 038–NY 699 043)

Introduction

The Pinskey Gill GCR site is a stream section (NY 6995 0382–NY 6993 0432) 2.5 km west of Ravenstonedale. It provides the finest section of the Pinskey Gill Beds (marine) in the Ravenstonedale district, and the oldest exposed sequence of Lower Carboniferous (Courceyan) age in the Stainmore Basin. It also includes, higher in the sequence, important exposures of the fluvial Shap Conglomerate. Early site descriptions of significance were by Dakyns *et al.* (1891) who provided the first measured section of the sequence, and by Garwood (1913, 1916) who gave details of the distribution of macrofossils. Later work at the site by Capewell (1955) and Ashton (1970) focused attention on sedimentological aspects, and subsequent micropalaeontological investigations by Johnson and Marshall (1971), Holliday *et al.* (1979) and Varker and Higgins (1979) revealed important biostratigraphical information.

Description

Originally referred to as the 'Lower Limestone Shales' by Dakyns *et al.* (1891) and later renamed the 'Pinskey Gill Beds' by Garwood (1913), this unit occupies a critical position at the base of the Dinantian succession in a region designated as the type area for the Lower Carboniferous sequence in north-west England (Garwood, 1913). It rests with angular unconformity on Lower Palaeozoic (Silurian) Bannisdale Slates (Turner, 1950, 1959a) and is overlain by the Shap Conglomerate (Garwood, 1913), a unit later referred to by Capewell (1955) as the 'Pinskey Gill Conglomerate' (Capewell, 1955), as the 'Feldspathic Conglomerate' (Johnson and Marshall, 1971; Mitchell, 1978) and as the 'Tebay Conglomerate' by Barraclough (1983).

Although parts of the sequence (including critical unit contacts) are obscured by drift, the discontinuous outcrops of the Pinskey Gill Beds at this site provide the best exposed and most complete section of this interval in the Ravenstonedale area. Borehole evidence indicates that the formation has a thickness of around 45–50 m (Holliday *et al.*, 1979). Details of the exposed section (*c.* 5–20 m above its base) described by Holliday *et al.* (1979) and Varker and Higgins (1979) are illustrated in Figure 5.7. The formation comprises an alternating sequence of thinly bedded, impure, fine-grained, dolomitic and sometimes vuggy limestones interbedded with grey, calcareous mudstones, siltstones and fine-grained, calcareous sandstones. From this sequence, Garwood (1913, 1916) recorded a sparse marine fauna dominated by bivalves (*Aviculopecten*, *Posidoniella* and *Myalina*?) and brachiopods (*Athyris* cf. *concentrica*, *Spirifer pinskeyensis*, *Lingula* and *Orbiculoidea*), with subordinate gastropods (*Naticopsis*), bryozoans (*Fenestella*) and fish remains (*Psephodus*) as well as 'plant

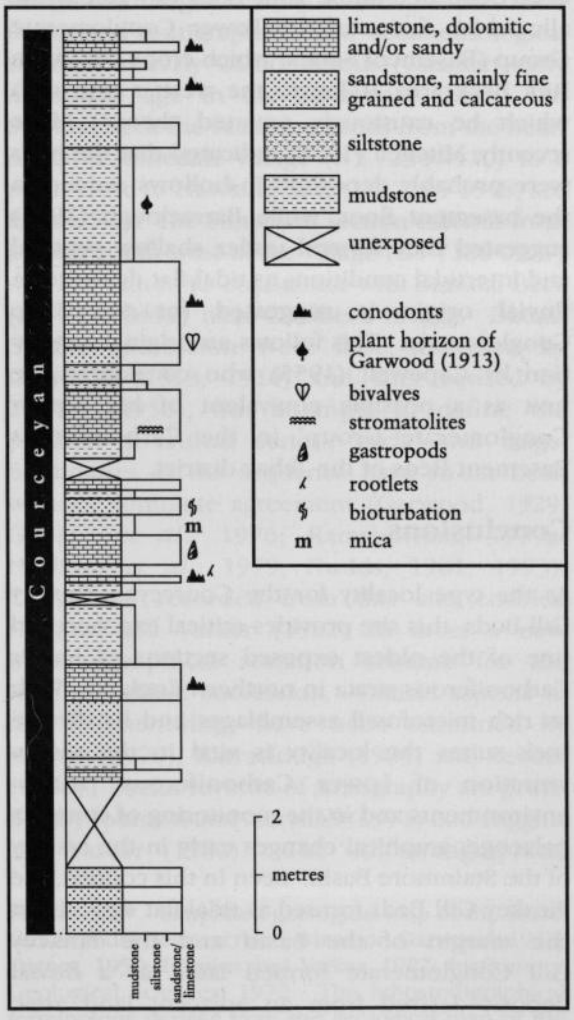


Figure 5.7 Sedimentary log of the exposed section of the Pinskey Gill Beds (Courceyan) at the Pinskey Gill GCR site. After Varker and Higgins (1979).

shales' containing *Pteridorbacis*. The formation has also yielded abundant miospores, derived mainly from the mudstones (Johnson and Marshall, 1971; Holliday *et al.*, 1979) and conodonts from the carbonate rocks (Varker and Higgins, 1979). Rare bioturbation features, algal nodules, quartz pebbles, seatearths and stromatolite bands are also reported from the sequence (Garwood, 1913; Holliday *et al.*, 1979; Varker and Higgins, 1979). Bed thicknesses are typically less than 2 m and the sequence dips gently to the NNE.

Overlying this unit the Shap Conglomerate comprises vari-coloured (red and green) sandstones, mudstones and a few conglomerate bands (Turner, 1950, 1959a; Holliday *et al.*, 1979). Despite suggested thicknesses of around 36–42 m (Johnson and Marshall, 1971; Holliday *et al.*, 1979), exposure of this unit is limited to a few metres of conglomerate just north of the Newbiggin–Weasdale road (NY 6982 0418). The conglomerates contain a remarkable suite of pebbles characterized by clasts of greywacke, quartz, volcanic rock, and a distinctive pink, perthitic, orthoclase feldspar similar to that which occurs in the Shap Granite. Provenance studies led Capewell (1955) to conclude that the unit may have been derived from the erosion of a granitic and Borrowdale Volcanic source located a few kilometres to the north (in an area now blanketed by a younger Carboniferous cover) rather than from the present outcrops of the Shap Granite and Borrowdale Volcanic Group exposed 15 km or more to the west.

Interpretation

Stratigraphical interest at this site stems largely from the fact that the Pinskey Gill Beds pre-date the Shap Conglomerate, which is regarded as basal to the Carboniferous succession in adjacent areas (Garwood, 1913; Capewell, 1955). The dating of this sequence has therefore been of critical importance in defining an accurate time framework for understanding the early evolution of the Stainmore Basin.

Early attempts to define an age for the Pinskey Gill Beds proved difficult for Garwood (1913), who admitted that his invertebrate faunas were diagnostic of neither the Devonian nor the Carboniferous periods, although the discovery of the fish tooth *Psephodus* was taken to indicate a Lower Carboniferous (Tournaisian) age and the formation was tentatively assigned to the *Zaphrentis* Zone (Garwood, 1913; Turner, 1959b). Miospores recovered from exposed beds here (Johnson and Marshall, 1971) and from borehole material (Holliday *et al.*, 1979) subsequently endorsed this view. Johnson and Marshall (1971) also noted striking similarities between the Pinskey Gill miospore assemblages and those described by Sullivan (1964a, 1968) from Tournaisian beds in the Forest of Dean (Lower Limestone Shales) and in Ayrshire (Cementstone Group). Among the more significant miospores identified were *Baculatisporites fusticulus*, *Pustulatisporites gibberosus*, *Dictyotriletes* (*Reticulatisporites*) *planus*, *Auroraspora macra* and *Discernisporites crenulatus*. A somewhat similar miospore assemblage from the Shap Conglomerate led Holliday *et al.* (1979) to assign both the Pinskey Gill Beds and the Shap Conglomerate to the CM miospore assemblage zone (Neves *et al.*, 1972, 1973) and to the Courceyan Stage (George *et al.*, 1976). The discovery of an impoverished conodont fauna in the Pinskey Gill Beds, dominated by *Bispathodus aculeatus aculeatus* and *Clydagnathus unicornis*, verified this view (Varker and Higgins, 1979; Higgins and Varker, 1982). Varker and Higgins (1979) attributed this fauna to the late K or early Z zones of the South-West Province and equated it with the *costatus costatus*/*Gnathodus delicatus* conodont zone of Rhodes *et al.* (1969). In a subsequent work, Higgins and Varker (1982) used this assemblage to define a new 'Fauna A' conodont zone at the base of the Carboniferous succession in the Ravenstonedale area.

However, regardless of these stratigraphical assertions, difficulties in determining the position of the Pinskey Gill sequence within the accepted chronostratigraphical framework of George *et al.* (1976) still remain. Reports of late Chadian foraminifera (N. Riley, pers. comm., 2002) from the Stone Gill Limestone above the Shap Conglomerate indicate that the position of the Courceyan–Chadian stage boundary, as originally defined by George *et al.* (1976) at the top of the 'Coldbeck Beds' (= Coldbeck Limestone of British Geological Survey, 1997b; and this account), may have been drawn at too high a level (Ramsbottom, 1977a). However, despite there being insufficient palaeontological evidence for the accurate placement of this boundary in the Ravenstonedale succession, Holliday *et al.* (1979) tentatively suggested a placement near the top of the Shap Conglomerate in the Ravenstonedale succession.

The association of interbedded dolomitic limestones and siliciclastic deposits containing rich microfloras, a low-diversity molluscan fauna, plant remains and rare seatearth and stromatolite bands suggests the Pinskey Gill Beds were deposited in a shallow, restricted and marginal marine environment close to the shoreline. Garwood (1913) regarded these beds as lagoonal in origin, a view later supported by Capewell (1955) who suggested they may have been deposited in the same body of water as the alluvial-fan facies of the Lower Conglomerate Group (Basement Series) which crops out in the Birk Beck area 10 km to the west, a unit with which he cautiously equated them. More recently, Mitchell (1978) indicated that the beds were probably deposited in hollows eroded in the basement floor, while Barraclough (1983) suggested they formed under shallow subtidal and intertidal conditions as tidal-flat deposits. A fluvial origin is suggested for the Shap Conglomerate. This follows an original suggestion by Capewell (1955) who considered the unit as a possible equivalent of his 'Upper Conglomerate Group' in the Carboniferous Basement Beds of the Tebay district.

Conclusions

As the type locality for the Courceyan Pinskey Gill Beds, this site provides critical exposures of one of the oldest exposed sections of Lower Carboniferous strata in northern England. With its rich microfossil assemblages and its diverse rock suites the locality is vital in the reconstruction of Lower Carboniferous palaeoenvironments and in the monitoring of complex palaeogeographical changes early in the history of the Stainmore Basin. Seen in this context, the Pinskey Gill Beds formed as tidal-flat deposits at the margin of the basin and the Pinskey Gill Conglomerate formed later, as a fluvial deposit derived from an adjacent land area, when the early Carboniferous seas temporarily retreated.

STONE GILL–SCANDAL BECK, CUMBRIA (NY 718 038–NY 721 044 and NY 723 041–NY 720 055)

Introduction

The Stone Gill–Scandal Beck GCR site is a composite stream section centred on Ravenstonedale village, and extending for approximately 1 km to the north of the village. This site includes arguably the finest available section of the upper part of the Ravenstonedale Group (Stone Gill Limestone and Coldbeck Limestone) and the lower part of the Orton Group (Scandal Beck Limestone, Brownber Formation and Breakyneck Scar Limestone) in north-west England and is one of the most important stratigraphical and sedimentological sections of early Carboniferous (Chadian–early Arundian) age in the Stainmore Basin. In Scandal Beck the section extends from the heart of Ravenstonedale village (NY 7230 0410) to a point close to Hawking Scar (NY 7195 0548; see Figure 5.8). The Stone Gill section extends from a point south-west of the village (NY 7180 0377) downstream to its confluence with Scandal Beck (NY 7213 0442) near Coldbeck Bridge. Details of the succession were first described by Garwood (1913, 1916) and later revised by Turner (1950), but attempts to define the position of critical 'series', 'cycle' and 'stage' boundaries in the sequence have so far been without complete agreement (Garwood, 1929; George *et al.*, 1976; Ramsbottom, 1977a; Holliday *et al.*, 1979; Nudds, 1981, 1993). Conodonts recorded from this site enabled Higgins and Varker (1982) to erect a new biostratigraphical zonation scheme for the Ravenstonedale succession. Critical aspects of the sedimentology have been examined by Ashton (1970), Barraclough (1983) and Leeder (1988). Useful reviews of stratigraphy are provided by Johnson and Marshall (1971) and Higgins and Varker (1982). The lithostratigraphical

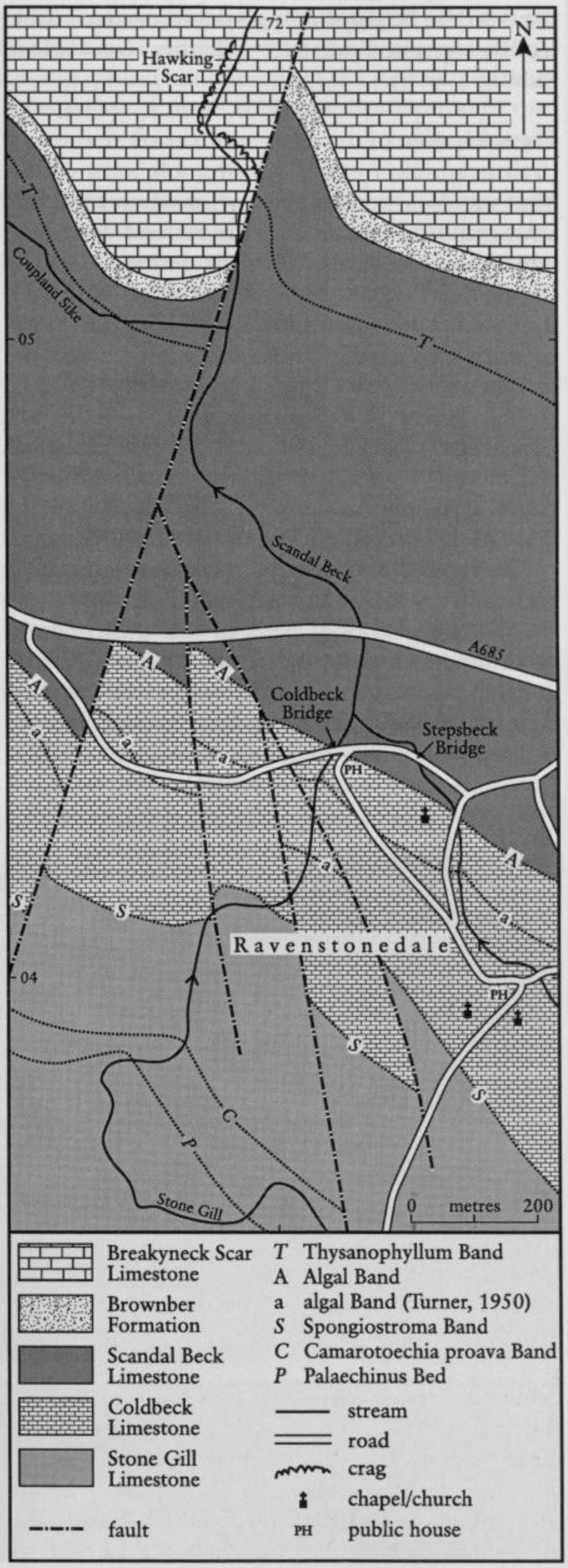


Figure 5.8▸ Simplified geological map of the Stone Gill–Scandal Beck section. Based on Garwood, 1913; Turner, 1950; Higgins and Varker, 1982; Institute of Geological Sciences, 1972. The lithostratigraphical terminology derives from the geological map of the Kirkby Stephen district (British Geological Survey, 1997b).

terminology used in this account follows that used on the British Geological Survey map of the Kirkby Stephen district (British Geological Survey, 1997b).

Description

The succession comprises a number of lithostratigraphical units, the nature and limits of which have yet to be precisely defined. Across the site, beds dip gently to the north-east, but the succession is disrupted by faulting and areas of poor exposure. Thus, reported unit thicknesses vary widely (Higgins and Varker, 1982).

The Stone Gill Limestone (*c*. 100–125 m) comprises a varied and extensively dolomitized succession (Figure 5.9), characterized mainly by thinly bedded fine-grained limestones (chiefly carbonate mudstones and wackestones) interbedded with calcareous mudstones and siltstones, and a distinctive fauna and flora. In addition, the lower unexposed beds of this unit (42 m), recorded in a borehole by Holliday *et al*. (1979), contain rare sandstones, seatearths and concentrations of plant debris. In the exposed section (63 m) logged by Higgins and Varker (1982), Garwood (1913, 1916) recorded calcareous algae ('*Solenopora*' *garwoodi*), corals (*Zaphrentis omaliusi*, *Syringopora*, *Vaughania cleistoporoides*), brachiopods (*Athyris glabristria*, *Spiriferina*, *Spirifer clathratus*, *Camarotoechia proava*), echinoids (*Archaeocidaris*, *Palaechinus*), ostracodes, and sparse plant, sponge (*Hyalostelia*) and nautiloid remains (*Orthoceras*). A number of these fossils appear concentrated within distinctive marker bands, the most obvious of which are the Vaughania Band and Palaechinus Bed recognized by Garwood (1913) near the base of the section (NY 7176 0380). Higher up in the unit, brachiopod beds containing abundant *Camarotoechia proava* mark the base of Garwood's C. proava Band. At its top is the stromatolitic Spongiostroma Band (NY 7190 0410) which Turner (1950) identified as a convenient boundary between Garwood's (1913) *Solenopora* and *Seminula gregaria* subzones. The location of most of these marker bands is illustrated in Figure 5.8.

Overlying the Spongiostroma Band, the Coldbeck Limestone (*c*. 80 m) extends downstream to a prominent algal band beneath Coldbeck Bridge (NY 7209 0435). Turner (1950) suggested that approximately 30–35 m of

Figure 5.9 General view of the peritidal and partially dolomitized beds of the Stone Gill Limestone (Chadian) at Stone Gill, Ravenstonedale. (Photo: P.J. Cossey.)

this succession had been removed by faulting. The formation is dominated by limestones (carbonate mudstones) and is distinguished from the underlying unit by the occurrence of abundant nodular and laminated algal horizons, and a sparser macrofauna. Dolomitized limestones, minor shale developments, *Composita gregaria* and rhynchonellids also occur (Turner, 1950; Ramsbottom, 1974; Higgins and Varker, 1982). The algal band beneath Coldbeck Bridge was originally used by Mitchell (1972) to define the position of the Tournaisian–Viséan boundary; and later by Ramsbottom (1973, 1974) to mark the junction between the first and second 'major cycles' of sediment deposition he recognized in the Ravenstonedale succession. For a short period, the same band was also used by George *et al*. (1976) to define the boundary between the Courceyan and Chadian stages (see 'Interpretation' below). This band does not, however, equate with the algal layer described by Turner (1950) which appears to lie slightly lower in the sequence. The varied lithofacies and restricted biofacies of both the Stone Gill Limestone and the Coldbeck Limestone indicates that these deposits most probably formed in very shallow water under hypersaline conditions at the head of the Stainmore Basin as nearshore, tidal-flat sediments (Ramsbottom, 1974; Mitchell, 1978; Barraclough, 1983).

North and east of Coldbeck Bridge the Scandal Beck Limestone (*c*. 100–125 m) continues the sequence to the base of the Brownber Formation (formerly the Brownber Pebble Bed). The lower part of the Scandal Beck Limestone is well exposed south of the Stone Gill–Scandal Beck confluence, but up sequence the exposure deteriorates. The unit comprises fine-grained bioclastic limestones (some dolomitized) with thin calcareous mudstone interbeds and a sparse microfauna. The Thysanophyllum Band (Garwood, 1913), characterized by the late Chadian coral *Dorlodotia pseudovermiculare*, occurs near the top of this unit at a level where marine faunas appear to become more common in the sequence. However, the occurrence of '*Thysanophyllum*' well below the level of the Thysanophyllum Band has also been reported by Turner (1948, 1950) from Garwood's (1913) 'Globosus/fawcettensis Beds'. The outcrop of the Thysanophyllum Band is significantly displaced (close to Coupland Sike and Breakyneck Scar) by a NNE–SSW-trending fault that crosses Scandal Beck at NY 7193 0528 (Figure 5.8).

The Brownber Formation comprises 4–6 m of calcareous sandstone and, in its upper part, quartz pebbles are common. The unit is a useful lithostratigraphical marker within the Ravenstonedale succession. A more complete description of the Brownber Formation is given by Barraclough (1983) who, along with Leeder (1988), regarded it as a shoreline (beach) deposit. Above this unit, discontinuous outcrops of fossiliferous and bioclastic limestones with a rich marine fauna belonging to the lower part of the Breakyneck Scar Limestone complete the sequence.

Interpretation

Although very little modern sedimentological work has been published, Barraclough (1983) suggested that the sequence was deposited towards the margin of the Stainmore Basin in a variety of marginal marine and offshore marine environments. The lower part of the succession (Stone Gill Limestone and the lower part of the Scandal Beck Limestone) was interpreted as a complex succession of tidal-flat cycles (with algal marsh, channel and pond deposits) while the upper part of the succession (the upper part of the Scandal Beck Limestone to Breakyneck Scar Limestone) was regarded as largely shallow, subtidal and offshore marine deposits. The transition from tidal-flat to open marine facies noted by Barraclough (1983) occurs below the Brownber Formation and close to the position of the Thysanophyllum Band. This transgressive event brought an end to the extensive phase of tidal-flat sedimentation that characterized the early Carboniferous history of the Stainmore Basin. Evidence of increased water depths at this level is provided by Higgins and Varker (1982) who recorded shallow subtidal and intertidal conodont faunas from the lower part of the succession (Stone Gill Limestone to lower Scandal Beck Limestone) which were joined by deeper-water forms only in the Breakyneck Scar Limestone.

Subsequent to Garwood's (1913) original description of the section, the site became the subject of a long and still ongoing debate regarding the placement of critical stratigraphical boundaries. Early discussions focused attention on the location of the Tournaisian–Viséan boundary (Johnson and Marshall, 1971) while later workers (after Ramsbottom, 1973; George *et al*., 1976) attempted to define the position of the Courceyan–Chadian and Chadian–Arundian stage boundaries.

Initially, Garwood (1913) assigned the whole of the Stone Gill–Scandal Beck section to the Tournaisian Series and, more specifically, to the *Athyris glabristria* Zone, but subsequently he concluded that the Tournaisian–Viséan boundary was best placed at the level of the Thysanophyllum Band (Garwood, 1929).

Since then, the position of this boundary, and the Courceyan–Chadian stage boundary with which it was once broadly equated, has been moved to a lower position within the sequence, largely on the basis of micropalaeontological evidence. Thus, Holliday *et al.* (1979) tentatively positioned the Courceyan–Chadian stage boundary within the Shap Conglomerate (i.e. below the level of the Stone Gill Limestone and outside of the limits of the Stone Gill–Scandal Beck section) and this view is followed in the present account (see Figure 5.3).

Following this trend and the discovery of the Arundian coral *Dorlodotia briarti* towards the top of the Scandal Beck Limestone, Nudds (1981) tentatively suggested the lowering of the Chadian–Arundian boundary from its original position 20 m below the Brownber Formation (George *et al.*, 1976) to the base of the Scandal Beck Limestone. Later, Riley (in Nudds, 1993) argued that, since the Scandal Beck Limestone is devoid of archaediscid foraminifera, the entire unit must be of late Chadian age. However, this view was challenged by Nudds (1993) who noted, in the upper part of the unit, the occurrence of *D. briarti* in prolific association with *Siphonondendron martini* – a form that is known to have made its first entry in the Arundian Age (Nudds, 1980; Mitchell, 1989; Riley, 1993). Nudds (1993) therefore maintained an early Arundian age for the upper Scandal Beck Limestone, as originally suggested by George *et al.* (1976).

After the publication of Ramsbottom's (1973) synthesis of Dinantian stratigraphy, the Stone Gill–Scandal Beck section became a test bed for Ramsbottom's contention that Lower Carboniferous successions could be subdivided into a number of major eustatically generated sedimentary cycles, the boundaries between which he believed were defined by sedimentological and palaeontological features indicative of regression and transgression (Barraclough, 1983; Leeder, 1988). In this context, Ramsbottom (1973) regarded the algal band at the top of the Coldbeck Limestone as the terminal regressive phase of his 'Major Cycle 1', between his 'Major Cycles 1 and 2' (later the D2a–D2b mesothemic cycle boundary; Ramsbottom, 1977a) and the Brownber Formation as a similar regressive interval that marked the Major Cycle 2/3 boundary. However, detailed facies analysis by Barraclough (1983) indicated that the algal band at the top of the Coldbeck Limestone was a relatively insignificant component of a more extensive cyclic peritidal sequence (the Stone Gill Limestone to lower Scandal Beck Limestone interval) within which there was no sign of any significant transgression or regression, and that the Brownber Formation occurred in the middle of a transgressive marine sequence rather than at its base. Furthermore, the more significant and most obviously transgressive facies change in the sequence (the transition from peritidal to open marine facies within the Scandal Beck Limestone) was not identified as a potential cycle boundary by Ramsbottom (1973, 1974). Leeder (1988) concluded that Barraclough's work and refinements to the biostratigraphy provided evidence that cast doubt on the reality of Ramsbottom's major cycles and suggested that attempts to correlate them worldwide (Ross and Ross, 1985) were therefore ill-founded.

Conclusions

This site provides a near-continuous section from the Stone Gill Limestone through to the Breakyneck Scar Limestone, one of the most extensive and complete sections of Lower Carboniferous (Chadian–early Arundian) age in northern England. With its varied macrofossil and microfossil assemblages and a diverse array of sedimentary features, the section is vital to the understanding of the stratigraphical and palaeogeographical evolution of the Stainmore Basin. Barraclough (1983) suggested that the lower part of the succession (Stone Gill Limestone to lower Scandal Beck Limestone) was deposited close to the head of the Stainmore Basin in a range of shallow, quiet-water, marginal marine environments similar to those of modern (Bahamian) tidal-flat areas, and that the upper part of the succession (upper Scandal Beck Limestone to Breakyneck Scar Limestone) was deposited in a more open marine environment. Uncertainties relating to the position of the Courceyan–Chadian boundary, the Chadian–Arundian stage boundary and the poor definition of lithostratigraphical (rock) units highlight the potential of this site in future research.

ASH FELL EDGE, CUMBRIA (NY 733 050–NY 739 045)

Introduction

The Ash Fell Edge GCR site lies 1.5 km ENE of Ravenstonedale on the road to Kirkby Stephen. The site offers the best available and continuous section of the upper part of the Ashfell Sandstone and lower part of the Ashfell Limestone in the Ravenstonedale district. It includes the busy A685 road cutting (NY 7360 0475), a significant part of the NW–SE-trending Ash Fell Edge escarpment (NY 7320 0510–NY 7392 0455) and a number of associated small but disused and overgrown quarries. The locality is renowned for the quality of its sedimentary features and the exceptional preservation of its fossils, and is important in understanding the tectono-sedimentary history of the Stainmore Basin during late Arundian and early Holkerian times. An early site description was provided by Garwood (1913, 1916) who gave details of the faunal succession. Later palaeontological work focused attention on the rich faunas and coral biostromes of the Ashfell Sandstone (Johnson and Nudds, 1975; Bancroft, 1986b; Nudds and Day, 1997), plant taphonomy (Nudds and Taylor, 1978) and conodont biostratigraphy (Higgins and Varker, 1982). Barraclough (1983) considered the sedimentology of the Ashfell Sandstone, but a comparable study of the Ashfell Limestone has yet to be undertaken. Logs of the succession are provided by Rose *et al.* (1973), Higgins and Varker (1982) and Barraclough (1983).

Description

The exposed Ashfell Sandstone–Ashfell Limestone succession is approximately 55 m thick and dips gently to the north-east. At its base, the topmost beds of the Ashfell Sandstone (*c.* 10 m) include thin sandstones and a mix of vari-coloured (red, purple, green, grey) and highly fossiliferous mudstones and limestones capped by a massive cross-bedded sandstone (Figure 5.10). This part of the succession is decribed in detail by Barraclough (1983) (Figure 5.11). A rich coral–brachiopod fauna is known from these beds, including *Koninckophyllum ashfellense*, *Amplexizaphrentis enniskilleni*, *Siphonodendron martini*, *Composita ambigua*, *Stenoscisma isorhyncha*, *Syringothyris cuspidata* and *Spiriferina laminosa* (Garwood, 1913, 1916), most of which are typical of the Arundian Stage. A few metres below the massive sandstone, a prominent interbedded red mudstone–limestone interval contains the in-situ remains of *Siphonodendron martini* coral colonies (the 'Lithostrotion martini Bed' of Garwood, 1913, and Turner, 1950). The fine preservation of growth bands on these corals enabled Johnson and Nudds (1975) to use them as geochronometers and determine that there were 391 days in a Lower Carboniferous year. Later work by Nudds and Day (1997) indicated that the corals were stunted forms, their growth being inhibited by the influx of terrigenous sediment. In addition, some of these corals supported a varied epifauna. Garwood (1913) reported that some '*Lophophyllum*' *ashfellense* corallites were attached to '*L.*' *martini* corallites by 'strong roots', while Bancroft

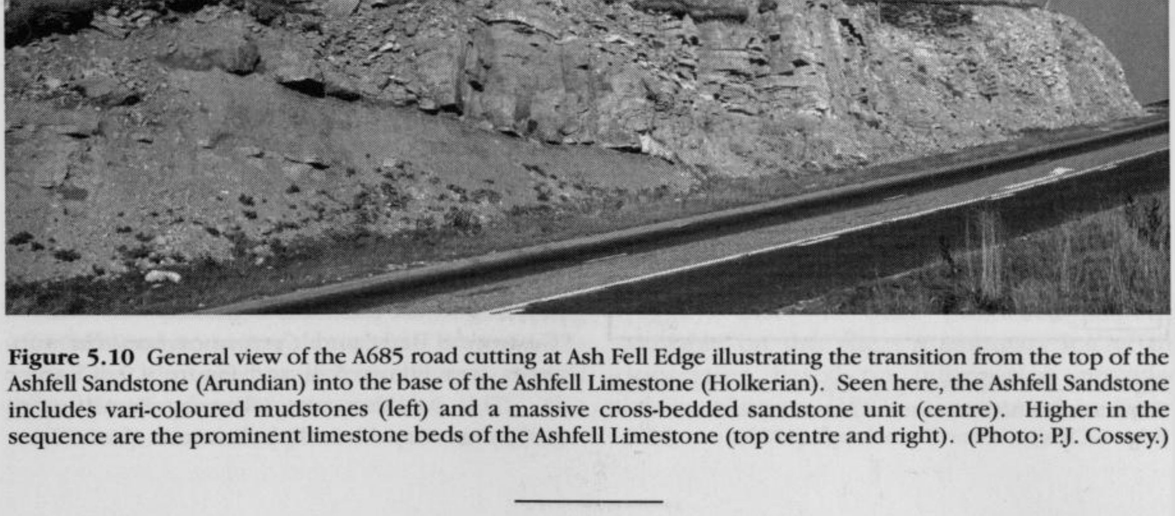


Figure 5.10 General view of the A685 road cutting at Ash Fell Edge illustrating the transition from the top of the Ashfell Sandstone (Arundian) into the base of the Ashfell Limestone (Holkerian). Seen here, the Ashfell Sandstone includes vari-coloured mudstones (left) and a massive cross-bedded sandstone unit (centre). Higher in the sequence are the prominent limestone beds of the Ashfell Limestone (top centre and right). (Photo: P.J. Cossey.)

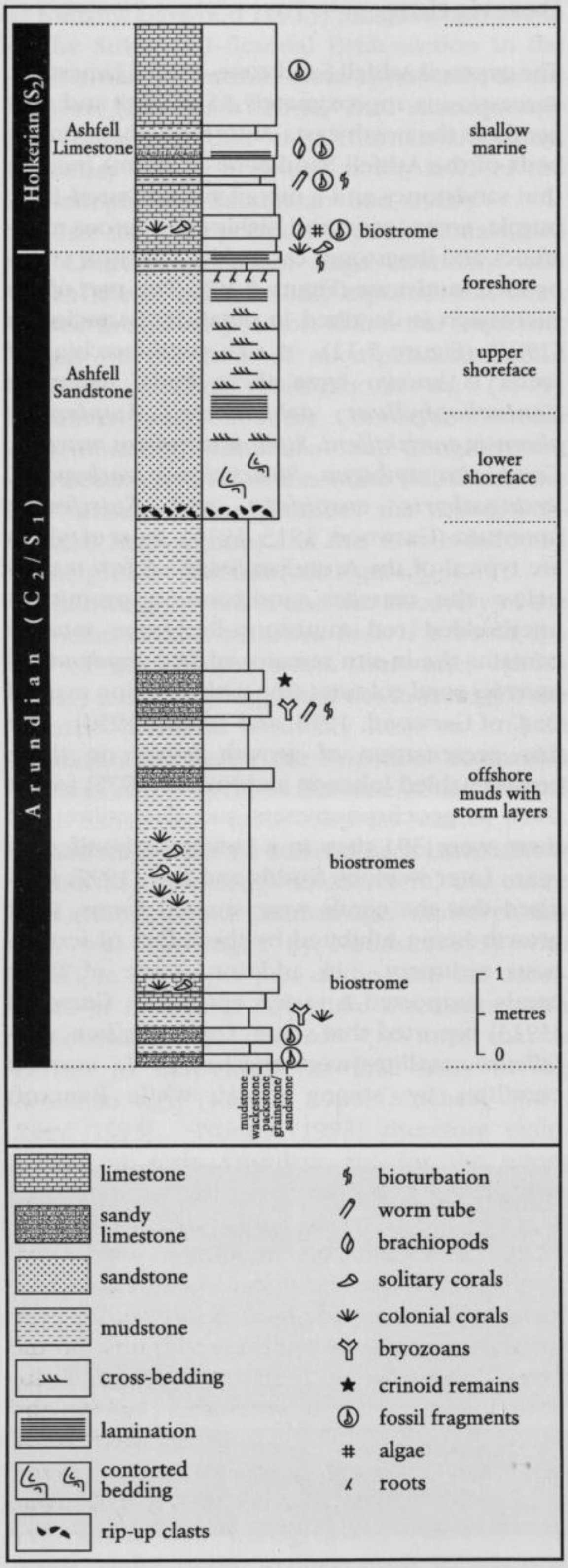


Figure 5.11 Sedimentary log across the Ashfell Sandstone–Ashfell Limestone boundary at the Ash Fell Edge GCR site. After Barraclough (1983).

(1986b) noted corallites encrusted by various bryozoans, including the fistuliporoid cystoporates *Eridopora macrostoma* and *Fistulipora incrustans*, as well as an unidentified stenoporid trepostome. Above this 'biostromal' coral development, are bryozoan-rich mudstones and rare thin sandy limestones capped by a massive sandstone with a sharp erosive base. The latter unit, a prominent leaf of the Ashfell Sandstone, is a well-sorted, quartz-rich calcareous sandstone with contorted bedding and rip-up clasts at its base, cross-bedding in the middle section and rootlets at its top (Barraclough, 1983).

The overlying Ashfell Limestone (*c.* 45 m) is dominated by pale, thinly bedded and fine-grained bioclastic limestones with sparse developments of shale, siltstone and sandstone. In the lowest 20 m of the succession Ramsbottom (1974) described four minor sedimentary cycles consisting of 'fining-upward limestones' and thin shale–sandstone interbeds. Rare bands of dolomitic and/or sandy limestone and a further 'biostromal' development of *S. martini* occur towards the base of the unit (Rose *et al.*, 1973; Barraclough, 1983). Further up the sequence, laminated beds, bioturbation fabrics, mottled horizons and graded beds become more common. About 10 m above the base of the Ashfell Limestone, Nudds and Taylor (1978) discovered a micritic plant bed (0.5 m) containing leafy stem lengths of the lycopod *Archaeosigillaria kidstoni* preserved as uncompressed external casts of radial fibrous calcite in association with evaporite pseudomorphs. Rich faunas of a typical Holkerian aspect also occur in these beds including some distinctive brachiopods (*Linoprotonia corrugato-hemispherica*, *Davidsonina carbonaria*), corals (*S. martini*, *Syringopora geniculata*), gastropods, crinoid remains, fish teeth (*Streblodus*, *Psephodus*) and rare chaetetids, most of which were identified by Garwood (1913, 1916).

Interpretation

The exposed section falls entirely within the *Productus corrugato-hemisphericus* Zone of Garwood (1913), the junction between the Ashfell Sandstone and Ashfell Limestone corresponding to the subzonal boundary between his 'Gastropod Beds' and '*Cyrtina carbonaria*' subzones (see Figure 5.3; and Figure 4.2, Chapter 4). This junction was taken by Ramsbottom (1973) as the boundary between his 'Major

Cycle 3' and 'Major Cycle 4' (later the D3–D4 mesothemic cycle boundary; Ramsbottom, 1977a) and was subsequently used to define the position of the Arundian–Holkerian stage boundary in the Ravenstonedale succession (George *et al.*, 1976). The section also falls within the *Cavusgnathus* condont zone of Higgins and Varker (1982).

The Ashfell Sandstone is a diachronous unit that extends from the River Eamont (Penrith) in the north-west to Garsdale (Sedbergh) in the south (Garwood, 1913; Turner 1959a, 1963). Although a number of early workers speculated on the origin of the sandstone (George, 1958; Turner, 1959a) the generally accepted view is that it represents a complex fluvio-deltaic sand-body sourced from the north-east and linked (possibly) to the similarly aged Fell Sandstone Group incursions of the Northumberland Basin (Ramsbottom, 1974; Gawthorpe *et al.*, 1989; Leeder, 1992). Barraclough (1983) interpreted this part of the succession as part of a prograding shoreline complex at the edge of the Ashfell delta. Beds beneath the massive sandstone were regarded as offshore muds with some storm layers, whereas the massive sandstone itself was thought to represent a shoreface sand deposit. Although Turner (1950) regarded the contorted layers of the sandstone as evidence of contemporaneous slumping, Barraclough (1983) suggested that they resulted from the de-watering of the underlying mudstone. Palaeocurrent evidence indicates that the Ashfell Sandstone was sourced from the east (Barraclough, 1983).

Despite the lack of sedimentological research on the Ashfell Limestone, its character suggests that it was deposited in a shallow marine environment of variable water depth and salinity, the presence of corals and brachiopods indicating open marine conditions at some levels, while the association of calcispheres, paraparchitid ostracodes and suspected evaporite nodules suggests restricted and possibly hypersaline conditions at other levels (e.g. the A. kidstoni Plant Bed of Nudds and Taylor, 1978).

To summarize, as the Ash Fell delta was abandoned at the end of Arundian times, an early Holkerian marine incursion resulted in the formation of an extensive carbonate platform over the subsiding delta lobe, and upon it the Ashfell Limestone was deposited. It was at this time that the geomorphological expression of the 'Stainmore (Ravenstonedale) Gulf' was effectively diminished (Gawthorpe *et al.*, 1989).

Conclusions

Ash Fell Edge is a classic mixed-interest site that exposes a particularly fine section of the Ashfell Sandstone and Ashfell Limestone, and a critically important exposure of the Arundian–Holkerian stage boundary. The site is vital for the correlation of successions across the Stainmore Basin and into neighbouring areas of the Askrigg and Lake District–Alston blocks. In addition, it is also of crucial significance in understanding the complex interaction between the deltaic and marine processes that influenced the formation of the Ashfell Sandstone (delta margin) and the Ashfell Limestone (marine carbonate platform) at a key stage in the evolution of the Stainmore Basin. The site remains a promising prospect for future sedimentological and biostratigraphical research.

LITTLE ASBY SCAR, CUMBRIA (NY 692 085–NY 704 091)

Introduction

Situated 5 km NNW of Ravenstonedale, the Little Asby Scar GCR site provides an excellent section of the top of the Ashfell Limestone (Holkerian), the Potts Beck Limestone (early Asbian) and the Knipe Scar Limestone (late Asbian). As the stratotype for the Asbian Stage and type locality for the Potts Beck Limestone, it is one of the most important reference sections in the British Lower Carboniferous Subsystem. The stratotype section is located at a south-facing crag overlooking the Potts Beck valley at the southern edge of the site (NY 6988 0827). This crag is split into two, forming an eastern and western scarp (see the caption to Figure 5.12). The locality extends for approximately 1 km to the north of the stratotype area and also includes a unique coral–demosponge bioherm. Apart from the regional descriptions of the succession outlined by Garwood (1913), Taylor *et al.* (1971), Ramsbottom (1974) and Mitchell (1978), and the detailed accounts of the stratotype provided by George *et al.* (1976), Ramsbottom (1981), Strank (1981) and White (1992), there is little published material available on this site. A summary log of the succession based on information provided by Ramsbottom (1981) is presented in Figure 5.12.

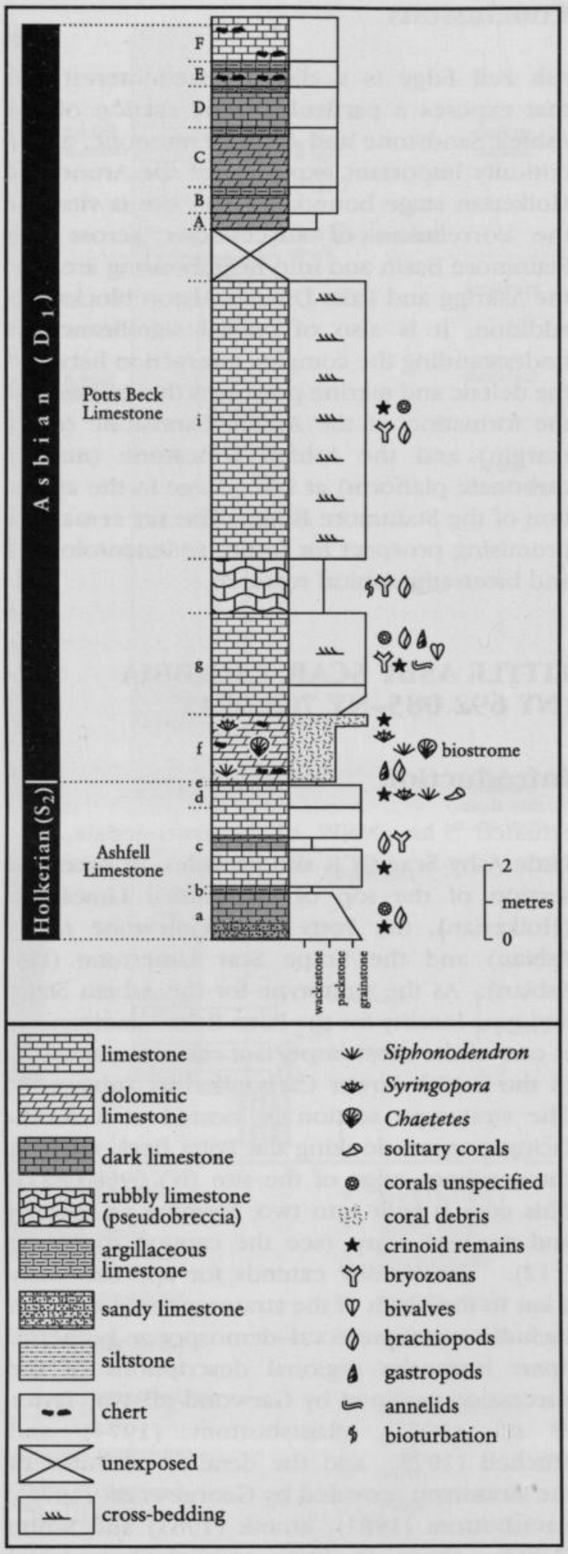


Figure 5.12 Sedimentary log across the Ashfell Limestone–Potts Beck Limestone boundary at the Asbian stratotype section, Little Asby Scar. Compilation after information in Ramsbottom (1981). Upper case bed letters are for the eastern scarp; lower case bed letters are for the western scarp.

Description

The exposed sequence dips gently to the north and includes the topmost beds of the Ashfell Limestone (*c.* 4 m) overlain successively by the Potts Beck Limestone (*c.* 70 m) and the Knipe Scar Limestone (*c.* 85 m). At the base of the succession the lowest beds of the Ashfell Limestone comprise dark-grey and sometimes sandy packstones–wackestones with a few shale intervals, these giving way to paler-coloured crinoidal grainstones higher up in the succession (Figure 5.12). The fauna includes a rich Holkerian foraminiferal assemblage together with a less diagnostic assemblage of conodonts, corals (particularly in the topmost bed), brachiopods and bryozoans (Ramsbottom, 1981; Strank, 1981). The boundary between the Ashfell Limestone and the Potts Beck Limestone, which also defines the base of the Asbian Stage, is marked by a thin (0.5 cm) siltstone band (bed 'e' of George *et al.*, 1976, and Ramsbottom, 1981; see Figure 5.12).

General descriptions of early Asbian successions (Potts Beck Limestone) in the Stainmore Basin refer to the occurrence of minor cycles of dark- to pale-coloured limestones with bioturbation fabrics and the typical early Asbian brachiopods *Daviesiella llangollensis* and *Dibunophyllum bourtonense* (Ramsbottom, 1974; Mitchell, 1978). Whereas most of these features can be recognized at the present site, no mention of the occurrence of *D. llangollensis* was made by Ramsbottom (1981) in his detailed description of the section, and his record of *D.* cf. *bourtonense* in the lowest of these beds has yet to be repeated (Riley, 1993).

The lower part of the Potts Beck Limestone consists of vari-coloured grainstones and packstones (Ramsbottom, 1981). Here, the succession can be subdivided into three units (Figure 5.12). The lowest unit is a spectacular, but as yet under-studied biostrome (*c.* 2 m thick) dominated by the in-situ and silicifed remains of corals (*Siphonodendron martin* and *Syringopora geniculata*) and large bulbous calcareous chaetetid demosponges up to 40 cm in diameter (Figure 5.13). Above this, a middle unit of cross-bedded, crinoidal grainstone (12 m), with a distinctive bioturbated horizon ('pseudobreccia') near its base, is capped by a packstone unit (*c.* 9 m) containing dolomite, shaly bands and scattered nodules of chert. Ramsbottom (1981) records a rich coral–

Figure 5.13 Biostrome containing *Siphonodendron martini*, *Syringopora geniculata* and *Chaetetes* at the base of the Potts Beck Limestone (early Asbian), Little Asby Scar. (Photo: P.J. Cossey.)

brachiopod fauna from the lower part of the limestone including the 'typical Asbian taxa – *Dibunophyllum*, *Axophyllum vaughani* and *Gigantoproductus maximus*'. However, the discovery of Holkerian foraminiferal assemblages extending through the lowest 19.6 m of the Potts Beck Limestone at this locality (Strank in Ramsbottom, 1981) casts doubt over the assignment of this part of the succession to the early Asbian Age (Riley, 1993). This matter is discussed further in the 'Interpretation' below. Other fossil groups reported from these beds include bryozoans, gastropods, bivalves, conodonts and a possible annelid (Ramsbottom, 1981).

Although there are no site-specific descriptions of the remaining and higher parts of the succession, Mitchell (1978) identified a 'shale and ferruginous sandstone' at the top of the Potts Beck Limestone 'in the area of Little Asby Scar', and the overlying Knipe Scar Limestone (late Asbian) is known to contain a number of limestone-dominated cyclothems in which pseudobreccias are common – particularly in the lower and upper parts of the formation (Garwood, 1913; Ramsbottom, 1974; Mitchell, 1978). A further terrigenous siliciclastic interval, above the Knipe Scar Limestone but beneath the Robinson Limestone (Mitchell, 1978), may also crop out within the bounds of the site. These siliciclastic intervals are believed to represent the forerunners of the Yoredale facies better developed within Brigantian successions seen elsewhere in the region (Mitchell, 1978).

Interpretation

The junction between the Ashfell Limestone and the overlying Potts Beck Limestone was originally used to mark the position in the Ravenstonedale succession of Ramsbottom's (1973) 'Major Cycle 4–5' boundary. Significantly, this same boundary was used by George *et al.* (1976) to define the base of the Asbian Stage, which broadly equates to the Lower *Dibunophyllum* Subzone (D_1) of Garwood (1913). Subsequently, the recognition of two major (mesothemic) cycles in the Asbian Stage (Ramsbottom, 1977a) enabled Mitchell (1978) to assign the Potts Beck Limestone to the lower part of the Asbian Stage (mesothem D5a) and the Knipe Scar Limestone and Robinson Limestone to the upper part of the Asbian Stage (mesothem D5b). However, Riley (1993) has indicated that since the first repeatable record of the Asbian coral *Dibunophyllum* occurred in association with the first Asbian foraminifera reported by Strank (in Ramsbottom, 1981) 19.6 m above the base of the Potts Beck Limestone, there was a case for the re-definition of the Asbian boundary at this higher level to coincide with the base of the Cf6a foraminiferal subzone (see Figure 1.4, Chapter 1), but 'no need to relocate the stratotype'. The recent discovery by M. Aretz and J.R. Nudds (unpublished) of *Axophyllum nanum*, *Clisiophyllum garwoodi*, *C. keyserlingi* and *Siphonophyllia siblyi* without associated *Dibunophyllum* in the biostrome at the base of the Potts Beck Limestone would appear to support this view (J. Nudds, pers. comm., 2001).

Despite the lack of published research, the general character of the exposed beds, with their diverse faunas, coral–sponge biostrome and varied lithofacies (argillaceous wackestones and packstones, bioclastic grainstones and burrowed horizons) indicates that the succession probably formed as a shallow, subtidal and open marine carbonate platform deposit during late Holkerian and Asbian times.

Away from the Stainmore Basin, the Potts Beck Limestone thins dramatically and much if not all of the early Asbian sequence appears to be missing from the successions across neighbouring block areas (Turner in Parkinson, 1950a; Ramsbottom, 1973, 1974; Mitchell, 1978; Akhurst *et al.*, 1997). However, the discovery of foraminiferal assemblages in the Lower Urswick Limestone and Sixth Limestone of Cumbria which are broadly comparable to those of the early Asbian Potts Beck Limestone at the present site (Strank, 1981; Athersuch and Strank, 1989) indicate that a major non-sequence between the Holkerian and Asbian stages over the whole of the Lake District Block is unlikely.

Conclusions

Little Asby Scar is the regional stratotype for the Asbian Stage and the standard section for the correlation of Asbian sequences throughout the British Isles. The exposed succession, which includes one of the thickest and most complete sections of the Asbian Stage in the north-west of England and the finest chaetetid biostrome in the Stainmore Basin, was probably deposited in open marine conditions on a gently subsiding carbonate platform. The section presents a varied lithofacies and biofacies mix, making it a prime site for future research, particularly in areas of biostratigraphy, sedimentology and palaeoecology.

JANNY WOOD, CUMBRIA (NY 783 036–NY 783 039)

Introduction

The Janny Wood GCR site is a stream section situated on the banks of the River Eden 5 km south of Kirkby Stephen (Cumbria) (NY 7832 0385–NY 7825 0363). The section offers a particularly fine and near-continuous Yoredale succession that includes the late Asbian (D_1) Knipe Scar Limestone, Robinson Limestone and Birkdale Limestone and the overlying early Brigantian (D_2) Peghorn Limestone and Smiddy Limestone. As the currently accepted regional stratotype for the Brigantian Stage it represents one of the most important Lower Carboniferous stratigraphical sites in Britain. Significant accounts of the site geology include Dakyns *et al.* (1891) who produced the first log of the succession; Burgess and Mitchell (1976) who correlated the section into neighbouring areas and re-defined the position of the D_1–D_2 boundary; and George *et al.* (1976) who established the site as the regional stratotype for the Brigantian Stage and defined its lower boundary at the base of the Peghorn Limestone. However, the most useful account is that by Ramsbottom (1981) who provided a detailed log of the section (Figure 5.14) and details of the distribution of various macrofossil and microfossil elements. The description that follows is based mainly on this work. Further details concerning the distribution of foraminifera in this section are given by Strank (1981) and White (1992).

Description

The sequence dips 30°–40° to the SSE and is approximately 75 m thick. Exposure is generally continuous and accessible (except in times of flood) within the stream bed but particularly obvious in a series of small waterfalls at the northern end of the site.

At the base of the section the Knipe Scar Limestone (*c.* 7 m) is a pale-grey cherty packstone with a late Asbian brachiopod fauna including *Gigantoproductus* cf. *janischewski*, *Latiproductus latissimus* and *Megachonetes papilionaceus*. A small fault separates this unit from the overlying, evenly bedded and darker-coloured packstones of the Robinson Limestone (*c.* 15 m). Burgess and Mitchell (1976) recognized this unit as being a pale bioclastic limestone. The Robinson Limestone is characterized by a rich coral and brachiopod fauna dominated by late Asbian forms (e.g. *G.* sp. *maximus* group) in association with a few taxa (e.g. *G. okensis* and *G.* cf. *gaylensis*) regarded as more typical of the Brigantian Stage (Burgess and Mitchell, 1976; Ramsbottom, 1981). Other taxa of D_2 (Brigantian) aspect reported by Pattison (in Burgess and Mitchell, 1976) from the Robinson Limestone include *Aulophyllum* sp. approaching *A. pachyendothecum*, *Diphyphyllum* aff. *lateseptatum* and *Gigantoproductus* sp. (*giganteus* group). The significance of this transitional fauna in late Asbian strata is discussed below. Above this, a clastic interval (7 m) with dark mudstone at the base and a fine-grained, thinly bedded, ripple cross-laminated sandstone at its top is capped by the Birkdale Limestone (2 m), a unit of similar lithofacies to the Robinson Limestone. A similar but thicker clastic interval (10 m) of hard siliceous sandstone with interbedded micaceous siltstone overlies the Birkdale Limestone. This interval also contains a *Stigmaria* horizon (N. Riley, pers. comm., 2002). The base of the Brigantian Stage was defined by George *et al.* (1976) at the junction between this

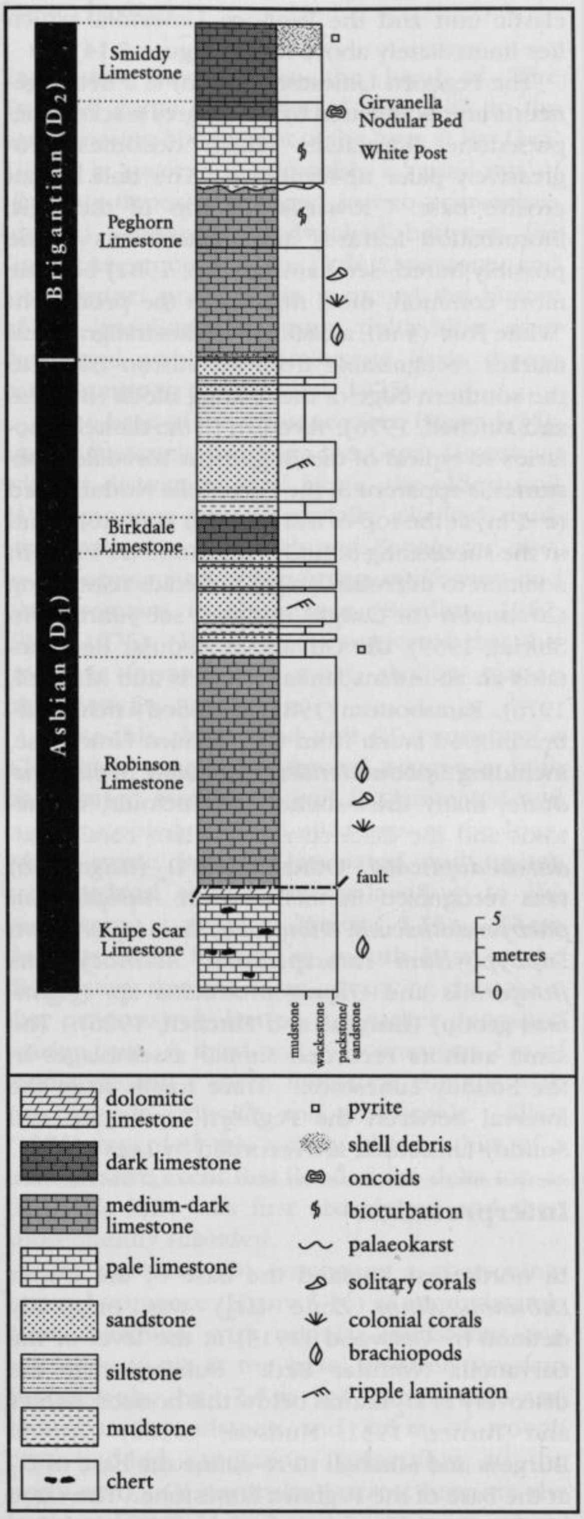


Figure 5.14 Sedimentary log of the Brigantian stratotype section at the Janny Wood GCR site, near Kirkby Stephen. Compilation after information from Ramsbottom, 1981.

clastic unit and the Peghorn Limestone which lies immediately above it (see Figure 5.14).

The Peghorn Limestone (17 m) is a heterogeneous unit dominated by a dark-grey wackestone/packstone lithofacies which becomes progressively paler up-sequence. The unit has an erosive base. Towards the top of the unit, bioturbation features and palaeokarsts (some possibly bored; see Ramsbottom, 1981) become more common, most notably in the prominent 'White Post' (4 m), a distinctive lithostratigraphical marker recognizable from the Alston Block to the southern edge of the Askrigg Block (Burgess and Mitchell, 1976). A return to the darker lithofacies so typical of the Brigantian Yoredale limestones is apparent in the Girvanella Nodular Bed (*c.* 1 m) at the top of the Peghorn Limestone and in the succeeding Smiddy Limestone (*c.* 5 m). In addition to microbial ('algal') oncoids containing *Girvanella* (or *Osagia* nodules; see Johnson in Shirley, 1959), the Girvanella Nodular Bed contains an abundant fauna (Burgess and Mitchell, 1976). Ramsbottom (1981) identified a rich coral–brachiopod fauna from the Peghorn Limestone, including *Siphonodendron junceum*, *S. pauciradiale*, many thick-shelled productoids, chonetoids and the distinctive Brigantian coral *Lonsdaleia duplicata*. Other typical D_2 (Brigantian) taxa recognized in this unit are *Aulophyllum pachyendothecum*, *Dibunophyllum bipartitum*, *Diphyphyllum lateseptatum*, *Actinocyathus floriformis* and *Gigantoproductus* sp. (*giganteus* group) (Burgess and Mitchell, 1976). The same authors recorded similar assemblages in the Smiddy Limestone. Trace fossils from the interval between the Peghorn Limestone and Smiddy Limestone are recorded by Lees (1991).

Interpretation

In north-west England the base of the Upper *Dibunophyllum* Zone (D_2) was originally defined by Garwood (1913) at the level of the Girvanella Nodular Bed. Subsequently the discovery of D_2 faunas below this horizon (Miller and Turner, 1931; Hudson, 1938a) enabled Burgess and Mitchell to re-define the base of D_2 at the base of the Peghorn Limestone. The same level was used by George *et al.* (1976) to define the base of the Brigantian Stage in the Janny Wood section. The Brigantian Stage thus broadly equates to the D_2 Zone of Vaughan (1905) and includes the D6a–D6b mesothems of Ramsbottom (1977a). Significantly, Burgess and Mitchell (1976) recognized that the faunal change at the D_1–D_2 boundary coincided with the upward change from pale to dark limestone and suggested that the faunas might be facies controlled. Noting the occurrence of D_2 Zone macrofossils in transitional faunas of late Asbian age both at this site and in other areas (Burgess and Mitchell, 1976; Pattison in Frost and Holliday, 1980; Somerville and Strank, 1984a; Wilson, 1989), and the absence of a diagnostic basal Brigantian microfauna in the Janny Wood section, Riley (1993) suggested re-locating the Brigantian stratotype to an ammonoid-bearing sequence where the base of the stage could be re-defined at the base of the *Arnsbergites falcatus* (P_{1b}) ammonoid zone. To date, however, no alternative stratotype section has been established. It should also be noted that, at Janny Wood, the base of the Peghorn Limestone is marked by a disconformity, the uppermost Asbian being represented by the lower part of an eroded palaeosol (N. Riley, pers. comm., 2002).

The section forms a small but significant part of a thick late Dinantian succession of cyclothemic 'Yoredale' beds that can be traced across the Stainmore Basin from the Alston Block to the southern margin of the Askrigg Block (Burgess and Mitchell, 1976; Dunham and Wilson, 1985). To the south, the Peghorn Limestone and Smiddy Limestone are recognized together as the Hawes Limestone (part of the Hawes Cyclothem), while the underlying siliciclastic beds above the Robinson Limestone are regarded as the lateral equivalents of the Thorny Force Sandstone (Dunham and Wilson, 1985). Regional variations in sequence thickness enabled Burgess and Mitchell (1976) to demonstrate that the Askrigg Block and Stainmore Basin areas formed part of a structurally continuous 'tilt-block' or 'half-graben' structure (Leeder, 1974b; Miller and Grayson, 1982) that subsided rapidly to produce a thicker Dinantian succession in the Stainmore–Ravenstonedale region than in those areas to the south where the subsidence rate was slower (Figure 5.6).

The late Asbian and early Brigantian limestones at Janny Wood were most probably formed in a shallow, open marine setting on a carbonate platform that was subject to periods of subaerial exposure but was otherwise subsiding continuously. The continuity of limestone deposition was interrupted twice during late Asbian times as a deltaic complex advancing from the north introduced terrigenous sediment into the area; influxes that resulted in the formation of two imperfectly developed coarsening-upward sequences both above and below the Birkdale Limestone. These siliciclastic intervals represent the forerunners of the deltaic Yoredale facies so common in the Brigantian and Pendleian successions of northern England (Hudson, 1924; Moore, 1958; Ramsbottom, 1974; Mitchell, 1978).

Conclusions

Despite reservations concerning its suitability as a stratotype section, Janny Wood continues to be the currently accepted regional stratotype for the Brigantian Stage and the standard section for the correlation of Brigantian successions throughout Britain. The exposed sequence of interbedded marine and deltaic rocks is important for understanding the complex patterns of shoreline advance and retreat and the development of the earliest Yoredale cyclothems in the Stainmore Basin as it subsided during late Dinantian times.

SLEIGHTHOLME BECK, COUNTY DURHAM (NY 956 107–NY 965 115)

Introduction

The Sleightholme Beck GCR site is a stream section (NY 956 107–NY 965 115) lying 4 km south-west of Bowes, between Barnard Castle and Brough-under-Stainmore and towards the southern margin of the Cotherstone Syncline in the Stainmore Basin. The section provides particularly fine sections of deltaic and barrier-island deposits associated with the development of the early Namurian (Pendleian, E_1) Great Limestone Cyclothem. Of critical importance is the varied suite of inorganic and biogenic sedimentary structures that provide spectacular evidence of the passage of storms and organic activity within the barrier-island deposits; arguably the finest Lower Carboniferous example of these deposits in northern England. Although aspects of the site geology are recorded by Reading (1957), Wells (1958), Burgess and Holliday (1979), Dunham and Wilson (1985), Hodge and Dunham (1991) and Fairbairn (2001), the account that is presented here is based mainly on the detailed sedimentological work of Elliot (1975).

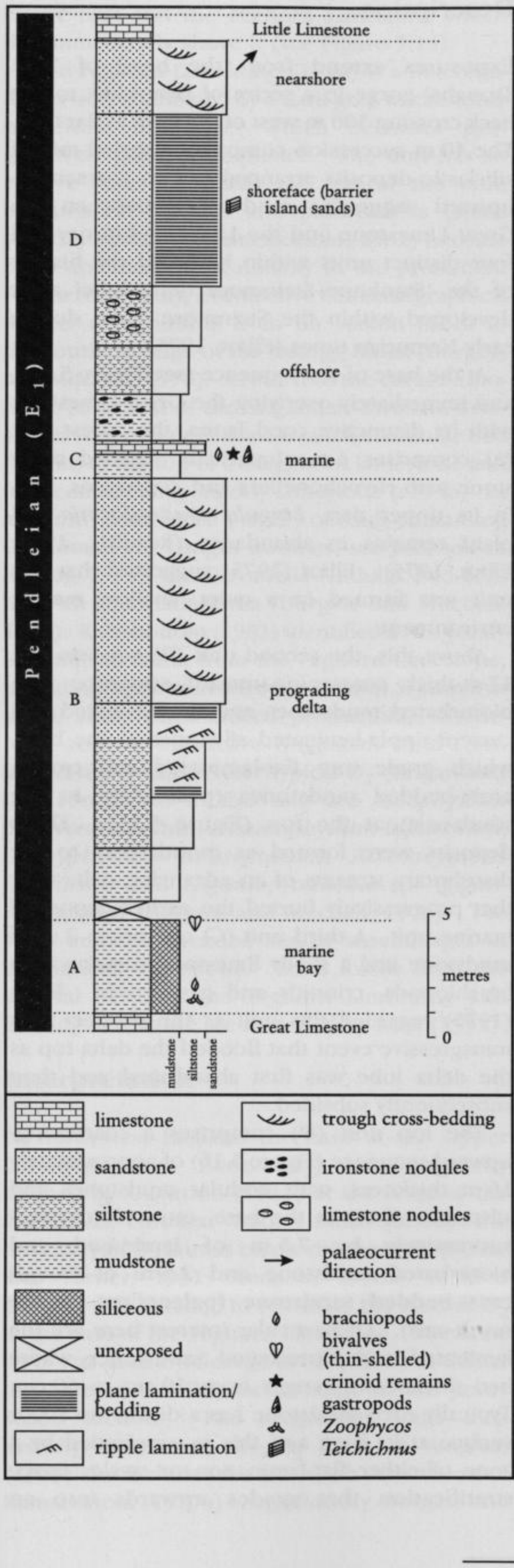
Description

Exposures extend from the head of 'The Troughs' gorge in a series of river cliffs to the beck crossing 300 m west of the farm at Bar Gap. The 40 m succession comprises a varied mix of siliclastic deposits arranged in two coarsening-upward sequences sandwiched between the Great Limestone and the Little Limestone; and four distinct units within it record the history of the 'Stanhope–Stainmore delta lobe' as it developed within the Stainmore Basin during early Namurian times (Elliot, 1975).

At the base of the sequence (see Figure 5.15), and immediately overlying the Great Limestone with its distinctive coral fauna, the oldest unit (A) comprises 4 m of partially silicified mudstone with rhynchonellids and *Zoophycos*, and, in its upper part, *Lingula squamiformis* and plant remains in abundance (Reading, 1957; Elliot, 1975). Elliot (1975) suggested that this unit was formed in a quiet, shallow marine environment.

Above this, the second unit (B) consists of a 17 m-thick coarsening-upward sequence with bioturbated mudstones and flat-laminated and current-ripple-laminated siltstones at the base, which grade into flat-laminated and trough cross-bedded sandstones (palaeoflow to the south-east) at the top (Figure 5.15). These deposits were formed as mouth bars to the distributary streams of an advancing delta lobe that progressively buried the earlier deposited marine unit. A third unit (C) comprises 2 m of mudstone and a shelly limestone coquina with brachiopods, crinoids and gastropods. Elliot (1975) regarded this unit as the product of a transgressive event that flooded the delta top as the delta lobe was first abandoned and then subsequently subsided.

The top unit (D) comprises a coarsening-upward sequence (Figure 5.16) of approximately 16 m thickness, with nodular mudstones and siltstones (6 m) at the base, erosively overlain successively by 7.5 m of laminated and bioturbated sandstone and 2.5 m of trough cross-bedded sandstone (palaeoflow to the north-east). Of particular interest here are the laminated and bioturbated sandstones where bed thicknesses ranges from 10 cm to 60 cm. Typically each sandstone has a distinctive scour surface at its base and this is superseded by a zone of either flat-lamination or swaley cross-stratification that grades upwards into an



◄**Figure 5.15** Sedimentary log through the deltaic and barrier-island deposits of the Great Limestone Cyclothem at Sleightholme Beck. After Elliot (1975). Units A–D represent stages recognized by Elliot in the development of the Stanhope–Stainmore delta lobe. A – coastal plain interval; B – progradation; C – abandonment phase; D – post-abandonment phase.

intensely bioturbated zone dominated by horizontal teichichnid burrows. In comparing this repeated lithofacies association with Recent barrier-island shoreface associations described by Howard (1971), Elliot (1975) suggested that these sandstones were the product of (i) repeated storms that scoured sediment from the seabed and re-deposited it in a series of swales as the storm abated, and (ii) burrowing organisms that re-colonized and reworked the upper layers of the storm deposits in the intervening fair-weather periods. The prominent discontinuity at the base of the sandstone interval is taken to indicate shoreface erosion of the barrier as it migrated towards land in a WNW direction. The transition into trough cross-bedded sandstones at the top of the sequence may reflect a shoreface–nearshore transition as the barrier migrated a short distance to the north-east later in its history (Elliot, 1975).

Interpretation

Elliot (1975) regarded the Sleightholme succession as the product of four separate depositional events or phases. These included a coastal plain phase, in which the now-silicified mudstones (unit A) were originally deposited in a pro-deltaic, and possibly brackish, marine bay close to the shoreline; a progradational phase, in which the lower coarsening-upward sequence (unit B) formed as the Stanhope–Stainmore delta lobe prograded into the pro-delta area; an abandonment phase, in which marine sediments (unit C) were deposited over the delta lobe as it became starved of sediment and then subsided; and a post-abandonment phase, in which the upper coarsening-upward sequence (unit D) was deposited – a product of offshore, shoreface and nearshore sedimentation on the flanks of a barrier island that migrated across the delta top after the delta was abandoned.

Further work by Hodge and Dunham (1991) indicated that the deltaic deposits at this site area may have been supplied by a branch of the

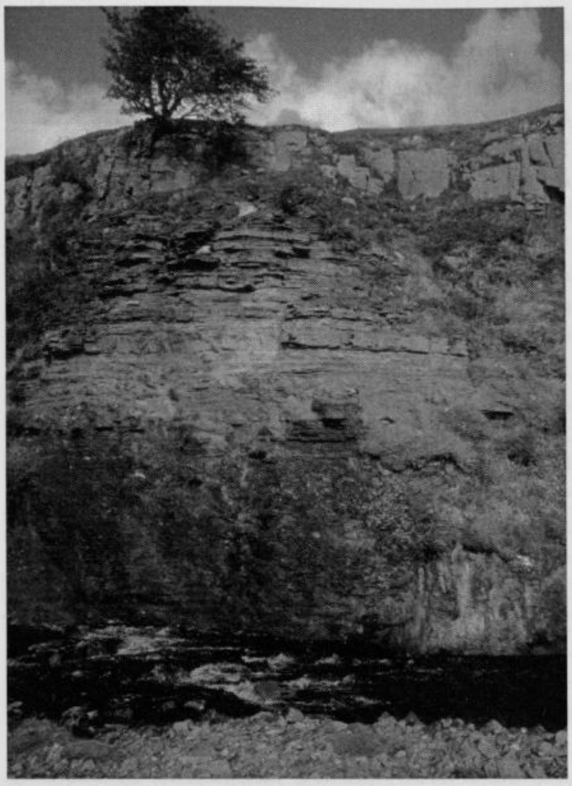


Figure 5.16 Coarsening-upward sequence of barrier-island deposits in the Great Limestone Cyclothem, Sleightholme Beck (unit D of Figure 5.15; see text for further details). Elliot (1975) interpreted the abrupt change from offshore mudstones and siltstones at the base of the sequence to the shoreface sands exposed higher in the sequence as marking the passage of a landward-migrating barrier-island complex. (Photo: P.J. Cossey.)

'Allercleugh Channel' (the main feeder to the Stanhope–Stainmore delta lobe) which extended southwards from Langdon Beck on the Alston Block towards Bowes, and that the post-abandonment (barrier-island) facies might represent an extension of the 'Skears Sandbar' seen to the north between Wolsingham and Middleton-in-Teesdale (see Figure 4.18 and **Rogerley Quarry** GCR site report, Chapter 4).

Stratigraphically, the sequence forms an integral part of the lowest Yoredale cyclothem within the Stainmore Group and is of basal Namurian (early Pendleian, E_1) age (Burgess and Holliday, 1979; Dunham and Wilson, 1985). In addition, and despite considerable lateral facies changes, lithostratigraphical correlations of the sequence into neighbouring areas are generally well established. Dunham and Wilson (1985) equate the two prominent sandstone bodies (units B and D) with the High Coal Sill and the White Hazle horizons of the Alston Block, and Reading (1957) and Wells (1958) equate the siliceous mudstones (unit A) with the Main Chert of North Yorkshire. The suggestion that the Langdon to Bowes branch channel may have been the 'large river' that sourced the silica in these deposits (as originally envisaged by Wells, 1955) cannot, however, be proven as the contemporaneity of channel development and silica precipitation have not been established (Hodge and Dunham, 1991).

Conclusions

This site provides an outstanding section through the Great Limestone Cyclothem and a detailed record of the history of the Stanhope–Stainmore delta lobe at its distal margin. In contrast to the section at **Rogerley Quarry** (see GCR site report, Chapter 4) where the same delta lobe can be seen in a more proximal setting, the section at Sleightholme Beck shows spectacular evidence of barrier-island sedimentation, including storm deposits formed during the delta's post-abandonment phase of development. Considered together, the Rogerley Quarry and Sleightholme Beck sites provide some of the clearest evidence of the processes operating within the delta systems of northern England during early Namurian times.

HOW GILL, COUNTY DURHAM (NY 955 205)

Introduction

The How Gill GCR site is situated 11 km WSW of Barnard Castle on the northern limb of the Cotherstone Syncline, and 20 km south of the Closehouse–Lunedale Fault. This site (NY 955 205) provides a critical 45 m section of the cyclothemic Stainmore Group that includes, at its top, one of the most important exposures of the Botany Limestone in the Stainmore Basin, noted here for its rich and distinctive Arnsbergian (E_{2b}) fauna. The Botany Limestone forms a prominent marker horizon that facilitates the correlation of lower Namurian successions throughout the Stainmore Basin and onto the adjacent Askrigg and Alston blocks.

The locality (formerly known as the 'Botany Hill' GCR site) includes a stream section (How Gill) and the remains of a small disused quarry (How Gill Quarry). Details of the site geology are recorded by Carruthers (1938), Reading (1957), Burgess and Holliday (1979) and Johnson *et al.* (1980b).

Description

The sequence begins in How Gill immediately above the marine 'Fossil Sandstone' of the Fossil Sandstone Cyclothem (Reading, 1957; Brenner and Martinsen, 1990), and within it three distinctive units can be recognized. These comprise a lower coarsening-upward clastic unit (29 m) topped by the Botany Grit, a middle shale unit (9 m) and an upper limestone–shale unit, the Botany Limestone (6–8 m). Moving upstream, progressively younger parts of the succession are encountered.

At the base of the lower unit are 20 m of silty mudstones and dark shales with thin, sharp-based sandstones. Mica and sporadic plant fragments characterize this part of the succession and scattered ironstone nodules occur towards the base. Up sequence the section gets progressively more sandy as the lower mud-dominated interval is overlain by 9 m of flaggy, micaceous, trough cross-bedded sandstones, which are capped by a quartzose feldspathic sandstone, the Botany Grit (0.6 m). The base of the Botany Grit is conglomeratic and an erosion surface separates it from the underlying sandstones. Palaeocurrent data from this grit indicate a flow direction from the north (Reading, 1957). A thin seatearth–coal couplet with rootlets and plant fragments above the grit marks the base of the succeeding shale unit, which is otherwise devoid of plant remains. A few thin siltstones in this middle unit show evidence of bioturbation.

Above this, the Botany Limestone is a highly fossiliferous but heterogeneous mix of nodular and thinly bedded limestones with intercalated shales of variable thickness (Figure 5.17). A thin but distinctive brachiopod-rich limestone (0.35 m) lies close to the base of the unit (also the base of the Botany Limestone Cyclothem)

Figure 5.17 The highly fossiliferous nodular bioclastic limestones and shales of the basal Arnsbergian (E_{2b}) Botany Limestone at How Gill. (Photo: P.J. Cossey.)

and is overlain by a metre of shale containing a rich marine fauna. Above this, nodular bioclastic limestones and thin shales give way progressively to better bedded and more fossiliferous limestones at the top of the unit. Limestone composition is highly variable, with individual beds containing variable quantities of lime, silica, sand and mud.

Garwood (1913), Reading (1957), Burgess and Holliday (1979) and Johnson *et al.* (1980b) recorded an exceptionally rich fauna from the Botany Limestone, including sponges, corals, annelids, bryozoans, brachiopods, bivalves, gastropods, nautiloids, goniatites, echinoids, crinoids and fish remains. Taxa from this horizon include *Hyalostelia paralella*, *Dibunophyllum bipartitum*, *Diphyphyllum*, *Fenestella*, *Penniretepora*, *Polypora*, *Thamniscus*?, *Brachythyris*, *Buxtonia*, *Chonetipustula*, *'Dielasma'*, *Echinoconchus punctatus*, *Eomarginifera*, *Leptagonia*, *Orbiculoidea*, *Pliochonetes buchianus*, *Productus carbonarius*, *Quasiavonia aculeata*, *Sinuatella sinuata*, *Straparollus* (*Euomphalus*), *Aviculopecten interstitialis*, *Limipecten dissimilis*, *Pernopecten sowerbii*, *Streblochondria*, *Cravenoceratoides*, *Epidomatoceras*, trilobite fragments and fish debris. Other significant records from the Botany Limestone include *Tylonautilus nodiferus*, *Dictyoclostus* and a variety of rugose corals, namely *Aulina rotiformis*, *Siphonodendron pauciradiale*, *Michelinia tenuisepta* (Burgess and Holliday, 1979), *Aulina botanica* (Nudds, 1977) and *Lithostrotion decipiens* (J. Nudds, pers. comm., 2000).

Interpretation

Early stratigraphical work focused attention on the age of the Botany Limestone and its rich macrofauna. Garwood (1913) suggested a Viséan age for the 'Botany Beds', while later detailed lithostratigraphical work (Carruthers, 1938; Reading, 1957) and biostratigraphical studies (Hill, 1938–1941; Smith and Yu, 1943; Nudds, 1977), which considered especially the distribution of coral taxa (e.g. *Aulina*), indicated that they were of Namurian (Arnsbergian, E_2) age. Smith (1917) and Carruthers (1938) equated the Botany Limestone with the Fell Top Limestone but Reading (1957) placed it higher in the sequence as the lateral equivalent of the Shunner Fell Limestone of the Askrigg Block, a unit generally considered to be of high E_2 age (King, 1914; Hudson, 1939; Rayner, 1953). Its position at the base of the middle Arnsbergian succession (E_{2b}) and its correlation with the Grindstone Limestone of the Alston Block, the Shunner Fell Limestone of the Askrigg Block (Figure 5.4), the High Wood Marine Beds of the Stainmore Outlier and both the Newton Limestone and Styford Limestone of the Northumberland Basin, is now generally well accepted (Ramsbottom, 1977a; Ramsbottom *et al.*, 1978). The occurrence of the goniatite *Cravenoceratoides* in the Botany Limestone and the common E_{2b} nautiloid *Tylonautilus nodiferus* in the Botany Limestone, Grindstone Limestone, Newton Limestone and Styford Limestone (Burgess and Holliday, 1979; Holliday and Pattison, 1990) supports this view. Beds of the 'Fossil Sandstone Cyclothem' beneath the Botany Limestone are therefore assumed to be of early Arnsbergian (E_{2a}) age.

Apart from the work of Elliot (1974a, 1975) and Brenner and Martinsen (1990), little has been published on the sedimentology of lower Namurian cyclothems in the Stainmore Basin. Despite this, the How Gill succession shows clear and unequivocal evidence of the interaction between the deltaic and marine sedimentary processes that were so influential in the development of Yoredale cyclothems throughout northern England in early Namurian times. The development of the lower coarsening-upward clastic unit and its seatearth–coal cap reflects deposition from a prograding delta lobe advancing from the north and the gradual establishment of delta-top conditions. This was followed by a period of marine flooding in which the Botany Limestone was deposited.

Conclusions

How Gill provides one of the finest and most complete (i.e. unfaulted) sections of the Botany Limestone Cyclothem in the Stainmore Basin and was formed by deltaic and marine processes during middle Arnsbergian (E_{2b}) times. The site is the type locality of the highly fossiliferous Botany Limestone, a distinctive lithostratigraphical unit widely used in the correlation of lower Namurian cyclothemic successions across northern England. In addition, the section remains a promising prospect for future micropalaeontological and sedimentological research.

MALHAM, NORTH YORKSHIRE (SD 884 654–SD 927 654–SD 904 628)

Introduction

The Malham GCR site (formerly referred to as the 'Malham, Gordale and Cawden Wedber Burns' GCR site) covers several square kilometres to the north of Malham village (SD 902 630). This site is one of the classic British Dinantian localities, with superb exposures of limestone cliffs and pavements. The site embraces a significant part of the Middle Craven Fault, and is bordered on its northern side by the North Craven Fault (Figure 5.18). It includes the gorge at Gordale Scar, a spectacular glacial meltwater feature that is terminated by the fault-scarp of the Middle Craven Fault. Numerous NW–SE-trending faults also cross the area (Figure 5.18a). The site lies in the transition zone between the shallow-water shelf area of the Askrigg Block to the north and the deeper-water area of the Craven Basin to the south. Strata range from Holkerian to Brigantian age and include the massive cyclic shelf limestones of the block as well as the reef complex of the transition zone. The area along the Craven Faults, including the Malham area, was first described in detail by Garwood and Goodyear (1924). More recently, the stratigraphy has been revised and the successions described in detail by British Geological Survey geologists working on the 1:50 000 map and memoir for the Settle district (Arthurton *et al.*, 1988; British Geological Survey, 1989).

Description

Most of the exposures within this site are of the Malham Formation (Figure 5.3; and Figure 5.21, see **Settle** GCR site report) and the type sections of its two members, the Cove Limestone Member and the Gordale Limestone Member, are within its boundaries. The type section of the Cove Limestone Member is at Malham Cove (SD 898 641) (Figure 5.19) where it is 72 m thick (Arthurton *et al.*, 1988). Its base is taken at the bottom of the cliff face, with crags of the underlying and darker-coloured Kilnsey Limestone Member cropping out in the narrow valley immediately south of the cove. The Cove Limestone Member is a massive, rather homogeneous pale-grey limestone, lacking obvious macrofossil remains apart from crinoids through much of its thickness. Petrographically, it consists of peloidal and bioclastic packstones, the bioclasts comprising foraminifera, *Koninckopora*, palaeoberesellids and brachiopod fragments, in addition to crinoids (Arthurton *et al.*, 1988). The Cove Limestone Member can also be seen in Gordale (SD 914 640) where the macrofossils *Axophyllum vaughani*, *Lithostrotion sociale*, *Linoprotonia* and *Megachonetes* and the foraminifera *Archaediscus* and *Koskinotextularia cribriformis* have been recorded (Arthurton *et al.*, 1988).

The Gordale Limestone Member is the major scar-forming limestone in the Settle area and is typically between 70 m and 75 m thick. In its type section at Gordale Scar (SD 913 640), however, it is 94 m thick (Arthurton *et al.*, 1988). The contact with the Cove Limestone Member was defined at the conspicuous bedding plane at the top of the lowest scar (Arthurton *et al.*, 1988). The Gordale Limestone Member is more variable than the Cove Limestone Member below. It is thickly bedded, pale- to medium-grey in colour, and weathers to form a series of scars that are well seen on the valley sides in the northern part of the site. In the area between the Craven Faults, it is the occurrence of muddier limestone lithologies (e.g. wackestones) that appears to be controlling the stepped topography, rather than the occurrence of shales as it is elsewhere in the Pennines (Arthurton *et al.*, 1988). Typical features of the Gordale Limestone Member are burrow-mottled beds and pseudobreccias, palaeokarstic surfaces and local cross-stratified grainstones. Macrofossils are concentrated in bands and include *Davidsonina septosa*, *Gigantoproductus maximus*, *Dibunophyllum bourtonense* and *Siphonodendron martini* (Arthurton *et al.*, 1988).

Arthurton *et al.* (1988) note that the Gordale Limestone Member consists of bioclastic wackestones, packstones and grainstones in which the dominant bioclasts are foraminifera, calcispheres, palaeoberesellids, crinoid fragments and ostracodes. One feature of the Gordale Limestone Member in the transition zone is the presence of coarse lithoclastic grainstone units. For example, a conglomerate a few metres above the base of the member is seen near Strideout Edge (SD 906 637) and contains lithoclasts up to 10 cm across (Arthurton *et al.*, 1988).

Much of the northern part of this site consists of Gordale Limestone Member, which forms the

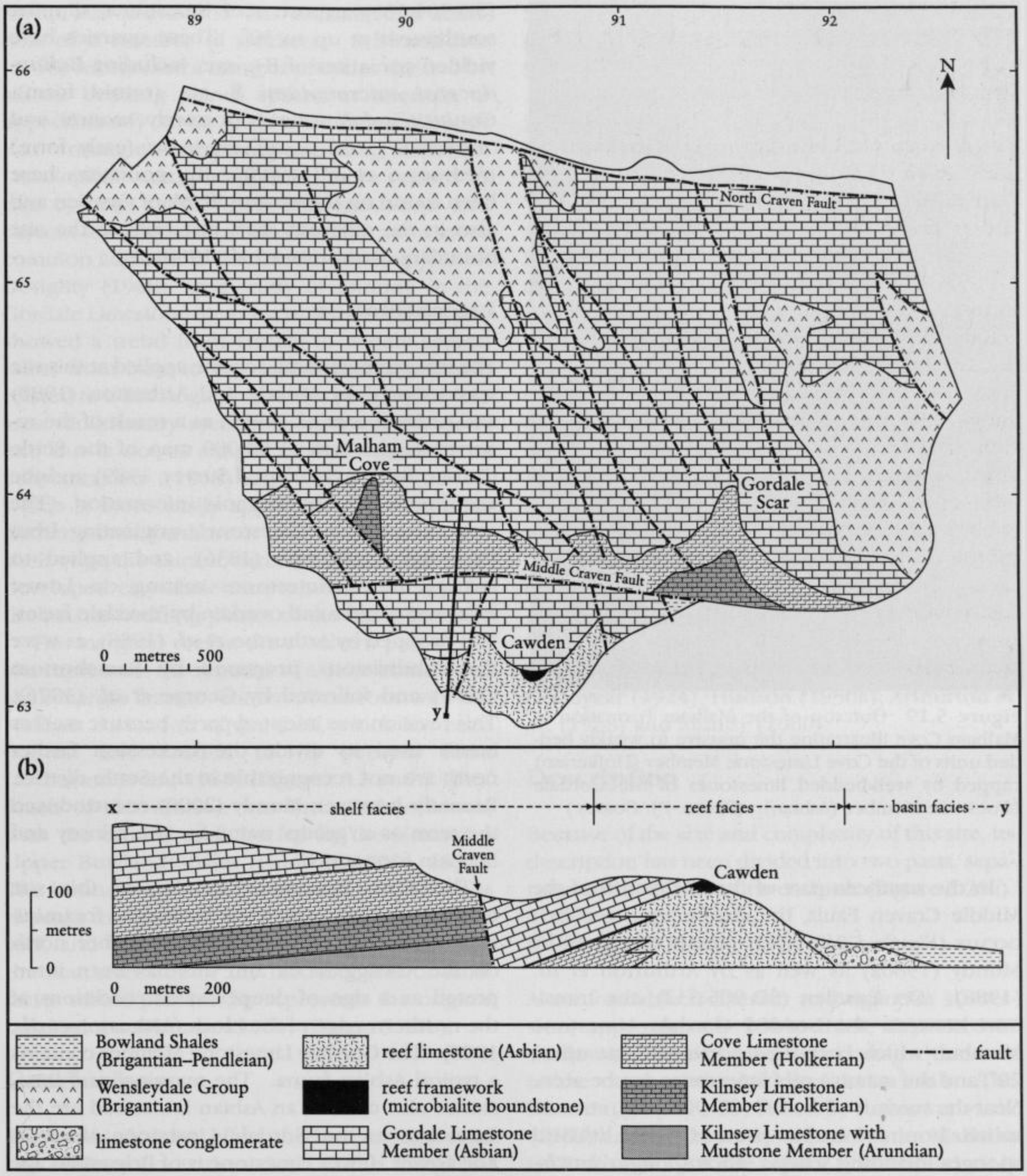


Figure 5.18 (a) Geological map of the GCR site at Malham with details north of the North Craven Fault omitted. After British Geological Survey (1989). Points x and y mark the approximate line of the section illustrated in (b). (b) Section across the Middle Craven Fault showing the relationship between shelf and basin-margin facies. Based on Mundy (1980b) and Mundy and Arthurton (1980).

classic limestone pavements of the hill tops and the scars of the valley sides. However, locally, the overlying Wensleydale Group is exposed, although only the Lower Hawes Limestone at the base of the group occurs in this area. It consists of bioclastic packstones darker in colour than the Gordale Limestone Member and contains thin oncoid-bearing horizons (Arthurton *et al.*, 1988). It can be seen in a small quarry next to the road at SD 907 649.

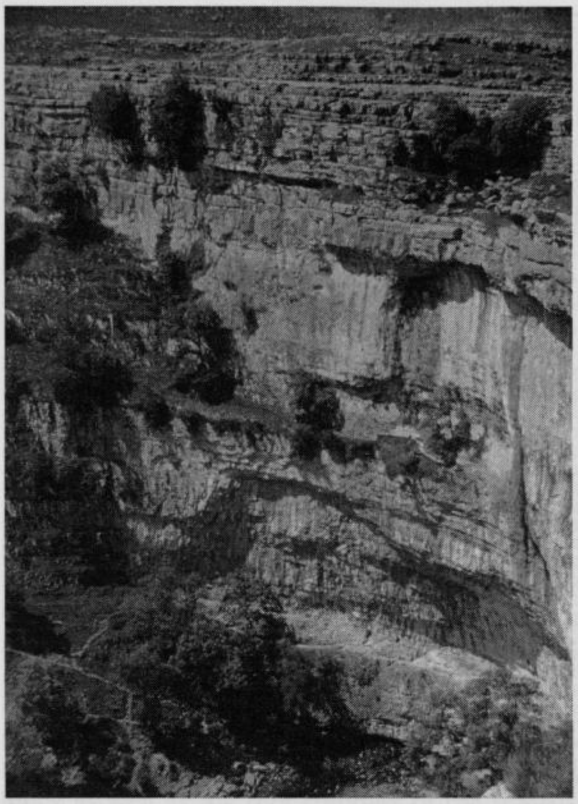


Figure 5.19 Outcrop of the Malham Formation at Malham Cove illustrating the massive to weakly bedded units of the Cove Limestone Member (Holkerian) capped by well-bedded limestones of the Gordale Limestone Member (Asbian). (Photo: P.J. Cossey.)

In the southern part of the site, south of the Middle Craven Fault, the shelf-margin reef-belt occurs (Figure 5.18). This area is described by Mundy (1980a) as well as by Arthurton *et al.* (1988). On Cawden (SD 905 632), the transition between the bedded Gordale Limestone Member, which here dips northwards at up to 20°, and the massive reef limestones can be seen. Near the summit of the hill (SD 905 631), stromatolitic boundstone is present with lithistid sponges including *Scheiia 'Microspongia' castletonense* (Rigby and Mundy, 2000), bryozoans (*Tabulipora* and fenestrates) plus a 'reef' brachiopod fauna that includes *Proboscidella proboscidea*, *Rugicostella nystiana*, *Stipulina deshayesiana*, *Streptorhynchus anomalus*, *Undaria erminea* (Arthurton *et al.*, 1988), and *Parmephrix eileenarum* and *Limbifera griffithiana* (D. Mundy, pers. comm., 2000). This is a particularly interesting fauna with many specialized taxa (Mundy, 1980b). Quarries at the foot of the hill on the south side of Cawden (SD 904 630) expose reef limestones dipping southwards at up to 30°. These quarries have yielded goniatites of B_{2b} age, including *Bollandoceras micronotum*, *B.* sp. (tumid form), *Goniatites globostriatus* (formerly '*moorei*' and '*maximus*') and *G. aff. crenistra* (early form) (Arthurton *et al.*, 1988). B_{2a} goniatites have been found on the western flank of Cawden and also in the adjacent reefs just outside the site boundary (Arthurton *et al.*, 1988).

Interpretation

The lithostratigraphical scheme applied at this site was adopted by Mundy and Arthurton (1980) and Arthurton *et al.* (1988) as a result of the resurvey of the area (1:50 000 map of the Settle district, British Geological Survey, 1989) and the acquisition of new borehole information. The term 'Great Scar Limestone', originating from the work of Phillips (1836), and applied to Askrigg Block limestones resting on Lower Palaeozoic rocks and overlain by Yoredale facies, was dropped by Arthurton *et al.* (1988), as were the subdivisions proposed by Ramsbottom (1974) and followed by George *et al.* (1976). This revision was adopted partly because marker bands used to divide the succession farther north are not recognizable in the Settle district. Recently, however, Mundy (2000) re-introduced the term as a 'group' name for the Kilnsey and Malham formations.

The Cove Limestone Member at this site contains a more restricted Holkerian foraminiferal assemblage than that found farther north on the Askrigg Block and this has been interpreted as a sign of deeper-water conditions at the northern edge of the block (Arthurton *et al.*, 1988). The Gordale Limestone Member contains a typical Asbian fauna. The marginal reef limestones also contain an Asbian fauna and are the same age as the Gordale Limestone Member. The Lower Hawes Limestone is of Brigantian age in the Settle area (Arthurton *et al.*, 1988).

The exposed shelf limestone succession at the Malham site records deposition more-or-less continuously from late Holkerian to early Brigantian times. The succession is thicker than that in the immediate area to the north, away from the block margin, and palaeokarstic surfaces are less well developed (Arthurton *et al.*, 1988), suggesting that subsidence rates were more rapid to the north where periods of emergence were less significant. Cyclicity in the

'Great Scar Limestone' has attracted the attention of a number of workers. Schwarzacher (1958) recognized a number of cycles divided by master bedding planes spaced at intervals of approximately 10 m, each cycle being a major scar-forming unit traceable over long distances. Lithological variation appeared to be related to this cyclicity, with fossil concentrations and current features such as cross-stratification more common adjacent to the master bedding planes. Doughty (1968), in a study of jointing in the Gordale Limestone Member, noted that each cycle showed a trend from closely to widely spaced joints from base to top, and that this was also related to a lithological variation. In the Gordale area sedimentary cyclicity is undoubtedly present, but is not as simple as that suggested by Schwarzacher (1958) and Doughty (1968), which is more easily applicable to successions farther north (Arthurton *et al.*, 1988). At the shelf edge the thicker succession lacks the well-developed clay–shale intervals that characterize the master bedding planes of the block interior.

The marginal reef in the southern part of the site represents the remains of a once-continuous shelf-margin feature, contemporaneous with the Malham Formation of the shelf, which has been faulted and eroded to its present form (Arthurton *et al.*, 1988) (Figures 5.2 and 5.18b). Much of this erosion was intra-Carboniferous, with the eroded reefs buried by the Namurian Upper Bowland Shales (Hudson, 1930a, 1932). The boundstone near the summit of Cawden is thought to represent the framework facies of the reef, and the southerly dipping limestones on the southern side of the hill, fore-reef or flank facies whose present dip represents the original palaeoslope (Mundy, 1980b) (Figure 5.18b).

Conclusions

This classic locality offers the best exposures of the Malham Formation close to the margin of the Askrigg Block. The type sections for both members of the formation, the Cove Limestone Member and the Gordale Limestone Member, are within the site. The cyclicity of the limestones is of great interest here and requires further work to understand its relationship to the simple cyclicity described from the interior of the block. The site also contains excellent exposures of part of the marginal reef complex, including an exposure of the buildup framework from which many rare fossils have been recovered.

SETTLE, NORTH YORKSHIRE (SD 845 624–SD 870 639–SD 844 644–SD 827 638)

Introduction

The Settle GCR site (formerly referred to as the 'Langcliffe–Attermire' GCR site) stretches across several square kilometres to the east of Settle, from High Hill in the west to Great Scar in the east, and from Langcliffe Scar in the north to Scaleber in the south (Figure 5.20). It is an area of complex geology between the North and South Craven faults in which various formations of Arundian to Pendleian age are magnificently displayed. The site lies in the transition zone between the Askrigg Block and the Craven Basin. In the north, shelf limestones are seen, but south of the Middle Craven Fault the shelf-marginal reef complex is crossed and strata take on a more basinal aspect. The area has aroused considerable geological interest since the classic description of the geology of Yorkshire by Phillips (1836). The most comprehensive accounts of the site geology are by Garwood and Goodyear (1924), Hudson (1930a), Arthurton *et al.* (1988) and Mundy (2000).

Description

Because of the size and complexity of this site, its description has been divided into two parts, separated by the Middle Craven Fault (Figure 5.20a).

North of the Middle Craven Fault

A conformable Holkerian to Brigantian succession, approximately 200 m thick, deposited in shallow-shelf environments, occurs in the area to the north of the Middle Craven Fault. The lithostratigraphy was revised by Arthurton *et al.* (1988) and has been described for the **Malham** GCR site (see GCR site report, this chapter). It is summarized in Figure 5.21.

Only the upper part of the Kilnsey Limestone Member is seen within the site, although it shows its thickest known development in the Stockdale Farm Borehole, which was drilled just outside the site boundary (SD 854 638) (Arthurton *et al.*, 1988). Where exposed, for example at the base of Little Banks (SD 847 639), the Kilnsey Limestone Member consists of bedded, medium-grey bioclastic packstones and grainstones. The Cove Limestone Member crops

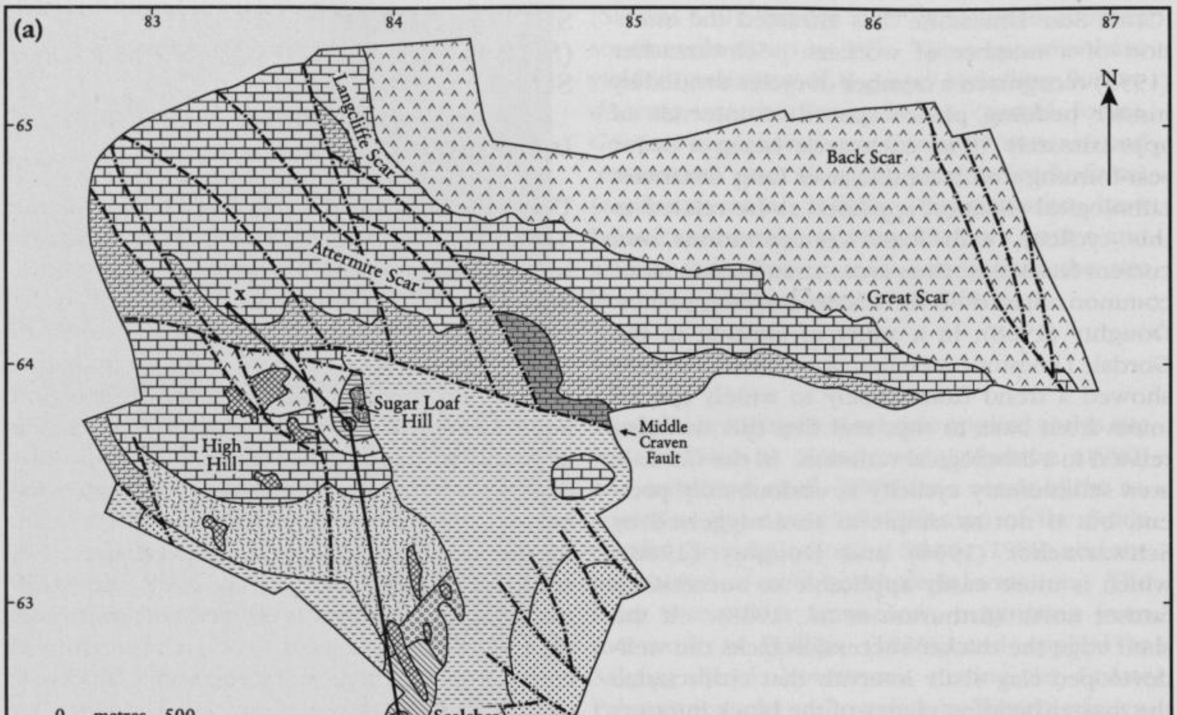


Figure 5.20 (a) Geological map of the Settle GCR site east of Settle. After British Geological Survey (1989). Points x and y mark the approximate line of the section illustrated in (b). (b) Cross-section showing relationships between the shelf, shelf-margin and basin between Warrendale Knotts and the South Craven Fault. Based on Mundy (1980b, 2000) and Mundy and Lord (1982), and including information from British Geological Survey (1989).

out in the ground immediately north of the Middle Craven Fault (Figure 5.20a) where it tends to form the steep grassy slopes at the bases of the scars developed in the overlying Gordale Limestone Member (e.g. at the base of Attermire Scar – SD 842 641). It occurs similarly at the

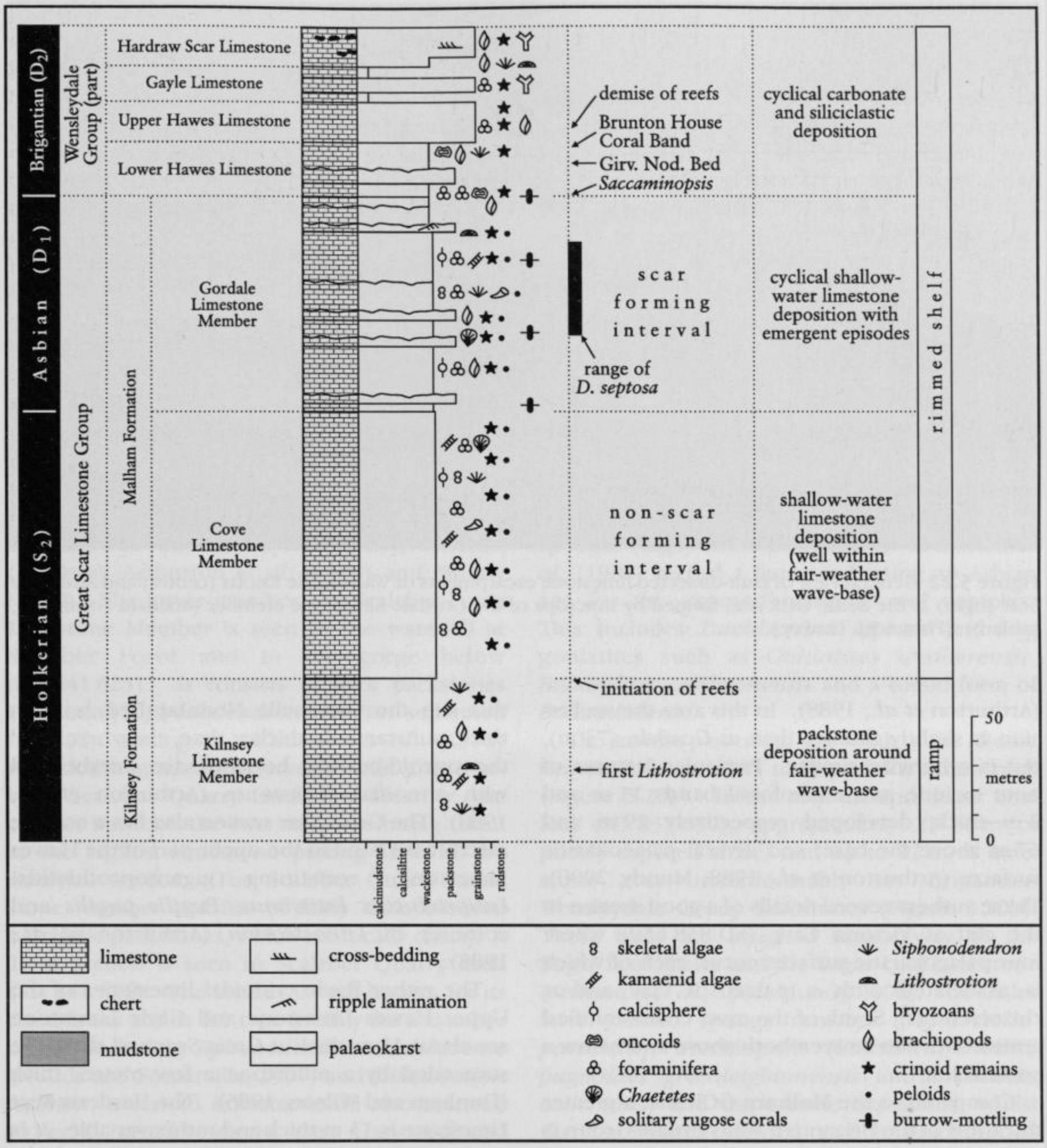


Figure 5.21 Composite log of the Lower Carboniferous succession between the North and Middle Craven faults at the southern end of the Askrigg Block close to Settle. After Mundy (2000), and including information from Arthurton *et al.* (1982, 1988). (Girv. Nod. Bed – Girvanella Nodular Bed.)

base of Langcliffe Scar in the northern part of the site (SD 838 650). The Cove Limestone Member has similar characteristics to that of the type section at **Malham** (see GCR site report, this chapter). Minor cyclicity in the Holkerian limestones north of Settle was described by Jefferson (1980) who recognized 'cycles' by the quantitative analysis of grain types seen in thin-section. Five minor cycles were recognized in the 55 m of exposed strata.

The Gordale Limestone Member forms the main cliffs of Attermire and Langcliffe scars (Figure 5.22). Its contact with the underlying Cove Limestone Member is defined in the type section at Gordale Scar (see **Malham** GCR site report, this chapter) at the top of the lowest scar

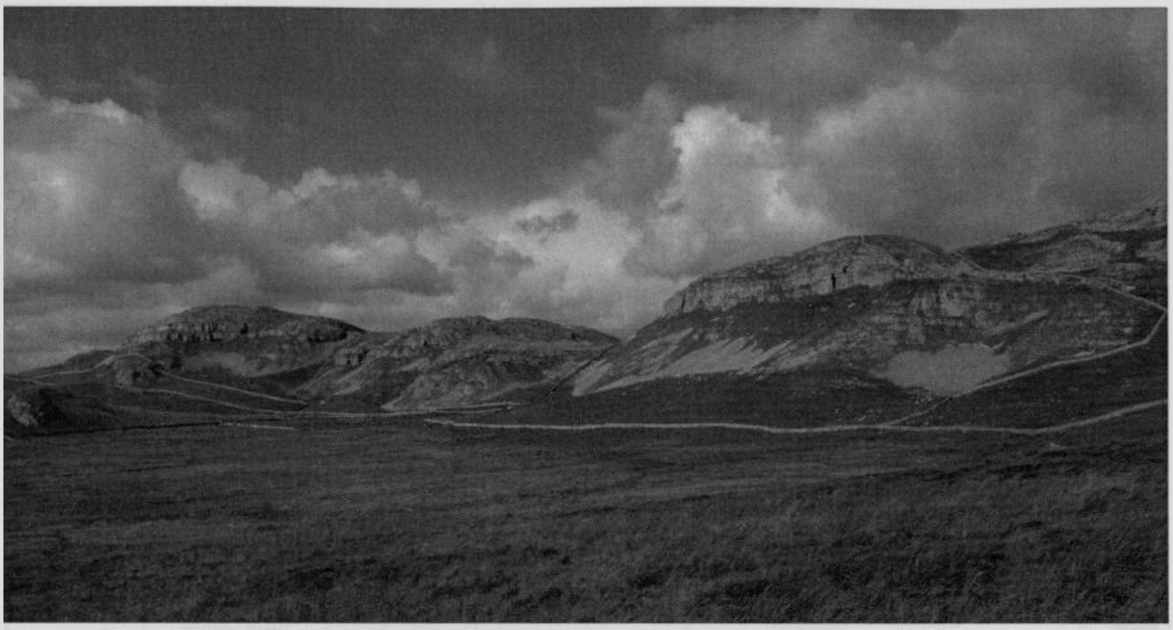


Figure 5.22 General view of fault-dissected limestone escarpments of Warrendale Knotts (centre) and Attermire Scar (right) at the Settle GCR site, formed by outcrops of the Gordale Limestone Member (Malham Formation, Asbian). (Photo: P.J. Cossey.)

(Arthurton *et al.*, 1988). In this area the succession is slightly thinner than at Gordale (73 m), but is otherwise similar. Particular features of note include two macrofossil bands 11 m and 2 m thick, developed respectively 29 m and 67 m above the base, and several palaeokarstic surfaces (Arthurton *et al.*, 1988; Mundy, 2000). These authors record details of a good section in the cliff at Victoria Cave (SD 838 650) where four palaeokarstic surfaces occur, each of which is associated with a palaeosol clay and/or rhizocretions. South of the cave, cross-stratified grainstones can be seen both above and below a palaeokarst.

Compared to the **Malham** GCR site, a greater thickness of the Brigantian Wensleydale Group is exposed here and the broad characteristics of the limestones within this unit are shown in Figure 5.21. The Lower Hawes Limestone is exposed at Great Scar (SD 858 643), where it is 21 m thick. A foraminiferal fauna including stellate archaediscids and *Climacammina* has been recovered from the lower part of the limestone. Oncoids are prominent in the upper part of the unit. These oncoids contain *Girvanella* filaments and *Aphralysia*. Together they form the Girvanella Nodular Bed that Garwood and Goodyear (1924) used for correlation throughout northern England. In this site the Girvanella Nodular Bed is 10 m thick, substantially thicker than elsewhere, and the oncoid-bearing horizons are interbedded with crinoidal packstones (Arthurton *et al.*, 1988). The Great Scar section also has a notable macrofossil band in the upper part of the Hawes Limestone, containing gigantoproductids, *Latiproductus latissimus*, *Pugilis pugilis* and colonies of *Lithostrotion* (Arthurton *et al.*, 1988).

The rather fissile crinoidal limestones of the Upper Hawes Limestone and Gayle Limestone are about 18 m thick at Great Scar and these are succeeded by a mudstone a few metres thick (Dunham and Wilson, 1985). The Hardraw Scar Limestone is 13 m thick and rather variable. It is mostly a fairly dark-coloured wackestone and packstone, but there is a paler, grainier unit in the middle (Arthurton *et al.*, 1988). Chert nodules and silicified fossils are also common. Arthurton *et al.* (1988) recorded a rich fauna from the Hardraw Scar Limestone at Great Scar, including *Diphyphyllum lateseptatum*, *Siphonodendron junceum*, *S. pauciradiale*, *Actinocyathus floriformis*, *Palaeosmilia murchisoni*, *Antiquatonia sulcata* and *Pugilis pugilis*. A band rich in trepostome bryozoans exposed in an old quarry (SD 863 644) also contains prominent silicified *Actinoconchus lamellosus*.

South of the Middle Craven Fault

Although shelf limestones do occur south of the Middle Craven Fault, the principal geological features of interest are the marginal reef complex, the Scaleber complex, the Namurian succession and localized areas of dolomitization and silicification.

The Scaleber complex includes exposures in and around Scaleber Beck at the southern end of the site (Figure 5.20a), close to the South Craven Fault. Exposures are referred to two locally developed members of the Kilnsey Formation, the Scaleber Force Limestone Member and the Scaleber Quarry Limestone Member (Mundy and Arthurton, 1980; Arthurton *et al.*, 1988), and to the Pendleside Limestone Formation, a formation better known from the Craven Basin (see Chapter 6). The succession has been described by Garwood and Goodyear (1924), Hudson (1930a,b), Arthurton *et al.* (1988) and Mundy (2000). The lower member, the Scaleber Force Limestone Member is seen in the waterfall at Scaleber Force and in the gorge below (SD 841 625). It consists of dark packstones containing *Siphonodendron martini* separated by shaly partings. Arthurton *et al.* (1988) recorded a gradational contact with the overlying Scaleber Quarry Limestone Member, the contact between the two members being taken at the highest mudstone parting seen in the waterfall section. The Scaleber Quarry Limestone Member consists of fairly dark-coloured bioclastic packstones, which are locally cherty. A 12 m section is seen in Scaleber Quarry itself (SD 841 626). The locality is well known for its coral fauna and is the type locality for a number of taxa including *Siphonodendron scaleberense* (Nudds and Somerville, 1987) and *Lithostrotion ischnon*, a cerioid lithostrotionid also referred to as *L. arachnoideum* (see Garwood and Goodyear, 1924; Hudson, 1930b; Mitchell, 1989; Riley, 1993), a form now considered as the junior synonym of *L. areneum* (Nudds, 1980).

The Scaleber Quarry Limestone Member is unconformably overlain by the Scaleber Conglomerate or Boulder Bed in a streamside exposure at SD 842 627. Elsewhere this conglomerate rests directly on the reef limestone (Arthurton *et al.*, 1988) and has been included as part of the Pendleside Limestone Formation. This conglomerate consists of partly dolomitized boulders of limestone from the marginal reef complex containing *Goniatites globostriatus* and *G. crenistria* of B_{2b} and P_{1a} age respectively, together with blocks containing oncoids and *Saccaminopsis* representing the Lower Hawes Limestone derived from the platform margin (Arthurton *et al.*, 1988; Mundy, 2000). Careful examination of geopetal fabrics in this unit has confirmed the presence of inverted blocks up to 50 m in length (Mundy, 2000).

The marginal reef complex, which Mundy (1994, 2000) refers to as the 'Cracoean' facies, outcrops in a belt from High Hill to Scaleber in the south-western part of the site (Figure 5.20a). The northern part of High Hill comprises northerly dipping beds of the Malham Formation (Gordale Limestone Member) and this passes southwards into and overlaps reef limestones (Figure 5.20b). Reef boundstone facies from High Hill contain stromatolites, bryozoans (Arthurton *et al.*, 1988) and lithistid sponges (Rigby and Mundy, 2000). Arthurton *et al.* (1988) record a fauna indicating an Asbian age for the exposed marginal reef complex. This includes *Davidsonina septosa* and B_{2b} goniatites such as *Goniatites wedberensis*, *Bollandites castletonensis* and a tumid form of *Bollandoceras*.

The eastern part of the site south of the Middle Craven Fault consists mainly of Namurian rock (Figure 5.20a). In the area around Sugar Loaf Hill (SD 837 637), approximately 25–30 m of poorly exposed shales and up to 12 m of limestone rest unconformably on Brigantian Wensleydale Group limestones (Figure 5.20b). These beds are assigned respectively to the Sugar Loaf Shales and the Sugar Loaf Limestone (Arthurton *et al.*, 1988; Mundy, 2000). The shales have yielded sponge remains ('*Hyalostelia*' *parallela*), brachiopods (*Buxtonia*, *Pleuropugnoides greenleightonensis* and *Productus concinnus*) and trepostome bryozoans, whilst the limestones yielded a rich brachiopod–molluscan fauna in which *P. concinnus* is abundant. With the exception of one small exposure of limestone just outside the site, these are the only outcrops of the Sugar Loaf Shales and the Sugar Loaf Limestone known to exist. These two units are the lateral equivalents of the lower part of the Upper Bowland Shales seen locally within the transition zone (see Figures 5.3 and 5.5). The Upper Bowland Shales, which rest conformably on Lower Bowland Shales in the Craven Basin, diachronously overstep older limestones of the reef-belt at this site (see Figures 5.5 and 5.20a) (Arthurton *et al.*, 1988).

The Upper Bowland Shales are exposed in Scaleber Beck and in tributaries just south of the site boundaries. Close to the top of this unit, the Cravenoceras malhamense Marine Band forms a feature along the hillside south of Stockdale Beck (SD 845 631 to SD 848 632). Arthurton *et al.* (1988) recorded *Posidonia corrugata*, *P. membranacea* and *Cravenoceras malhamense* from this locality. Above the Bowland Shales and forming the topographically elevated area in the south-eastern corner of the site (Figure 5.20a) is the poorly exposed and highly faulted ground of the overlying Pendle Grit Formation (British Geological Survey, 1989).

A feature of the Askrigg Block–Craven Basin transition zone is local metasomatic replacement of the limestones by silica and dolomite. At this site there is only slight silicification, for example of the Scaleber Quarry Limestone Member at SD 841 626, but there is major dolomite replacement, particularly in the faulted ground around High Hill, Sugar Loaf Hill and Scaleber Beck (Arthurton *et al.*, 1988; Mundy, 2000; and see Figure 5.20a). These discordant dolomite bodies appear to follow the trend of NW–SE-trending faults (Mundy, 2000) and are thought to be derived from dolomitizing fluids escaping the Bowland Shales during mudrock diagenesis (Gawthorpe, 1987b). The dolomites are coarse-grained, ferroan, and weather to brown, partly de-dolomitized mosaics. Crystals have the curved crystal faces and strongly undulose extinction of 'saddle' or 'baroque' dolomites (Arthurton *et al.*, 1988).

Interpretation

The shelf limestone succession north of the Middle Craven Fault records cyclic shallow marine deposition. In the Holkerian succession, the cyclicity, recognized on the basis of microfacies (Jefferson, 1980), is subtle, reflecting moderate changes in relative sea level. During Asbian times, marine deposition was punctuated by periods of emergence, indicated by the palaeokarstic surfaces present in the Gordale Limestone Member. The significance of the cyclicity in this part of the succession is discussed elsewhere (see **Malham** GCR site report, this chapter). The nomenclature relating to the Wensleydale Group succession follows that for the sections in Wensleydale itself (see Figure 5.4), but at this site the succession is much thinner and the siliciclastic deposits between the named limestones are mostly absent. Clearly the influence of the Yoredale deltas was much reduced at the southern margins of the Askrigg Block and the area was dominated by shallow marine carbonate-producing environments.

Garwood and Goodyear (1924) used the Girvanella Nodular Bed to define the base of the D_2 (Brigantian) in this area. However, farther north in the Brough area, the lithological change to dark-grey limestone, which marks the onset of the Wensleydale Group, occurs a little below the level of the Girvanella Nodular Bed and is accompanied by the appearance of the first Brigantian macrofauna (Burgess and Mitchell, 1976; and see **Janny Wood** GCR site report, this chapter). At this site, however, a Brigantian macrofauna appears with the Girvanella Nodular Bed roughly halfway up the Lower Hawes Limestone, but Brigantian foraminifera have been recorded from the lower part of the section at Great Scar and thus the base of the Brigantian Stage is now taken to coincide with the base of the Wensleydale Group (Arthurton *et al.*, 1988; and see Figures 5.3 and 5.21).

South of the Middle Craven Fault, relationships between the units are more complex (Mundy, 2000). These are illustrated in the cross-section shown in Figure 5.20b. The marginal reef complex is the lateral equivalent of the Malham Formation, but is much eroded such that there is little evidence for the original fore-reef slope (Arthurton *et al.*, 1988). The macrofauna indicates an entirely Asbian age for the remaining exposed part of the reef, but the record of the P_{1a} goniatite *Goniatites crenistria* from a block in the Scaleber Boulder Bed indicates (according to Mundy, 2000) that the reef may have persisted into Brigantian times, although Riley (1993) and the present authors (see Figure 1.4, Chapter 1), take the P_{1a} goniatite zone to mark the top of the Asbian Stage.

Garwood and Goodyear (1924) regarded the Scaleber succession as D_2 (Brigantian). Hudson (1930a,b), however, recognized the presence of S_2 (Holkerian) faunas in the Scaleber Quarry Limestone Member. An Arundian age for the Scaleber Force Limestone Member is suggested by the presence of *Siphonodendron martini* and the absence of cerioid lithostrotionids, and foraminiferal assemblages from an adjacent borehole have confirmed this view (Arthurton *et al.*, 1988). The abundance of cerioid lithostrotionids plus the foraminifera from the adjacent borehole confirm the Scaleber Quarry Limestone Member as Holkerian in age. These two units, which are only known from these exposures and from adjacent boreholes, most probably represent upper-ramp deposits formed at a time when gentle slopes persisted out into the Craven Basin (Gawthorpe, 1986).

By Asbian times a marginal reef complex had been established along a line just south of the Middle Craven Fault, which may have persisted into Brigantian times. In later Brigantian times uplift of the southern margin of the Askrigg Block led to erosion of the reef complex. As water depths increased, the Bowland Shales were deposited, onlapping the eroded surface of the limestone complex (Arthurton *et al.*, 1988).

Faunal evidence equates the Sugar Loaf Shales with beds of E_1 age above the Undersett Limestone farther north, a correlation from which the lateral equivalence of the Sugar Loaf Limestone and the Main Limestone of the northern Pennines can be deduced (Arthurton *et al.*, 1988). A Pendleian age for these units is suggested by Arthurton *et al.* (1988).

The mineralization, including late dolomitization and silicification, was a hydrothermal process. With regard to the areas of dolomite around High Hill and Sugar Loaf Hill, this is confirmed by the presence of 'saddle' or 'baroque' dolomites which form in warm waters (Radke and Mathis, 1980). The age and origin of mineralizing fluids is discussed by Dunham and Wilson (1985).

Conclusions

This locality is one of the most important sites in northern England, with key exposures across the southern margin of the Askrigg Block. Virtually the whole of the exposed Lower Carboniferous succession in the area, from Arundian to early Namurian age, can be examined within the site. In addition to the well-displayed faunas and successions of the Askrigg Block and shelf-margin reef complex, unique features include the Scaleber complex, which properly belongs to the Craven Basin, and the Sugar Loaf Shales and Sugar Loaf Limestone of early Namurian age. The site is particularly important for demonstrating the relationships between shelf, shelf-margin and basinal successions and as such is an extremely valuable locality for both teaching and research.

SCHOOL SHARE, NORTH YORKSHIRE (SD 844 623)

Introduction

The School Share GCR site is a stream section located in the bank of Black Gill Beck (SD 844 623) 2.5 km ESE of Settle. This site offers a unique section of the School Share Boulder Bed close to the base of the Upper Bowland Shales. Also recorded from this site, but regretfully no longer clearly visible, is the non-sequence between the Lower Bowland Shales (Brigantian, P_2) and the Upper Bowland Shales (Pendleian) marking the Dinantian–Namurian boundary. Situated in the transition zone between the Askrigg Block and the Craven Basin just 1.5 km south of the Middle Craven Fault, the existence of these features provides compelling evidence of a contemporaneous (late Brigantian–early Pendleian) phase of earth movements along the line of the Middle Craven Fault. The locality was first mentioned by Marr (1899) but the most detailed accounts of the site geology are by Garwood and Goodyear (1924) and Dixon and Hudson (1931). A more recent account is by Arthurton *et al.* (1988) and it is upon this work that the following account is largely based.

Description

At the base of the section, below the School Share Boulder Bed, Dixon and Hudson (1931) described two shale units separated by a sharp erosive contact (non-sequence) at beck-level. This included a lower unit (Lower Bowland Shales) comprising 2.4 m of dark, closely jointed shales with bullions containing the P_2 (Brigantian) goniatites *Lyrogoniatites* and *Sagittoceras* cf. *meslerianum*; and a higher unit (Upper Bowland Shales) consisting of 5.5 m of dark shales with small limestone clasts and bullions, but seemingly without joints or readily identifiable stratigraphically useful goniatites (Arthurton *et al.*, 1988). Currently the lower part of this succession (including the non-sequence) is obscured by weathered debris from the stream bank (Figure 5.23).

Overlying these units, the School Share Boulder Bed (*c.* 5 m) is a limestone debris bed containing angular blocks of medium- to dark-coloured oncoidal wackestone and crinoidal packstone loosely set in a pyritic mudstone matrix (Figure 5.23). An irregular erosion surface

Figure 5.23 Outcrop of the School Share Boulder Bed (a submarine debris bed) in the Upper Bowland Shale Formation (Pendleian) at the School Share GCR site. (Photo: JNCC.)

separates it from the underlying shales (Arthurton *et al.*, 1988). Garwood and Goodyear (1924) discovered a rich coral–brachiopod fauna in these boulders, including spiriferoids, gigantoproductids, cerioid lithostrotionids and *Orionastraea ensifer* (most probably the *Pleionastraea matura* of Nudds, 1999) and abundant *Girvanella* from some of the more nodular (oncoidal) limestone blocks. Together these features suggest that the blocks were derived from Brigantian (D_2) limestones of Yoredale facies in the Wensleydale Group (Arthurton *et al.*, 1988), which are most typically developed on the Askrigg Block area north of the Middle Craven Fault.

The Upper Bowland Shales above the debris bed comprise a further 5 m of the dark calcareous mudstone containing bullions and a Pendleian (E_{1b}) fauna that includes *Posidonia corrugata* and the diagnostic goniatite *Tumulites pseudobilinguis* (formerly *Eumorphoceras pseudobilingue*; see Arthurton *et al.*, 1988; Brandon *et al.*, 1998). Regrettably, the geometry and lateral continuity of beds recognized at this site cannot be established as parts of the section are badly weathered and disrupted by faulting (Garwood and Goodyear, 1924; British Geological Survey, 1989).

Interpretation

Sedimentological and palaeontological evidence indicates that at this site the Bowland Shales were deposited during late Dinantian and early Namurian times as a deep-water marine facies close to the contemporary southern margin of the Askrigg Block and within the transition zone of the Craven Fault System. However, a significant stratigraphical gap between the Lower Bowland Shales (P_2) at the base of the section and the Upper Bowland Shales (E_{1b}) at the top of the section is indicated by: the erosion surface (non-sequence) recognized by Dixon and Hudson (1931); the development of the School Share Boulder Bed and its associated erosion surface; and the apparent absence of early Pendleian (E_{1a}) strata. Although this stratigraphical gap represents a relatively 'small hiatus' within the School Share succession (Dixon and Hudson, 1931), it is generally regarded as the local equivalent of the more extensive sub-Pendleian and basal Namurian unconformity that is recognized throughout the Craven District at the base of the Upper Bowland Shales (Hudson, 1930a; and see **Settle** GCR site report, this chapter).

The development of this unconformity and of the School Share Boulder Bed has been widely attributed to a period of 'mid-Carboniferous' or late Brigantian–early Pendleian earth movements which, in the Craven District, were centred mainly along the line of the Middle Craven Fault. This fault, arguably the most significant of the basin-margin faults active within the Craven Fault System at the end of the Viséan Epoch, profoundly influenced the character of Lower Carboniferous successions in the area – most notably in separating the shallow-water facies of the Askrigg Block to the north, from deeper-water facies in the Craven Basin to the south (Ramsbottom, 1974; Arthurton *et al.*, 1988; Kirby *et al.*, 2000; Mundy, 2000).

The formation of the School Share Boulder Bed was considered in detail by Dixon and Hudson (1931) who suggested a local origin for the boulders on account of their angularity, size, composition and unweathered appearance. These same authors concluded that the deposit was most probably the product of a subaqueous 'land-slip' emanating from an active submarine fault-scarp raised by earth movements at the end of Viséan times. Evidence of late Brigantian faulting and the occurrence of in-situ Wensleydale Group lithofacies similar to that seen in the boulders south of the Middle Craven Fault (Arthurton *et al.*, 1988; British Geological Survey, 1989) support the idea of an active submarine fault-scarp in the vicinity of School Share at this time. An alternative view put forward by Walker (1967) was that the slopes necessary for the generation of submarine debris slides in the vicinity of School Share were primarily the result of an extended late Viséan period of differential subsidence and sedimentation across the basin margin, during which carbonate shoals built up at the southern edge of the Askrigg Block which temporarily starved the Craven Basin of sediment. The present authors' view is that both contemporaneous faulting and differential subsidence/sedimentation were influential in the formation of the School Share Boulder Bed. More recently, N. Riley (pers. comm., 2002) has interpreted the boulder bed and overlying disturbed shales as a submarine canyon fill.

Conclusions

The development of the School Share Boulder Bed and associated unconformity provides important evidence of a late Brigantian–early Pendleian episode of tectonic instabilty within the Craven Fault System. The occurrence of these features remains critical to our understanding of the tectono-sedimentary evolution of the transition zone between the Askrigg Block and the Craven Basin; one of the most complex areas of Lower Carboniferous geology in Britain.

CRACOE KNOLLS AND SWINDEN QUARRY, NORTH YORKSHIRE (SE 983 615, SE 988 602, SE 996 605, SE 996 609, SE 003 608, SE 007 615, SE 016 614, SE 027 617)

Introduction

The district around Cracoe and Thorpe, North Yorkshire, is a classic area for the study of late Dinantian (Asbian) knoll reefs, comprising the most easterly exposures of the Craven Reef-Belt at the margins of the Askrigg Block and Craven Basin. The term 'Cracoean', originally used as a stratigraphical unit by Bisat (1928), has been used as a facies term by Hudson and Philcox (1965) and Mundy (1994, 2000) to emphasize the distinction between this 'knoll reef' facies from the older 'Waulsortian' facies developed in areas to the south (see **Salthill**, **Coplow** and **The Knolls** GCR site reports, Chapter 6, and the **Dovedale** and **Wetton to Beresford Dale** GCR site reports, Chapter 7). The site embraces a number of separate localities, mostly centred on one of the reef structures. These are the working quarry at Swinden (SD 983 615), Skelterton Hill (SD 988 602), Carden Hill (SD 996 605), Butter Haw Hill (SD 996 609), Stebden Hill (SE 003 608), Elbolton (SE 007 615), Thorpe Kail (SE 016 614) and Byra Bank (SE 027 617). Controversy about the origin of the structures has resulted in many publications on the area since the pioneering work of Tiddeman (1889, 1891). These include Marr (1899), Wilmore (1910), Garwood and Goodyear (1924), Hudson (1930a, 1932), Bond (1950a,b), Black (1954, 1958) and Mundy (1980a; 2000).

Description

The fullest descriptions of the geology of the Cracoe area, including the localities within this site, are by Bond (1950a), Black (1958) and Mundy (1980a; 2000). Bond (1950a) produced a detailed lithostratigraphy for the area, but, because of rapid lateral facies variation in the reef complex, this has been regarded as too simplistic and unworkable by later authors (Black, 1958; Mundy, 1980a). Mundy (1980a) considered the outcrops in this area in three groups: the NE–SW-trending Swinden outcrop; the WNW–ESE-trending outcrop parallel to the Craven Fault System, including the sites of Elbolton, Thorpe Kail and Byra Bank; and the isolated outcrops to the south, including Stebden, Butter Haw, Carden and Skelterton hills. This grouping has been followed in the present description. A geological map of the central part of the area, showing the distribution of reef limestones, debris beds and later geological units, is presented in Figure 5.24. Swinden lies partly on the British Geological Survey map of the Settle district (British Geological Survey, 1989) and has been described in the accompanying memoir (Arthurton *et al.*, 1988). The NE–SW-trending hill was thought to be a domal structure by Bond (1950a) and Black (1958), but quarrying has since revealed a northwards-younging succession (Arthurton *et al.*, 1988) complicated by locally severe fault disturbance (Mundy, 2000). Localities within the site boundary are probably all within the area of reef limestones, comprising unbedded pale-grey wackestones, though little evidence of this facies remains, the bulk of it having been removed by recent quarrying (D. Mundy, pers. comm., 2000). B_2 goniatites, including *Goniatites hudsoni*, *Beyrichoceras* aff. *vesiculiferum* and *Bollandoceras micronotoides*, were recorded from the Swinden reef limestones by Bisat (1934).

The belt of reef limestones from Elbolton to Thorpe Kail and Byra Bank is also mostly of B_{2b} age, although at Elbolton P_{1a} limestones form flank deposits (Mundy, 1980a, 2000) banked up against the older reef structure on the southern and western sides of the hill (Figure 5.24). On Elbolton, the B_{2b} reef limestones pass from massive, on the southern side, to bedded elsewhere on the hill. Mundy (1980a) presented geopetal evidence which indicated that these bedded rocks were originally horizontal. Peloids and oncoids were also reported from these beds (Mundy, 1980a). *Gigantoproductus*, in

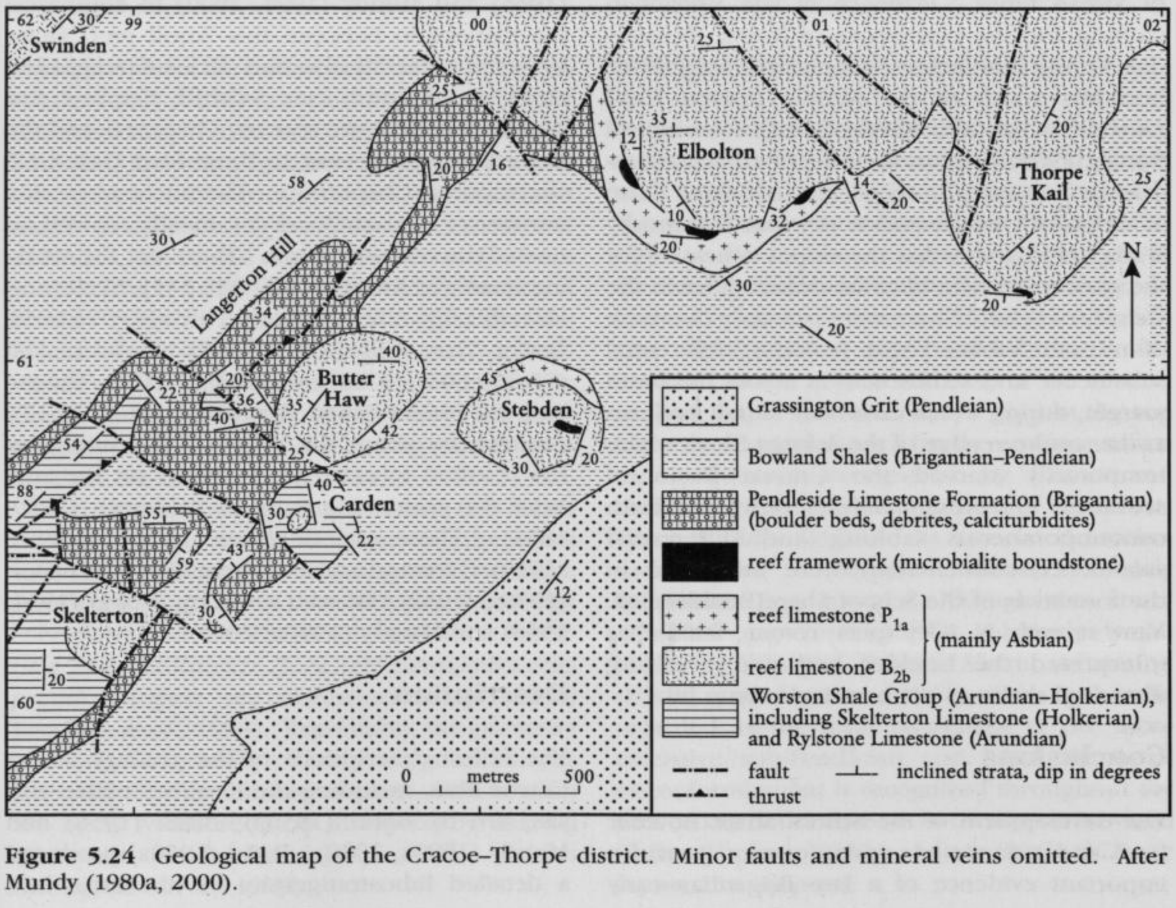


Figure 5.24 Geological map of the Cracoe–Thorpe district. Minor faults and mineral veins omitted. After Mundy (1980a, 2000).

association with large-diameter examples of *Koninckopora inflata*, occur at the top of the hill. Hudson and Cotton (1945a) recorded B_{2b} goniatites from the north-western slopes of Elbolton, but none were found in the detailed investigations of Mundy (1980a). The P_{1a} limestones are richly fossiliferous and form flanking deposits dipping at up to 35° (Mundy, 1980a). P_{1a} goniatites, including *Goniatites crenistria* and *Beyrichoceratoides truncatum*, were first described from these beds by Bisat (1928). Microbial boundstones are known from three places at Elbolton (Figure 5.24).

Although Thorpe Kail comprises entirely B_2 limestones, the structure is similar to that of Elbolton, with bedded limestones forming the central and northern parts of the hill, and more massive reef limestone, including local microbial boundstone, on the southern side (Mundy, 1980a). Similar structures are found eastwards along the reef-belt to Byra Bank.

Butter Haw Hill and Stebden Hill comprise reef limestones with quaquaversal dips (Bond, 1950a) in the peripheral flank limestones. Studies of geopetal infillings by Mundy (1980a) have shown that the major component of these dips is an original depositional dip. On Butter Haw Hill the reef limestones are entirely of B_{2b} age, but P_{1a} limestones are represented on the northern side of Stebden Hill (Figure 5.24) Goniatites of B_{2b} age recorded from Butter Haw Hill and/or Stebden Hill include *Bollandoceras micronotum*, *Beyrichoceras rectangularum*, *B. cf. vesiculiferum*, *Beyrichoceratoides vesicus*, *B'toides implicatum*, *Bollandites castletonensis*, *Goniatites globostriatus*, *G. hudsoni*, *Nomismoceras vittiger* and *Merocanites* (Mundy, 2000). Goniatites of P_{1a} age recorded from Stebden Hill include *B'toides truncatum and G. crenistria* (Mundy, 2000).

Stebden Hill was the focus of one of the most detailed palaeoecological investigations of Lower Carboniferous strata undertaken anywhere in the British Isles (Mundy, 1980a; 2000). For example, more than 13 000 shelly fossils (brachiopods and molluscs) were examined in collections from Elbolton and Stebden Hill and, in all, 206 fossil genera and 325 species were identified (Mundy, 1980a). Six biotic associations, each named after a dominant endemic component, were recognized, together with intermediate mixed assemblages (Mundy, 2000). In the B_{2b} reef limestones these associations include the *Plicatifera* Association, developed in the oldest exposed beds, followed by three synchronous associations – the *Saharopteria*, *Conocardium* and *Koninckopecten* associations. The subsequent *Geniculifera* and *Productus* associations are of P_{1a} age. The temporal and spatial distribution of these six faunal associations is illustrated in Figure 5.25a.

The *Saharopteria* Association comprises the reef framework, exposed on the summit of Stebden Hill (Figure 5.25b). Primary frame-builders described by Mundy (1980a, 1994,

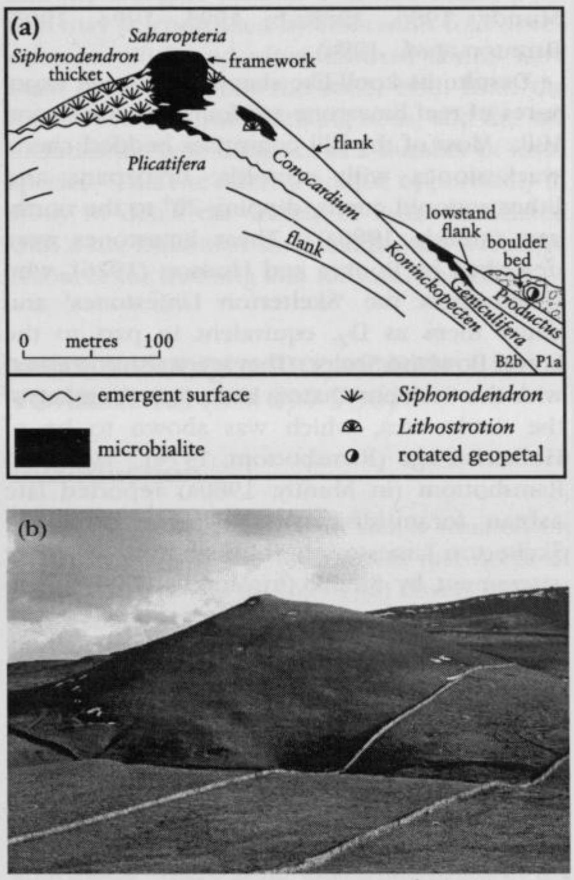


Figure 5.25 (a) Schematic section through the reef mound at Stebden Hill illustrating the temporal and spatial relationships between reef associations. Approximate orientation is from south (left) to north (right). Vertical height from the top of the microbialite framework to the base of the boulder bed is 120 m. After Mundy (2000). (b) The distinctive outline of the Asbian reef mound at Stebden Hill near Cracoe, viewed from the north-west. The crest of the mound is in framework facies whereas the sloping ground immediately below the reef crest is in flank facies. Fields in the lower ground are underlain by Namurian Bowland Shales. (Photo: D. Mundy, reproduced here by kind permission of the Yorkshire Geological Society.)

2000) include microbial stromatolites, lithistid sponges (Rigby and Mundy, 2000), encrusting bryozoans, tabulate corals and the cemented pseudomonotid bivalve that gives its name to the association. The associated fauna includes very abundant examples of the rugose coral *Cyathaxonia cornu*, elsewhere considered to be characteristic of deeper-water Dinantian facies (Mundy, 1978). Several recent publications on Dinantian brachiopod faunas draw on specimens collected from the Craven Reef-Belt, and from Stebden Hill and Elbolton in particular (Mundy and Brunton, 1985; Brunton and Mundy, 1986, 1988a,b, 1993, 1994, 1997; Brunton *et al.*, 1994).

Despite its knoll-like shape, only small exposures of reef limestone are found on Skelterton Hill. Most of the hill comprises bedded cherty wackestones with crinoids, bryozoans and lithostrotionid corals, dipping 20° to the north-east (Mundy, 1980a). These limestones were described by Booker and Hudson (1926), who called them the 'Skelterton Limestones' and dated them as D_2, equivalent in part to the Lower Bowland Shales. They were also correlated with the Scaleber Quarry Limestone Member of the Settle area, which was shown to be of Holkerian age (Ramsbottom, 1974). However, Ramsbottom (in Mundy, 1980a) reported late Asbian foraminiferal assemblages from the Skelterton Limestones; although a more recent assessment by Strank (in Mundy, 2000) considered them to be of Holkerian 'aspect'.

Limestone boulder beds of Brigantian age have been described from a number of localities along the reef-belt, for example in the Cracoe–Burnsall area by Black (1940, 1957). These comprise clasts of both reef limestones and dark Yoredale-type limestones containing *Lonsdaleia duplicata*, *Actinocyathus floriformis* and *Gigantoproductus* (Black, 1957). At this site, the lower slopes of Carden Hill are made up of boulder beds (= limestone debris beds of Mundy, 1980a) (Figure 5.24). The boulder beds are difficult to distinguish from in-situ reef limestone, but can be recognized by the varied attitude of geopetal infillings (Mundy, 1980a, 2000). Clasts within the boulder beds here are entirely of reef limestone. The majority of these limestone debris beds are assigned to the Pendleside Limestone Formation (Mundy, 2000).

Hudson (1932) described an unconformable relationship between the Bowland Shales and the reef limestones. This relationship was further studied by Black (1940) who noted the way the shales onlap the limestone surface. Stebden Hill is completely encircled by the Bowland Shales (Figure 5.24) and the summit of the hill is at about the level of contact between the Grassington Grit and the Bowland Shales. According to Black (1940), the lowest Bowland Shale around Stebden is of P_{1b} (Brigantian) age; the mudrock succession extending up into the E_1 Zone (Pendleian). Within the area of the sites described here, Bowland Shales of E_1 age are exposed in Thorpe Beck on the south-east side of Elbolton (SE 011 614) (Bond, 1950a).

Interpretation

Most of the debate about the geology of the Cracoe area has focused on the origin of the reef structures. Tiddeman (1889) advanced the idea that they were original depositional structures made by mounds of animal debris. Rival theories stressed the importance of structural processes, and Marr (1899) suggested that the knolls were entirely tectonic in origin, but this fails to account for the observed facies variations. Hudson (1930a, 1932) took up Tiddeman's idea that these were original depositional structures and suggested that there may have been a continuous reef-belt along the line of the Middle Craven Fault. He further suggested that this reef-belt was faulted and eroded prior to deposition of the Bowland Shales. Bond (1950a,b) developed Hudson's ideas by suggesting that many of the dips in the reef limestones indicated pre-Bowland Shales folding as well as faulting.

Black (1958) analysed the structure of the area in detail and concluded that there was undoubtedly an original knoll topography along the reef-belt, but that while this was more-or-less symmetrical in the case of Stebden Hill, Elbolton and Thorpe Kail showed a high degree of asymmetry. According to Black (1958), this original knoll topography was then buried gradually by deposition of Bowland Shales, which, as a result, rest conformably on nearby shelf limestones and onlap the reef structures. Some uplift and erosion occurred at this time to account for the formation of the boulder beds. Black (1958), therefore, regarded many of the dips in the reef limestones as primary depositional dips, but was unable to conclusively demonstrate this.

Black's ideas were further developed by Mundy (1980a) who used geopetal structures to distinguish depositional from tectonic dips. He confirmed that the reef-belt from Elbolton to Byra Bank is essentially marginal to the shelf to the north, comprising an apron reef with depositional dips into the Craven Basin on the southern side, but passing into horizontal shelf limestones on its northern side. The reef limestones of Stebden and Butter Haw, however, are separated from this continuous reef-belt. Both show bedded flanking limestones with quaquaversal dips and would seem to be true knoll reefs as envisaged by Tiddeman (1889). Mundy (1980a) inferred an original topography of 110 m for Stebden Hill in upper B_2 times. According to Mundy (2000), the top of Stebden Hill is 30 m below the base of the Grassington Grit. The reef was thus covered by Bowland Shales in P_{1b} (Brigantian) times.

The reef at Swinden seems to be a special case. Its north-east to south-west orientation indicates that it is not part of the WNW–ESE-trending marginal reef complex. It has been suggested by Mundy (1980a) that reef limestones here developed as an elongate structure along an embryonic fold line – that of the Hetton Anticline. The development of embryonic fold structures in this region during Early Carboniferous times is considered further by Arthurton (1984).

The biotic associations of Mundy (1980a, 2000) reflect both temporal and spatial variations in the reef environment. The oldest limestones (B_{2b}) exposed at Stebden Hill contain a *Plicatifera* Association, interpreted as having developed in marginal reef slope sediments on a soft substrate. Of the three subsequent synchronous (B_{2b}) associations, the framework *Sabaropteria* Association developed in the shallowest water and passes down the reef slope via mixed assemblages into first the *Conocardium* Association and then the *Koninckopecten* Association. The P_{1a} *Geniculifera* Association developed on the middle and lower reef slopes. The subsequent *Productus* Association (late P_{1a}) is thought to represent re-colonization in shallow water after intra-P_{1a} uplift and emergence (Mundy, 1980a, 2000). Independent evidence for this phase of uplift is provided by the breccia beds of this age and by fissuring and vadose cement fabrics at the summit of Stebden Hill (Mundy, 1980a, 2000).

Conclusions

The district around Cracoe is one of the classic areas for British Lower Carboniferous geology. Late Dinantian reef limestones (Cracoean facies) are particularly well displayed here and it is possible to study their relationships with laterally equivalent and overlying beds. The area is invaluable for showing three different types of contemporaneous reef occurrence: the marginal reef along the line of the Middle Craven Fault, the isolated knolls of Stebden and Butter Haw, and the elongate bank of Swinden whose position may be controlled by embryonic fold development. Rich and often unusual faunas have been described from the reefs, both from the framework and from flanking beds, and the site includes the type localities of a number of fossil species. This site offers a unique opportunity to study in detail the variety of facies associated with a late Dinantian shelf margin and is a major resource for teaching and for future research.

MEAL BANK QUARRY, NORTH YORKSHIRE (SD 697 736)

Introduction

The Meal Bank Quarry GCR site is situated on the right bank of the River Greta just north of Ingleton. This site (SD 697 736) covers most of the ground between the North and South Craven faults which are here only about 500 m apart. The disused quarry shows one of the finest sections of Dinantian strata close to the Craven Faults between Ribblesdale in the east and the Dent Fault in the west. Highlights of the site include the best-exposed coal seam within a Dinantian shelf limestone succession in England and Wales. There is no modern account of the site, the most detailed description being that of Garwood and Goodyear (1924). The site was also described by Dunham *et al.* (1953), but these authors added little to the original description.

Description

Limestones exposed in the quarry were attributed to the S_2 and D_1 zones by Garwood and Goodyear (1924). A modern stratigraphical nomenclature has not been applied to this area, but using the scheme of Arthurton *et al.* (1988)

for the Dinantian succession of the Askrigg Block and the transition zone between the Craven Faults in the Settle area a few kilometres to the south-east, the succession at Meal Bank would fall entirely within the Malham Formation (Holkerian–Asbian).

The oldest beds are found at the north end of the quarry. Adjacent to the North Craven Fault the beds dip to the north, but southwards along the quarry face they turn over to dip to the south. This part of the succession (*c.* 18 m thick) was attributed to the Nematophyllum minus Beds (Holkerian, S_2) by Garwood and Goodyear (1924), with the index fossil *N. minus* (= *Lithostrotion aranea* of Mitchell, 1989; = *L. vorticale*, J. Nudds, pers. comm., 2000) found in the lowest exposed strata. Roughly 50 m of strata attributed to the D_1 Zone (Asbian) are also exposed and the succession is apparently complicated by thrusting. The limestones are medium grey, massive, sparsely fossiliferous at the base and with several developments of burrow mottled 'spotted beds' or 'pseudobreccias' where darker limestone patches are enclosed by paler areas.

Midway through the Asbian succession a major palaeokarstic surface is overlain by a prominent palaeosol clay and capped by an impure coal seam (Figure 5.26) first recorded by Ricketts (1869) and later analysed by Shelley (1967). These features have attracted interest because they are particularly well developed and accessible just above the quarry floor. Marr (1899) regarded the coal as a slice of Coal Measures from the Ingleton Coalfield to the south of the South Craven Fault that had been thrusted into its present position. Kendall (1918), however, considered it to be contemporaneous with the limestones. Garwood and Goodyear (1924) initially preferred the Marr suggestion, but reported on a discussion with E.E.L. Dixon who had pointed out the presence of an underclay with rootlets immediately beneath the coal, sitting on an eroded, potholed limestone surface. The existence of an 'unconformity' at this level was noted by Moore *et al.* (1974). As the coal is traced up the quarry face it is cut out by the succeeding limestone.

Other features of interest include a highly fossiliferous nodular bed about 13 m above the

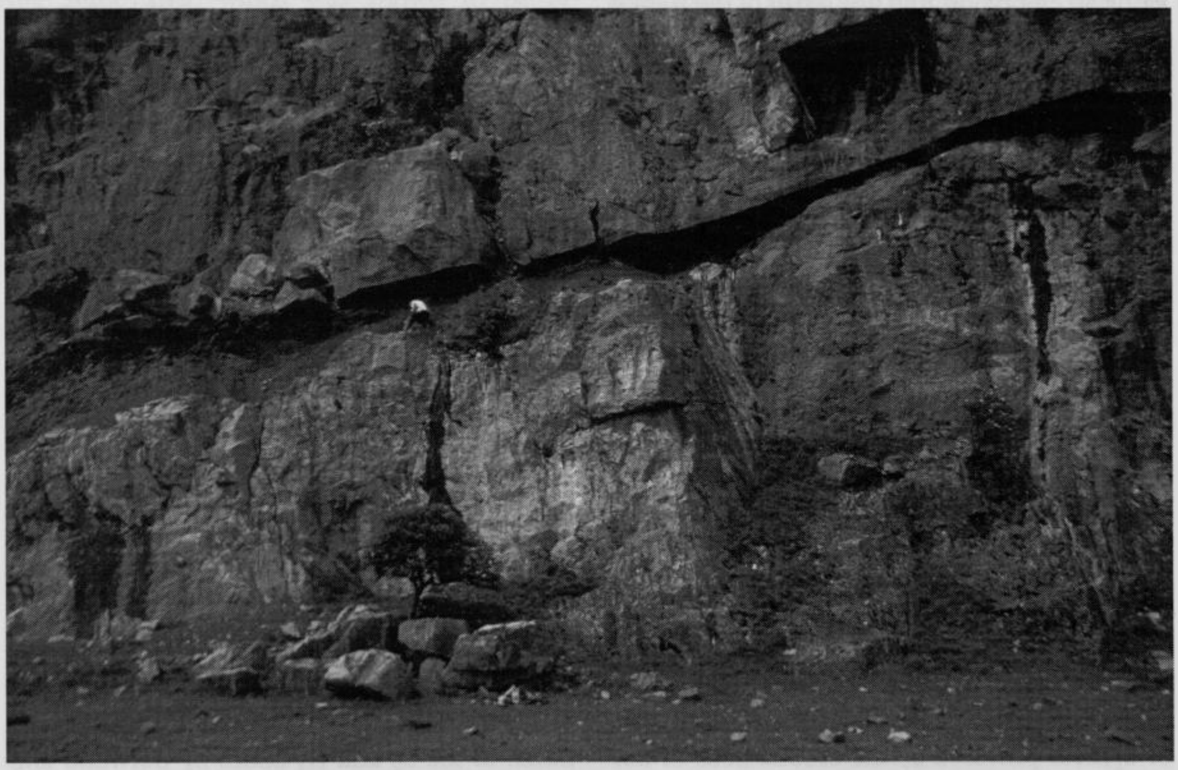


Figure 5.26 Massive limestones of the Malham Formation (Asbian) at Meal Bank Quarry, Ingleton. A thick clay palaeosol capped by a coal seam occurs above the prominent palaeokarst at the centre of the quarry face. (Photo: A.E. Adams.)

coal. A rich coral–brachiopod fauna with especially large productoids from this horizon was recorded by Garwood and Goodyear (1924). A further 9 m above this is the Davidsonina septosa Band. At the south end of the quarry, adjacent to the South Craven Fault, the limestones have been extensively dolomitized (Garwood and Goodyear, 1924).

Interpretation

Although they lie in the transition zone between the North and South Craven faults, the limestones of Meal Bank Quarry are entirely of shelf aspect. In the Settle area, to the east, the Malham Formation is thicker in the transition zone than on the Askrigg Block proper (Arthurton *et al.*, 1988). Around Ingleton and at Meal Bank this relationship is difficult to prove since the base and top of the formation are not seen. No reef structures are known from the transition zone in this area.

The palaeokarstic surface and its associated coal and seatearth indicate that a prolonged period of emergence interrupted marine limestone deposition. Rootlets and thin carbonaceous horizons are not unusual in late Dinantian palaeosols, but rarely are coals well developed. The presence of the coal suggests that either the climate was particularly humid during this episode of subaerial exposure, or that the thick underclay inhibited the drainage of groundwater allowing the coal to form. The nature of the upper contact of the coal has long been debated, it being interpreted as either a thrust or an erosion surface (Garwood and Goodyear, 1924; Dunham *et al.*, 1953).

The distinctive nodular bed higher in the limestone succession was correlated with a similar bed at Trowbarrow by Garwood and Goodyear (1924). Such nodular beds in late Dinantian successions often result from calcretization as a result of subaerial exposure in semi-arid conditions (Vanstone, 1996).

Conclusions

Meal Bank Quarry provides the best exposure of the Malham Formation in the transition zone on the south-western margin of the Askrigg Block. The site is particularly notable for the best developed coal seam associated with a palaeokarstic surface in the Lower Carboniferous shelf limestone successions of England and Wales.

PEN-Y-GHENT GILL, NORTH YORKSHIRE (SD 852 737–SD 857 734)

Introduction

Pen-y-ghent Gill is a tributary of Littondale. The site lies in the upper part of the gill (SD 852 737 to SD 857 734), on the east side of Pen-y-ghent hill, and is 10 km NNE of Settle. The locality displays an outstanding section of the lower part of the Wensleydale Group (Brigantian) on the southern part of the Askrigg Block and includes the Hawes Limestone, Gayle Limestone and Hardraw Scar Limestone. The geology of the area in general is described by Garwood and Goodyear (1924) and Dunham and Wilson (1985); however, the most detailed site-specific information is in an unpublished field guide (Rose *et al.*, 1973). Records of foraminifera from this section are reported by Longerstaey (1975).

Description

This locality is particularly well known for its exposure of the Girvanella Nodular Bed which occurs within the Hawes Limestone. It can be seen in the stream section just below the bridge carrying the minor road across Pen-y-ghent Gill (SD 857 734) (Figure 5.27). The main part of the bed consists of 1.2 m of dark-grey limestone containing crinoid debris and abundant oncoids (the algal nodules or *Osagia* nodules of previous workers) (Rose *et al.*, 1973). The oncoids, which are up to a few centimetres across, mostly comprise a bioclastic nucleus coated with crudely concentric layers of micritic carbonate within which the microscopic calcified tubes of *Girvanella* can sometimes be found. Approximately 8 m of Hawes Limestone occurs above the Girvanella Nodular Bed. This part of the succession comprises dark-grey crinoidal limestones with shaly partings. In the lower part there are scattered oncoids, and higher up, there are a number of units rich in the problematic organism *Saccaminopsis*.

A 10 cm-thick shale marks the boundary with the overlying Gayle Limestone, the basal bed of which is a 0.35 m-thick unit containing *Gigantoproductus* (Rose *et al.*, 1973). Overall, the lithology of the Gayle Limestone is similar to that of the Hawes Limestone, with dark-coloured crinoidal limestones separated by muddy partings. Corals, *Saccaminopsis* and shells with oncoidal coatings occur at a number of levels.

Figure 5.27 Outcrop of the Girvanella Nodular Bed (below hammer, left of centre) in the Hawes Limestone (basal Brigantian) at the Pen-y-ghent Gill GCR site. (Photo: P.J. Cossey.)

There follows a less well-exposed section comprising interbedded limestones and shales. In the absence of distinctive intervening siliciclastic deposits, the contact between the Gayle Limestone and Hardraw Scar Limestone is difficult to define. However, the uppermost part of the succession, exposed near the confluence of two streams (SD 853 737) and comprising massive beds of cherty limestone with silicified corals and *Gigantoproductus* is attributed to the upper part of the Hardraw Scar Limestone and probably correlates with the Orionastraea Beds of Garwood and Goodyear (1924) (Rose *et al.*, 1973). This part of the succession is rich in colonial corals, particularly *Siphonodendron junceum* (Dunham and Wilson, 1985).

Interpretation

The Girvanella Nodular Bed has been taken as an important marker band throughout northern England and was originally used to define the position of the D_1–D_2 biozone boundary (e.g. Garwood, 1913; Garwood and Goodyear, 1924). However, since Arthurton *et al.* (1988) recorded Brigantian foraminifera in the lower part of the Hawes Limestone beneath the Girvanella Nodular Bed in the Settle district, a few kilometres to the south of this site, the Asbian–Brigantian (D_1–D_2) boundary has been taken at the base of the Hawes Limestone, several metres below the occurrence of oncoids at Pen-y-ghent Gill. The revised position of this boundary occurs at the base of Yoredale facies and the Wensleydale Group in this area.

The environmental significance of the widespread development of oncoids at this time is unclear. Garwood and Goodyear (1924) interpreted it as recording a shallowing of the sea permitting growth of calcareous algae. Overall the abundance of fine matrix suggests low-energy environments, but with the growing oncoids turned over occasionally to allow more-or-less symmetrical growth. A further requirement for their development would be a slow sedimentation rate. The environmental significance of bands with abundant *Saccaminopsis* is also unclear, although they are common in Brigantian shelf deposits of northern England and North Wales.

Compared with the lower part of the Yoredale sequence in its type area of Wensleydale, the succession in Pen-y-ghent Gill lacks the well-defined siliciclastic intervals between the named limestones, which makes the boundaries of the limestones difficult to define. Although the growth of deltas in the north is reflected in the argillaceous content of the succession, which becomes significant in the Hawes Limestone, the more typical deltaic facies of northern England did not spread as far south as this locality during early Brigantian times and the environment was entirely shallow marine.

Conclusions

Overall, the succession of the lower part of the Wensleydale Group at this locality contrasts with that in Wensleydale itself in being wholly marine. The site is also important for its fine exposure of the Girvanella Nodular Bed. Further work is needed to establish the environmental significance of this and other fossil bands, including those with abundant *Saccaminopsis*.

WHITFIELD GILL–MILL GILL, NORTH YORKSHIRE (SD 920 931–SD 945 909, SD 928 928 and SD 924 931–SD 931 929)

Introduction

This locality comprises a 4 km stream section extending from Askrigg village (SD 945 909) in a WNW direction up Mill Gill and then Whitfield Gill to SD 920 931. It also includes scars on the hillside on the north side of Whitfield Gill: Whitfield Scar (SD 928 928) and High Scar (SD 924 931 to SD 931 929). The site provides an outstanding Brigantian–Pendleian section of the Wensleydale Group extending from the Gayle Limestone to the Main Limestone. It also represents one of the finest developments of the Yoredale facies on the Askrigg Block, thus facilitating the study of this classic style of cyclicity first recognized early in the study of the geology of northern England. The most detailed account of the section can be found in Moore (1958), with further details provided by Dunham and Wilson (1985). Foraminiferal faunas from part of the section are described by Hallett (1970) and Strank (1981).

Description

The stream section provides almost complete exposure of the succession from the Gayle Limestone to the Middle Limestone (Figure 5.28). The former is exposed in Mill Gill immediately west of Askrigg village (SD 943 911). It consists of bedded limestones with shale partings overlain by more massive crinoidal limestones (Moore, 1958). A feature of the Gayle Limestone at this locality is the presence of an irregular upper surface (Hudson and King, 1933) consisting of small buildups with abundant corals and bryozoans (Moore, 1958).

Above the Gayle Limestone, some 28 m of siliciclastic deposits are exposed in a coarsening-upward succession. The lower part consists of shales with siderite nodules containing a diagnostic fauna including *Goniatites sphaericostriatus* and *Posidonia becheri*, described by Hudson (1924, 1925). Further goniatite discoveries from these shales reported by Dunham and Wilson (1985) include *Sudeticeras* cf. *turneri*. The upper part of the shales is unfossiliferous and passes up into flaggy-weathering siltstones and fine-grained sandstone. The top of this sandstone floors the waterfall at Millgill Force (SD 938 915). The top 15 m of the coarsening-upward succession was logged by Lees (1991) as part of his study of trace fossils in Yoredale cyclothems. Siltstones near the base of the logged section contained *Macaronichnus*, *Teichichnus* and *Chondrites* and were placed in the author's *Planolites montanus–Chondrites* trace-fossil association. Lees (1991) recorded *Crossopodia*, *Macaronichnus*, *Asterosoma* and *Helminthopsis* from the overlying wave-rippled and cross-bedded fine- and medium-grained sandstones. These were placed in his *Crossopodia–Macaronichnus* trace-fossil association.

The overlying limestone, originally known as the 'Hardraw Limestone' (Phillips, 1836), was re-designated the 'Hardrow Scar' Limestone by Moore (1958). However, the definitive stratigraphical chart of the Kirkby Stephen 1:50 000 geological map (British Geological Survey, 1997b), uses the spelling Hardraw Scar Limestone and this usage is followed in the present account. The limestone forms the waterfall at Millgill Force and exposures upstream as far as Slape Wath (SD 937 918).

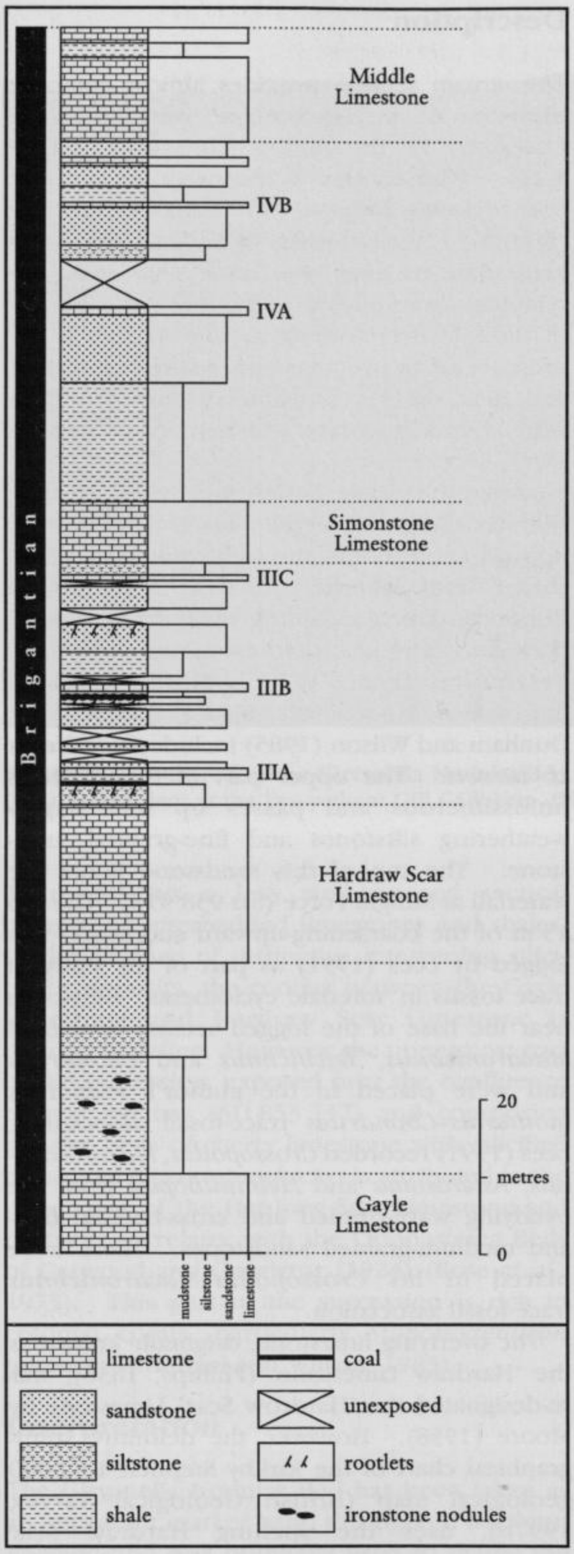


Figure 5.28 Sedimentary log of the lower part of the Brigantian 'Yoredale' succession at the Whitfield Gill–Mill Gill GCR site. After Moore (1958).

The Hardraw Scar Limestone is about 20 m thick. The lower part comprises massive crinoidal limestone which becomes better bedded upwards. A brachiopod band referred to as the 'Orthotetid Bed' by Moore (1958) occurs near the middle of the limestone. It contains *Schellwienella crenistria*, *Gigantoproductus dentifer* and *Productus concinnus* (Prentice, 1949; Moore, 1958). The upper part of the limestone is also massively crinoidal with rubbly weathering bands caused by concentrations of pressure solution seams. The uppermost unit is a partially dolomitized fine-grained limestone (Moore, 1958).

The succession between the Hardraw Scar Limestone and the Simonstone Limestone is complex and less well exposed than the lower part of the succession. It contains three minor limestones, numbered IIIA, B and C by Moore (1958) (Figure 5.28). Beneath Limestone IIIA, a thin fossiliferous shale rests on a coal and seatearth. The shale is plant-rich at the base and passes through a unit with flattened bivalves and fish debris to become more calcareous with colonial corals and brachiopods at the top (Moore, 1958). Limestone IIIA is a sparsely crinoidal fine-grained limestone. Beds above the limestone are poorly exposed with mostly fine sandstones present, capped by a thin coal and succeeded by Limestone IIIB which is sandy, especially at the base.

About 10 m of shale and sandstone separates Limestone IIIB from Limestone IIIC. The latter is about 30 cm thick and contains scattered fine crinoid debris. The Simonstone Limestone appears a few metres above Limestone IIIC. It is about 7 m thick, with coarsely crinoidal limestone succeeded by interbedded limestones and shales, further crinoidal limestones and, at the top, fine-grained 'algal' limestones (Moore, 1958). The fauna includes small colonies of *Siphonodendron junceum*, found throughout the limestone, and *Orionastraea*, seen particularly at the top.

Approximately 50 m of predominantly siliciclastic deposits occur between the Simonstone Limestone and the Middle Limestone in Whitfield Gill. Broadly, this consists of shales overlain by sandstones, but the sandstones are interrupted by two thin limestones (IVA and IVB of Moore, 1958) overlain by shale units (Figure 5.28). The shale immediately overlying the Simonstone Limestone is especially fossiliferous;

a typical Yoredale coral–brachiopod fauna from this horizon is listed by Moore (1958). Current ripple-laminated, fine-grained sandstones above these shales and beneath Limestone IVA are well exposed at Whitfield Gill Force (SD 934 922) (Dunham and Wilson, 1985). Trace fossils recorded from this level by Lees (1991) include *Crossopodia*, *Eione* and *Helminthopsis*.

The Middle Limestone is divided into three massive units separated by shales and thinly bedded limestones. The lowest massive limestone unit has at its base a coral bed, containing *Lithostrotion decipiens*, *Diphyphyllum fasciculatum* and *Orionastraea* (J. Nudds, pers. comm., 2000), and a palaeokarstic surface at the top (Dunham and Wilson, 1985). Separating the lower and middle parts of the Middle Limestone are mudstones, including a nodular band of limestone containing the sponge *Erythrospongia lithodes* first recorded by Hudson (1929). The central part of the Middle Limestone consists of dark-coloured limestones with gigantoproductids and chert nodules, and the uppermost unit includes a band of oncoids near its top. Abundant and diverse foraminiferal faunas were recorded from the Middle Limestone in Whitfield Gill by Strank (1981), contrasting with the observation by Hallett (1970) that Middle Limestone foraminiferal faunas were generally rather scarce. An abundant conodont assemblage also from the Middle Limestone was recorded by Varker (1968).

Strata above the Middle Limestone are poorly exposed in Whitfield Gill. The Undersett Limestone and Main Limestone are seen respectively at Whitfield Scar and High Scar. The Undersett Limestone is particularly notable for its abundant bryozoan fauna, a feature that sets it apart from other Yoredale limestones (Moore, 1958). The Main Limestone is one of the more prominent scar-forming limestones, typically being more than 20 m thick. It comprises medium- to dark-grey bioclastic, often crinoidal, limestones with bands of corals and gigantoproductids. *Actinocyathus floriformis* and *Lonsdaleia duplicata* are particularly common.

Interpretation

Wensleydale, formerly known as 'Uredale' or 'Yoredale', is the type area for the 'Yoredale Series' of Phillips (1836) who was responsible for naming many of the limestones. The initial [British] Geological Survey work also concentrated on the limestones and the nomenclature was slightly revised (Dakyns *et al.*, 1890, 1891). Although the cyclicity of the succession was implicit in these studies, it was not until the work of Hudson (1924, 1933) that the nature of the cyclicity – limestone overlain consecutively by shale then sandstone and sometimes a seatearth–coal couplet – was firmly stated. The biostratigraphy of Yoredale successions on the Askrigg Block is reviewed by Dunham and Wilson (1985). Brigantian faunas are found up to the Undersett Limestone, with fossils of Namurian aspect appearing in the siliciclastic beds between the Undersett Limestone and Main Limestone. In Mill Gill, the goniatites in the shales above the Gayle Limestone indicate a P_{1c} age (Dunham and Wilson, 1985). Correlations of early Brigantian limestones between the Askrigg Block and the Alston Block have been considered by Burgess and Mitchell (1976), with the Gayle Limestone correlated with the Grain Beck Limestone and Lower Little Limestone. Higher in the succession, the three parts of the Middle Limestone were correlated by Dakyns *et al.* (1891) with the Single Post Limestone, Cockleshell Limestone and Scar Limestone, the Middle Limestone thus splitting northwards (Figure 5.4), a correlation that is now generally well accepted (e.g. British Geological Survey, 1997b). The term 'Wensleydale Group' is now applied to these Yoredale facies Brigantian strata of the Askrigg Block area (Arthurton *et al.*, 1988; British Geological Survey, 1997b,c).

The Whitfield Gill–Mill Gill site provides a section of the late Dinantian Yoredale facies that is typical of the Askrigg Block area. The Gayle Limestone and its overlying siliciclastic beds (comprising the Gayle Limestone Cyclothem) make up a typical Yoredale cyclothem consisting of marine limestone overlain by a coarsening-upward succession of terrigenous origin. The overlying Hardraw Scar Limestone Cyclothem, comprising the Hardraw Scar Limestone and overlying beds to the base of the Scar Limestone, is more complex, the thin limestones occurring here within the otherwise siliciclastic part of the succession suggesting several superimposed orders of cyclicity.

Moore (1958, 1959, 1960) was the first to study the sedimentology of the Yoredale facies in detail and to establish that they were deposited from deltas periodically building out into a shallow marine carbonate-producing environment, followed by periods of abandonment, subsidence, re-establishment of the shallow marine environment and then repetition of the whole process. Lees (1991) stressed the importance of wave and storm reworking in the Brigantian Yoredales of England, citing the Gayle Limestone Cyclothem of Mill Gill as an example. In his model, Lees (1991) interpreted the *Planolites montanus–Chondrites* trace-fossil association as representing distal, offshore deposits and the *Crossopodia–Macaronichnus* association as representative of wave-reworked sandstones at the coastal interface (beach zone) between the open sea and delta front.

The origin of the Yoredale-style cyclicity has been much debated and is reviewed by Bott and Johnson (1967) and by Leeder and Strudwick (1987). Moore (1958, 1959) suggested that shifting of delta distributaries coupled with regional subsidence was sufficient to produce the repetitions. Others favoured a tectonic (e.g. Bott and Johnson, 1967) or eustatic (e.g. Ramsbottom, 1973) mechanism, leading to relatively rapid sea-level rise, to account for the more extensive limestones. Leeder and Strudwick (1987), in their preliminary studies of the causes of Yoredale cyclicity, favoured a combined tectono-sedimentary mechanism while not ruling out the possibility of eustatic effects.

Conclusions

Whitfield Gill–Mill Gill provides one of the best and most easily accessible sections of the Yoredale facies on the Askrigg Block. Much of the succession from the Gayle Limestone to the basal Namurian Main Limestone is visible. The site is particularly valuable for exposing a complete and 'typical' Yoredale cyclothem as well as more complex cycles. It is thus one of the most important sites for studying the causes and effects of late Dinantian cyclicity in Britain.