British Lower Carboniferous Stratigraphy

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Chapter 4

Lake District Block and Alston Block

A.E. Adams and P.J. Cossey

INTRODUCTION

The Lower Carboniferous rocks of the Lake District Block (Kirby *et al.*, 2000) crop out in two distinct areas of the Lake District north and south of its central Lower Palaeozoic core. Outcrops also occur east of the Eden Valley on the Alston Block. To the north of the Lake District, the outcrop runs in an arc from Egremont in the west, north-east to Cockermouth and Caldbeck, then south-east to Penrith (Figure 4.1a). Beyond Penrith, the outcrop continues in a south-easterly direction through Shap to Kirkby Stephen. This outcrop tract (see Figure 5.1, Chapter 5) forms part of the Stainmore Basin succession considered in Chapter 5 and is therefore not shown on Figure 4.1a. South of the Lake District, the faulted outcrop runs discontinuously from Millom in the west, eastwards to Ulverston and Grange-over-Sands. The eastern part of this outcrop extends from Kendal in the north, southwards well into north Lancashire (Figure 4.1a). The southernmost part of this outcrop (see Figure 6.1, Chapter 6) is of basinal aspect and is more properly considered as part of the Craven Basin (Chapter 6). East of the Eden Valley, on the Alston Block, outcrops are almost entirely of Lower Carboniferous rocks, although eastwards they disappear under Upper Carboniferous cover (Figure 4.1b).

Dinantian strata are quite well exposed in west Cumbria, between Egremont and Cockermouth, where there has been extensive quarrying, and are also known from the subsurface as a result of the exploration for, and exploitation of, haematite. In north Cumbria and on the east side of the Lake District, the succession is less well known. Namurian strata are poorly exposed throughout the northern area. In south Cumbria and north Lancashire, the limestone formations are quite well exposed, in natural, often strongly karstified crags, in quarries, and along shorelines. Extensive subsurface information has again been obtained from the western part of the area as a result of haematite mining. Dominantly terrigenous clastic units at the base and top of the Lower Carboniferous sequence are mostly known only from boreholes. On the Alston Block only the limestones are reasonably well exposed, but much information on the stratigraphy has come from a number of key boreholes and from the results of exploration for mineral deposits.

History of research

South Cumbria and north Lancashire

The initial geological mapping in this area was undertaken in the latter part of the 19th century and accompanied by the publication of one-inch geological map sheets. However, the only memoir to appear at this time was a short account of the Barrow area (Aveline, 1873). As part of his survey of the haematite deposits of the area, Kendall (1885, 1893) provided the first detailed descriptions of Carboniferous rocks. The first detailed faunal studies, accompanied by efforts to correlate the successions in south Cumbria with those of Shap and Ravenstonedale, were made by Garwood (1907, 1913, 1916).

Little was published on the area between the wars, although Hudson (1936) recognized the presence of a shelf margin south of Carnforth. The [British] Geological Survey began re-surveying during 1937–1938, particularly in the western part of the area where there were extensive haematite workings. War intervened and the only immediate publication to result from this work was a new lithological classification (Dunham and Rose, 1941). After further revisions, the re-survey was published as an economic memoir (Rose and Dunham, 1977).

Interest in the stratigraphy, depositional environments and diagenesis of Lower Carboniferous successions resulted in a number of PhD theses. Nicholas (1968) studied the stratigraphy and sedimentary petrology of the western part of the area, Strank (1981) included the Holkerian type section and Trowbarrow Quarry in her study of foraminiferal faunas, Barraclough (1983) studied key sections in his work on the causes of cyclicity in the Dinantian sequence, Horbury (1987) looked at the sedimentology of the Urswick Limestone, Abdel Aziz (1989) looked at the Dalton Beds and Park Limestone, and White (1992) studied late Dinantian foraminiferal assemblages in the southern Lake District. Papers on particular aspects of the Lower Carboniferous geology of south Cumbria include Leviston (1979) on the Martin Limestone, Adams and Cossey (1981) on the contact between the Martin Limestone and the Red Hill Oolite, Adams (1984) on reefs in the Red Hill Oolite at Elliscales Quarry, Horbury (1989) on the cyclicity in the Urswick Limestone, Horbury and Adams (1989) on cementation of

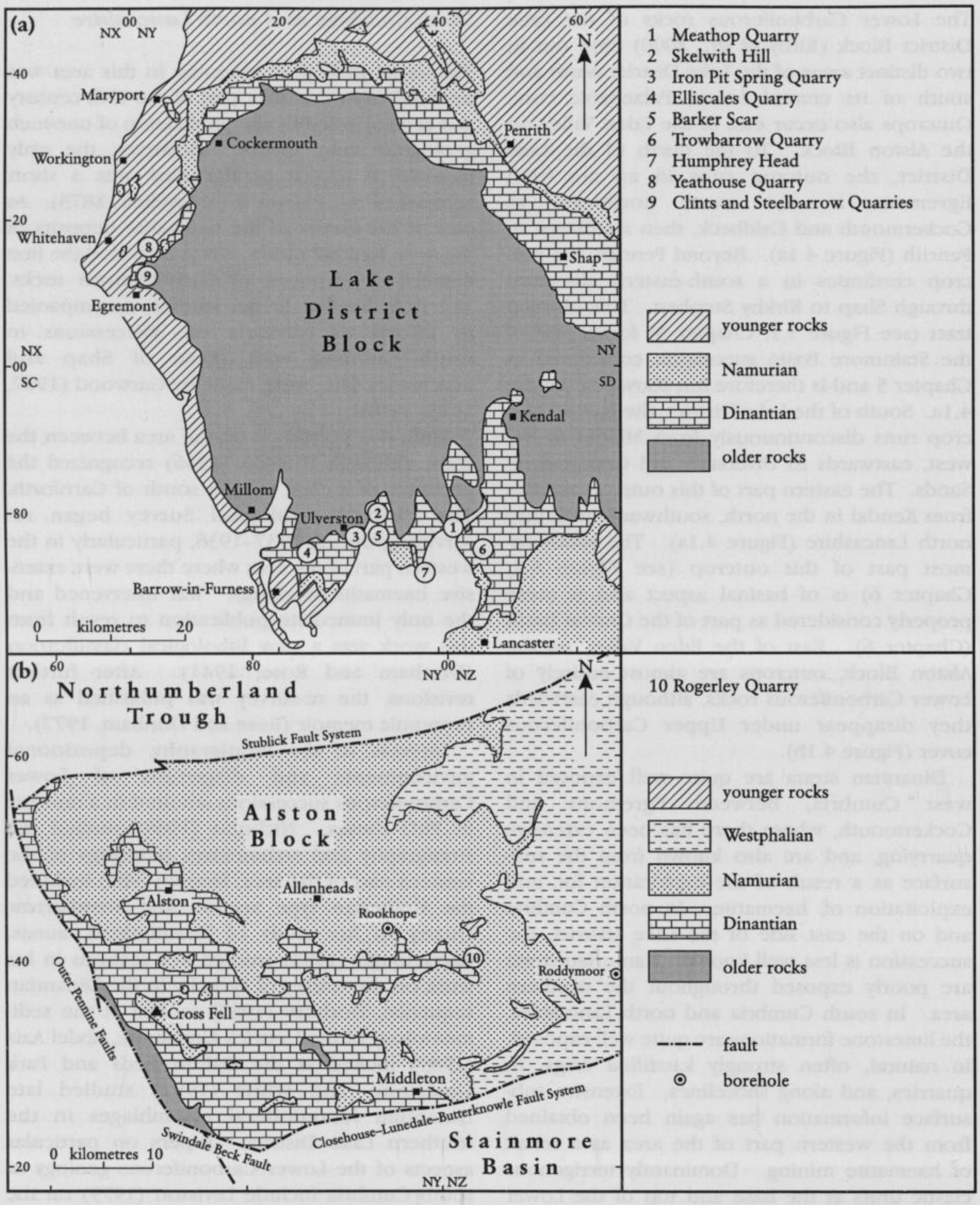


Figure 4.1 Geological maps of the Lake District Block and the Alston Block areas showing the distribution of Carboniferous outcrops and the locations of GCR sites mentioned in the text. (a) The Lake District Block (after Moseley, 1978). (b) The Alston Block (after Dunham, 1990). Note that details of the geology outside of the Alston Block area are omitted.

the Urswick Limestone, Horbury (1992) on some small reefs near the shelf edge in north Lancashire, Adams *et al.* (1992) on the significance of the microflora of the Urswick Limestone, and Horbury and Adams (1996) on microfacies in the Urswick Limestone.

Overviews of the Carboniferous geology of the area include Mitchell (1978), Ramsbottom (1978a) and Adams *et al.* (1990). More recent work by the British Geological Survey has led to the publication of the 1:50 000 map and memoir for Ulverston (British Geological Survey, 1997a; Johnson *et al.*, 2001); the map and memoir for the Lancaster district (British Geological Survey, 1995a; Brandon *et al.*, 1998) and, following subsurface investigations of the Craven Basin district to the south, palaeogeographical maps of the area (Kirby *et al.*, 2000).

West and north Cumbria

Early mentions of Lower Carboniferous geology in this area can be found in papers by Sedgwick and Peile (1835), Brockbank (1869) and Holmes (1881). The first detailed descriptions were by Kendall (1885), but undoubtedly the most significant contributions to understanding the Lower Carboniferous geology of the area were by Edmonds (1922) on the limestones between Lamplugh and Egremont, and the [British] Geological Survey memoirs for Whitehaven and Workington (Eastwood *et al.*, 1931), Maryport (Eastwood, 1930), Cockermouth and Caldbeck (Eastwood *et al.*, 1968) and Penrith (Arthurton and Wadge, 1981). Other contributions to the stratigraphy of the area were made by Butcher (1974) and Welsh (1980).

The sedimentology of the limestones of west Cumbria was studied by Stabbins (1969a,b) and the sedimentology of the Asbian part of the succession was discussed in detail by Thurlow (1996). In recent years interest in the subsurface geology of the Sellafield area south of the west Cumbrian outcrop has led to some revisions to the local geology (Barclay *et al.*, 1994) and these results have been incorporated into a new British Geological Survey memoir for the west Cumbrian district (Akhurst *et al.*, 1997). Overviews of the geology include Shackleton (1962) on the limestones of west Cumbria, Mitchell (1978) and Ramsbottom (1978a) on the Dinantian and Namurian rocks of the Lake District area respectively, and Johnson (1992) on the Dinantian cyclicity in west Cumbria.

Alston Block

The Lower Carboniferous succession on the Alston Block was originally established by Forster (1809, 1821). Phillips (1836), working mostly farther south on the Askrigg Block, introduced the term 'Yoredales' for the cyclic sequences of limestones, shales and sandstones of late Viséan age, and much early work involved correlating the characteristic parts of the sequences (the limestones) from the Askrigg Block to the Alston Block and northwards to the Northumberland Basin (e.g. Gunn, 1898, 1899; Turner, 1927; Trotter and Hollingworth, 1932). Garwood (1913) included the southern part of the Alston Block in his study of the Lower Carboniferous rocks of north-west England and described the faunas and correlation with the Ravenstonedale area. Turner (1927) enlarged on Garwood's work and provided more details of the faunas. A borehole at Crook (Roddymoor) in the eastern part of the block revealed one of the thickest successions of Lower Carboniferous strata on the Alston Block (Woolacott, 1923).

Detailed descriptions of the succession were first supplied by Dunham (1948, revised 1990) in the [British] Geological Survey memoir on the Northern Pennine Orefield, and subsequently by Johnson and Dunham (1963) in their account of the geology of the Moor House National Nature Reserve. Critical stratigraphical information was subsequently obtained from the Rookhope Borehole, drilled primarily to investigate the Weardale Granite (Dunham *et al.*, 1965), and the Allenheads boreholes (Dunham and Johnson, 1962; Dunham, 1990). Details of the 'Yoredale' successions are provided by Johnson and Hickling (1970). A more general account of the geology of the Alston Block area was given by Taylor *et al.* (1971); details of the geology of the Cross Fell region have been supplied by Burgess and Wadge (1974). Further accounts of the stratigraphy (including revisions) and the correlation of sequences into neighbouring areas appear in Holliday *et al.* (1975), Burgess and Mitchell (1976), George *et al.* (1976) and Johnson *et al.* (1995). Areas in the southern, western and north-eastern regions of the Alston Block are described respectively in the [British] Geological Survey memoirs for Brough-under-Stainmore (Burgess and Holliday, 1979), Penrith (Arthurton and Wadge, 1981) and Newcastle-upon-Tyne, Gateshead and Consett (Mills and

Holliday, 1998). Late Dinantian and Namurian strata from West Allendale near the northern margin of the Alston Block were described by Johnson *et al*. (1980a). Foraminiferal assemblages in the Dinantian strata of the Rookhope and Allenheads No.1 boreholes were described by White (1992). The most important sedimentological work has been that of Elliott (1973, 1974a, 1975, 1976b) on the deltaic deposits of early Namurian 'Yoredale' successions.

Stratigraphy

Stratigraphical studies in the three areas of Lower Carboniferous outcrop discussed here have evolved separately, although many authors have made correlations between these and adjacent areas. Thus the three areas are here considered separately.

South Cumbria and north Lancashire

Up to about 1390 m of Lower Carboniferous strata are known in this area and these most probably attain their greatest thickness in the Furness district. The initial survey of the area in the latter part of the nineteenth century led to recognition of three divisions, comprising a major unit of Carboniferous Limestone underlain by a variable unit, mostly of conglomerates, sandstones and shales, referred to the Basement Beds, and overlain by sandstones, shales and limestones referred to the Yoredales. Kendall (1885, 1893) refined this slightly by adding a unit termed the 'Lower Limestone Shales' between the Basement Beds and the main limestone. The first detailed stratigraphical scheme was erected by Garwood (1913) who proposed a zonation for the area (Figure 4.2) based on the characteristics of the Lower Carboniferous successions seen in the Shap–Ravenstonedale type district to the east (see Figures 5.1 and 5.3, Chapter 5). As described by Rose and Dunham (1977), this zonation scheme comprises a number of faunal assemblage zones, most of which are defined on lithological characteristics, with individual zone boundaries marked by faunal bands.

Dunham and Rose (1941) proposed the lithological classification, which can be applied across the whole of the south Cumbria and north Lancashire area. Some modifications were made as a result of further work, and incorporated in the [British] Geological Survey memoir of Rose and Dunham (1977) (Figure 4.2). They recognized up to 240 m of basal clastics, up to 600 m of shelf limestone and approximately 100 m of mixed carbonates and clastics of Dinantian age, plus 450 m of marine shales and sandstones attributed to the Namurian Series. Dating of the latter showed that they are entirely of Pendleian age and hence belong to the Lower Carboniferous Subsystem as used in this volume.

In their paper on the regional stages of the Dinantian Subsystem, George *et al*. (1976) chose Barker Scar as the stratotype for the Holkerian Stage, the base of the stage coinciding with the Dalton Beds–Park Limestone boundary. This has subsequently been discovered to be an unfortunate choice since much of the succession is dolomitized at this level (Abdel Aziz, 1989) and there is thought to be a non-sequence at the boundary (Riley, 1993). Further complications at Barker Scar arise from the recent re-definition of the Dalton Beds–Park Limestone boundary below the Arundian–Holkerian stage boundary (Johnson *et al*., 2001; and see **Barker Scar** GCR site report, this chapter). Mitchell (1978) further discussed the stratigraphy of Dinantian rocks and correlated them with the successions in west and north Cumbria, Shap and Ravenstonedale. Ramsbottom (1978a) provided similar correlations for the Namurian Series. Note that recent slight revisions to the lithostratigraphical nomenclature of the Dinantian sequence in south Cumbria (Johnson *et al*., 2001) were published after the present text was submitted for publication. These revisions have not therefore been adopted in the present account.

West and north Cumbria

About 700 m of Dinantian and early Namurian strata are known in north and west Cumbria. The stratigraphy of the west Cumbrian Carboniferous sequence has recently been reviewed by Akhurst *et al*. (1997). The classification developed by Kendall (1885), Edmonds (1922) and Eastwood *et al*. (1931) has been adopted for the exposed succession (Figure 4.2), with limestones and shales numbered from the top downwards, but in the subsurface, in the Sellafield area, the south Cumbrian nomenclature has been found to be more applicable (Barclay *et al*., 1994). The major mass of limestone in this area is also known as the 'Chief Limestone Group', which spans strata from

Chadian to Namurian age. The nomenclature of the Chief Limestone Group in west Cumbria is shown in Figure 4.3. As this succession is traced eastwards the amount of terrigenous sediment in the upper part increases.

In the Namurian Series, strata above the First Limestone (which is correlated with the Great Limestone of the Alston Block), are referred to the Hensingham Group. The lowest unit of the group is the Hensingham Grit, found only in west Cumbria. Eastwards, the succession thickens and comprises mostly mudstones with thin sandstones and limestones. Most of the succession has been dated as Pendleian and Arnsbergian in age (Ramsbottom, 1978a) (Figure 4.2).

Alston Block

The Lower Carboniferous succession on the Alston Block is up to nearly 700 m in thickness, consisting of maxima of nearly 450 m of Dinantian strata and 250 m of early Namurian strata. Because of mining interests in the area, the basic geological succession was worked out earlier than in many other areas (Forster, 1809, 1821) and subsequent work has served only to confirm and refine the lithological units and to add biostratigraphical information.

On the Alston Block, the oldest strata are thin sandstones and conglomerates known from the Roddymoor, Allenheads and Rookhope boreholes and referred to the Basement Beds (Dunham, 1990). The first appearance of marine strata marks the base of the Orton Group, recognized in areas to the south and west of the Alston Block where it embraces strata from Chadian to Holkerian age (Burgess and Holliday, 1979). On the Alston Block, no Carboniferous strata older than Holkerian age have been recorded, and the Orton Group, consisting of limestones, shales and sandstones, is typically 20–40 m thick (Dunham, 1990). The Orton Group is known from immediately north of the Swindale Beck Fault, from the Cronkley Inlier in Teesdale and from the Roddymoor Borehole. The occurrence of marine rocks of this age both here and towards the block margin indicate that these areas were flooded by sea water at an earlier stage than in many of the remaining central areas where the earliest Carboniferous and marine beds recognized are Asbian in age (Johnson and Dunham, 1963; Burgess and Holliday, 1979; Ridd *et al.*, 1970; Johnson *et al.*, 1995).

The Asbian succession, formerly referred to the Lower Limestone Group and now the Lower Alston Group, consists of the Melmerby Scar Limestone, the thickest individual limestone in the Lower Carboniferous succcession, overlain by the Robinson Limestone with alternations of shale and sandstone (Figure 4.2). The Brigantian succession, formerly the Middle Limestone Group and now the Upper Alston Group, is characterized by Yoredale facies. The best documented and the most complete sequence is that recorded in the Rookhope Borehole (see Figure 4.4; and Johnson and Nudds, 1996). Much of the Namurian succession is of Pendleian–Arnsbergian age and was originally referred to the Upper Limestone Group (Dunham, 1990). It begins with the Great Limestone (see Fairbairn, 1978, 1980, 2001), second only in thickness to the Melmerby Scar Limestone in the whole Carboniferous succession, and is overlain by alternating sandstones and shales with subordinate limestones. Further details of the stratigraphy in this area are provided by Johnson *et al.* (1995).

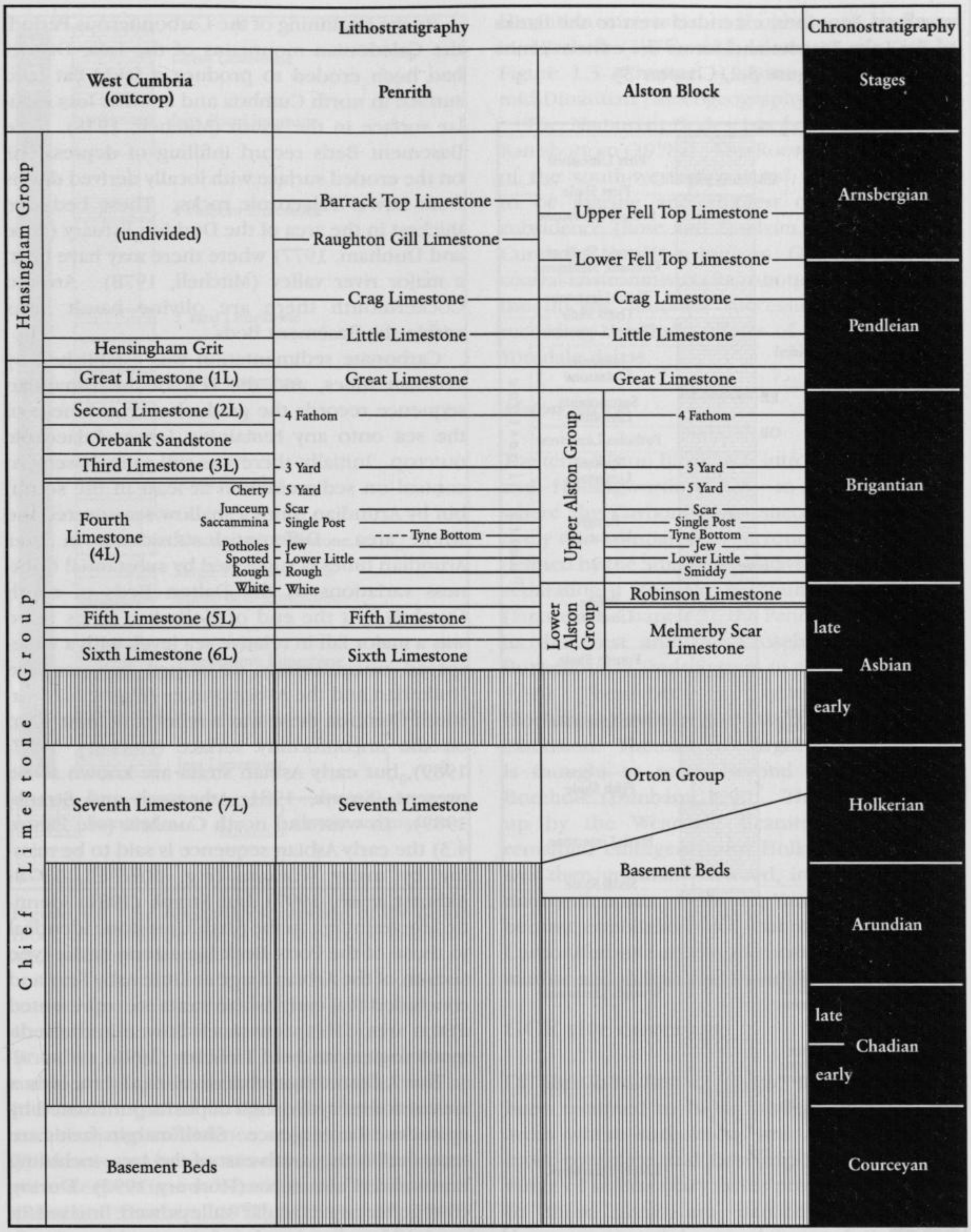
Geological setting

Cumbria and north Lancashire

During Early Carboniferous times, most of the Lake District area lay on the relatively stable Lake District Block (Kirby *et al.*, 2000) and was underlain by a Caledonian basement comprising Lower Palaeozoic sedimentary rocks and the Lake District granitic batholith (Bott, 1978; Moseley, 1978). To the north, this block was bounded by the Maryport Fault, an active structure that separated the block from the Solway Basin (Chadwick *et al.*, 1993a,b) (Figure 3.1, Chapter 3). The block had a gentle regional dip to the south and for much of Dinantian times probably acted as a ramp (Adams *et al.*, 1990) passing gradually into the deeper waters of the westwards extension of the Craven Basin, although in the southeast of the area the Hutton Monocline may have been an active structure separating the block from the Lancaster Fells Basin (Gawthorpe *et al.*, 1989) (Figure 6.1, Chapter 6). Certainly by Asbian times a shelf margin had developed in the Carnforth area (Hudson, 1936; Horbury, 1987, 1992). The southward-dipping flank to the Lake District Block is now generally referred to as the 'South Lake District High' (Gawthorpe *et al.*, 1989). The Stainmore Basin, which separates the Askrigg Block and Alston Block of the

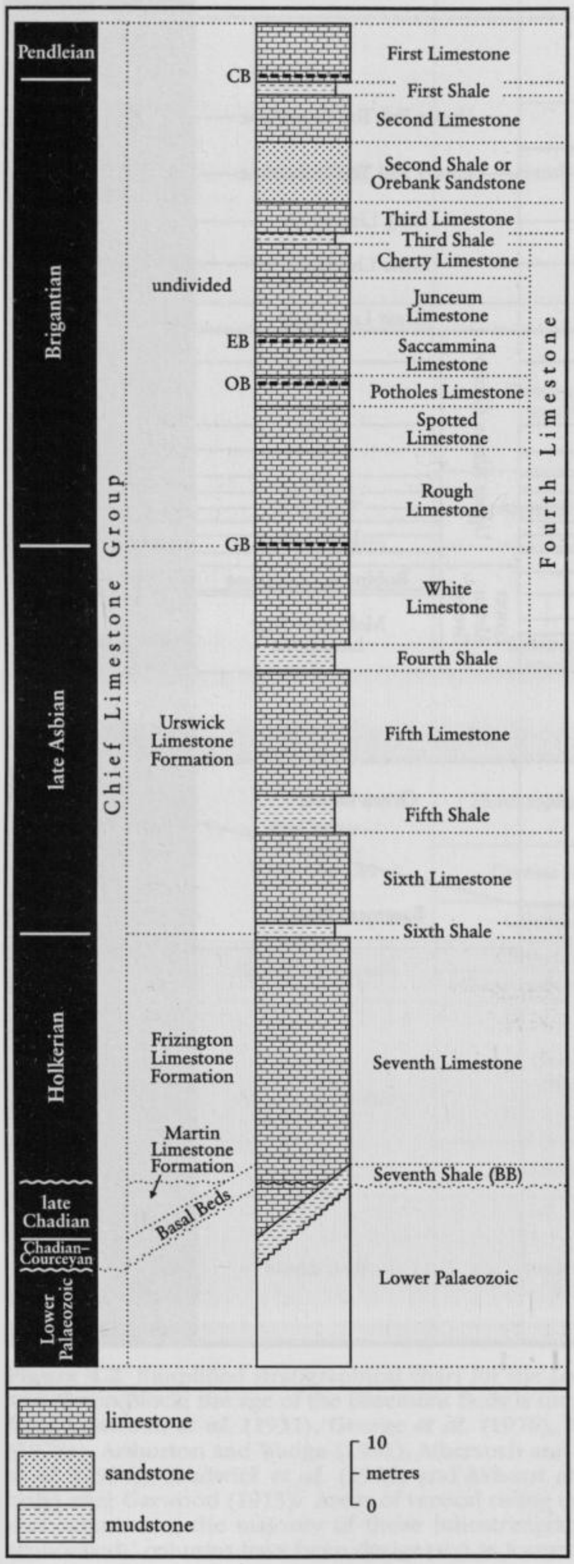
Chronostratigraphy	Biostratigraphy		Lithostratigraphy	
Stages	Zones	Subzones	South Cumbria	West Cumbria (concealed)
Arnsbergian	(undivided)	(undivided)		
Pendleian			Roosecote Mudstones	
Brigantian	Dibunophyllum	*Dibunophyllum muirheadi*	Gleaston Formation	
		Lonsdaleia floriformis		
Asbian late		*Cyathophyllum murchisoni*	Urswick Limestone	Urswick Limestone
Asbian early				
Holkerian	*Productus corrugato-hemisphericus*	*Nematophyllum minus*	Park Limestone	Frizington Limestone
		Cyrtina carbonaria		
Arundian	*Michelinia grandis*	Gastropod Beds	Dalton Beds	
		Chonetes carinata		
		Camarophoria isorhyncha	Red Hill Oolite	
Chadian late	*Athyris glabristria*	*Seminula gregaria*	Martin Limestone	Martin Limestone
		Algal Band		
Chadian early		*Solenopora*		
Courceyan	(undivided)	(undivided)	Basement Beds	Basal Beds

Figure 4.2 Simplified stratigraphical chart for the Lower Carboniferous succession of the Lake District Block and Alston Block; the age of the Basement Beds is uncertain in many areas. Compilation based on information from Eastwood *et al.* (1931), George *et al.* (1976), Rose and Dunham (1977), Mitchell (1978), Ramsbottom (1978a), Arthurton and Wadge (1981), Athersuch and Strank (1989), Horbury (1989), Dunham (1990), Barclay *et al.* (1994), Chadwick *et al.* (1995) and Akhurst *et al.* (1997). Zonal biostratigraphy (Chadian–Brigantian only) after Garwood (1913). Areas of vertical ruling indicate non-sequences. Not to scale. Note that following text submission, the majority of those lithostratigraphical units in the 'South Cumbria' and 'West Cumbria (concealed)' columns have been designated as formations (Johnson *et al.*, 2001).



Lithostratigraphy
Chronostratigraphy
West Cumbria (outcrop)
Penrith
Alston Block
Stages
Hensingham Group
(undivided)
Hensingham Grit
Barrack Top Limestone
Raughton Gill Limestone
Crag Limestone
Little Limestone
Upper Fell Top Limestone
Lower Fell Top Limestone
Crag Limestone
Little Limestone
Arnsbergian
Pendleian
Chief Limestone Group
Great Limestone (1L)
Second Limestone (2L)
Orebank Sandstone
Third Limestone (3L)
Fourth Limestone (4L)
Cherty
Junceum
Saccammina
Potholes
Spotted
Rough
White
Fifth Limestone (5L)
Sixth Limestone (6L)
Seventh Limestone (7L)
Basement Beds
Great Limestone
4 Fathom
3 Yard
5 Yard
Scar
Single Post
Tyne Bottom
Jew
Lower Little
Rough
White
Fifth Limestone
Sixth Limestone
Seventh Limestone
Upper Alston Group
Great Limestone
4 Fathom
3 Yard
5 Yard
Scar
Single Post
Tyne Bottom
Jew
Lower Little
Smiddy
Robinson Limestone
Lower Alston Group
Melmerby Scar Limestone
Orton Group
Basement Beds
Brigantian
late
Asbian
early
Holkerian
Arundian
late
Chadian
early
Courceyan

northern Pennines, extended west to the flanks of the Lake District and forms the eastern limits of the block (Figure 3.2, Chapter 3).



◂Figure 4.3 Stratigraphy of the Lower Carboniferous Chief Limestone Group in west Cumbria. (BB – Basement Beds; GB – Girvanella Band (= Girvanella Nodular Bed, see **Clints and Steelbarrow Quarries** GCR site report, this chapter); OB – Orionastraea Band; EB – Erythrospongia Band; CB – Chaetetes Band.) After Akhurst *et al.* (1997).

By the beginning of the Carboniferous Period, the Caledonian mountains of the Lake District had been eroded to produce a fairly flat land surface in north Cumbria and a rather less regular surface in the south (Mitchell, 1978). The Basement Beds record infilling of depressions on the eroded surface with locally derived debris from Lower Palaeozoic rocks. These beds are thickest in the area of the Duddon Estuary (Rose and Dunham, 1977) where there may have been a major river valley (Mitchell, 1978). Around Cockermouth there are olivine basalt lavas within the Basement Beds.

Carbonate sedimentation was established by Chadian times, and the rest of the Dinantian sequence records the gradual encroachment of the sea onto any remaining Lower Palaeozoic outcrop. Initially, there was still some basement control on sedimentation at least in the south, but by Arundian times a shallow sea covered the whole area. Differential subsidence in later Arundian times is suggested by substantial thickness variations in the Dalton Beds of south Cumbria. At the end of Holkerian times there was a major fall in relative sea level, with a widespread unconformity developed between the Holkerian and the Asbian stages (Figure 4.2). In south Cumbria there was a relief of at least 20 m on the unconformity surface (Horbury, 1987, 1989), but early Asbian strata are known to be present (Strank, 1981; Athersuch and Strank, 1989). In west and north Cumbria (see Figure 4.3) the early Asbian sequence is said to be missing by many workers (e.g. Mitchell, 1978; Akhurst *et al.*, 1997), but Strank (1981) identified foraminifera in the Sixth Limestone identical to those of the Potts Beck Limestone in the type section of the Asbian Stage at Little Asby Scar and concluded that early Asbian strata are represented in the area. This view was followed in the sedimentological study of Thurlow (1996).

The Asbian Stage characteristically records a succession of cyclic shelf deposits punctuated by episodes of emergence. Shelf-margin facies are recorded in the south-east of the area, including unusual reef structures (Horbury, 1992). During emergence, spectacular valleys were incised in

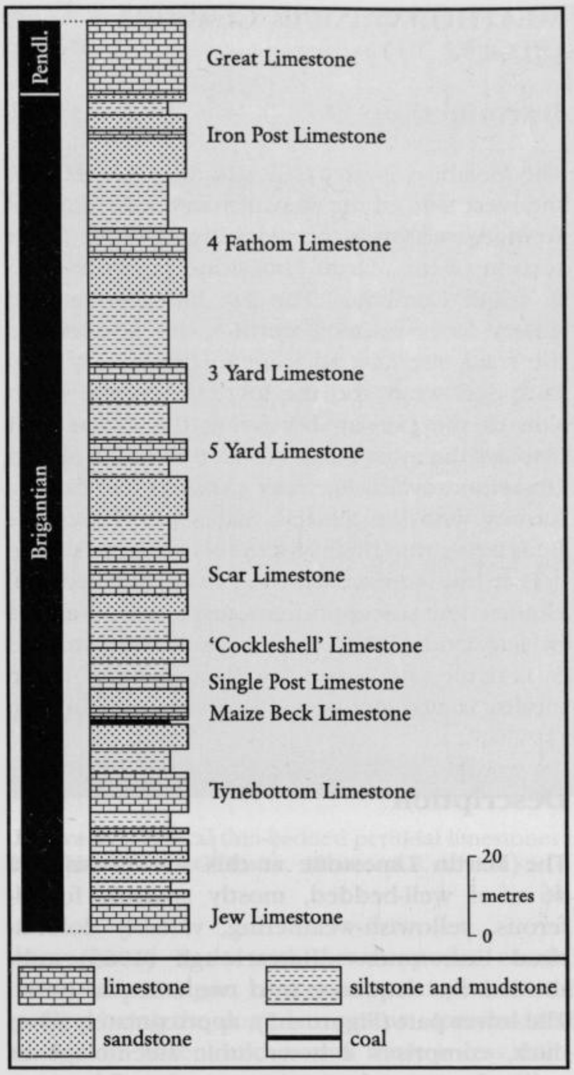


Figure 4.4 The Brigantian succession of the Alston Block as typified by that of the Rookhope Borehole. After Holliday *et al.* (1975).

shelf-margin successions (Horbury, 1987; Brandon *et al.*, 1998). The Brigantian Stage marks a change in sedimentation style, with an increased input of terrigenous clastic material and increased subsidence, at least in some areas. Thickness and facies patterns suggest that waters were deepest in a sub-basin in the Furness area (Rose and Dunham, 1977; Adams *et al.*, 1990). On the evidence of abundant basalt pebbles and associated Carboniferous Limestone fragments in Permian conglomerates in the Humphrey Head Borehole, Adams and Wadsworth (1993) inferred the presence of late Dinantian basaltic lavas in south Cumbria, not seen at outcrop today. General accounts of the development of the Dinantian succession in Cumbria can be found in Mitchell (1978) and Adams *et al.* (1990). Figure 1.3 (Chapter 1) shows the generalized mid-Dinantian palaeogeography of the area.

The Namurian Series has been reviewed by Ramsbottom (1978a). The Roosecote Mudstones of the south-western part of the area appear to be marine and suggest continued rapid subsidence (Rose and Dunham, 1977). In west Cumbria, the Hensingham Grit may record coastal environments (Ramsbottom, 1978a), with the thicker, muddier successions farther east recording the distal effects of the encroaching Yoredale deltas.

Alston Block

The term 'Alston Block' was introduced by Trotter and Hollingworth (1928) to define an area where the Carboniferous successions are relatively thin compared to surrounding areas. It is defined by the Stublick Fault System in the north, separating it from the Northumberland Trough (Figure 3.1, Chapter 3), the Pennine Fault System in the west and the Closehouse–Lunedale–Butterknowle Fault System in the south (Figure 4.1b). These latter fault systems separate the block from the Stainmore Basin and its westward extension. The eastern margin is obscured, but is thought to reach beyond the Roddymoor Borehole (Dunham, 1990). The block, buoyed up by the Weardale Granite (Bott, 1967), remained emergent until Holkerian times, but was then gradually covered, initially by mostly marine deposits. However, Yoredale facies soon became established such that most of the Lower Carboniferous succession consists of alternating marine and deltaic and fluvio-deltaic deposits.

GCR site coverage

On the Lake District Block, site selection has been confined to those western and southern areas where successions are at their thickest, most complete and best exposed. The great range of sedimentary facies present at GCR sites in these areas are particularly useful in demonstrating the progressive evolution of the carbonate platform that developed over the block area during Early Carboniferous times. In an attempt to ensure representative coverage, sites have been chosen that reveal the most important sections of the principal lithostratigraphical intervals (formations) and/or sections that span critical chronostratigraphical stage boundaries, many of which include features of additional specific sedimentological and/or palaeontological interest.

In the carbonate-dominated successions of south Cumbria the GCR sites include **Meathop Quarry** (Chadian, Martin Limestone), **Skelwith Hill** (Chadian–Arundian, Martin Limestone–Red Hill Oolite, non-sequence with calcretes and breccias), **Iron Pit Spring Quarry** (Arundian, Dalton Beds, 'Arnside Fauna'), **Elliscales Quarry** (Arundian, reefs), **Barker Scar** (Arundian–Holkerian, Dalton Beds–Park Limestone, Holkerian Stage stratotype), **Trowbarrow Quarry** (Asbian, Urswick Limestone, sedimentology) and **Humphrey Head** (Asbian–Brigantian, Urswick Limestone–Gleaston Formation, Girvanella Nodular Bed, faunas). Recent quarrying near Carnforth has revealed several potential GCR sites close to the southern margin of the Lake District Block; however, these require further evaluation before amendments to the GCR site list in this area are considered. In the mixed clastic and carbonate successions of west Cumbria, the sites include **Yeathouse Quarry** (?Courceyan/Chadian–Asbian, Basal Beds–White Limestone) and the **Clints and Steelbarrow Quarries** complex (Asbian–Brigantian, Fifth Limestone–Fourth Limestone). The absence of early Namurian (Pendleian–Arnsbergian) GCR sites in Cumbria is a function of poor exposure.

Site coverage on the Alston Block is, by comparison, relatively poor and confined to the exceptional sedimentological site at **Rogerley Quarry** (distributary channel in the Great Limestone Cyclothem, Pendleian). Reasons for the dearth of sites in this area include the attenuated and incomplete Lower Carboniferous succession and, most significantly, the apparent uniformity of facies (particularly of 'Yoredale-style' sedimentary cyclicity) between the Alston Block and neighbouring regions where the facies is represented at other GCR sites (e.g. **Tipalt Burn** in the Northumberland Trough and the **How Gill** and **Sleightholme Beck** sites in the Stainmore Basin) and at the Moor House National Nature Reserve (Johnson and Dunham, 1963). Notwithstanding these comments and the discontinuous nature of Lower Carboniferous exposure in the region, the potential for the identification of new GCR sites on the Alston Block (especially those of an Asbian or Brigantian age) remains.

MEATHOP QUARRY, CUMBRIA (SD 432 791)

Introduction

The Meathop Quarry GCR site (SD 432 791), on the west side of the Kent Estuary, 3 km ENE of Grange-over-Sands, provides arguably the finest section of the Martin Limestone (late Chadian) in south Cumbria. The site includes the old quarry faces running north–south adjacent to the road, the face adjacent to the railway, running east–west, and the low cliff on the south side of the railway, bordering the estuary. It displays the most complete section of the Martin Limestone available, from close to the unconformity with the Silurian Slates (the Basement Beds being thin or absent in this area; see Figure 4.2) to the contact with the overlying Red Hill Oolite. The succession was originally described by Garwood (1913) and has since been studied by Leviston (1979) and Barraclough (1983). The locality is also mentioned by Rose and Dunham (1977).

Description

The Martin Limestone at this site consists of 46 m of well-bedded, mostly sparsely fossiliferous, yellowish-weathering, variably dolomitized limestones. Barraclough (1983) subdivided the sequence into two unequal parts. The lower part (Figure 4.5), approximately 33 m thick, comprises a heterolithic assemblage of pellet-dominated mudstones, wackestones, packstones and grainstones, stromatolite and oncoid units, calcretized beds and calcareous shales. Dolomite is present in many beds, especially in coarser units and in the stromatolites. At its base, Garwood (1913) recorded the Camarotoechia proava Band and, some 2–4 m above the base of the section, an algal limestone development (Garwood's 'Algal Layer') associated with beds containing desiccation polygons. One prominent desiccation horizon 4 m up from the base and formerly displayed as a magnificent polygonal mud-cracked bedding-plane surface (e.g. Leviston, 1979, plate 1) has now been partly lost as a result of specimen collection.

The remaining 12 m of Martin Limestone is much less variable than the lower part. Barraclough (1983) described it as 'mixed faunal packstone', comprising poorly sorted

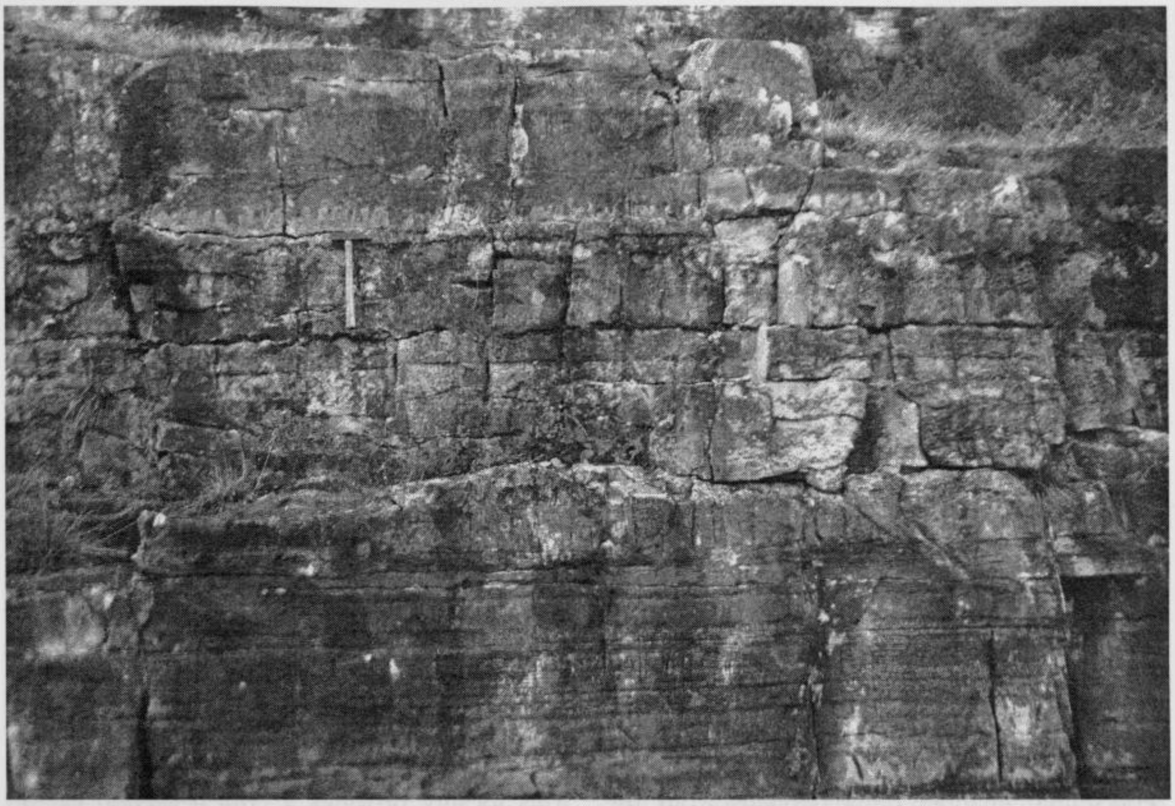


Figure 4.5 Typical thin-bedded peritidal limestones in the lower part of the Martin Limestone (Chadian) at the Meathop Quarry GCR site. (Photo: A.E. Adams.)

bioturbated beds with brachiopods, corals, foraminifera, algae, bryozoans, calcispheres and pellets being the dominant grains. Interbedded shales are absent and overall there is less dolomite, although some is present in most beds.

At the top of the quarry, the Spirifer furcatus Band described by Garwood (1913) is a rubbly weathering bed containing oncoids and fragmented fossils that Mitchell (1978) assigned to the Red Hill Oolite (Arundian). Garwood (1916) later described this as the richest development of the Spirifer furcatus Band in the 'North-West Province'.

Beds below the 'Algal Layer' were originally ascribed to the *Solenopora* Subzone by Garwood (1913) and those above this horizon to the *Seminula gregaria* Subzone. Much of Garwood's *Athyris glabristria* Zone is therefore represented in the section. Details of the fauna and flora were also provided by Garwood (1913), who recorded *Archaeosigillaria vanuxemi* and fragments of *Bothrodendron* (Jackson, 1910) from calcareous shales in the lower part of the succession, and a rich coral fauna from the higher *Seminula gregaria* Subzone beds that included a number of 'new' taxa, namely *Siphonophyllia 'Campophyllum' ciliata*, *Axophyllum 'Carcinophyllum' simplex*, *Carruthersella compacta*, *Koninckophyllum 'Lophophyllum' meathopense* and *K. 'L'. vesiculosum*, an assemblage most typical of the Chadian Stage (Mitchell, 1989; Riley, 1993). In addition, N. Riley (pers. comm., 2002) has noted the presence of *Eoparastaffella* and bilaminar *Koninckopora* in the *Seminula gregaria* Subzone beds indicating a late Chadian, basal Viséan age for this part of the succession. Fossils are not, however, abundant and much of the fauna is fragmented.

Interpretation

Garwood (1913) correlated the oncoid-bearing unit (his 'Algal Layer') in the lowest part of the succession at Meathop with a similar 'Algal Layer' at the top of the Coldbeck Beds (= Coldbeck Limestone; see Figure 5.3, Chapter 5) at Ravenstonedale that Mitchell (1972) and

Ramsbottom (1973) took as a marker for the Tournaisian–Viséan boundary in northern England (see **Stone Gill–Scandal Beck** GCR site report, Chapter 5). Thus the lowest 4 m of limestones at Meathop Quarry were originally assigned to the Tournaisian Series (Courceyan Stage) and the overlying beds to the Viséan Series (Chadian Stage) (Rose and Dunham, 1977). However, the Coldbeck Limestone is now attributed entirely to the Chadian Stage, with the 'Algal Layer' indicating a mid-Chadian regression (Ramsbottom, 1977a). The Martin Limestone is now regarded as being entirely of Chadian age, with the oncoid band and associated desiccated surface attributed to the mid-Chadian regression (Mitchell, 1978).

Nicholas (1968) and Leviston (1979) recognized that the Martin Limestone in south Cumbria records shallow marine and tidal-flat deposition. Barraclough (1983) made more detailed interpretations and suggested that in the lower part of the succession, the finer-grained units represented channel, pond and algal marsh sub-environments of a tidal-flat complex and the coarser grainstone units represented channel delta deposits from the seaward side of the tidal flat. The mixed faunal packstones that form the upper part of the succession at Meathop Quarry were interpreted as shallow offshore shelf deposits by Barraclough (1983) and thus represent a transgressive episode that flooded the tidal-flat complex.

The brecciated appearance of the Spirifer furcatus Band has been taken as evidence of a non-sequence at the base of the Arundian Stage (Mitchell, 1978), although Adams and Cossey (1981) and Barraclough (1983) noted the absence of any features diagnostic of emergence, in contrast to sections across the Chadian–Arundian boundary around the Leven Estuary to the west, where emergent features are well developed.

Conclusions

Meathop Quarry is the best exposure of the lowest part of the Carboniferous Limestone succession in south Cumbria. The site is valuable for its excellently displayed carbonate rocks and structures representing the deposits of a tidal-flat complex and for the evidence for drowning of the complex as a result of relative sea-level rise during Chadian times.

SKELWITH HILL, CUMBRIA (SD 331 809)

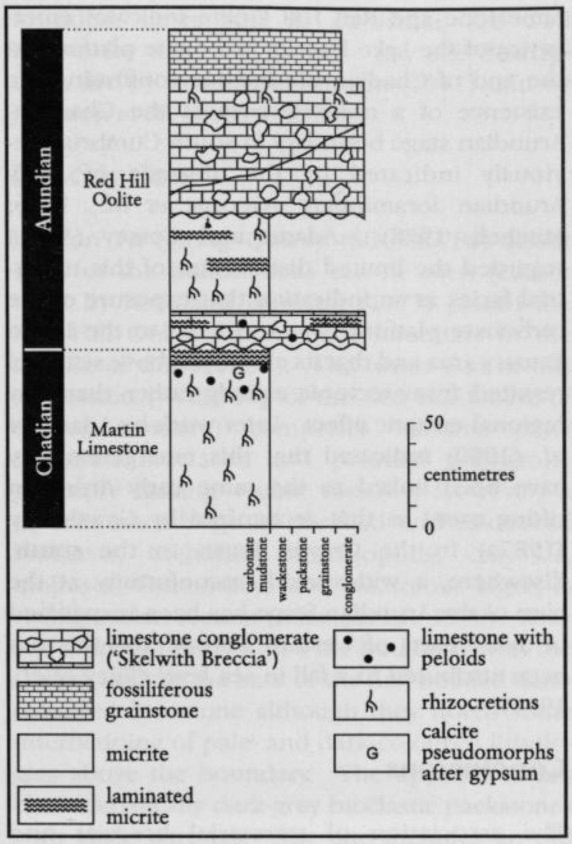
Introduction

The Skelwith Hill GCR site (SD 331 809) is a shoreline cliff section on the eastern side of the Leven Estuary, 2.5 km south-east of Greenodd, south Cumbria. It shows an exceptional section of terrestrial deposits at the junction between the predominantly marine sequences of the Martin Limestone and the Red Hill Oolite. The development of multiple calcrete profiles and possible mudflows seen here mark this as one of the most important sites for the exposure of the Chadian–Arundian stage boundary in south Cumbria. Significant descriptions of the geology are given by Nicholas (1968), Rose and Dunham (1977), Leviston (1979) and Barraclough (1983), but the account that follows is based largely on the sedimentological study by Adams and Cossey (1981).

Description

This locality provides a critical section of the junction between the Martin Limestone and the Red Hill Oolite (Dunham and Rose, 1941; Rose and Dunham, 1977) (Figures 4.6 and 4.7). Locally this boundary defines the line of division between the *Seminula gregaria* Subzone (*Athyris glabristria* Zone) and the *Camarophoria isorhyncha* Subzone (*Michelinia grandis* Zone) of Garwood (1913, 1916), the boundary between 'Major Cycles 2 and 3' of Ramsbottom (1973), and the Chadian–Arundian stage boundary of George *et al.* (1976). Early accounts make reference to fabrics of algal origin close to, but either side of, the Martin Limestone–Red Hill Oolite boundary (Nicholas, 1968; Rose and Dunham, 1977; Leviston, 1979), and to the development of limestone breccias, considered as marine in origin, at the base of the Red Hill Oolite (Leviston, 1979). The existence of breccias at this level was taken by Ramsbottom (1973) and Mitchell (1978) to indicate a stratigraphical break and non-sequence at the Chadian–Arundian boundary prior to the main Arundian transgressive event. In their re-evaluation of the Skelwith succession, Adams and Cossey (1981) described this part of the sequence in detail (see Figure 4.6).

At the base of the sequence, less than 2 m of Martin Limestone is exposed, comprising



◄**Figure 4.6** Simplified sedimentary log across the Martin Limestone–Red Hill Oolite boundary at the Skelwith Hill GCR site. After Adams and Cossey (1981).

unfossiliferous grey micrites with thin, discontinuous, sub-horizontal sheets of laminated micrite and short, elongate and crudely sub-vertical rods of sparry calcite (rhizocretions) which increase in density towards the top of the formation. Although formerly regarded as algal structures, the repeated association of these thin micritic layers with rhizocretions (rootlet structures), both at this level and in the overlying breccia, has resulted in their re-interpretation as laminar calcretes and the product of subaerial weathering in soil profiles during periods of emergence (Adams and Cossey, 1981). Some calcite pseudomorphs after gypsum also occur near the top of the Martin Limestone.

The breccia at the base of the overlying Red Hill Oolite (referred to here as the 'Skelwith Breccia') ranges in thickness from 0.3 m to 1.0 m and comprises 'rounded and subangular blocks of dark-grey limestone up to 5 cm in diameter set in a marly dolomitic matrix' (Rose and Dunham, 1977). Sorting in the breccia is generally poor, but matrix-supported fabrics are common and

Figure 4.7 Terrestrial breccias and calcretes at the junction of the Martin Limestone (Chadian) and the Red Hill Oolite (Arundian) at the Skelwith Hill GCR site. The prominent pale bed containing calcrete fabrics behind the hammer separates the two units of the Skelwith Breccia, one in the foreground below the hammer and the other immediately above the deeply weathered (recessed) layer. The stratigraphical position of these breccia beds is illustrated in Figure 4.6. (Photo: P.J. Cossey.)

clast composition is variable. Although the predominant clasts are either homogeneous micrites or fine pellet grainstones, some of the micrite clasts contain rhizocretions and are most probably locally derived from the underlying beds. Nicholas (1968) reported other clasts coated with micrite laminae and unusually blackened 'pebbles', the like of which cannot be seen at any level beneath the Dalton Beds in south Cumbria. Locally the breccia is split into two thinner units (Figure 4.7; and see Nicholas, 1968) separated by a micritic limestone with laminar calcrete fabrics and rhizocretions similar to those of the underlying Martin Limestone (Adams and Cossey, 1981). Calcrete laminae and rhizocretions also occur throughout the lower breccia, but rhizocretions only are found in the higher interval close to its top surface. Both breccia layers have irregular but sharp bases.

Above the Skelwith Breccia, Rose and Dunham (1941) reported 10 m of Red Hill Oolite with a rich coral–gastropod fauna in the basal 4 m section and rare shells together with *Syringopora* higher up in the sequence. The fauna includes *Michelinia megastoma*, *Spirophyllum 'Koninckophyllum' praecursor*, *Clisiophyllum*, *Palaeosmilia murchisoni*, *Axophyllum simplex*, *Syringopora* cf. *reticulata* and *Spiriferellina*, and is typical of the Arundian Stage. Lithologies are dominated by fossiliferous bioclastic and peloidal grainstones, but ooids are altogether lacking (Adams and Cossey, 1981; Adams *et al*., 1990).

Interpretation

The formation of multiple calcrete profiles at the top of the Martin Limestone and in the Skelwith Breccia at the base of the Red Hill Oolite indicates a period of prolonged subaerial exposure at the end of Chadian times and repeated episodes of soil formation in a terrestrial environment that was receiving a continuous supply of sediment (Adams and Cossey, 1981). The occurrence of laminar calcretes within the breccia indicates a terrestrial origin for the breccia, rather than a tectonic or marine origin as previously supposed by Garwood (1913) and Leviston (1979). Adams and Cossey (1981) considered the breccia to be a product of repeated mudflows, while Barraclough (1983) regarded it as an in-situ alteration product due to calcretization.

The development of terrestrial deposits sandwiched between marine beds of the Martin Limestone and Red Hill Oolite indicates emergence of the Lake District carbonate platform at the end of Chadian times; thus confirming the existence of a non-sequence at the Chadian–Arundian stage boundary in south Cumbria previously indicated by the absence of early Arundian foraminifera (George *et al*., 1976; Mitchell, 1978). Adams and Cossey (1981) regarded the limited distribution of this terrestrial facies as an indication that exposure of the carbonate platform was restricted to the Leven Estuary area and that its elevation above sea level resulted from tectonic activity rather than any regional eustatic effect. Later work by Adams *et al*. (1990) indicated that this emergence may have been linked to the same early Arundian rifting event as that recognized by Gawthorpe (1987a) in the Craven Basin to the south. Elsewhere, a widespread unconformity at the base of the Arundian Stage has been recognized in many parts of western Europe and this has been attributed to a fall in sea level (Riley *et al*., 1995).

Conclusions

The association of terrestrial breccias and calcrete palaeosols at this site provides convincing evidence of a break in the continuity of marine limestone deposition (non-sequence) in south Cumbria during early Arundian times. The spectacular calcretes seen here are among the finest and most complex of their kind to be found anywhere in the Lower Carboniferous successions of northern England. They developed within ancient soil profiles as the Lake District carbonate platform became exposed above sea level at the end of Chadian times. Together these features make Skelwith Hill a site of outstanding regional stratigraphical and sedimentological significance.

IRON PIT SPRING QUARRY, CUMBRIA (SD 311 783 and SD 308 786)

Introduction

The Iron Pit Spring Quarry GCR site is a disused quarry complex at Plumpton, 2 km east of Ulverston that offers important Arundian sections through the highly fossiliferous Dalton Beds. The localities are important for showing the deepening of the environment in mid-

Arundian times and, in particular, are well known for their rich faunas. Key site descriptions are by Rose and Dunham (1977) and by Johnson *et al.* (2001).

Description

In Iron Pit Spring Quarry (SD 308 786) about 12 m of the Dalton Beds can be seen (earlier work by Rose and Dunham (1977) placed the Red Hill Oolite–Dalton Beds boundary in the middle of this section). The lower 6 m of this succession (= the top of the Red Hill Oolite of earlier workers) comprises massive pale-coloured bioclastic and peloidal grainstone generally lacking visible fossils. However, a diverse assemblage of abraded and micritized bioclasts, including brachiopods, crinoids, molluscs, foraminifera and calcareous algae, is visible in thin-section (Adams *et al.*, 1990). Rose and Dunham (1977) took the boundary with the Dalton Beds at the base of the first bedded dark-coloured limestone although they noted some interbedding of pale- and dark-coloured lithologies above the boundary. The upper 6 m are characteristically dark-grey bioclastic packstones with shale partings. The site includes an old quarry to the south-east of Iron Pit Spring (SD 311 783) which exposes higher levels in the Dalton Beds (*c.* 17 m thick). The succession here comprises well-bedded dark-grey crinoidal limestones with shaly partings.

Interpretation

The Dalton Beds, particularly the lower part, are famous for their rich faunas, recognized by Garwood (1913, 1916) and named by him the 'Arnside Fauna'. At Iron Pit Spring, Rose and Dunham (1977) recorded a diverse coral assemblage, including *Caninia* sp. *cylindrica* group, *Clisiophyllum mutliseptatum*, *Koninckophyllum meathopense*, *Palaeosmilia murchisoni* and '*Zaphrentis*' *kentensis*. Numerous brachiopods are also recorded by Rose and Dunham (1977), with *Delepinea carinata*, the diagnostic fossil of Garwood's (1913) *Chonetes carinata* Subzone and a form recognized as typical of mid-Arundian times (Riley, 1993), being particularly abundant in the lower part of the unit.

The Dalton Beds record a deepening of the Lake District carbonate platform to at least below normal wave-base and were interpreted as mid- to outer-ramp deposits by Adams *et al.* (1990). These somewhat deeper, calmer waters were favourable for the development of a prolific fauna.

Conclusions

This site is ideal for studying the prolific 'Arnside Fauna' and represents a valuable teaching and research resource. The site is also invaluable for recording the progressive deepening of the Lake District carbonate platform in Arundian times.

ELLISCALES QUARRY, CUMBRIA (SD 224 747)

Introduction

The Elliscales Quarry GCR site is a disused quarry (SD 224 747), 1 km north-west of Dalton-in-Furness, which offers a unique exposure of patch reefs within the Arundian (C_2) succession. Although Adams (1984) followed Rose and Dunham (1977) in regarding these reefs as part of the Red Hill Oolite, recent work by Johnson *et al.* (2001) considered them part of their newly defined Dalton Formation (= Dalton Beds of this chapter), and it is the latter view which is followed in the present account. Highly fossiliferous carbonate buildups at Elliscales Quarry provide rare evidence of particular significance in understanding the construction of organic frameworks in Lower Carboniferous reef systems. Accounts of the geology have been presented by Garwood (1913), Nicholas (1968) and Rose and Dunham (1977), but this report is based mainly on the sedimentological work of Adams (1984) who considered the anatomy and development of the Elliscales reefs in detail.

Description

Adams (1984) described the bedded facies adjacent to the Elliscales reefs as finely bioclastic peloidal packstones with some grainstones, and the reefs as pale-weathering masses of unbedded, mottled and fossiliferous fine-grained limestones with vertical walls and dome-shaped tops. Two prominent reefs are exposed on the north and west faces of the quarry (Figure 4.8), while smaller developments of reef limestone are recorded from the quarry floor (Adams, 1984). The reefs are up to 5 m in width, 15 m in height and 25 m or more in length. A few thin

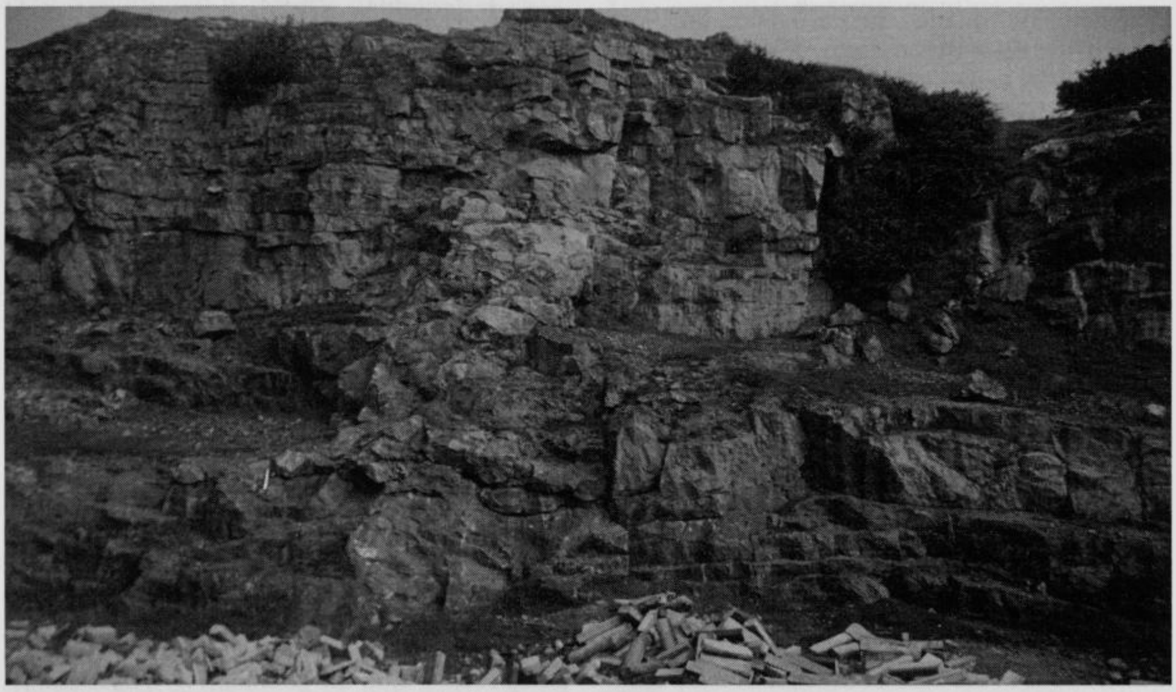


Figure 4.8 The north face of Elliscales Quarry showing the near-vertical walls of an unbedded reef limestone mass (centre) surrounded by dolomitized beds within the Arundian succession. The vertical height of the reefs is approximately 10 m. (Photo: A.E. Adams.)

tongues of reef material extend into the inter-reef beds, and contacts between the two facies are generally sharp. In places, however, textures and contacts are obscured by dolomitization and haematization.

Frame-building organisms in the reef facies include *Syringopora* (tabulate coral), solenoporoid algae, the problematic *Aphralysia* and a few microbial thrombolites and stromatolites. Typically these organisms are found in their life position and as delicate upward-branching attached or encrusting growth forms. The more erect of these growth forms most probably acted as baffles to gentle currents carrying suspended sediment in a fairly low-energy environment (Adams, 1984). Within the reefs a strong ecological zonation is evident, with *Syringopora* at the base, passing up into a *Syringopora–Aphralysia*–thrombolite association in the middle, and a solenoporoid alga–*Aphralysia*–thrombolite association at the top (Figure 4.9). The upward replacement of *Syringopora* by the more robust branches of solenoporoid algae is attributed to increased energy levels and light penetration as a result of shallowing. Reef growth is thought to have been initiated by the attachment of *Syringopora* to a partially lithified substrate. Although Adams (1984) followed Bełka (1981) in assigning *Aphralysia* to the Foraminifera, its systematic position remains uncertain (R. Riding, pers. comm., 1999).

Other fixed forms recognized as contributing to the development of the reef framework and assisting in the binding and trapping of fine-grained sediment include fenestelloid, fistuliporoid and branching bryozoans (the most common group), tuberitinid foraminifera, spirorbid worms, rhodophyte algae (ungdarellids), cyanobacteria (*Girvanella*) and other micro-problematica (*Garwoodia*). Additional forms identified by Adams (1984) as less-significant elements of the reef core include the brachiopods (*Cleiothyridina* cf. *glabristria*, *Stenoscisma isorhyncha*, *Schizophoria* and *Derbyia*), corals (*Michelinia megastoma*, *Caninia ciliata*, *Clisiophyllum ingletonense*, *Palaeosmilia murchisoni* and *Koninckophyllum praecursor*) (Garwood, 1913; Rose and Dunham, 1977), 'coiled nautiloids or goniatites' (Nicholas, 1968), echinoids, crinoids, ostracodes, endothyrid and tetrataxid foraminifera, calcispheres, the ?cyanobacterium *Renalcis* (Adams, 1983) and ?*Uraloporella* (Adams, 1984), an organism of uncertain biological affinity.

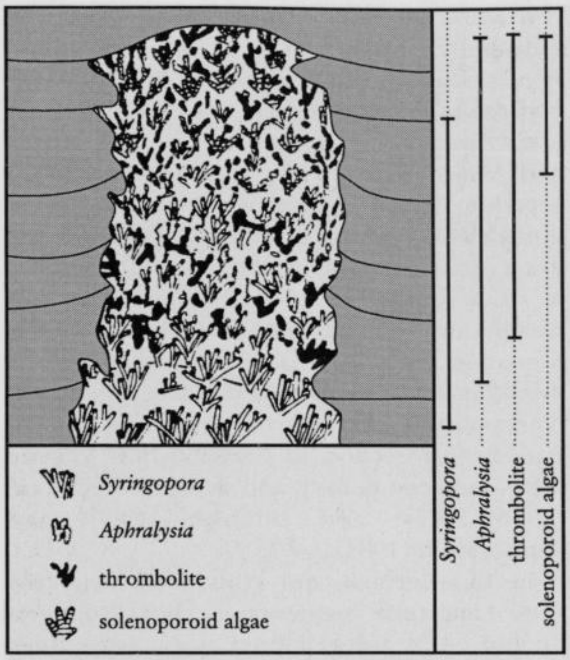


Figure 4.9 Schematic section of the reef illustrated in Figure 4.8 showing the ecological succession of frame-building organisms in the reef core. The vertical height is approximately 10 m. Organisms not drawn to scale. After Adams (1984).

Interpretation

Adams (1984) was the first to determine that the Elliscales reefs were ecologically zoned biogenic structures built by sessile organisms that encrusted one another to produce a rigid and wave-resistant organic framework. The presence of abraded grain calcarenites and lithified blocks of the reef framework in talus bands on the reef flanks confirmed that the developments were at least partially cemented and resistant to occasional periods of turbulence (Adams, 1984). The gentle arching of limestone beds over the tops of the reefs indicates that reef elevation above the sea floor during growth must have been minimal (Nicholas, 1968; Adams, 1984). The greater quantity of 'carbonate mud' noted adjacent to the reefs than in other areas is attributed to the sheltering effect provided by the presence of the reefs, despite their low elevation (Nicholas, 1968).

Although similar but much smaller reefs occur in the Martin Limestone at Marton Quarry, 3 km north-east of Elliscales, their distribution over the Lake District Block may not be confined to the Furness district as previously envisaged (Adams, 1984) since blocks of strikingly similar reef material also occur at Meathop to the east. However, attempts to account for their development in a regional palaeogeographical context have been hampered by poor exposure of Arundian successions in the area. Originally, Nicholas (1968) suggested that the reefs developed on the back of an embryonic fold structure, the 'High Haume Anticline', but regional thickness trends for formations within the Arundian succession conflict with this view (Rose and Dunham, 1977; Adams, 1984). Further speculation by Nicholas (1968) that the reefs developed in a shelf-margin setting was rejected by Adams (1984) who, in consideration of Lower Carboniferous isopach data for northern England presented by George (1958), suggested that any shelf edge, if present, would have had a north-east–south-west trend and been located some kilometres to the south-east of the present site. Following this view, Adams (1984) considered the buildups as 'patch reefs' that developed on a shelf area, and that their north–south elongation was the product of gentle (possibly tidal) current movements oblique to the shelf margin. Reef growth was rapid in response to high sedimentation rates as the shelf subsided.

Conclusions

The reefs at Elliscales Quarry contain an ecologically diverse fauna and flora that is unique within the Arundian successions of south Cumbria. The exceptional preservation of frame-building organisms (chiefly lime-secreting algae, coral and other micro-organisms) make this one of the most important sites in Britain for understanding the organic evolution of Lower Carboniferous reef systems. At no other site in north-west England can the organic framework to an ancient reef of this particular type be so clearly demonstrated.

BARKER SCAR, CUMBRIA (SD 332 785–SD 338 775)

Introduction

Located 3 km to the WSW of Holker on the eastern side of the Leven Estuary, this coastal site reveals a near-continuous section from the top of the Dalton Beds (Arundian), through the Park Limestone (Holkerian) and into the base of the

Urswick Limestone (Asbian). The sequence is exposed in a line of cliffs that flank an area of salt marsh on the western side of Old Park Wood. Discontinuous outcrops extend from the northern end of Barker Scar (SD 332 785) southwards to Capes Head (SD 333 778) then south-east to Raven's Barrow Point (SD 338 775). The locality was originally proposed as the stratotype for the base of the Holkerian Stage (George *et al.*, 1976) and as such it is one of the most important British Lower Carboniferous stratigraphical sites. Although, more recently, Riley (1993) questioned its suitability as a stratotype and Johnson *et al* (2001) re-defined the position of the Dalton Beds–Park Limestone boundary, claims of a non-sequence in the section have yet to be substantiated and an alternative stratotype section has yet to be proposed.

The site is mentioned briefly by both Garwood (1913) and Mitchell (1978), but the account that follows is based mainly on the detailed measured sections and palaeontological records provided by Rose and Dunham (1977) and Ramsbottom (1981). Additional sedimentological information is provided by Abdel Aziz (1989).

Description

At the northern end of the site and at the base of the exposed succession, Rose and Dunham (1977) identified a 30 m sequence of the Dalton Beds dipping gently to the south-east. The lower part of this sequence comprises well-bedded, medium-dark grey, argillaceous, dolomitic and occasionally carbonaceous limestones with intercalated shales. Increasing concentrations of sand and decreasing levels of mud characterize the upper beds where the limestones become more massive. The dominant lithofacies of the Dalton Beds here is of dolomitized peloidal and bioclastic packstone (Abdel Aziz, 1989). Rose and Dunham (1977) and Ramsbottom (1981) recorded an Arundian faunal assemblage from these beds. This included a diverse array of brachiopods, corals, foraminifera and conodonts, several of which are regarded as diagnostic for the stage (e.g. *Linoprotonia* cf. *hemisphaerica*, *Composita ambigua*, *C. ficoidea*, *Megachonetes* cf. *papilionaceus*, *Clisiophyllum multiseptatum*, *Haplolasma subibicina*, *Amplexizaphrentis ashfellense*, '*Zaphrentis*' cf. *kentensis*, *Palaeosmilia murchisoni*, *Siphonodendron martini*, *Globodiscus* aff. *oblongus*, *Eoparastaffella* aff. *iniqua*, *Mestognathus beckmanni*, *Apatognathus*, *Ligonodina levis*, *Spathognathodus cristulus*, *Neoprioniodus* and *Hindeodella*). The Clisiophyllum multiseptatum Band identified by Garwood (1913) as a marker for the top of the *Michelinia grandis* Zone occurs 3.5 m above the base of the section. A sandy mudstone (0–0.15 cm) recessed by weathering occurs 2.25 m from the top of the formation and helps to define the position of the Arundian–Holkerian stage boundary. The stratotype point is located towards the top of the Barker Scar section at SD 3330 7827 (Figure 4.10), between beds 'j' and 'k' of George *et al.* (1976), Rose and Dunham (1977) and Ramsbottom (1981).

In the Cartmel and Holker districts, the Park Limestone sequence (*c.* 120–130 m) is dominated by pale-coloured and massive limestones that contain less clay than the underlying Dalton Beds (Rose and Dunham, 1977). The lower 45 m of Park Limestone at Barker Scar are described by Ramsbottom (1981) as medium- to pale-grey calcarenites with a few coral–brachiopod bands. Abdel Aziz (1989) identified these beds as peloidal and bioclastic grainstones, and from them Rose and Dunham (1977) and Ramsbottom (1981) recorded a typical Holkerian fauna. This included both the stage-diagnostic brachiopod *Linoprotonia corrugatohemispherica* and the coral *Axophyllum vaughani* from the base of the sequence and, towards the top of the succession, a number of other corals that made their first entry in the Holkerian Stage, namely *Diphyphyllum smithi*, *Caninophyllum bristoliense*, *Lithostrotion araneum* and *Clisiophyllum rigidum* (Mitchell, 1989; Riley, 1993). Other significant taxa recorded from these beds include the foraminifera *Pojarkovella nibelis*, *Holkeria avonensis* and several archaediscid species (Ramsbottom, 1981; Strank, 1982b).

The middle and upper parts of the Park Limestone are discontinuously exposed between Capes Head and Raven's Barrow Point, but few details of this part of the section have been published. Rose and Dunham (1977) recorded some 5 m of Urswick Limestone with an Asbian coral–brachiopod fauna resting on top of the Park Limestone at Raven's Barrow Point.

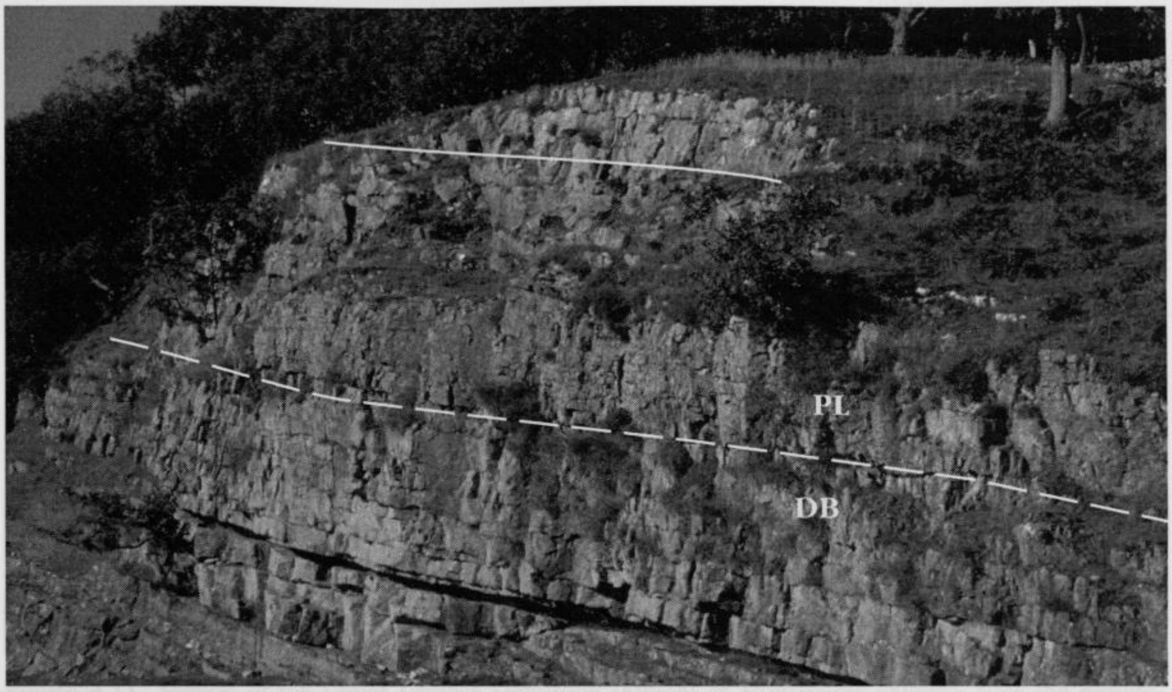


Figure 4.10 The Holkerian Stage stratotype at Barker Scar. The base of the stage (solid line) is defined a few metres above the Dalton Beds (DB)–Park Limestone (PL) boundary (Johnson *et al.*, 2001). The height of the cliff is approximately 10 m. (Photo: JNCC.)

Interpretation

George *et al.* (1976) defined the base of the Holkerian Stage at the junction between the Dalton Beds (Arundian) and the overlying Park Limestone (Holkerian). This was positioned at the distinctive lithological break below the bed at the base of the Park Limestone in which Holkerian faunas first enter the sequence. The boundary corresponds to the line of division between Major Cycles 3 and 4 of Ramsbottom (1973) and the junction between the Gastropod Beds (= upper Dalton Beds) and *Cyrtina carbonaria* Subzone of Garwood (1913). The bulk of the section (including the Arundian–Holkerian stage boundary) therefore falls in Garwood's *Productus corrugato-hemisphericus* Zone (see Figure 4.2). The Holkerian Stage thus broadly equates with the S_2 Zone of Vaughan (1905). However, more recent work by Riley (1993) has indicated that a significant non-sequence might be present in the Barker Scar section and that the stratotype may need relocating. Suspicions of a non-sequence here are based on the apparent absence both of Garwood's (1913) Davidsonina carbonaria Beds (Ramsbottom, 1981; Burgess in Riley, 1993) and of a late Arundian transition fauna comprising foraminifera and *Siphonodendron* colonies with a cerioid tendency, which are both widely recognized in areas where thicker and more complete Arundian and Holkerian sequences are known. An alternative view considers that the absence of the Davidsonina carbonaria Beds might be more apparent than real and that their presence may be masked by the extensive effects of dolomitization that Abdel-Aziz (1989) reported in the section. To date, unequivocal evidence of a non-sequence in the Barker Scar section has yet to be presented and further work is clearly required in order to establish the facts (Riley, 1993). Thus, until such evidence is reported, it seems likely that the Holkerian stratotype will remain at the present site. Note that in a recent re-evaluation of the section Johnson *et al.* (2001) used lithological criteria to define the position of the Dalton Beds–Park Limestone boundary a few metres below the position of the Arundian–Holkerian stage boundary (at the base of bed 'j' of George *et al.*, 1976; Rose and Dunham, 1977; Ramsbottom, 1981), but made no mention of relocating the stratotype to a different site.

Adams *et al.* (1990) suggested that the Dalton Beds were deposited well below wave-base as a mid- to outer-ramp facies on a rapidly subsiding, southward-dipping carbonate ramp, and that the Park Limestone was formed as inner-ramp facies in shallow waters of around 10–30 m close to wave-base. Increased levels of carbonate and reduced levels of clay and bituminous material at the top of the Dalton Beds and in the overlying Park Limestone were attributed to progressive shallowing caused either by a slow-down in the subsidence rate, or by an increased rate of carbonate production that resulted in the shallow-water facies of the Park Limestone prograding over the deeper-water facies of the Dalton Beds (Adams *et al.*, 1990). The suggestion that increased levels of dolomite at the top of the Dalton Beds might also be a sign of shallowing (Ramsbottom, 1973) was rejected by Adams *et al.* (1990) who considered the dolomite as a product of burial diagenesis.

Conclusions

This site provides the finest and most complete section of the upper part of the Dalton Beds and Park Limestone in south Cumbria. The limestone-dominated succession was largely formed between fair-weather and storm wave-base on a gently dipping sea floor during mid-Dinantian times. As the accepted regional stratotype for the Holkerian Stage, Barker Scar is recognized as the standard section for the correlation of Holkerian sequences throughout northern England. Despite concerns regarding its suitability as a stratotype section, the site remains critical to the understanding of Lower Carboniferous stratigraphy in Britain.

TROWBARROW QUARRY, LANCASHIRE (SD 480 758)

Introduction

Trowbarrow Quarry near Silverdale (SD 480 758) is one of the most spectacular exposures of Carboniferous Limestone in northern England. Over 150 m of rock is exposed, including the whole of the Urswick Limestone (Asbian) and the base of the overlying Gleaston Formation (Brigantian). The diversity of limestone lithologies, including features indicative of subaerial exposure, are beautifully displayed. The site is also well known for its abundant fauna and flora, including a particularly rich microfossil assemblage. Elements of the site geology were first recorded by Garwood (1913). More recent work of significance includes the sedimentological work of Horbury (1987, 1989) and the biostratigraphical studies of Strank (1981) and Athersuch and Strank (1989).

Description

The succession at Trowbarrow is affected by the Silverdale Disturbance and bedding is close to vertical throughout the quarry (Figure 4.11). Garwood (1913) recognized that the exposure mostly lay in the D_1 Zone and appears to have interpreted the succession as younging to the west. Biostratigraphical and sedimentological evidence (Strank, 1981; Horbury, 1987; Athersuch and Strank, 1989) has since confirmed that the succession youngs eastwards. The quarry displays a complete section of the late Asbian Upper Urswick Limestone and the base of the Brigantian Gleaston Formation. The early Asbian Lower Urswick Limestone, including the Woodbine Shale, is less well exposed.

As with all other Asbian shelf limestone successions in Britain, the Trowbarrow sequence is punctuated by emergent surfaces and palaeosol clays. This, together with the repeated occurrence of limestone lithologies defines a marked cyclicity. The most important sedimentological work on the Urswick Limestone, including the section at Trowbarrow, is that of Horbury (1987, 1989) and a summary log based on his work is reproduced in Figure 4.12. Two major carbonate facies dominate the succession. These comprise bedded, rubbly weathering, argillaceous wackestones and packstones, and thickly bedded, pale-coloured grainstones. 'Pseudobrecciation' (colour mottling) is present at some levels in both facies.

The argillaceous wackestones and packstones frequently contain fossils interpreted as being preserved with little disturbance, including colonial and solitary rugose corals, *Syringopora*, productoid brachiopods and *Straparollus*. Microfossils visible in thin-section include foraminifera, sponge spicules, *Saccaminopsis*, bryozoans, and algae such as *Coelosporella*, *Stacheoides*, *Kamaena* and *Kamaenella*. The rubbly appearance sometimes evident results from the weathering of *Thalassinoides* burrows (Horbury, 1987, 1989).

Figure 4.11 Section of the Upper Urswick Limestone (Asbian) at Trowbarrow Quarry. Note the pseudo-brecciated appearance (possible bioturbation mottling) of bedding plane surfaces seen to the right of the illustration. The younging direction ('way up' of the sequence) is also to the right (to the east). The height of the quarry face is approximately 20 m. (Photo: A.E. Adams.)

There are few macrofossils in life position in the grainstones, the exceptions being a few colonial corals and local concentrations of brachiopods such as *Davidsonina septosa*. In thin-section there is an abundant microbiota visible, dominated by *Kamaenella*, but *Koninckopora*, *Ungdarella* and foraminifera are also common. Peloids with some ooids and intraclasts make up the remaining grains.

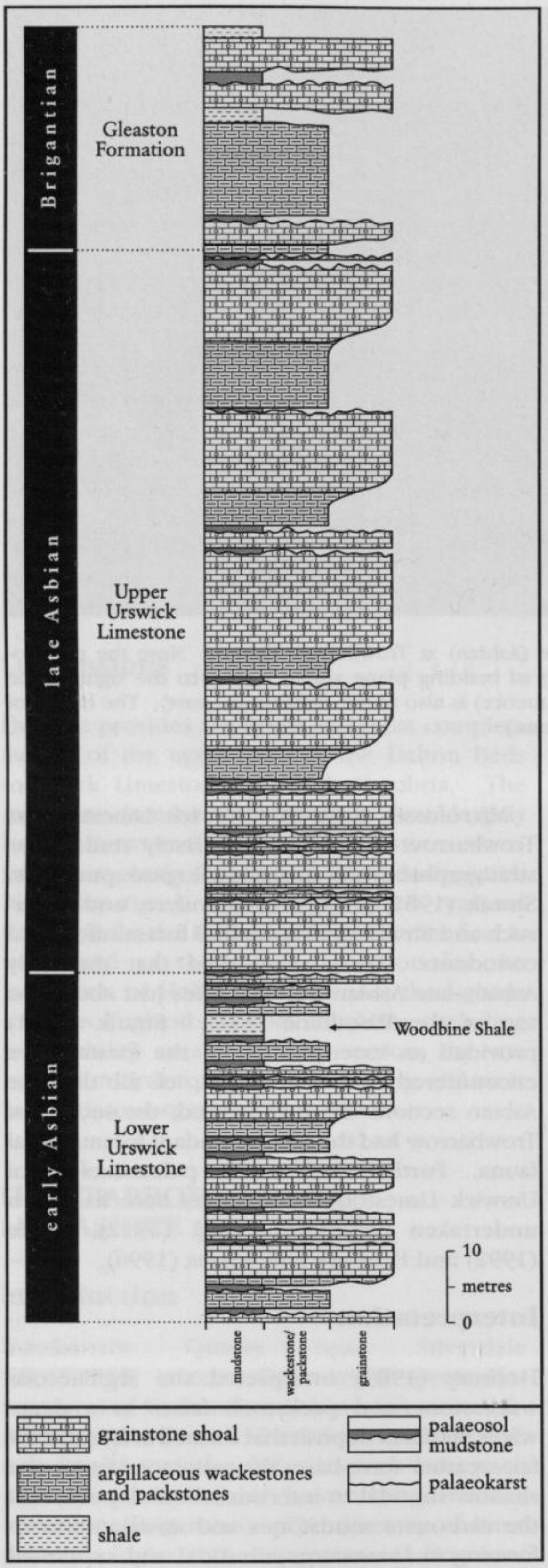
These two carbonate facies, arranged in couplets, make up the bulk of the visible section (Figure 4.12), but other carbonate lithologies are present. These include thin porcellanous limestones (carbonate mudstones) and stromatolites.

Non-carbonate facies comprise terrigenous clastic mudstones. These include calcareous shales, the most important of which is the 4 m-thick Woodbine Shale close to the top of the Lower Urswick Limestone (Figure 4.12). Garwood (1913) recorded a rich fauna of corals, brachiopods, bivalves, gastropods and nautiloids from this shale and noted that many specimens were compressed. Other terrigenous clastic mudstones include variegated clays which are found overlying palaeokarstic surfaces. These have been identified as K-bentonites by Horbury (1987, 1989).

Microfossils from the Urswick Limestone at Trowbarrow have been extensively studied for stratigraphical and palaeoecological purposes. Strank (1981) studied foraminifera, and Athersuch and Strank (1989) studied foraminifera and conodonts. They established that the early Asbian–late Asbian boundary lies just above the top of the Woodbine Shale. Strank (1981) provided an extensive list of the foraminifera encountered and noted that, of all the late Asbian sections she had studied, the section at Trowbarrow had the most abundant foraminiferal fauna. Further work on the palaeoecology of Urswick Limestone microbiotas here has been undertaken by Adams *et al.* (1992), White (1992) and Horbury and Adams (1996).

Interpretation

Horbury (1989) interpreted the argillaceous wackestone and packstone facies as a deep-water platform deposit that formed at least below fair-weather wave-base; the grainstone facies as a shallow subtidal to intertidal shoal deposit; and the carbonate mudstones and stromatolites as forming in low-energy intertidal and supratidal environments. The particularly rich and typical



Asbian faunas and floras in the sequence (Garwood, 1913; Athersuch and Strank, 1989) may reflect close proximity to the Asbian shelf margin, with a freer exchange of sea water from shallow shelf to open sea, than at localities in the interior of the Lake District carbonate platform.

In common with other shelf sequences of Asbian and early Brigantian age, the succession at Trowbarrow is strongly cyclic, with episodes of subaerial exposure resulting in karstification of limestones beneath palaeosol clays of volcanic origin. The completeness of the Asbian succession at Trowbarrow means that it is particularly valuable for studying how cycle style varies vertically and in comparison with other areas. Horbury (1989) interpreted the succession in terms of the interplay of tectonically controlled shoaling cycles up to 20 m thick, caused by platform down-faulting, and emergence relating to smaller-scale glacio-eustatic cyclicity.

Both the early Asbian and late Asbian strata show an upward increase in the volume of the argillaceous wackestones and packstones (Figure 4.12), indicating that overall the platform was submerged to progressively increasing water depths during each of the two episodes, probably reflecting increased rates of subsidence (Horbury, 1989). The early Asbian–late Asbian boundary is characterized by several phases of emergence, and Horbury (1989) suggested that this resulted from several eustatic cycles operating at a time of little net subsidence.

Conclusions

Trowbarrow is one of the most important shelf limestone localities in northern England. The Asbian Urswick Limestone is exposed in its entirety and the carbonate facies are exceptionally well displayed, together with features indicative of periodic emergence. The site provides valuable evidence of the styles and causes of cyclicity in the Urswick Limestone and contains a rich biota in which the abundant foraminiferal fauna is particularly notable. The effects of the Silverdale Disturbance are also well seen in the quarry.

◂**Figure 4.12** Simplified sedimentary log of the Urswick Limestone (Asbian) at Trowbarrow Quarry illustrating the distribution of the principal lithofacies and emergent surfaces. Note that the base of this section also marks the top of the underlying Park Limestone. After Horbury and Adams (1989).

HUMPHREY HEAD, CUMBRIA (SD 392 737–SD 391 747)

Introduction

Situated on the western side of the Kent Estuary, 8 km SSW of Grange-over-Sands, Humphrey Head (SD 393 740) offers one of the most important and fossiliferous sections of the Upper Urswick Limestone (Asbian, D_1) and the lower Gleaston Formation (Brigantian, D_2) in south Cumbria. Close to the base of the Gleaston Formation is an exceptional development of the 'Girvanella Nodular Bed', an oncoid horizon described by Garwood (1913, 1916) as the finest of its type in northern England. The sequence was deposited on a carbonate platform overlying the Lake District Block some 15 km from the NE–SW-trending platform margin bordering the Lancaster Fells Basin to the south-east (Horbury, 1989). The most informative accounts of the site geology are provided by Garwood (1913), Rose and Dunham (1977), Horbury (1987) and Johnson *et al.* (2001).

Description

Exposure at this site is largely confined to the coastal outcrops that extend down the east side of the Humphrey Head peninsula from the eastern end of Pigeon Cote Lane (SD 391 747) south to Humphrey Head Point (SD 392 732) and up the west side of the peninsula to the southern end of Holy Well Lane (SD 391 740). Exposure then continues as an inland cliff along the east side of Holy Well Lane to the western end of Pigeon Cote Lane (SD 388 747).

The Upper Urswick Limestone and lower Gleaston Formation are best exposed on the eastern side of the peninsula where the succession dips moderately to the east at 25°. Here, in a strike-section along the shoreline, the junction between the two formations can be traced almost continuously for a distance of approximately 500 m, with the Urswick Limestone cropping out in small cliffs at the top of the beach and the Gleaston Formation in the lower foreshore area. Minor displacements of the boundary between the two formations are caused by a number of small NW–SE-trending faults. On the western side of Humphrey Head the eastern branch of the Humphrey Head Fault forms a prominent haematite-stained N–S-trending fault scarp in the Urswick Limestone. To the west of this fault, on its downthrow side, further exposures of the Gleaston Formation crop out on the shore near Holy Well.

The Urswick Limestone at this site comprises a varied sequence of pale, bioclastic and rubbly bedded limestones. A detailed log of the sequence is provided by Horbury (1987) who records a 26 m section, the lower part of which is dominated by grainy bioclastic limestones with disarticulated productoids, rolled solitary corals and some colonial corals, palaeokarsts and rhizocretions. In its upper part, disarticulated productoids and rolled solitary corals are less common and zones of intense bioturbation mottling (*Thalassinoides* burrows) and pressure solution give the limestone a distinctive rubbly or 'pseudobrecciated' texture. The upper part of the Urwick Limestone contains the distinctive Asbian (D_1) brachiopod *Davidsonina septosa*, and at its top, downward-penetrating rhizocretions associated with a prominent palaeokarst indicate a period of emergence. Another bed of *D. septosa* 15 m from the top of the sequence is the likely equivalent of the 'Cyrtina' septosa Band recorded by Garwood (1913) from beneath the Girvanella Nodular Bed at Humphrey Head. A sparse coral–brachiopod fauna recorded from the topmost 5.7 m of the Urswick Limestone by Rose and Dunham (1977) includes *Siphonodendron junceum*, *S. pauciradiale*, *S. martini*, *Lithostrotion portlocki*, *'Caninia' juddi* and *Linoprotonia hemisphaerica*; the latter concentrated in a 30 cm band, 2 m from the top of the sequence.

The overlying Gleaston Formation (11 m), in contrast to the Urswick Limestone, comprises darker, thinly bedded, argillaceous limestones that are locally very fossiliferous; and towards its base, the formation is said to contain mega-ripples (N. Riley, pers. comm., 2002). About 7 m above the base is the Girvanella Nodular Bed of Garwood (1913), a 90 cm-thick development containing abundant spherical, oval and kidney-shaped oncoids (Figure 4.13). Typically these microbial ('algal') structures are 2–3 cm in diameter and consist of irregular laminae containing *Girvanella* concentrically arranged around a brachiopod or coral fragment nucleus. Encrustations of tabuliporoid and fistuliporoid bryozoans occur sandwiched between the laminae of some oncoids. A rich fauna dominated by corals is associated with the Girvanella Nodular

Figure 4.13 Bedding-plane view of Garwood's (1913) Girvanella Nodular Bed near the base of the Gleaston Formation (Brigantian) at the Humphrey Head GCR site. (Photo: P.J. Cossey.)

Bed and the 60 cm interval immediately above it (which also contains '*Girvanella*' nodules) (Rose and Dunham, 1977). These include *Dibunophyllum bipartitum*, *Clisiophyllum keyserlingi*, *Axophyllum vaughani*, *Siphonodendron junceum*, *S. pauciradiale*, *S. martini*, *Diphyphyllum lateseptatum*, *Lithostrotion portlocki* and *Pugilis*?, many of which are common in the Brigantian (D_2) successions of northern England. Garwood (1913, 1916) also recorded an extensive D_2 fauna from these beds, including *Aulophyllum fungites* (now *A. pachyendothecum*) and reef-like masses of '*Lithostrotion*', *Actinocyathus* '*Lonsdaleia*' *floriformis* and *Palastraea regia*; the occurrence of *Siphonodendron* colonies in abundance immediately below the Girvanella Nodular Bed may indicate the position of Garwood's 'reef-like' coral development. An additional record of significance from the Girvanella Nodular Bed is the discovery of *Aphralysia carbonaria* first reported by Garwood (1914).

Other taxa from Gleaston Formation beds beneath the Girvanella Nodular Bed include *Productus hispidus* and the typical Brigantian (D_2) corals *Lonsdaleia duplicata* and *L. alstonensis*, while abundant *Saccaminopsis* is found above the Girvanella Nodular Bed, 35 cm from the top of the exposed sequence (Rose and Dunham, 1977). A 'Stick Bed' (*c*. 1 m) recorded by Rose and Dunham (1977) and containing 'worm burrows' 2 m above the base of the formation resembles some of the bioturbated beds near the top of the Urswick Limestone recorded by Horbury (1987).

Interpretation

In establishing the zonal sequence for Lower Carboniferous rocks in north-west England, Garwood (1913) took the Girvanella Nodular Bed as a marker for the base of the Upper *Dibunophyllum* (D_2) Subzone, a subzone originally defined by Vaughan (1905) in south-west England (see **Avon Gorge** GCR site report, Chapter 9). However, the recognition of typical D_2 (Brigantian) faunas below the Girvanella Nodular Bed at a number of sites in northern England, including this site (Miller and Turner, 1931; Hudson, 1938a; Burgess and Mitchell, 1976), enabled George *et al*. (1976) and Rose and Dunham (1977) to establish the D_1–D_2 subzone boundary (= Asbian–Brigantian stage boundary) slightly lower in the sequence at the junction between the Urswick Limestone and the Gleaston Formation. Rose and Dunham (1977) equated those beds of the Gleaston Formation below the Girvanella Nodular Bed at Humphrey Head with the Lower Hawes Limestone of the Askrigg Block, and those from the base of the Girvanella Nodular Bed to the top of the section with the Upper Hawes Limestone.

Horbury (1989) regarded the Urswick Limestone as the product of four tectonically generated shoaling-upward cycles that resulted from alternating phases of rapid and slow but steady subsidence, onto which were superimposed the effects of a smaller scale glacio-eustatically controlled cyclicity. Seen in this context, the lower beds of the Urswick Limestone at this site are considered as part of a high-energy, shallow-water carbonate sand-body (Facies 2 of Horbury, 1989) with a depositional relief of approximately 10 m that developed on the Lake District carbonate platform as it slowly subsided, while the upper beds of the Urswick Limestone are considered as a sub-fair-weather wave-base facies (Facies 1 of Horbury, 1989) that formed as the platform subsided more rapidly. Rhizocretions and palaeokarsts at different levels in the sequence were produced during glacio-eustatically controlled regressive episodes of platform emergence (Horbury, 1989).

In addition to the faunal changes noted above, the Asbian–Brigantian stage boundary is also characterized by a distinctive lithofacies change as the dominantly pale massive Urswick Limestone gives way to the highly variable, darker (muddier) and sometimes sandy facies of 'Yoredale' aspect in the Gleaston Formation (Mitchell, 1978). Although a detailed sedimentological appraisal of this formation has yet to be undertaken, the association of oncoids (the Girvanella Nodular Bed), rich coral faunas and argillaceous limestones suggests deposition in a shallow subtidal environment on a carbonate platform that was, most probably, subsiding quite rapidly. Furthermore, in comparing the Brigantian sequences of south Cumbria with those in other areas in Britain and in Derbyshire in particular, Adams *et al.* (1990) intimated that regional variations in thickness may be attributed to penecontemporaneous tectonic activity (including fault re-activation) that resulted in the dissection and collapse of the platform and the generation of 'intra-shelf basins'. Thus the Brigantian rocks at Humphrey Head may be regarded as the deposits of a sub-basin with a development history that was distinctly different to others on the platform.

Conclusions

This site provides an outstanding section of the Upper Urswick Limestone (late Asbian, D_1) and lower Gleaston Formation (early Brigantian, D_2), one of the finest stage boundary sections in south Cumbria, and arguably the most spectacular exposure of the Girvanella Nodular Bed in Britain. The sequence was deposited in a variety of dominantly shallow and subtidal marine environments on the Lake District carbonate platform as it subsided during the later part of Asbian and in early Brigantian times. The occurrence of rich fossil assemblages and a range of rock types, especially in the poorly understood Gleaston Formation, highlights the value of this site to future palaeontological and sedimentological research.

YEATHOUSE QUARRY, CUMBRIA (NY 041 170–NY 043 168)

Introduction

The Yeathouse Quarry GCR site, near the village of Frizington, 7 km east of Whitehaven, includes the small quarry at Yeathouse (NY 041 170), the entrance cutting to the original quarry complex, and exposures along the course of the old mineral railway to the south-east (NY 043 168). The exposed succession includes a significant unconformity between the Dinantian and Lower Palaeozoic rocks, parts of the Seventh Limestone and a fairly complete section from the top of the Sixth Shale to the base of the White Limestone. While this last section is attributed entirely to the Asbian Stage (e.g. George *et al.*, 1976; Mitchell, 1978), there is disagreement concerning the presence or absence of strata attributable to early Asbian times, as discussed in the 'Introduction' to this chapter. Although many sources (Barclay *et al.*, 1994; Akhurst *et al.*, 1997) indicate that early Asbian strata are absent in west Cumbria (Figure 4.2), the description that follows is based on the detailed sedimentological work of Thurlow (1996) who, following earlier biostratigraphical work by Strank (1981), regarded the section from the top of the Sixth Shale to the base of the White Limestone as belonging to the early Asbian sequence. A significant early description of the succession was provided by Eastwood *et al.* (1931) and further biostratigraphical information has been given by Welsh (1980).

Description

At the south-east end of the site, on the north-east side of the old railway on the slope down to Windergill Beck (NY 045 166), the unconformity between the Dinantian succession and the Skiddaw Group is exposed (Figure 4.14). The unconformity was revealed by a scrape in 1991–1992, organized by the Groundwork Trust at the request of the Cumberland Geological Society. Just over a metre of coarse pebbly sandstones were seen to rest on cleaved Skiddaw Group deposits. These Carboniferous deposits lie within the Basement Beds of Eastwood *et al.* (1931) and were referred elsewhere to the Pu Zone by Welsh (1980).

Between the unconformity and the entrance cutting to Yeathouse Quarry, parts of the Holkerian Seventh Limestone (= the Frizington Limestone Formation of Barclay *et al.*, 1994) containing *Lithostrotion* can be seen. Directly overlying the Basement Beds are coarse sucrosic dolomites and sandy packstones with hummocky cross-stratification (N. Riley, pers. comm., 2002) interbedded with a few homogeneous grey carbonate mudstones. Above this, thin beds of cross-stratified fine-grained sandstone appear. To the north-west of the site of Yeathouse Station, 7 m of cherty, argillaceous limestones occur, interbedded with fine sandstones and siltstones. These are presumed to lie high up within the Seventh Limestone.

Figure 4.14 The unconformity between Lower Carboniferous Basement Beds and the slates of the Silurian Skiddaw Group exposed in the old railway cutting at the Yeathouse Quarry GCR site. Note keys (right of centre) for scale. (Photo: A. Thurlow.)

The most recent sedimentological work on the Asbian successions of north and west Cumbria is that of Thurlow (1996) and the descriptions and interpretations that follow are based on his logs (see Figure 4.15). The Sixth Limestone and the Fifth Shale (now partly obscured by vegetation) are seen in the quarry entrance cutting (NY 042 169). The top of the Sixth Shale is a clay with carbonate concretions. About 11 m of Sixth Limestone are seen with the lower part of the succession containing cross-stratified crinoidal grainstones. In the middle part, coarse, brown-coloured dolomite occurs and the upper part of the succession consists of two units of bioclastic wackestone and packstone with a diverse fauna including *Siphonodendron*, *Syringopora*, *Caninia*, *Palaeosmilia*, crinoids, brachiopods, bivalves and gastropods, separated by a thin palaeosol clay. Strank (1981) recorded a foraminiferal fauna from the Sixth Limestone at Yeathouse which she regarded as comparable with that of the Potts Beck Limestone in the early Asbian type section (see **Little Asby Scar** GCR site report, Chapter 5).

The Fifth Shale, also known as the 'Chonetes Shale', is 9 m thick at Yeathouse and consists of two terrigenous clastic units separated by a unit of crinoidal wackestone and packstone. The lower terrigenous clastic unit is a dark-grey to black shale with thin horizons crowded with chonetoids, productoids and productoid spines. The upper unit comprises interbedded mudstones and very fine sandstones. Mudstones are bioturbated by *Planolites* and are rich in plant debris; sandstones are calcite-cemented and have gutter casts on their bases, hummocky cross-stratification within and rippled tops. The Fifth Shale at Yeathouse is the type horizon for the trilobite *Linguaphillipsia cumbriensis*, described by Riley (1984).

The Fifth Limestone at this site is 16 m thick. The base is seen at the mouth of the cutting leading into the quarry, where it is rather sandy. In

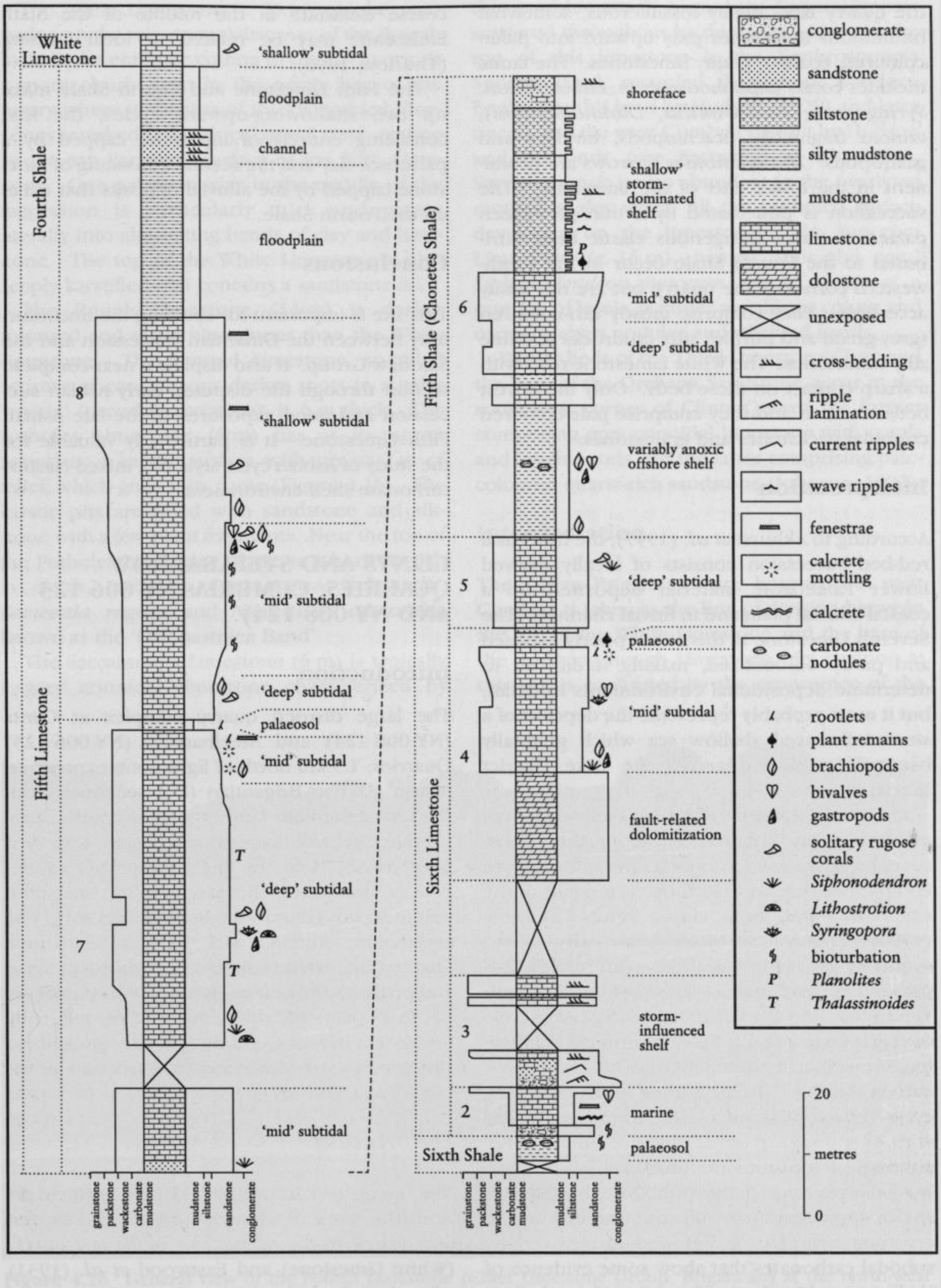


Figure 4.15 Simplified sedimentary log of the Chief Limestone Group succession at Yeathouse Quarry from the Sixth Limestone to the White Limestone. After Thurlow (1996). Numerical subdivisions of the succession refer to Thurlow's (1996) notation of sedimentary cycles.

the quarry face, highly fossiliferous, somewhat bituminous limestones pass upward into paler-coloured, coarser, grainy limestones. The fauna includes corals (*Siphonodendron*, *Lithostrotion*, *Syringopora*, *Palaeosmilia*, *Dibunophyllum*), crinoid fragments, brachiopods, bivalves and gastropods. *Thalassinoides* burrows are prominent in the lower part of the limestone. The succession is punctuated by a thin grey-green palaeosol clay. Terrigenous clastic beds attributed to the Fourth Shale occur in the south-western corner of the quarry, but are not easily accessible. They comprise mostly vari-coloured (grey-green and purple) silty mudrocks and fine silty sandstones. The White Limestone rests with a sharp contact on these beds. Only the lowest beds are seen and they comprise pale-coloured crinoidal packstones and grainstones.

Interpretation

According to Akhurst *et al.* (1997), the thin basal red-bed succession consists of locally derived Lower Palaeozoic material deposited on a coastal alluvial plain and in fluvial channels. The Seventh Limestone at this site is poorly exposed and partly dolomitized, making it difficult to determine depositional environments in detail, but it most probably represents the deposits of a storm-influenced shallow sea which gradually became established across the Lake District Block.

Cyclicity is a feature of Asbian shelf sequences everywhere in Britain. Those of the Asbian succession in west Cumbria are rather more complex than many elsewhere as a result of the significant terrigenous clastic input. Thurlow (1996) recognized six cycles in the 'early' Asbian sequence of west Cumbria, with cycles 2–6 present at Yeathouse, cycles 2–5 in the Sixth Limestone, and the Fifth Shale comprising cycle 6. Each cycle broadly records upward shallowing, sometimes with evidence for subaerial exposure at the top. The beginning of the following cycle shows evidence of deepening compared with the upper part of the preceding cycle, although a transgressive unit may be present. For example, cycle 6, the Fifth Shale, begins with shales deposited in an offshore, variably anoxic environment. This is followed successively by subtidal carbonates that show some evidence of shallowing, by clastic deposits of a shallow storm-dominated shelf, and by lower shoreface sandstones (Thurlow, 1996). The occurrence of coarse dolomite in the middle of the Sixth Limestone may be related to local faulting (Thurlow, 1996).

The Fifth Limestone and Fourth Shale make up two shallowing-upward cycles, the first consisting entirely of limestone capped by a palaeosol clay and the second consisting of limestone capped by the alluvial deposits that make up the Fourth Shale.

Conclusions

This site is important for showing the unconformity between the Dinantian succession and the Skiddaw Group. It also displays a near-complete section through the disputed early Asbian succession and good exposures of the late Asbian Fifth Limestone. It is particularly valuable for the study of Asbian cycle style in a mixed clastic–carbonate shelf environment.

CLINTS AND STEELBARROW QUARRIES, CUMBRIA (NY 006 123 AND NY 008 124)

Introduction

The large disused quarry complex at Clints (NY 008 124) and Steelbarrow (NY 006 123) Quarries, 1.5 km north of Egremont, exposes an Asbian (D_1) to Brigantian (D_2) sequence from the top of the Fifth Limestone and Fourth Shale to the Orebank Sandstone (Figure 4.3). At Steelbarrow, only the higher intervals of the Fourth Limestone (the Saccammina Limestone and Junceum Limestone) are well exposed. The succession overlaps with that at **Yeathouse Quarry**, but extends up into the Brigantian Stage and provides the best easily accessible exposures of this part of the Lower Carboniferous Subsystem in west Cumbria. Key elements of the site geology are described by Eastwood *et al.* (1931) and Thurlow (1996).

Description

The account that follows derives principally from the work of Thurlow (1996) who logged and described the Asbian part of the succession (White Limestone) and Eastwood *et al.* (1931) who described the higher Brigantian part of the succession. The section is dissected by a number of NNW–SSE-trending normal faults.

The White Limestone (*c.* 20 m) can be seen resting on the micaceous siltstones of the Fourth Shale in the entrance cutting to Clints Quarry. It is more clearly seen in the north face of the quarry where it consists of thickly bedded limestones interbedded with palaeosol clays, resting on the top karstified surface of the Fifth Limestone. One palaeosol clay in the middle of the succession is particularly thick and passes laterally into alternating bands of clay and limestone. The top of the White Limestone is also deeply karstified and contains a sandstone fill.

The Rough Limestone (14 m) is darker coloured and more bituminous than the White Limestone. The Spotted Limestone, so-called because of conspicuous darker spots in a paler 'matrix' (pseudobrecciation), is 6 m thick. The Potholes Limestone (6 m) has at its upper boundary a karstic surface with up to 2 m of relief, which gives it its name (Figure 4.16). The karstic pits are filled with sandstone and siltstone with a few plant fragments. Near the top of the Potholes Limestone, there is a horizon rich in corals, including *Orionastraea edmondsi*, *Corwenia rugosa* and *Nemistium edmondsi*, known as the 'Orionastraea Band'.

The Saccammina Limestone (6 m) is typically a grey crinoidal limestone characterized by the problematical organism *Saccaminopsis* scattered throughout its thickness. Close to the top of this limestone is the Erythrospongia Sponge Band, recorded throughout northern England at this level by Hudson (1929) and later traced into the west Cumbria district by Hudson and Edmonds (see Eastwood *et al.*, 1931). *Saccaminopsis* is also abundant in the overlying mottled shales which fill the potholed surface developed on the limestone. The Junceum Limestone (*c.* 16 m), named after the coral *Siphonodendron junceum* which occurs at a number of levels, is rather variable in colour and contains chert nodules and silicified fossils.

Higher beds of the Third Limestone (2 m) and the base of the Orebank Sandstone occur in the south-west corner of Clints Quarry, the former comprising grey crinoidal limestone with corals and brachiopods and the latter comprising pale-coloured quartz-rich sandstone (Johnson, 1992).

Interpretation

The Asbian–Brigantian stage boundary in west Cumbria is taken as the line of division between the top of the White Limestone and the base of the overlying Rough Limestone. Its position at this site is confirmed by the occurrence of the

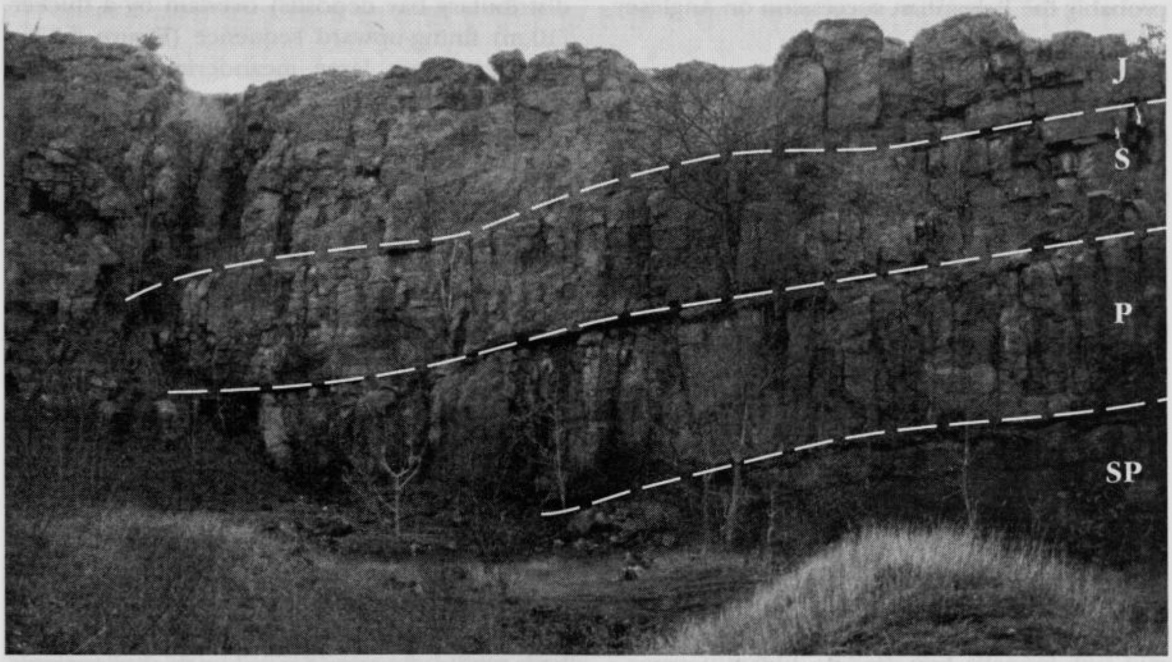


Figure 4.16 General view of the Fourth Limestone (Chief Limestone Group, Brigantian) at the north-west corner of the Clints Quarry GCR site. The components of the succession, which are separated by dashed lines, are from the base up: the Spotted Limestone (SP), the Potholes Limestone (P), the Saccammina Limestone (S) and the Junceum Limestone (J). The height of the cliff face is approximately 17 m. (Photo: P.J. Cossey.)

typical Asbian (D_1) brachiopod *Davidsonina septosa* in the White Limestone, and the typical Brigantian (D_2) faunas recorded from the Potholes Limestone (e.g. *O. edmondsi*, *N. edmondsi* and *C. rugosa*) in association with *Palastraea regia* (Smith *et al.*, 1925; Eastwood *et al.*, 1931; Mitchell *et al.*, 1979). Just above this boundary, and at the base of the Rough Limestone, Smith *et al.* (1925) recorded the 'Girvanella Band' (= the Girvanella Nodular Bed of this volume), the typical lower Brigantian (D_2) marker bed.

As with other Asbian and Brigantian shelf deposits in the British Isles, the succession at this site is strongly cyclic, with episodes of shallow marine carbonate sedimentation punctuated by periods of subaerial exposure and the development of karstic surfaces. Some of these are overlain by clay palaeosols of probable bentonitic origin, but others are overlain by probable fluvial sands (e.g. at the top of the Potholes Limestone). In addition there are shales, such as that at the top of the Saccammina Limestone, which show evidence of a marine origin. The succession is thus intermediate in type between the carbonate shelf successions of south Cumbria and Derbyshire and the Yoredale-type mixed carbonate–clastic successions of the Askrigg and Alston blocks. The closest parallel is probably the Brigantian succession on Anglesey.

Conclusions

This site is the finest and most easily accessed Brigantian section in west Cumbria. It is particularly valuable for demonstrating the cyclicity of the limestones, with the palaeokarstic surfaces well developed and with strong relief. Its value also lies in the presence of marine and fluvial clastics which make the succession intermediate in style between Yoredale-type cycles and pure carbonate cycles.

ROGERLEY QUARRY, COUNTY DURHAM (NZ 019 375–NZ 022 373)

Introduction

The Rogerley Quarry GCR site lies 2 km west of Frosterley and close to the A689 between Stanhope and Wolsingham (Weardale). This disused quarry (NZ 019 375) provides an outstanding section of the clastic intervals associated with the development of the Great Limestone Cyclothem towards the southern margin of the Alston Block during early Namurian times (Pendleian, E_1). The site is also extremely valuable in understanding the complexities of fluvio-deltaic sedimentation during Pendleian times and it includes a spectacular profile through an ancient river channel, one of the finest of its kind in Britain. The account that follows is based largely on the definitive sedimentological work of Elliot (1973; 1974a,b; 1975; 1976b; 1986) and its re-evaluation by Hodge and Dunham (1991).

Description

The principal interest lies in the 20 m-thick clastic interval exposed between the top of the Great Limestone and the base of the Little Limestone (Figure 4.17). The sequence was described in detail by Elliot (1975, 1976b) who interpreted it as part of a delta lobe extending for 700 km^2 across the Alston Block (Figure 4.18) with a complex development history marked by phases of progradation, abandonment and post-abandonment.

Immediately overlying the Great Limestone, the progradational phase includes two thin (4.5 m) coarsening-upward sequences (interdistributary bay deposits) overlain by a thicker (10 m) fining-upward sequence (Figure 4.17a) deposited by a large meandering distributary channel. A prominent erosion surface at the base of the palaeochannel cuts down through the interdistributary bay deposits to within a metre of the top of the Great Limestone (Figure 4.17a,b). The quarry face lies at right angles to the palaeochannel axis such that distinctive lateral changes within the channel fill may be viewed in profile along its length. The channel-fill includes at its base a conglomeratic lag deposit with mud-flakes scoured from the underlying beds, and is succeeded by trough cross-stratified, coarse sandstones (with a palaeoflow to the south or south-east) that grade upward into parallel-bedded sandstones. These are capped by a finer member of interbedded current ripple-laminated sandstones and siltstones containing a few rootlets and the in-situ remains of *Stigmaria* root systems. Individual beds within the coarse member thicken towards the south-east and are separated by sigmoidal bedding planes with a depositional dip of approximately 5° in the same direction.

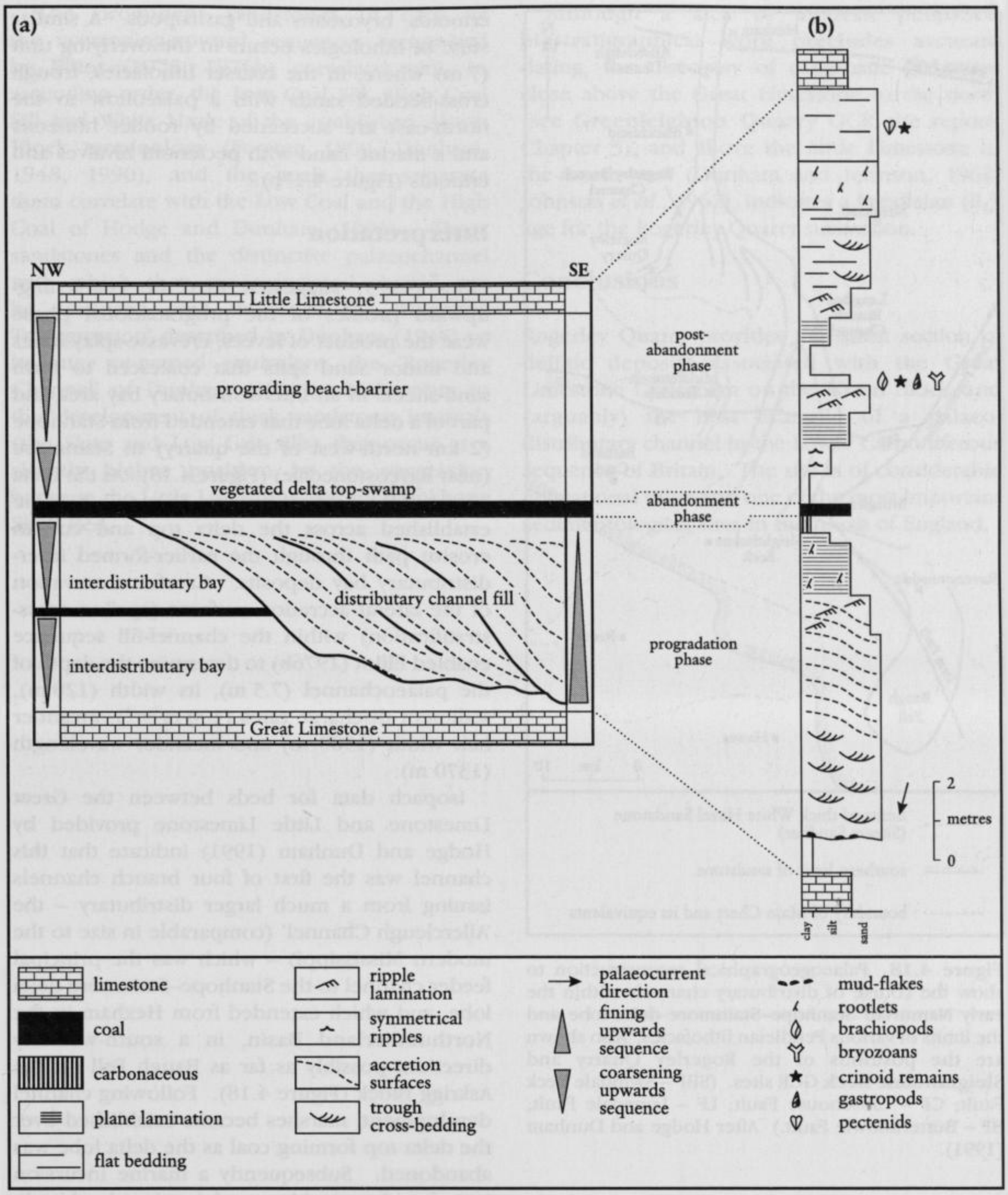


Figure 4.17 (a) Interpretation of the palaeoenvironments represented within the Great Limestone Cyclothem (Pendleian) in the vicinity of Rogerley Quarry, and (b) simplified sedimentary log of the Rogerley Quarry succession. After Elliot (1975, 1976b).

Considering their orientation with respect to the palaeoflow, Elliot (1976b) regarded these gently dipping planes as lateral accretion surfaces resulting from the sideways migration of point-bar deposits towards the channel axis.

Above this, a prominent coal seam extending across the top of both the channel and inter-distributary bay deposits marks the end of the progradational phase and the onset of lobe abandonment (Figure 4.17a). A similar but

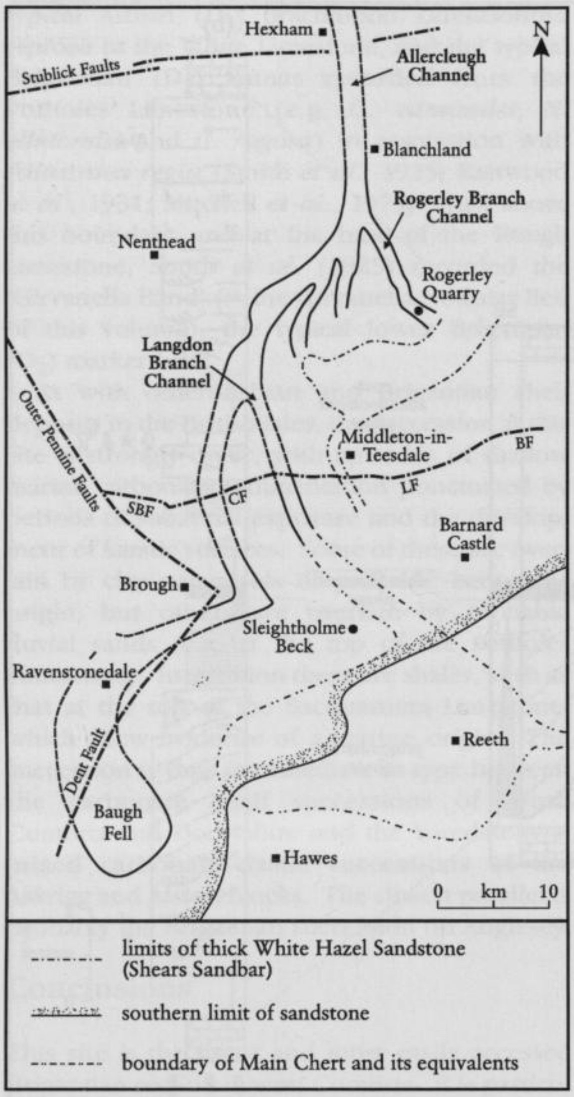


Figure 4.18 Palaeogeographical reconstruction to show the course of distributary channels within the early Namurian Stanhope–Stainmore delta lobe and the limits of various Pendleian lithofacies. Also shown are the positions of the Rogerley Quarry and **Sleightholme Beck** GCR sites. (SBF – Swindale Beck Fault; CF – Closehouse Fault; LF – Lunedale Fault; BF – Butterknowle Fault.) After Hodge and Dunham (1991).

thinner 'abandonment' coal separates the two coarsening-upward sequences of the progradational phase. Higher in the succession are two further coarsening-upward units of the post-abandonment phase. The lower of these (3 m) includes mudstones, siltstones and sandstones with low-amplitude symmetrical ripples, flat laminations and current-ripple laminations overlain by a marine band containing brachiopods, crinoids, bryozoans and gastropods. A similar suite of lithologies occurs in the overlying unit (7 m) where, in the coarser lithofacies, trough cross-bedded sands with a palaeoflow to the north-east are succeeded by rootlet horizons and a marine band with pectenoid bivalves and crinoids (Figure 4.17b).

Interpretation

Elliot (1975) suggested that the coarsening-upward profiles of the progradational phase were the product of levees, crevasse-splay lobes and minor sand spits that coalesced to form sand-sheets in an interdistributary bay area and part of a delta lobe that extended from Stanhope (2 km north-west of the quarry) to Stainmore (near Ravenstonedale) (Figure 4.18). As the delta prograded, a distributary channel became established across the delta top and cut an erosive path through the earlier-formed interdistributary bay deposits. Careful observation of the lateral accretion surfaces (epsilon cross-stratification) within the channel-fill sequence enabled Elliot (1976b) to determine the depth of the palaeochannel (7.5 m), its width (120 m), sediment discharge rates (100 m^3s^{-1}), meander belt width (1500 m) and meander wavelength (1370 m).

Isopach data for beds between the Great Limestone and Little Limestone provided by Hodge and Dunham (1991) indicate that this channel was the first of four branch channels issuing from a much larger distributary – the 'Allercleugh Channel' (comparable in size to the modern Mississippi) – which was the principal feeder channel to the Stanhope–Stainmore delta lobe, and which extended from Hexham in the Northumberland Basin, in a south-westerly direction, possibly as far as Baugh Fell on the Askrigg Block (Figure 4.18). Following channel development, marshes became established over the delta top forming coal as the delta lobe was abandoned. Subsequently a marine incursion introduced coastal-bay and barrier-island sediments over the top of the delta lobe as it subsided during the post-abandonment phase of development (Elliot, 1974a, 1975). While accepting much of the sedimentological detail in Elliot's (1975) work, the continuity and geographical limits of his delta lobes were questioned by Dunham (1990) and Hodge and Dunham (1991) because of conflicts with established correlations across the Alston Block.

The prominent sandstones in each of the coarsening-upward sequences recognized by Elliot (1975, 1976b) correlate with, in ascending order, the Low Coal Sill, High Coal Sill and White Hazle of the established Alston Block terminology (Forster, 1809; Dunham, 1948, 1990), and the coals that separate them correlate with the Low Coal and the High Coal of Hodge and Dunham (1991). These sandstones and the distinctive palaeochannel with which they are associated should not be confused with those of the 'Rogerley Transgression' described by Dunham (1948) or its later re-named equivalent, the 'Rogerley Channel' of Dunham (1990), which relate to the development of thick sandstone intervals (the Slate and Low Grit sills) that occur at a slightly higher position in the succession between the Little Limestone and the Rookhope Shell Bed.

Although a lack of modern published biostratigraphical work precludes accurate dating, the discovery of diagnostic goniatites close above the Great Limestone to the north (see **Greenleighton Quarry** GCR site report, Chapter 3), and above the Little Limestone to the north-west (Dunham and Johnson, 1962; Johnson *et al.*, 1962), indicates a Pendleian (E_1) age for the Rogerley Quarry succession.

Conclusions

Rogerley Quarry provides the finest section of deltaic deposits associated with the Great Limestone Cyclothem on the Alston Block, and (arguably) the best example of a palaeo-distributary channel in the Lower Carboniferous sequence of Britain. The site is of considerable educational value and one of the most important sedimentological sites in the north of England.