Chapter 3 Northumberland Trough

M.A. Purnell and P.J. Cossey

Introduction

The Lower Carboniferous rocks of the Northumberland Trough outcrop as an easterly widening wedge between the Southern Uplands to the north and the Alston Block to the south (Figure 3.1). A number of sub-basins are recognized in the Northumberland Trough: the Solway Basin in the west, the Northumberland Basin, and the Tweed Basin to the north of the Cheviot Block (Figure 3.2). Except for excellent coastal sections in the east and west, exposure is limited to streams and a few quarries, with many areas of outcrop bounded by faults. Because of this sporadic pattern of exposure and rapid lateral facies changes, both within and between sub-basins, several areas have Lower Carboniferous successions that are sedimentologically distinctive. Precise correlation between these areas is difficult, and stratigraphical terminology varies, with no standard scheme applicable to all of the sub-basins (Figure 3.3).

History of research

The occurrence of coal and other mineral deposits in northern England has meant the Northumberland Trough area has attracted the attention of geological researchers since the early days of the science. Some of the first accounts of Carboniferous sequences in the area date from the early 19th century (e.g. Forster, 1809; Thompson, 1814; Winch, 1817) and by the middle of the 19th century these successions had been described in some detail. Subsequent classic work on the geology of the Northumberland Trough includes that of Tate (1867), Lebour (1875a), Smith, S. (1910) and Garwood (1913).

Johnson (1995) includes a detailed historical account of studies on the Carboniferous geology of the region. More recent attempts to understand the Lower Carboniferous geology of the area, as part of wider investigations into Carboniferous stratigraphy, have resulted in publications by Rayner (1953), Leeder (1974a, 1976, 1988), Johnson (1984), Barrett (1988), Kimbell *et al.* (1989), Leeder *et al.* (1989) and Chadwick *et al.* (1995). Biostratigraphical work in the trough, especially in the lower parts of the Carboniferous sequence, has been hampered by the paucity of stratigraphically significant macrofossils. Work on the conodont biostratigraphy of marine strata throughout the Northumberland Trough represents an attempt to overcome these difficulties (Armstrong and Purnell, 1987; Purnell, 1989).

The first detailed account of the geology of the Kirkbean Outlier (Solway Basin) is contained in the explanation of the [British] Geological Survey maps of the area (Horne, 1896).

Subsequent work on the Lower Carboniferous successions in this region includes that by Smith, S. (1910) and Craig (1956), the latter representing a major revision of the stratigraphical classification and correlation of the rocks. More recently, Maguire *et al.* (1996) published a detailed analysis of Dinantian depositional environments in the Solway area, and important coastal sections in the Kirkcudbright–Dalbeattie area have been re-surveyed to produce a new British Geological Survey map (British Geological Survey, 1993a) and memoir (Lintern and Floyd, 2000) of the region.

Exposures of Lower Carboniferous strata in the Langholm area were first described by Peach and Horne (1903) as part of their work on the Canonbie Coalfield. Garwood (1931) later provided detailed descriptions of several sections and proposed new stratigraphical subdivisions and correlations with strata exposed in other areas of the Northumberland Trough. [British] Geological Survey activity in the area culminated in the publication of the Langholm memoir (Lumsden *et al.,* 1967). Around the same time, Leeder published a series of papers describing the detailed sedimentology of the siliciclastic facies (Leeder, 1974b) and the carbonate and laminated microbial facies (Leeder, 1975a,b) of the lower part of the Carboniferous sequence exposed in the area. Micropalaeontological work in the region includes that of Rhodes *et al.* (1969) who described conodonts from Harden Burn, and Mandi and Butterworth (1994) who investigated miospore assemblages in an attempt to resolve some outstanding problems of local correlation.

The area of the Northumberland Trough that now lies within north-west Cumbria around Bewcastle and Brampton was first mapped in the closing decades of the 19th century, with one-inch maps published in 1889 and 1890. However, the first detailed accounts of the geology were provided by Garwood (1931) for the Bewcastle district, and Trotter and Hollingworth (1932) for Brampton. Johnson (1959) described sections exposed in the Roman Wall area, and the re-survey of the Bewcastle area led to the publication of a new one-inch map and memoir (Day, 1970), which included extensive revisions to the lithostratigraphy. Subsequent work on the Lower Carboniferous rocks of the area includes Leeder's analyses of the sedimentology (1973, 1974b, 1975a,b) and sediment deformation (1987b), and recent work by Armstrong and Purnell (1987), Purnell (1989, 1992) and Purnell and von Bitter (1992) on conodont biostratigraphy within the Northumberland Trough focused particularly on the Bewcastle area. Investigation of the hydrocarbon potential of the region resulted in the drilling of the Easton Borehole, which proved thick evaporite sequences not encountered at the surface (Ward in Chadwick *et al.*, 1993a, 1995).

To the east and north, in areas that cover most of Northumberland and the eastern Scottish Borders, the primary six-inch geological surveys were carried out between 1870 and the end of the 19th century, resulting in the publication of a series of one-inch maps. Some of these maps were accompanied by memoirs, including Otterbum and Elsdon (Miller, 1887), Plashetts and Kielder (Clough, 1889), the country between Wooler and Coldstream (Gunn and Clough, 1895) and Berwick-upon-Tweed (Gunn, 1897). These memoirs established subdivisions of the Carboniferous strata of the Northumberland Trough that have persisted to today. Other early work in the area includes that of Lebour (1873, 1875b,c). Memoirs resulting from the resurvey in the 1920s include Fowler (1926, 1936) and Carruthers *et al.* (1930) for Berwick-upon-Tweed, Norham and Scremerston, Rothbury; Amble and Ashington, and the country between Wooler and Coldstream. A substantial part of the area was discussed in detail by Westoll *et al.* (1955). More recent works of significance include those by Fowler (1966), Frost (1969), Greig (1988), and Holliday and Pattison (1990).

Stratigraphy

As a result of syn-depositional extensional faulting, the thickness of Lower Carboniferous strata deposited in different areas of the Northumberland Trough varies considerably. Maximum thickness has been estimated to be 1500 m in the northern Tweed Basin, and more than 2000 m in the Northumberland Basin (Johnson, 1984). More recent work, based largely on seismic evidence, indicates that the Lower Carboniferous strata in the Northumberland Basin may have reached a compacted thickness of about 5000 m, overlain by 1000–2000 m of Silesian strata (Chadwick *et* al., 1995).

The first subdivision of Carboniferous strata in the Northumberland Trough was proposed by Tate (1863) for the sequence exposed in north Northumberland. He initially recognized four divisions (Tuedian, Mountain Limestones, Millstone Grit and Coal Measures), later dividing the Mountain Limestones into a lower Carbonaceous Group and an upper Calcareous Group (Tate, 1867). Miller (1887) extended Tate's classification to the south and west into mid-Northumberland and the Liddesdale–Langholm area. He objected to the term Tuedian as 'belonging to an unwholesome class of terminology' (Miller, 1887, p. 5) and divided these strata into three: Lower Freestones, Cementstones and Rothbury Limestones, and Fell Sandstones. He introduced the 'Scremerston Coal Series' as a synonym for the Carbonaceous Group. Fowler (1926) proposed three divisions to replace the Calcareous Group of earlier workers: the base of the Lower Limestone Group defined at the Dun Limestone (which Fowler erroneously equated with the Redesdale limestone); the base of the Middle Limestone Group defined at the Oxford Limestone; and the base of the Upper Limestone Group at the Dryburn (or Great) Limestone. The top of the Upper Limestone Group was taken at the base of the ill-defined 'Millstone Grit'. Except for recognizing that the Dun Limestone is not equivalent to the Redesdale Limestone, classification of the Lower Carboniferous sequence in north Northumberland has remained essentially unchanged since the work of Fowler (1926; see (Figure 3.3)).

In what is now north-west Cumbria Trotter and Hollingworth (1932) assigned the lower part of the Carboniferous sequence in the Brampton area to the Cementstone Group and the Fell Sandstone Group, as identified to the east, but they were unable to recognize the twofold lithological division of overlying rocks into the Carbonaceous (Scremerston Coal) Group, and the Calcareous Group. Thus they assigned rocks above the Fell Sandstone Group to the Craighill Sandstone Group, the Birdoswald Limestone Group, and the Lower Limestone, Middle Limestone and Upper Limestone groups. This scheme was also adopted by Johnson (1959).

Garwood (1931) extended the terminology applied to the Carboniferous sequence in north Northumberland (e.g. Tate, 1863; Lebour, 1875a; Miller, 1887) into the Bewcastle area of north-west Cumbria and the adjacent Scottish Border country. He designated the Bewcastle district as the type area for the Cementstone Group in 'North Cumberland', and in contrast to the practice in other areas, introduced a fourfold subdivision of the Cementstone Group into the Lynebank Beds, Bewcastle Beds, Main Algal Series, and Cambeck Beds (terms that were later elevated to formation status by Leeder, 1974b). However, detailed mapping in the Bewcastle area led Day (1970) to the conclusion that none of the existing classifications of Lower Carboniferous strata could be applied in north-west Cumbria. He divided the sequence into the Lower Border Group (including Garwood's four Cementstone Group subdivisions), extending from the lowest exposed Carboniferous strata to the Whitberry Member; the Middle Border Group, extending up to the base of the Clattering Band; the Upper Border Group, extending up to the base of the Naworth Bryozoa Band (= Goat Island Limestone; = Dinwoodie Beds of the Archerbeck Borehole); the Lower Liddesdale Group, extending up to the base of the Callant Limestone (approximately equivalent to the Low Tipalt Limestone); and the Upper Liddesdale Group, extending up to the base of the Catsbit (or Great) Limestone. This scheme has been followed by subsequent workers in the area (Figure 3.3). For similar reasons to those outlined by Day (1970), Frost and Holliday (1980) rejected earlier attempts at classification and extended Day's scheme eastwards to the Bellingham area with only minor re-definition of local markers for the bases of some of the groups (see (Figure 3.3)). The terminology used in this account for lithostratigraphical marker bands in the Lower Border Group follows that of Purnell (1992) (see (Figure 3.4)).

In the Liddesdale district, Peach and Horne (1903) subdivided the lower part of the Carboniferous sequence into the Birrenswark Volcanic Group, the Whita Sandstone and the Cementstone Group. Garwood (1931) subdivided the Cementstone Group into the Lower Beds and the Main Algal Series, believing the latter to represent a northward extension of the series defined in the Bewcastle area. Strata between the top of the Main Algal Series and the base of the Fell Sandstone Group, although not named, were considered by Garwood (1931) tocorrespond to the Cambeck Beds. Pringle (1948) assigned Lower Carboniferous strata of the area to the Calciferous Series, but adopted the group level classification of Peach and Horne (1903) and followed Garwood's subdivision of the Cementstone Group. More recent stratigraphical schemes (Lumsden *et al.,* 1967; Day, 1970) have defined the lower boundary of the Lower Border Group at the base of the Birrenswark Lavas (Figure 3.3). However, the Whitberry Member, which occurs at the top of this group in the Bewcastle area, was found not to occur in the Newcastleton–Langholm area (Lumsden *et al.,* 1967); consequently the upper boundary of the group was taken at the base of the Harden Member, 'considered to be the nearest mappable horizon to the likely position of the 'Whitberry Band' (Lumsden *et al.,* 1967). As a result of this correlation part of the sequence previously assigned to the Cementstone Group became the lower part of the Middle Border Group. This lithostratigraphical classification was also followed by Greig (1971). Refinements to the lithostratigraphy of the Lower Border Group in the Newcastleton-Langholm area were later established by Leeder (1974b).

In the western part of the Northumberland Trough, Horne (1896) assigned Lower Carboniferous strata of the Kirkbean Outlier to the Calciferous Sandstone Series, recognizing four subdivisions: sandstones and shales with marine bands; Thirlstane Sandstones; sandstones, shales and thin marine limestones; and the CoraRine Limestone of Arbigland Bay. This classification was followed by Pringle (1948), but Craig (1956) substantially revised the lithostratigraphy of the outlier. He divided the sedimentary sequence into the Basal Cementstones and the Southerness Beds, together equated with the Cementstone Group strata to the east; the Gillfoot Beds, Powillimount Beds and Thirlstane Sandstone, equated with the Fell Sandstone Group; and the Arbigland Group. The basic framework of this classification (Craig, 1956) has been followed by subsequent authors (Greig, 1971; Deegan, 1973; George *et al.,* 1976; Ord *et al.,* 1988; Maguire *et al.,* 1996; Lintern and Floyd, 2000) and is employed here (see (Figure 3.3); and (Figure 3.7), Kirkbean GCR site report, this chapter).

The various stratigraphical schemes currently in use in different areas of the Northumberland Trough are summarized in (Figure 3.3). This diagram also shows correlations between the different sections and with Lower Carboniferous chronostratigraphical stages. The history of correlation and mis-correlation in the region is long and complex, and the position of some boundaries and/or time-lines remains uncertain. This is primarily due to rapid lateral facies and thickness variations, and because of the lack of stratigraphically useful macrofossils, especially towards the base of the sequence.

The first attempts at biostratigraphy were made by Garwood (1913), who later (Garwood, 1931) applied a coral–brachiopod zonation to the sequence exposed around Bewcastle, chiefly through correlation with his earlier (1913) zonation of the Lower Carboniferous strata in the Ravenstonedale area to the south. Partly because of Garwood's pioneering work, but also because the sequence exposed around the Bewcastle and Brampton areas of north Cumbria is among the thickest, most complete, and best known in the Northumberland Trough, much of the subsequent stratigraphical work attempted correlation with these strata. Studies of note include Rayner (1953), Weston *et al.* (1955), Johnson (1959), Johnson *et al.* (1962), Hull (1968), George *et al.* (1976) and Ramsbottom *et al.* (1978). Micropalaeontological studies have helped to resolve some of the long-standing difficulties in correlation in the region (e.g. Neves *et al.,* 1973; Armstrong and Purnell, 1987; Purnell, 1989, 1992; Mandi and Butterworth, 1994).

The position of the Devonian–Carboniferous boundary in the Northumberland Trough sequence is not known. In some areas, Lower Carboniferous 'cementstones' unconformably overlie Silurian strata, but in the northern part of the area rocks of Old Red Sandstone facies are intercalated with, or conformably overlain by, Cementstone Group rocks (e.g. Leeder, 1973) and in some localities the base of the Carboniferous sequence lies within Old Red Sandstone facies (Leeder, 1974b). In some sections exposed along the northern margins of the Northumberland Trough, the Cementstone Group overlies the Birrenswark Lavas and Kelso Lavas, and the base of the Carboniferous System is traditionally taken at the base of the lavas (Leeder, 1971). Along its southern margin, the base of the sequence is not exposed.

Until quite recently the Lower Border Group and the Cementstone Group were taken to be of Courceyan age (George *et al.,* 1976); however, although biostratigraphical evidence is scant, foraminifera and conodonts from the lower part of the Lower Border Group at Bewcastle indicate a Chadian age (Ramsbottom, 1977a). This has been confirmed by more detailed conodont work (Armstrong and Purnell, 1987; Purnell, 1989), indicating an early Chadian to Holkerian age for the Lower Border Group at Bewcastle. This work also suggests that the Lower Border Group in the Newcastleton area (near Langholm) is of Courceyan age, but miospores indicate that supposed lateral equivalent non-marine rocks exposed just to the south, nearer to Langholm, are of Chadian age. This highlights the problems with lithostratigraphical correlation within the Northumberland Trough and it is unfortunate that correlations between the marine Lower Border Group in the Bewcastle area and Cementstone Group sequences elsewhere rely almost entirely on lithostratigraphical evidence. Thus, although microfossils in particular provide some constraints, the positions of the boundaries between the Courceyan, Chadian, Arundian and Holkerian stages in this region are not known at present (Figure 3.3).

Using foraminifera, the base of the Asbian Stage is correlated with a horizon within the Glencartholm Volcanic Beds in the Archerbeck Borehole (George *et al.,* 1976), which is correlated with the Clattering Band in the Bewcastle sequence (Day, 1970). Correlations into other parts of the basin are lithostratigraphical. Biostratigraphically useful macrofossils become more common higher in the sequence, but many of the stratigraphical problems in the Northumberland Trough have arisen because biostratigraphy and lithostratigraphy have been conflated, with marker beds of supposed or established palaeontological significance being used to correlate between areas (e.g. Frost and Holliday, 1980). Hence the Upper Liddesdale Group corresponds to the D_2 coral–brachiopod zone (Johnson, 1959; Day, 1970) and the Brigantian Stage (George *et al.,* 1976) because the lower boundary of the division was selected to coincide with the incoming of stratigraphically significant fossils. The position of the base of the Brigantian Stage in the Northumberland Trough is based on correlation of the Low Tipalt Limestone with the Peghorn Limestone at the basal Brigantian stratotype ((Figure 3.5); and see Janny Wood GCR site report, Chapter 5).

Goniatite faunas provide good evidence that the base of the Pendleian Stage lies close to the base of the Great Limestone (Johnson, 1962; and see (Figure 3.6)). Lithostratigraphical correlation supported by limited biostratigraphical data suggest that the base of the Arnsbergian Stage lies at a position close to the Corbridge Limestone in the Northumberland Trough (e.g. Ramsbottom, 1977a; Ramsbottom *et al.,* 1978; Holliday and Pattison, 1990; Johnson *et al.,* 1995; Mills and Holliday, 1998; and see (Figure 3.6)).

Geological setting

The Northumberland Trough is one of a number of sedimentary basins that developed in northern Britain during Late Palaeozoic times. It is now widely accepted that the formation and evolution of these basins was controlled by back-arc extension north of an orogenic belt associated with northward subduction (Chadwick and Holliday, 1991) and closure of a 'proto-Tethys' Ocean (Leeder, 1976, 1982, 1988). However, there is some disagreement over the controls on the location of the Northumberland Trough. A number of authors (e.g. Trotter and Hollingworth, 1928; Johnson, 1967; Kimbell *et al.*, 1989) have suggested that its margins represent re-activated Caledonide structures associated with the Iapetus suture. Post-orogenic Caledonide granite bodies may also have Influenced its location through buoying-up of block regions (e.g. Bott, 1967; Leeder, 1982). The relative contributions of these processes is uncertain, but the Maryport–Stublick–Ninety Fathom Fault System (Figure 3.1) undoubtedly formed the Northumberland Trough's active southern margin.

Rapid, fault-controlled subsidence of the Northumberland Trough took place during early Dinantian times (Johnson, 1984; Collier, 1989; Kimbell *et al.,* 1989; Chadwick *et al.,* 1995), accompanied initially by extrusion of the Hirrenswark Lavas and Kelso Lavas along its northern margin (Leeder, 1974a). Deposition of early syn-extensional strata (Courceyan–Chadian) was largely restricted to rapidly subsiding, fault-bounded, basinal areas (Chadwick *et al.*, 1995). During later phases of extension, deposition gradually spread more widely, until in Asbian (Johnson, 1984) or Brigantian times (Leeder, 1988), rapid subsidence gave way to slow regional down-warping of both the Northumberland Trough and the adjacent bounding block areas.

During deposition of Lower Carboniferous strata, sedimentation kept pace with subsidence (Johnson, 1984) and there is little evidence for water depth ever exceeding 50 m (Leeder and McMahon, 1988). For much of Early Carboniferous times, the Northumberland Trough was a narrow gulf-like extension of the open sea, widening to the south-west and with marine influences thus decreasing towards the north and east. Its sedimentary rock successions reflect the interplay of fluvio-deltaic and shallow-marine depositional systems (Leeder, 1974a,b, 1975a,b; Johnson, 1984; Smith and Holliday, 1991) that were controlled by tectono-sedimentary (Leeder, 1987b; Leeder *et al.,* 1989) and eustatic (Ramsbottom, 1973) influences. The emergent margins of the Northumberland Basin were sources of clastic sediment during the early period of deposition (Leeder, 1974b), but for much of Dinantian times axial drainage systems were dominant, building from the north and east towards a shallow sea in the west (Robson, 1956; Frost, 1969; Leeder, 1974b; Turner *et al.,* 1993, 1997). Marginal clastic deposition persisted in the Solway Basin, adjacent to the active North Solway Fault System (Deegan, 1973; Ord *et al.,* 1988).

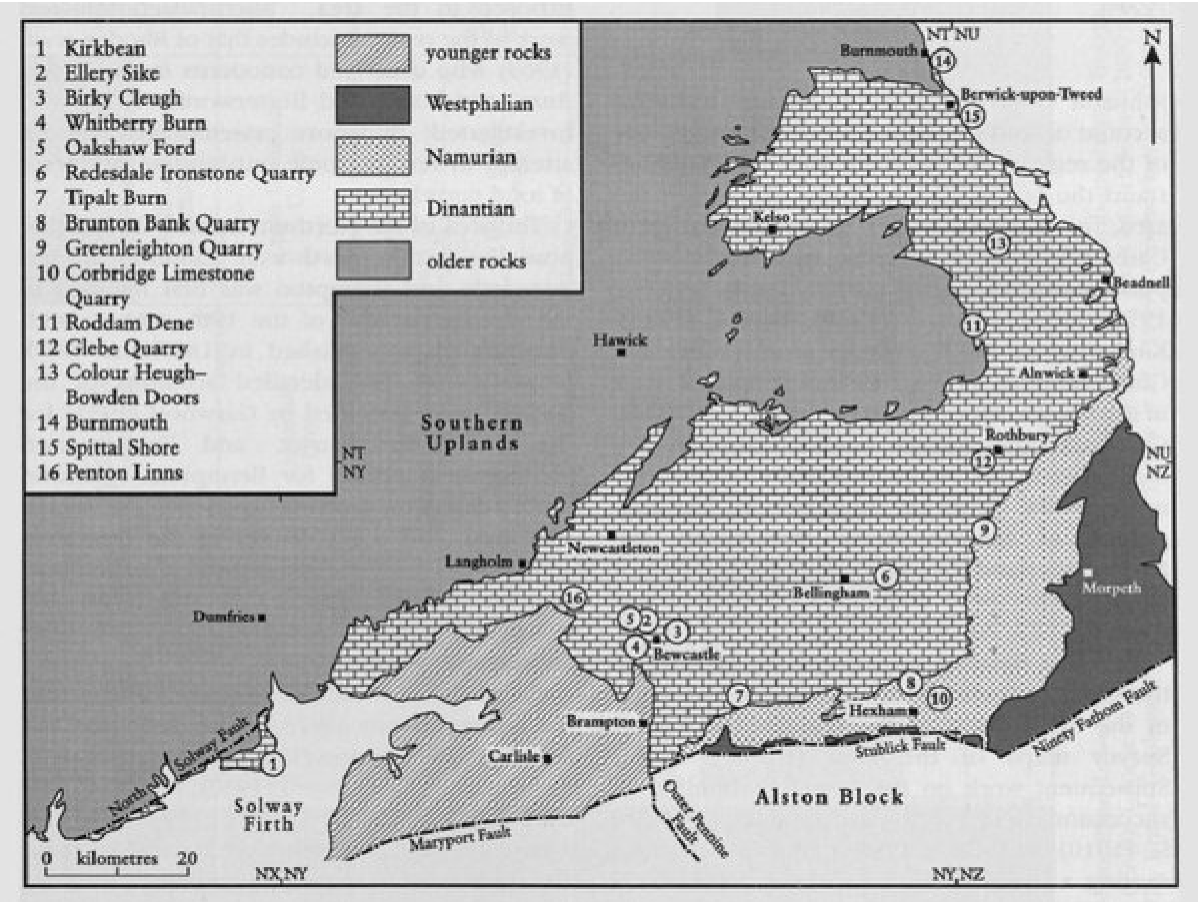
GCR site coverage

The selection of sites in this area reflects the wide-ranging character of the Lower Carboniferous successions developed in different areas of the Northumberland Trough. The localities form a network of sites in which the alternating roles of both fluvio-deltaic and marine processes are particularly evident. In general, however, as noted above, marine facies with stratigraphically useful taxa are more common in those areas (and GCR sites) to the south-west, where there are, as a result, significantly fewer correlation problems than there are in those areas to the north-east. The GCR site coverage includes a mixture of dual- or multiple-interest localities that together provide the best available framework for understanding the stratigraphical and palaeogeographical evolution of the region and which also facilitate regional stratigraphical correlations into neighbouring areas.

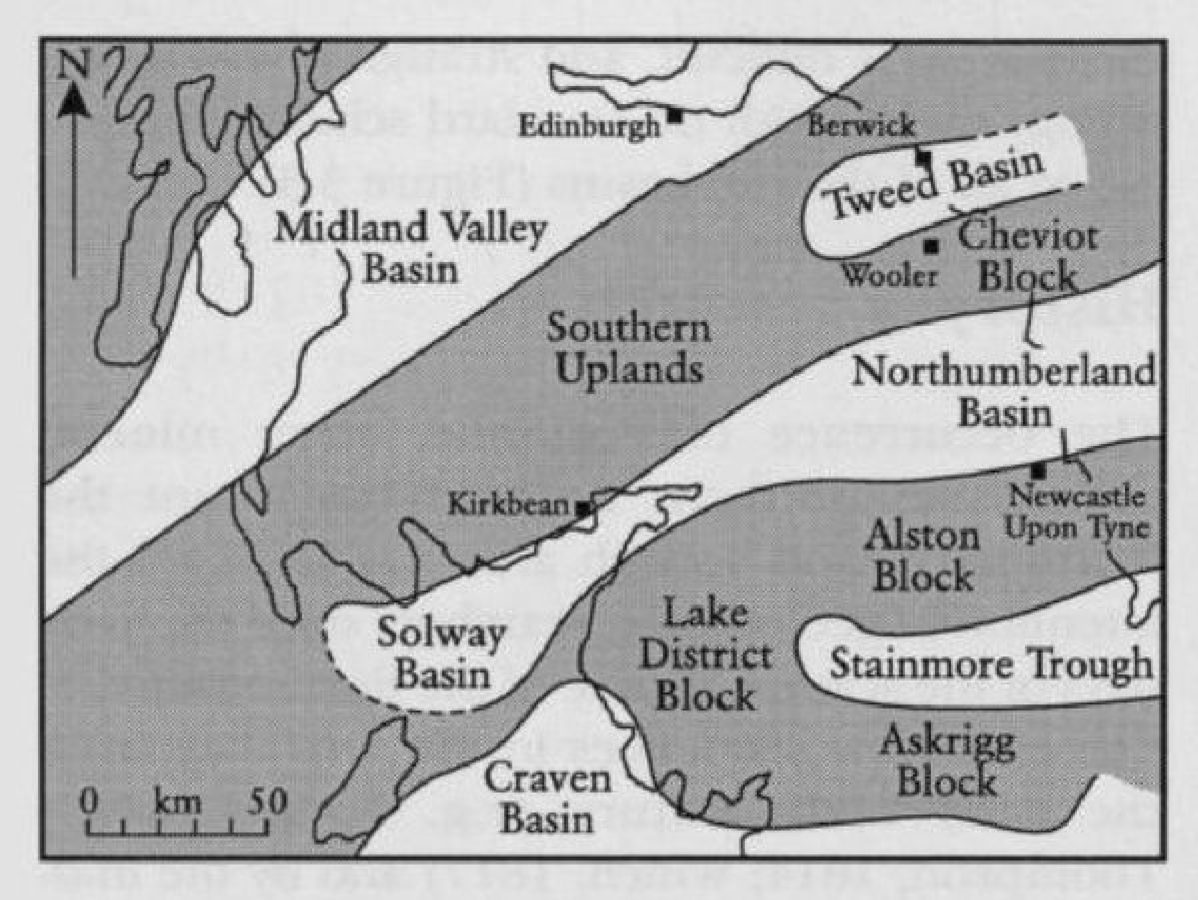
Without exception, all of the sites selected in this region were chosen because of their combined stratigraphical and sedimentological or palaeontological interest. While some sites were chosen primarily because they included a particularly well exposed or extensive stratigraphical section, such as the coastal sites in the Solway Basin at Kirkbean (Southerness Limestone Formation, Gillfoot Sandstone Formation, Powilli-mount Sandstone Formation and Arbigland Limestone Formation, ?Chadian–Asbian) and in the Tweed Basin at Burnmouth (Cementstone Group/Fell Sandstone Group and parts of the Scremerston Coal Group and Lower Limestone Group, Tournaisian–Asbian) and Spittal Shore (Scremerston Coal Group, Lower Limestone Group and Middle Limestone Group, Asbian–Brigantian), others were selected because they included exceptional sections or type sections of a particular stratigraphical unit (or units), or because they provided key sections across critical formation or group boundaries. Examples of such sites in the Bewcastle area include Ellery Sike (Lynebank Formation, Lower Border Group, Chadian), Birky Cleugh (type section of the Main Algal Formation, Lower Border Group, Arundian–Holkerian), Whitberry Burn (Holkerian, Cambeck Formation and Lower Border Group-Middle Border Group boundary) and Oakshaw Ford (Holkerian–Asbian boundary and type locality for various lithostratigraphical units in the Middle Border Group and Upper Border Group), whereas else where in the Northumberland Basin such sites include Redesdale Ironstone Quarry (Redesdale Ironstone Shale, Redesdale Limestone and Upper Border Group–Lower Liddesdale Group boundary, Asbian), Tipalt Burn (Upper Liddesdale Group, Brigantian), Greeleighton Quarry (Great Limestone, Stainmore Group, base of the Pendleian Stage) and Corbridge Limestone Quarry (Corbridge Limestone, Stainmore Group, base of the Arnsbergian Stage).

An additional group of sites were picked either partly or primarily because of their intrinsic sedimentological or palaeontological interest. These include two sites from the Cheviot Block, namely Colour Heugh–Bowden Doors (Fell Sandstone Group, Arundian–Holkerian fluvial facies) and Roddam Dene (Roddam Dene Conglomerate, Courceyan? alluvial-fan facies), and three sites from the Northumberland Basin, namely Brunton Bank Quarry (biostromes in the Great Limestone, Pendleian), Glebe Quarry (microbial oncoids in the Glebe Limestone Member, Cementstone Group, late Chadian or early Arundian) and Penton Linns (rich and well-preserved faunas, especially crinoids, in the Upper Liddesdale Group, Brigantian).

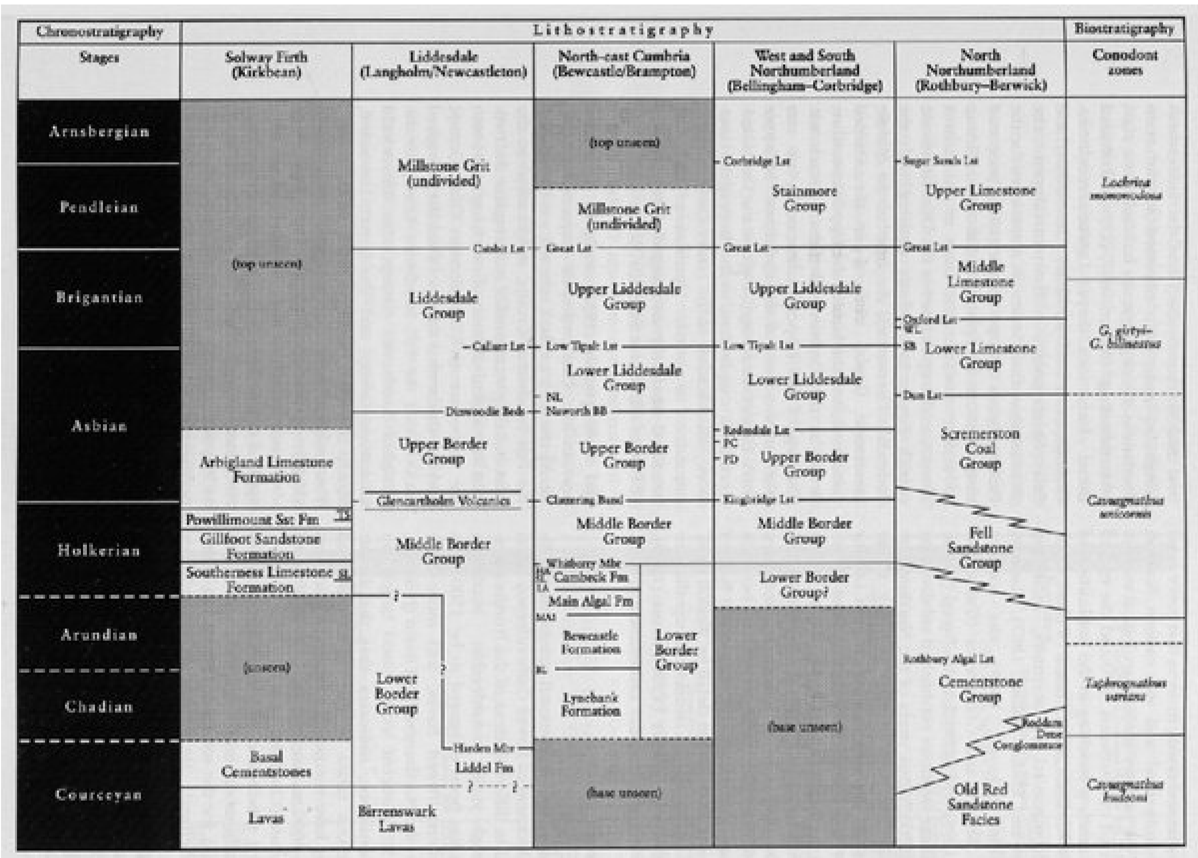
[References](#)



(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.

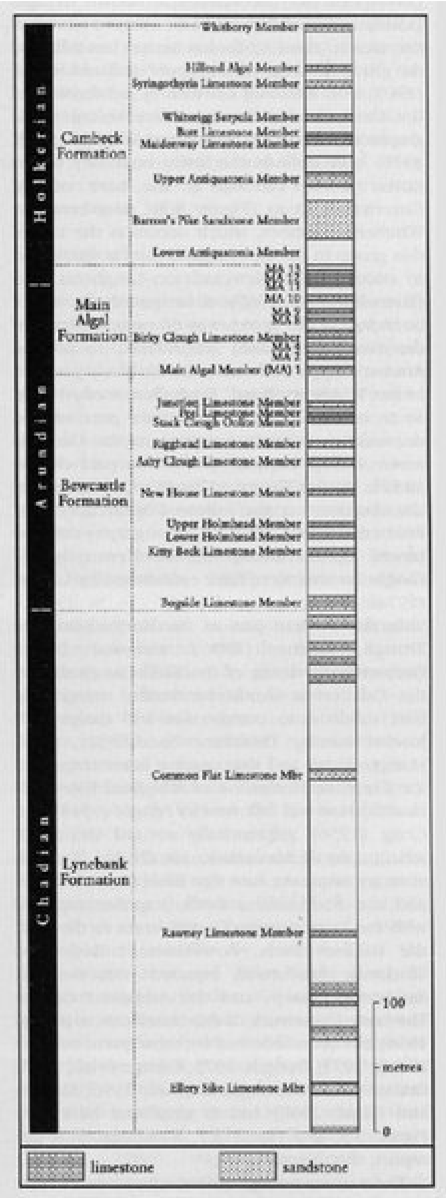


(Figure 3.2) Simplified palaeogeography of northern England and southern Scotland illustrating the distribution of Lower Carboniferous sedimentary basins. Note the positions of the Tweed Basin, Northumberland Basin and Solway Basin, which together constitute the Northumberland Trough area. Based on Johnson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

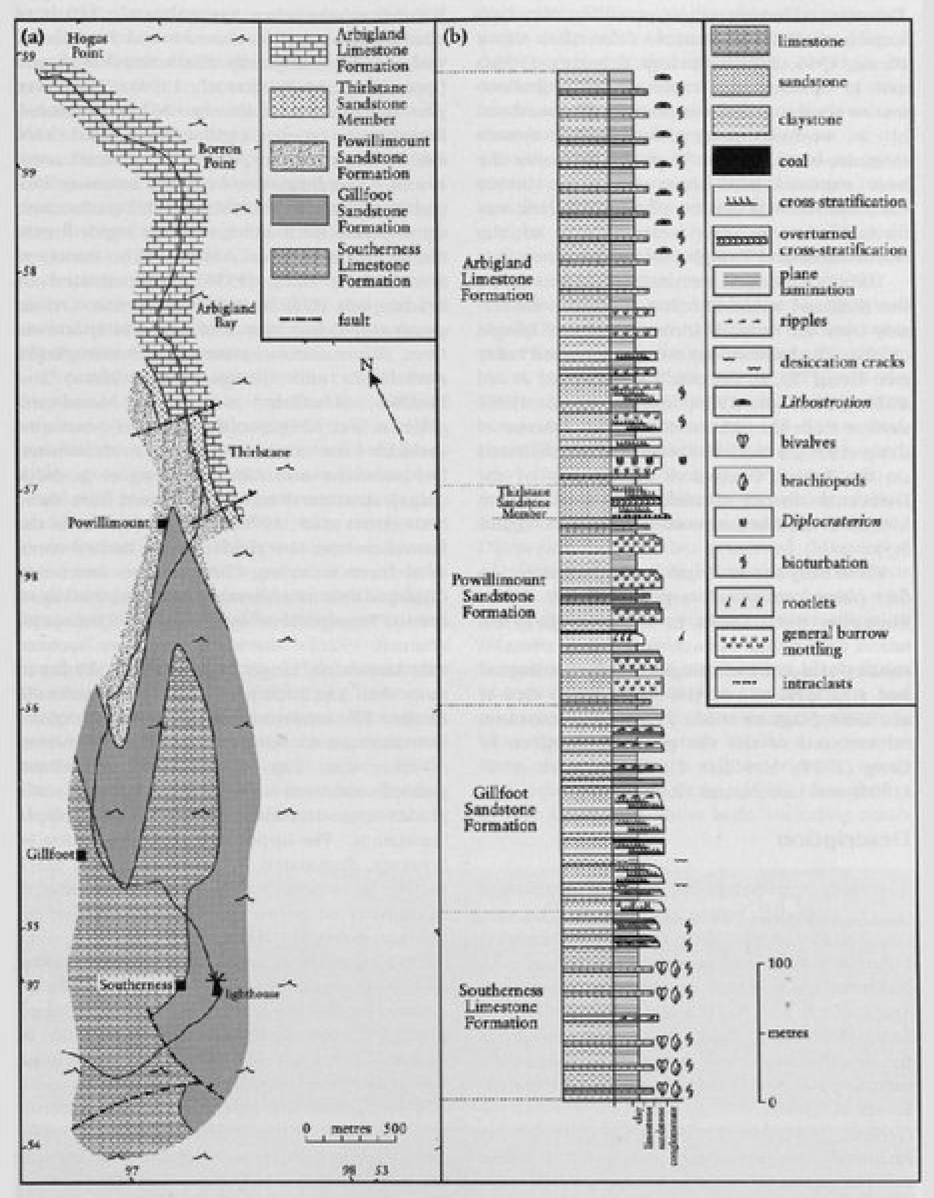


(Figure 3.3) Simplified Lower Carboniferous stratigraphical chart of the Northumberland Trough. Compilation based on information from Lumsden et al. (1967), Day (1970), George et al. (1976), Ramsbottom et al. (1978), Frost and Holliday

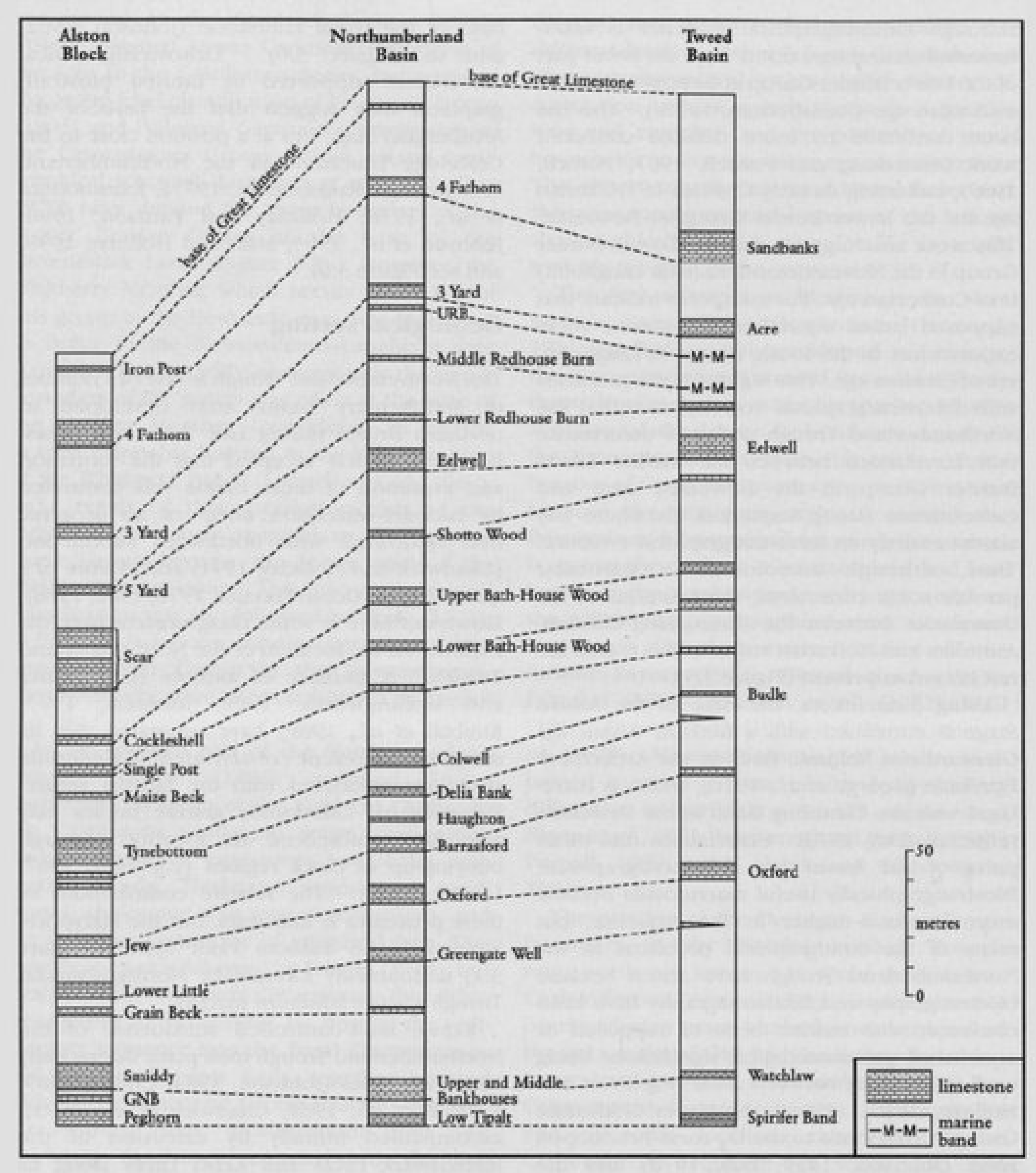
(1980), Armstrong and Purnell (1987), Smith and Holliday (1991), Purnell (1992), British Geological Survey (1993a), Turner et al. (1993), Chadwick et al. (1995), Johnson et al. (1995) and Maguire et al. (1996). Note that the implied correlations between the lithostratigraphy and both the biostratigraphy and the chronostratigraphy remains uncertain in many areas. SL — Syringothyris Limestone Member; TS — Thirlstane Sandstone Member; BL — Bogside Limestone Member; MAI — Main Algal 1 Member; LA — Lower Antiquatonia Member; HA — Hillend Algal Member; Naworth BB — Naworth Bryozoa Band; NL — Naworth Limestone; PD — Plashetts Dun Limestone; PC — Piper's Cross Limestone; SB — Spirifer Band; WL — Watchlaw Limestone; Lst — Limestone; SSt — Sandstone; Mbr — Member; Fm — Formation. Conodont zones from Armstrong and Purnell (1987) and Purnell (1989, 1992). Not to scale.



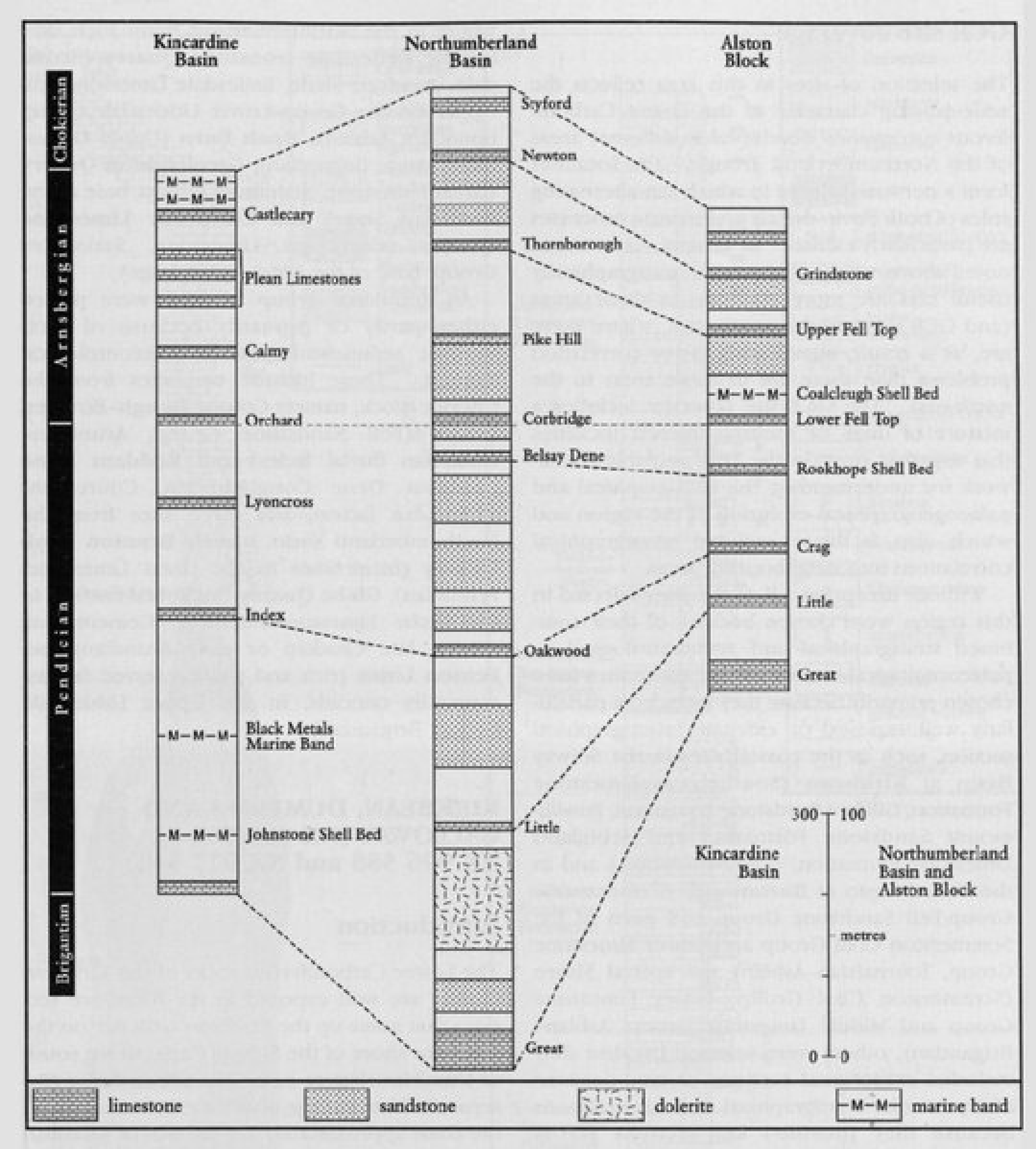
(Figure 3.4) Lithostratigraphical terminology for the Lower Border Group in the Bewcastle area. The position of MA 14 (Main Algal 14 Member) immediately below the Lower Antiquatonia Member is omitted for clarity. After Purnell (1992).



(Figure 3.7) (a) Geological map and (b) simplified sedimentary log of the Lower Carboniferous succession at the Kirkbean GCR site, using the lithostratigraphical nomenclature of the British Geological Survey (1993a). (a) After Craig (1956); (b) courtesy of K. Maguire.



(Figure 3.5) Stratigraphy of the Upper Liddesdale Group (Brigantian, D_2) limestones from the Alston Block to the Northumberland Basin and the Tweed Basin. (GNB — Girvanella Nodular Bed; URB — Upper Redhouse Burn.) After Frost and Holiday (1980).



(Figure 3.6) Correlation of lower Stainmore Group successions (Pendleian, E_1–Arnsbergian, E_2) between the Kincardine Basin, the Northumberland Basin and the Alston Block. After Ramsbottom et al. (1978).