Chapter 4 Lake District Block and Alston Block

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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 4.1)a. 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 4.1)a. 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 4.1)a. 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 4.1)b).

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 Camforth. The [British] Geological Survey began resurveying 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 sedi-mentology 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 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 Pelle (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 cydicity 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 (Figure 5.1) and (Figure 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 Sellafleld 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 northern Pennines, extended west to the flanks of the Lake District and forms the eastern limits of the block ((Figure 3.2), Chapter 3).

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 Swank (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 sedi-mentological 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 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 4.1)b. 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.

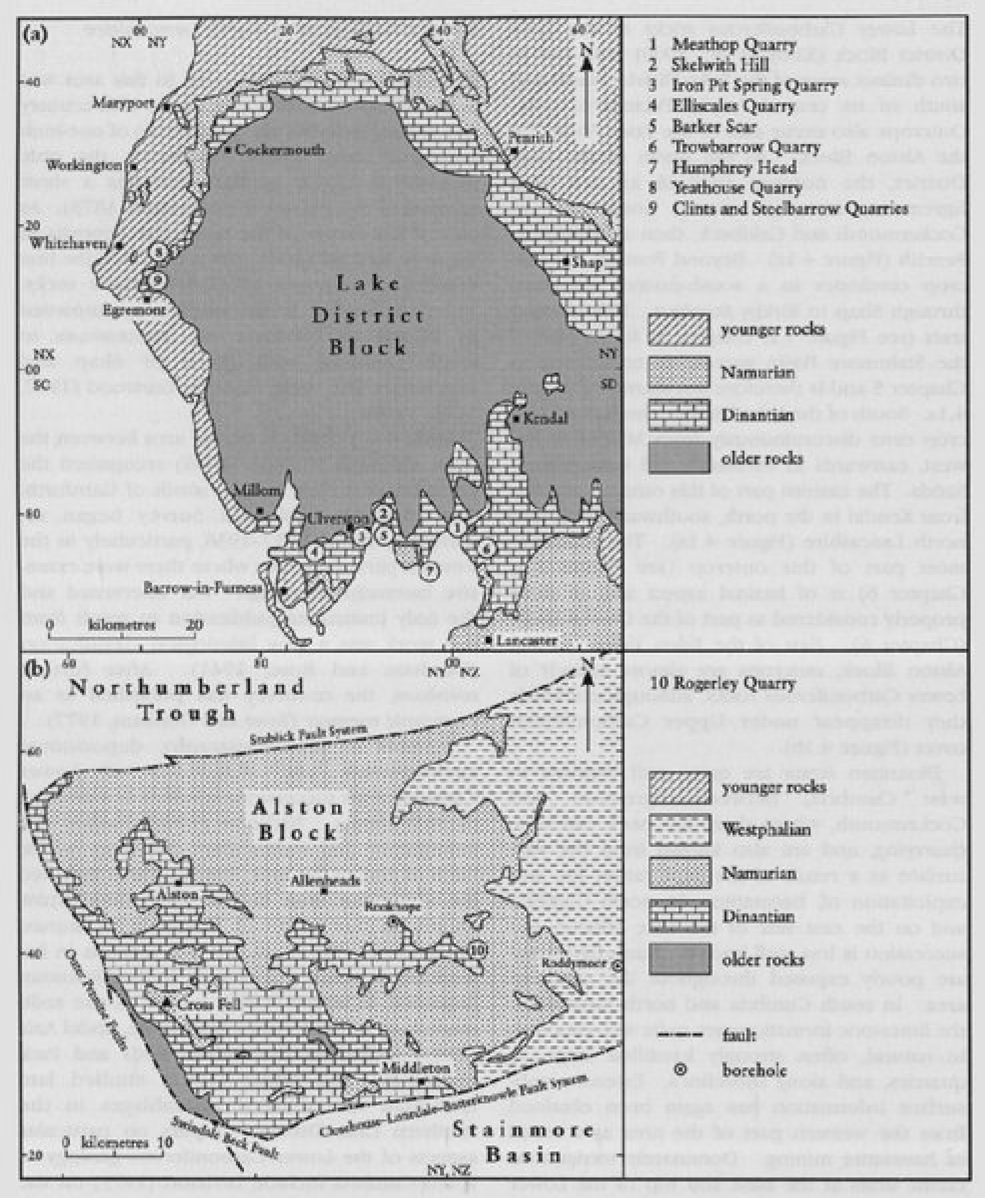
GCR site coverage

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.

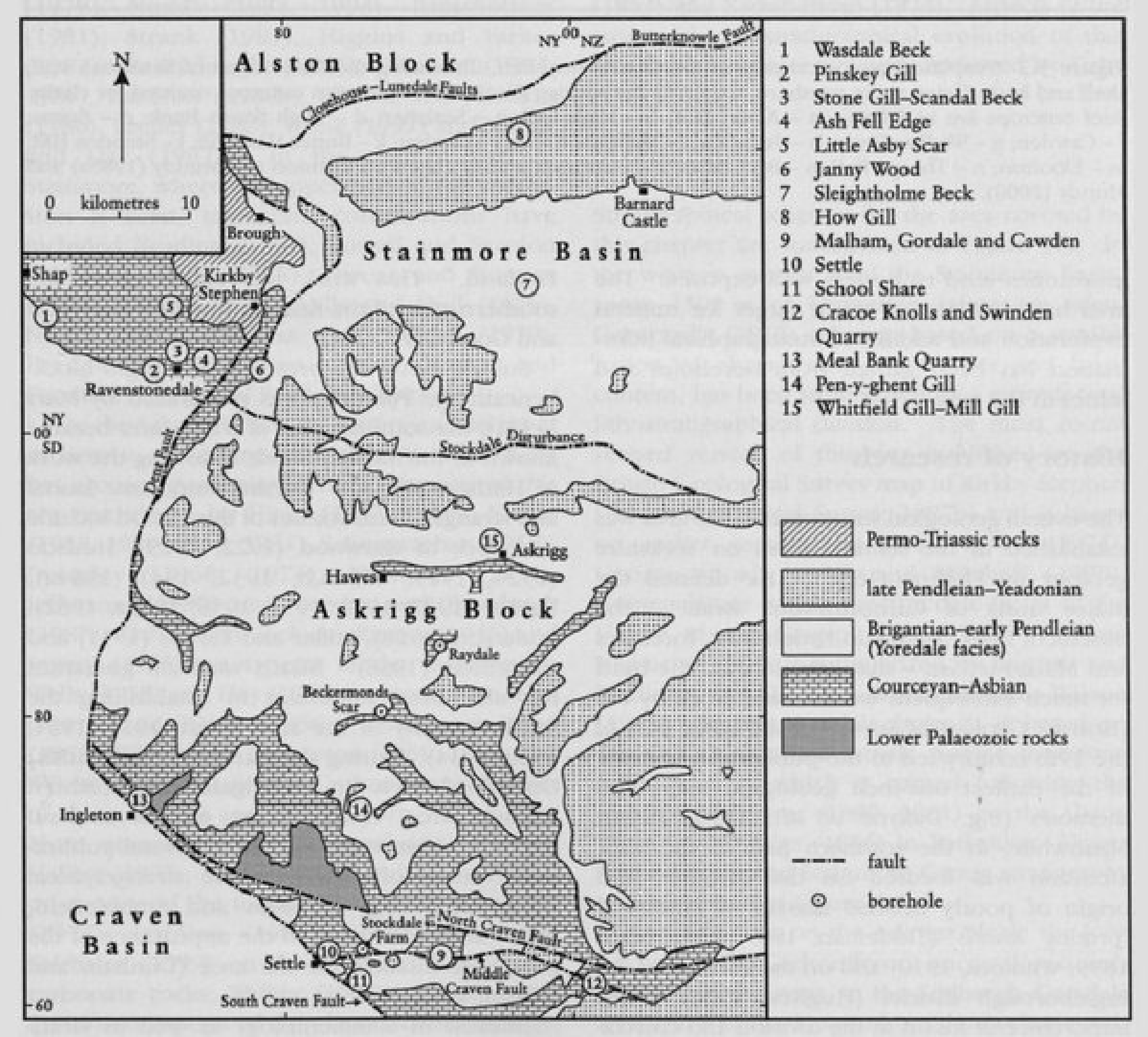
In the carbonate-dominated successions of south Cumbria the GCR sites include Meathop Quarry (Chadian, Martin Limestone), Skelwith Hill (Chadian–Arundian, Martin Limestone–Red Hill Oolite, non-sequence with calcretes and breccias), Iron Pit Spring Quarry (Arundian, Dalton Beds, 'Arnside Fauna'), Elliscales 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.

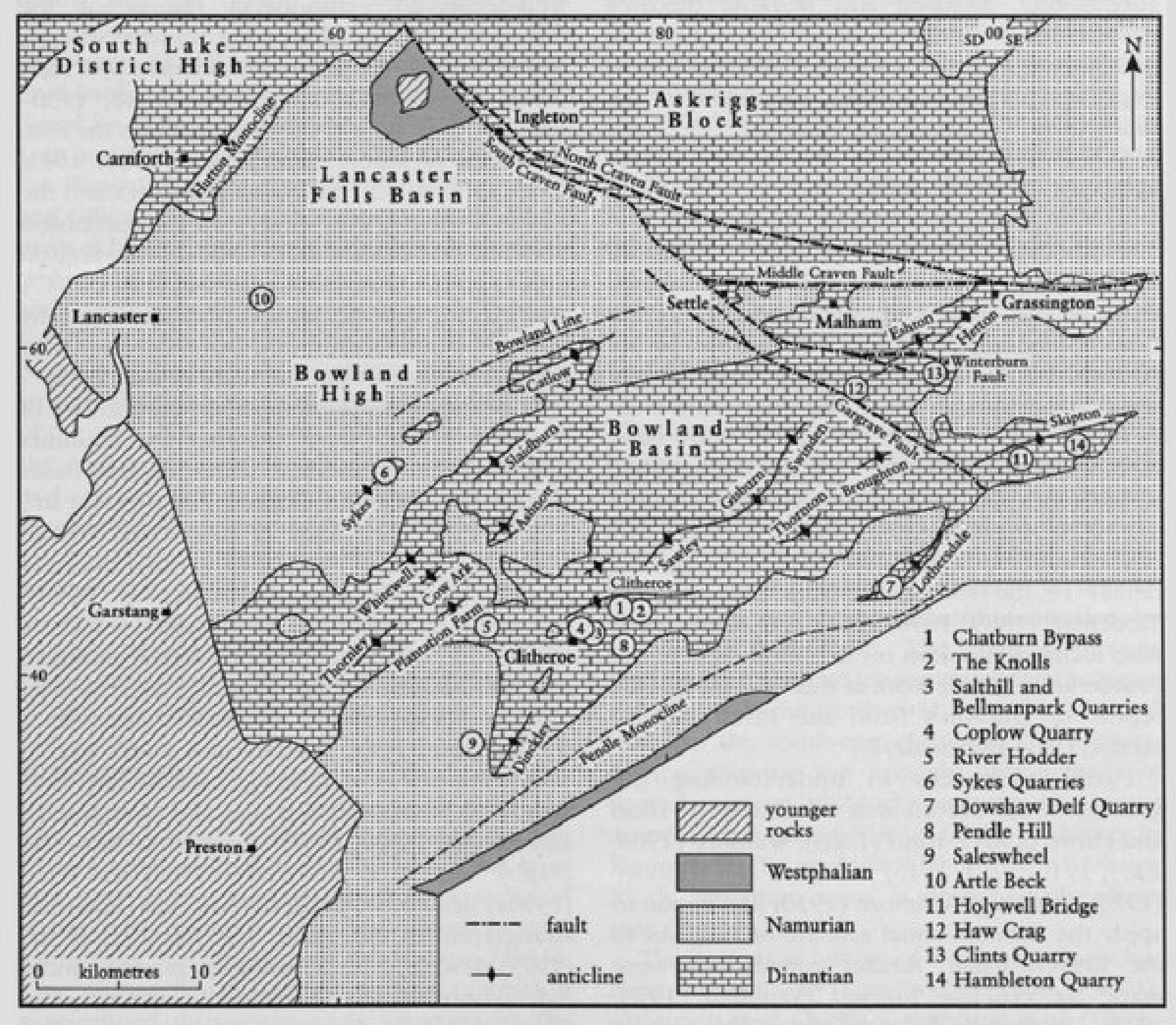
References



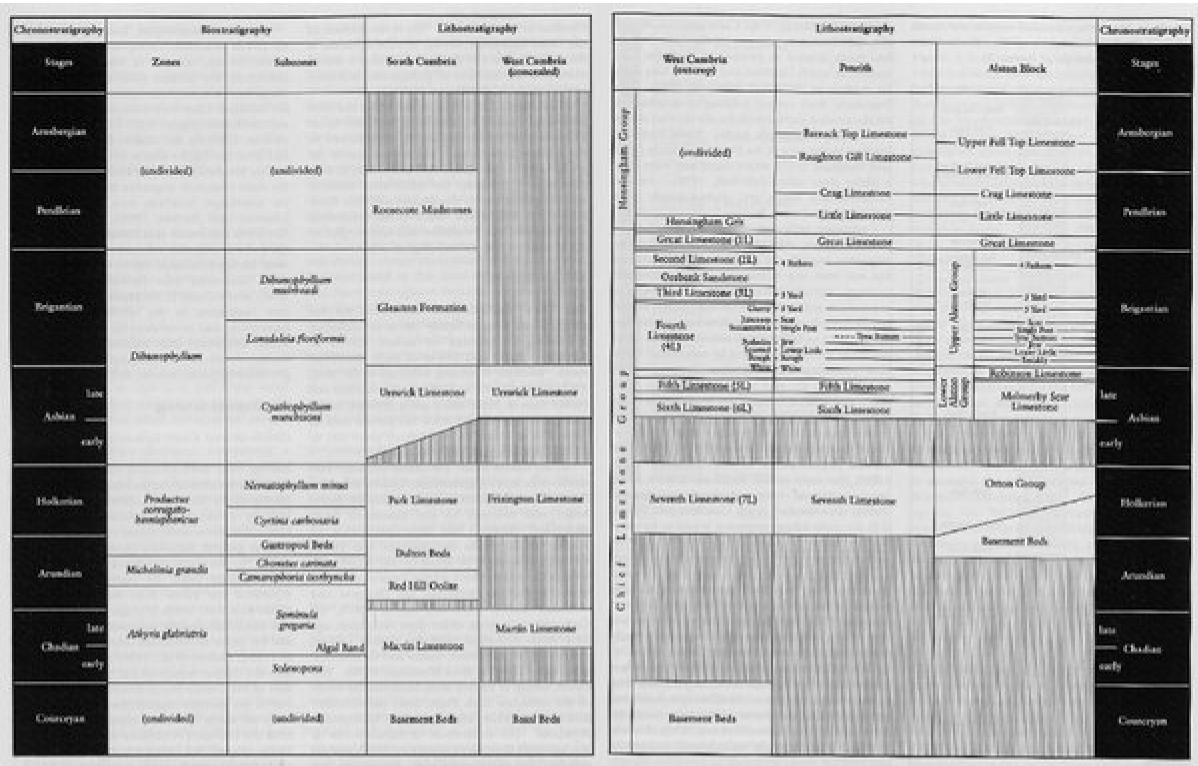
(Figure 4.1) Geological maps of the Lake District Block and the Alston Block areas showing the distribution of Carboniferous outcrops and the locations of GCR sites mentioned in the text. (a) The Lake District Block (after Moseley, 1978). (b) The Alston Block (after Dunham, 1990). Note that details of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



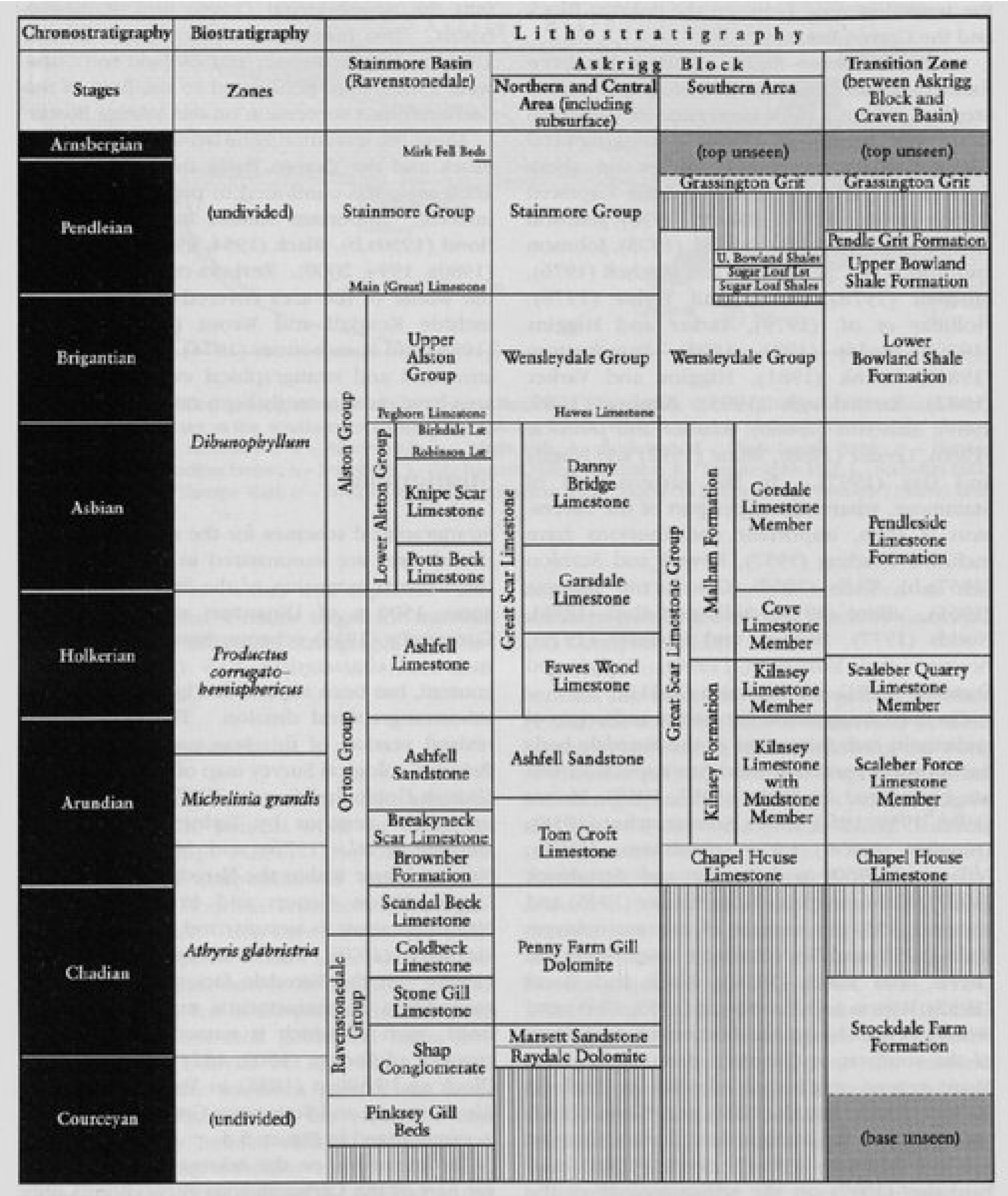
(Figure 5.1) Geological map of the Askrigg Block and Stainmore Basin illustrating the distribution of Carboniferous outcrops and the locations of GCR sites described in the text. Note that outside the area delineated by the bounding faults, only the geology of the Ravenstonedale area is shown, and that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



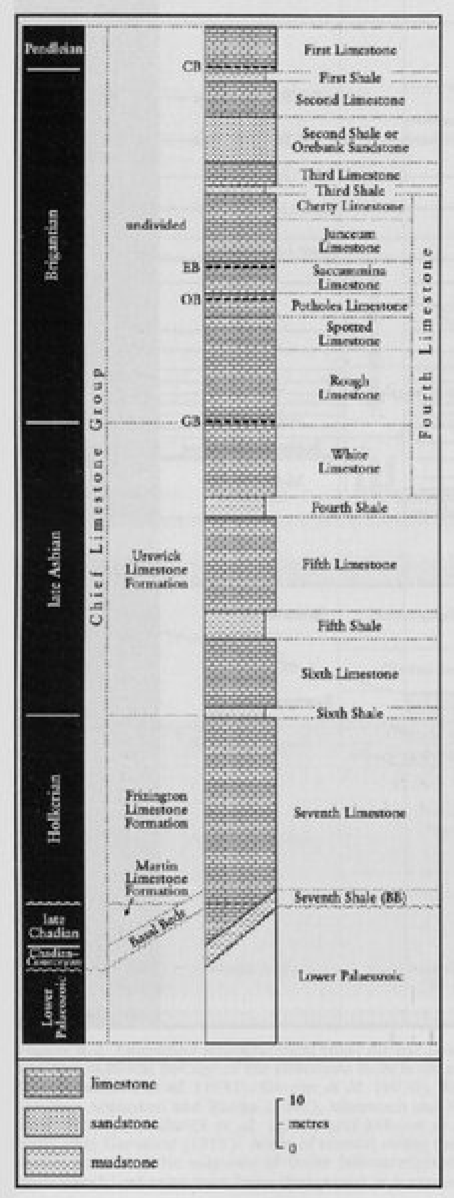
(Figure 6.1) Geological map of the Craven Basin illustrating the distribution of Carboniferous outcrops and the locations of GCR sites described in the text. Note that in the Bowland Basin area, the hinge traces of major folds within the Ribblesdale Fold Belt are also shown. The Central Lancashire High lies to the south of the Pendle Monocline beneath the area obscured by the key. Based on Riley (1990a) and Brandon et al. (1998).



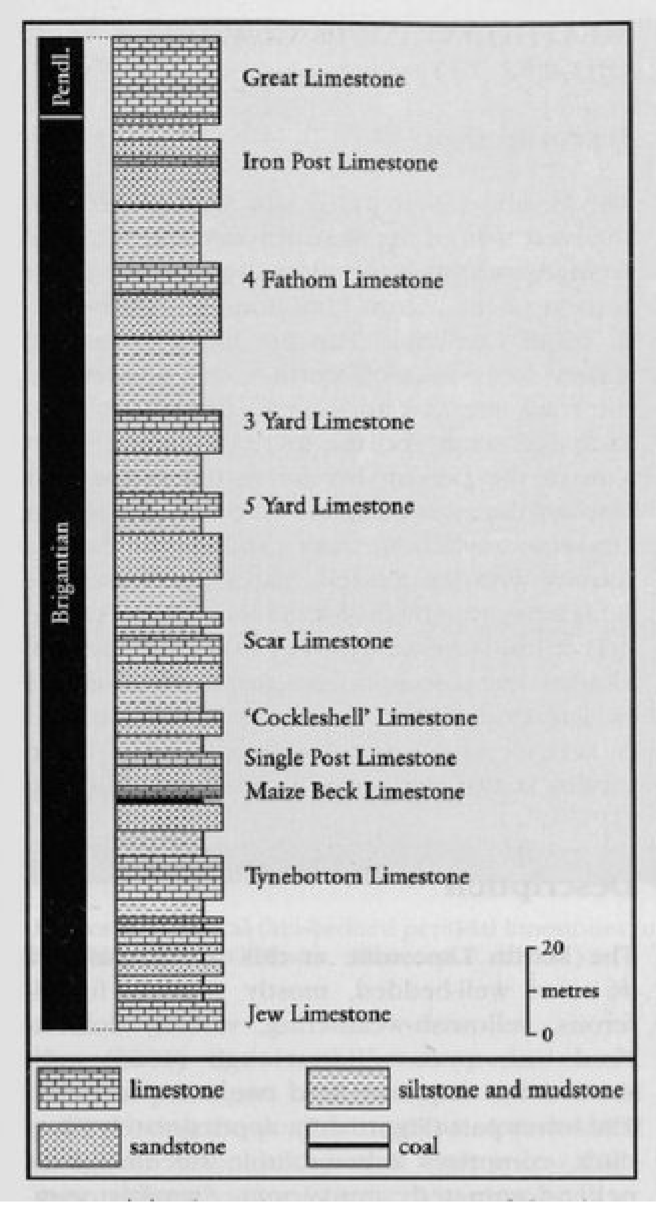
(Figure 4.2) Simplified stratigraphical chart for the Lower Carboniferous succession of the Lake District Block and Alston Block; the age of the Basement Beds is uncertain in many areas. Compilation based on information from Eastwood et al. (1931), George et al. (1976), Rose and Dunham (1977), Mitchell (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).



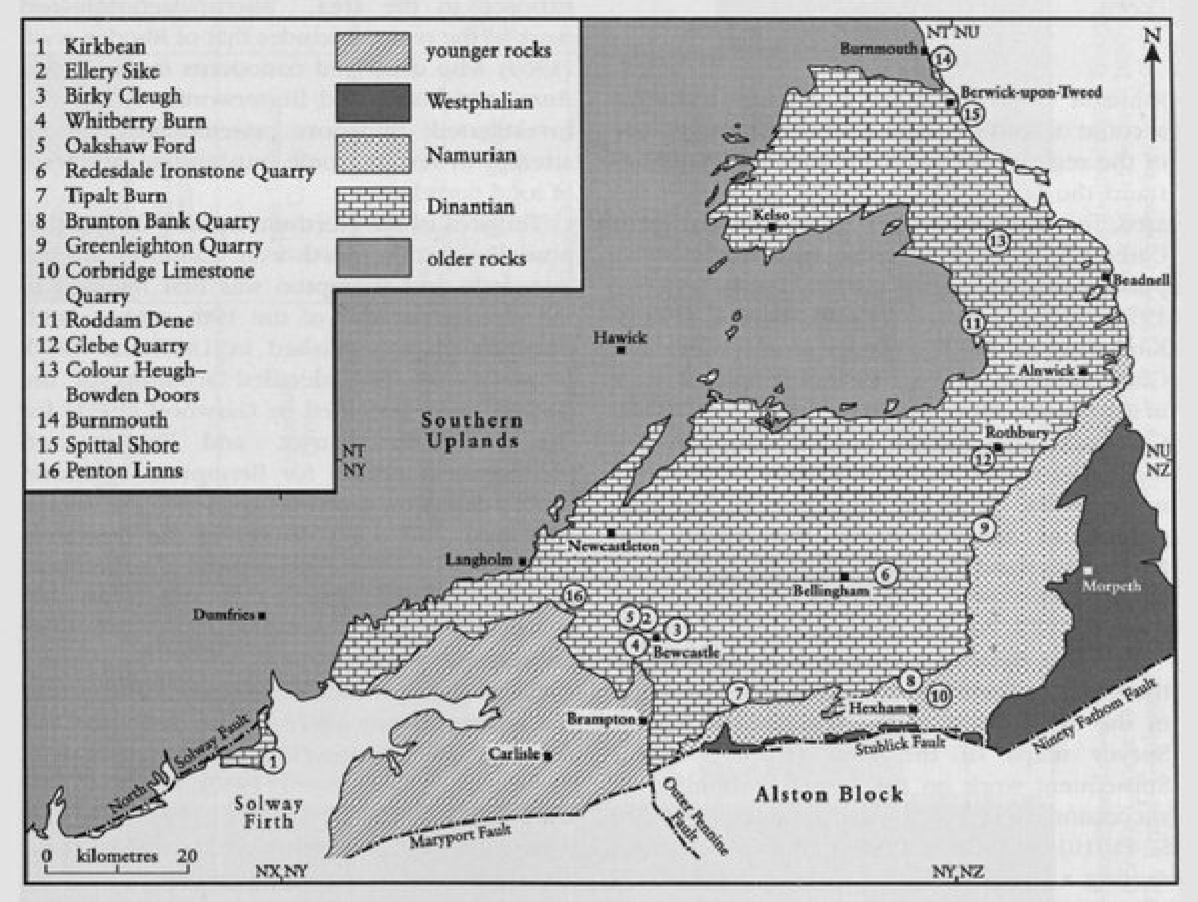
(Figure 5.3) Simplified stratigraphical chart for the Lower Carboniferous sequence of the Askrigg Block and Stainmore Basin. Compilation based upon and modified after George et al. (1976), Dunham and Wilson (1985), Arthurton et al. (1988), British Geological Survey (1997b,c), and Mundy (2000). Zonal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



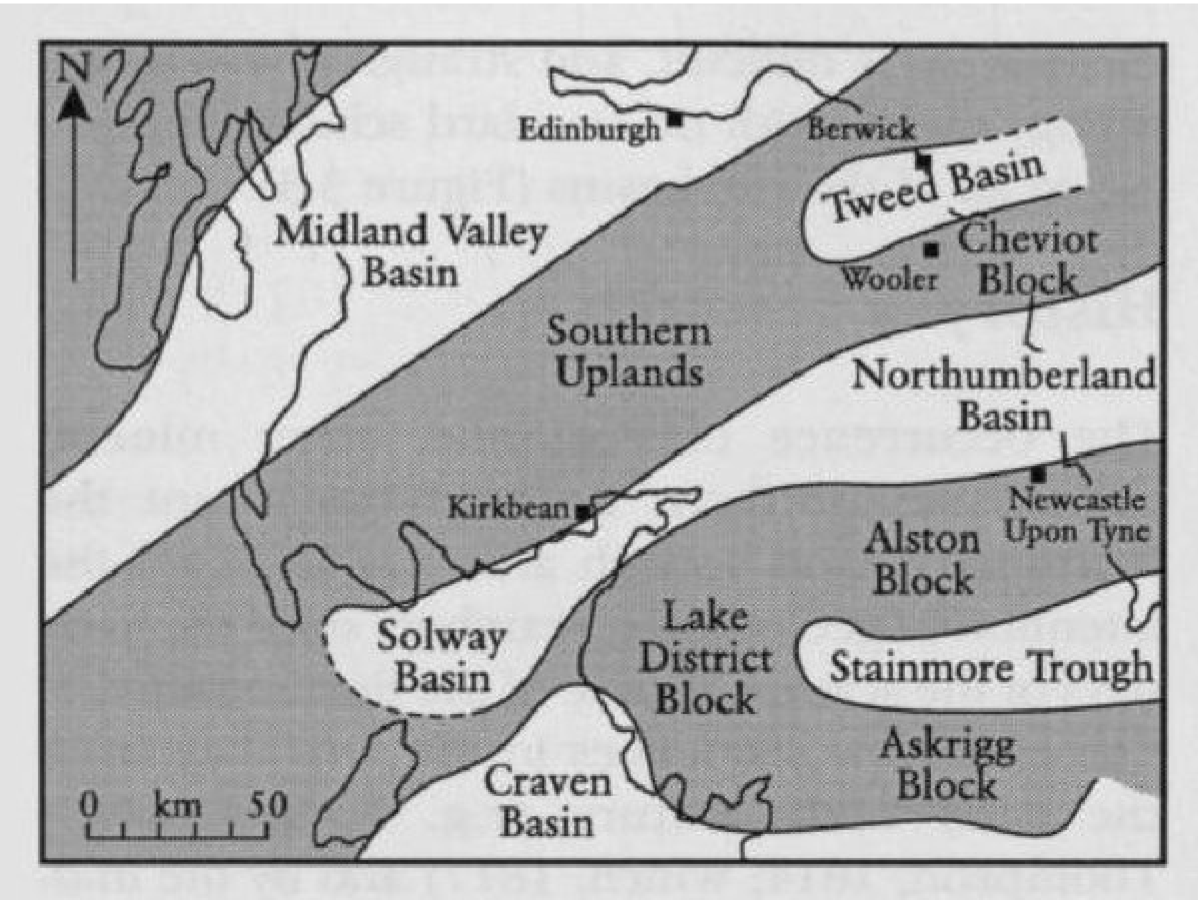
(Figure 4.3) Stratigraphy of the Lower Carboniferous Chief Limestone Group in west Cumbria. (BB — Basement Beds; GB — Girvanella Band (= Girvanella Nodular Bed, see Clints and Steelbarrow Quarries GCR site report, this chapter); OB — Orionastraea Band; EB — Erythrospongia Band; CB — Chaetetes Band.)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



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



(Figure 3.1) Geological map of northern England illustrating the distribution of Carboniferous outcrops in the Northumberland Trough and the locations of GCR sites described in the text. Details of the geology south of the Maryport–Stublick–Ninety Fathom Fault System and in the Southern Uplands area are omitted. After Johnson et al. (1995), and including information from Ord et al. (1988), Leeder (1992) and Chadwick et al. (1993a,b, 1995). Note that the position of the Maryport Fault is extrapolated from the subsurface.



(Figure 3.2) Simplified palaeogeography of northern England and southern Scotland illustrating the distribution of Lower Carboniferous sedimentary basins. Note the positions of the Tweed Basin, Northumberland Basin and Solway Basin, which together constitute the Northumberland Trough area. Based on Johnson (1984) and Armstrong and Purnell (1993).

(Figure 1.3) The main structural elements controlling the palaeogeography of Britain during Early Carboniferous times. Note the distribution of the Tweed Basin, Solway Basin and Northumberland Basin which together constitute the Northumberland Trough area as considered in Chapter 3 of this volume. Based, in part, on Johnson (1984), Gawthorpe et al. (1989), Ebdon et al. (1990), Fraser and Gawthorpe (1990), Armstrong and Purnell (1993) and Corfield et al. (1996).