Chapter 11
Craven Basin and southern Pennines

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Carboniferous rocks within this area occupy the region contiguous with the northern Pennines to the north (Chapter 12) and the Peak District to the south (Chapter 10). All of the stages of the Carboniferous are present at outcrop, with the exception of Stephanian strata, which are absent. The oldest Tournaisian strata crop out within the Craven Basin, and are represented by ramp carbonate rocks (Bowland High Group) deposited on the Bowland High and adjacent Lancaster Fells and Bowland sub-basins. These carbonate rocks are overlain by mainly Visean hemipelagic mudstone and carbonate turbidites (lower part of Craven Group). To the south of the Pendle Fault System (Fig. 11.1), further platform carbonate rocks are proved in the subsurface above the Central Lancashire High (Trawden Limestone Group) and the Holme High and Heywood High (Holme High Limestone Group). These carbonate rocks, which developed during the Tournaisian to late Visean, are known only from well records and geophysical information and are not divided into formations. During the Visean, the platform carbonate rocks pass laterally into more basinal successions in the Harrogate, Rossendale and Huddersfield sub-basins (Craven Group). The lithostratigraphical nomenclature for the Tournaisian and Visean strata is that of Waters *et al.* (2009), adapted from Riley (1990).

Namurian strata occur at outcrop along the axis of the Pennine Anticline, in the Rossendale Anticline and flanking the Craven inlier of Tournaisian and Visean strata (Figure 11.1). The relict Dinantian palaeotopography is partially infilled by hemipelagic mudstone and siliciclastic turbidites (upper part of the Craven Group). Subsequently, fluvio-deltaic deposits and intervening pro-delta mudstone (Millstone Grit Group) extend across the region, the base of the group occurring mainly at the base of the first mappable quartzo-feldspathic sandstone (Waters *et al*. 2009). The overlying Westphalian strata are mainly found to the west (Lancashire Coalfield) and east (Yorkshire-Nottinghamshire Coalfield) of the Pennine Anticline and in a small outlier in the northern part of the area (Ingleton Coalfield). These strata are dominated by fluvio-lacustrine deposits (Pennine Coal Measures Group), with subsequent deposition of late Westphalian red-bed alluvial deposits (Warwickshire Group) locally preserved.

Tournaisian

The platform carbonate rocks were deposited on geographically isolated horsts or tilt-block highs, with distinct group names applied for each development. The Bowland High Group developed upon the Bowland High, a NW-dipping tilt-block, which passes northwards into the Lancaster Fells sub-basin and abruptly to the south, along the Bowland Line into the Bowland sub-basin. The Chatburn Limestone Formation, comprising well bedded, grey packstone with chert lenses and subordinate thin beds of calcareous mudstone and siltstone, was deposited in a relatively uniform and widespread shallow marine carbonate shelf. The overlying Clitheroe Limestone Formation comprises ramp carbonate rocks (mainly pale grey, crinoidal packstone and wackestone) with Waulsortian mud-mounds. The Central Lancashire High _Fig. 11.2, Col. 7) has a thin succession of alluvial fan, fluvial channel and floodplain deposits, termed the Roddlesworth Formation, overlain by platform carbonate rocks

of the Trawden Limestone Group. The Holme High, a south-dipping tilt-block, and the westward continuation into the Heywood High are associated with development of the platform carbonate rocks of the Holme High Limestone Group (Fig. 11.2, Col. 5).

The Bowland High Group extends across the Lancaster Fells sub-basin, the Bowland High, and the Bowland sub-basin from Clitheroe in the southwest to Skipton in the northeast (Fig. 11.2, Cols. 1, 2 & 3). At Chatburn (Fig. 11.2, Col. 2), the type locality for the group and for the Chadian Substage, the group was earlier assigned a Tournaisian (Courceyan) to Chadian age (George *et al*. 1976). However, subsequent investigations (Riley 1990, 1993a) indicated an apparent absence within the group of the diagnostic Chadian foraminifer *Eoparastaffella*, suggesting the group is entirely Tournaisian in age. Foraminiferal assemblages from the Chatburn Limestone and Clitheroe Limestone formations exposed in the Whitewell Anticline (Fig. 11.2, Col. 2) indicate the Cf4α1 Subzone [O1] (Aitkenhead *et al*. 1992). The base of the group does not crop out and has not been proved in boreholes.

In the Boulsworth No.1 Borehole [SD 9269 34479], the Roddlesworth Formation of the Central Lancashire High (Fig. 11.2, Col. 7) comprises a basal quartz conglomerate overlain by dolomitic siltstone with beds of dolostone and anhydrite and sandstone with siliceous and dolomitic cement. The formation includes miospores of the *Lycospora pusilla* Zone, but as *L. pusilla* is rare in the assemblage a Tournaisian age is preferred [^1] (Riley & McNestry 1988). The formation rests unconformably upon the Devonian Old Red Sandstone Group in the Roddlesworth Borehole [SD 65494 21120] and upon deformed Lower Palaeozoic strata in the Holme Chapel Borehole [SD 8608 2878]. The lower, dolomitic parts of the Holme High Limestone and Trawden Limestone groups are lithologically similar to the Chatburn Limestone Formation of the Bowland High Group, and have been tentatively correlated across the region, but seismic data suggest that the formation does not extend onto the Central Lancashire High (Kirby *et al*. 2000).

Visean

Platform carbonate rocks continued to accumulate over the Holme and Heywood highs (Holme High Limestone Group) and Central Lancashire High (Trawden Limestone Group) until late Visean times (Fig. 11.2, Cols. 5 & 7). The uppermost part of the platform carbonate succession is proved in the subsurface on the Askern High, north of the Gainsborough Trough. However, the carbonate platform associated with the Bowland High Group was drowned towards the end of the Tournaisian and was replaced by a thick succession of hemipelagic mudstone and carbonate turbidites (Craven Group). The succession of Hodder Mudstone, Hodderense Limestone and Pendleside Limestone formations can be correlated widely over the Craven Basin (Riley 1990). By the Brigantian, the hemipelagic mudstone of the lower Bowland Shale Formation extended over the Central Lancashire High. Similar hemipelagic successions accumulated within the Gainsborough Trough during the Visean.

The presence of the foraminifers *Archaediscus* sp. stage *angulatus* and the dasyclad alga *Koninckopora inflata* from the upper part of the Holme High Limestone Group in the Wessenden No. 1 Borehole [SE 05462 06491] (Fig. 11.2, Col. 5) indicate an Asbian (probably early Asbian) age [O1] (Riley 1993c). The lower part of the Trawden

Limestone Group present in the Roddlesworth Borehole (Fig. 11.2, Col. 7) contains *Glomodiscus* and *Uralodiscus*, indicative of the Cf4β-γ subzone [O2] (early to mid Arundian), and the upper part contains *Asterarchaediscus*, indicative of the Cf6δ subzone [O3] (Brigantian) (Riley 1993b).

An unbottomed succession of white to dark grey, massive, brachiopod-rich limestone and limestone breccia is proved in the Croxteth No.1 Borehole [SJ 40316 94266] (Fig. 11.2, Col. 8). The borehole is located within the Rainford Basin (Kirby *et al*. 2000) and links to the carbonate successions of the Central Lancashire and Heywood highs have not been established. The interval is therefore identified as Carbonifeous Limestone Supergroup. A Holkerian age is presumed for the lower part of the formation and a 49 m-thick succession of mud-mound carbonate rocks is interpreted as of Asbian age (Macgraw & Ramsbottom 1956). The presence of the ammonoid *Lusitanoceras (=Goniatites) granosus* indicates a P_{2a} age for the upper part of the limestone[+1] (Macgraw & Ramsbottom 1956).

The Hodder Mudstone Formation ranges from Chadian to Holkerian age. The formation comprises a basal limestone boulder conglomerate, packstone and grainstone (the Limekiln Wood Limestone Member). Subsequent deposition is dominated by hemipelagic mudstone (including the Phynis Mudstone Member) interbedded with bioclastic limestone turbidites (including the Hetton Beck Limestone, Embsay Limestone and Chaigley Limestone members). Local developments of siliceous and calcareous sandstone (including the Twiston Sandstone Member) are recognised (Fig. 11.2). In the Chatburn area (Fig. 11.2, Col. 2) the first appearance of the foraminfers *Eoparastaffella*, diagnostic of the base of the Cf4α2 Subzone and Visean Stage, occurs at the base of the formation [O2] (Riley 1990). This boundary is seen as an unconformity at Salthill Quarry, Clitheroe (Cossey *et al*. 2004, p271-274), and throughout the Craven Basin. Brandon *et al.* (1998) recorded Cf4α2 Subzone foraminiferal assemblages from the Hetton Beck Limestone Member of the Sykes Anticline [O1] (Fig. 11.2, Col. 1) and Cf4γ Subzone to Cf5 Zone assemblages from the overlying undifferentiated Hodder Mudstone Formation [O2]. The first entry of the primitive archaediscid foraminifers of the *Eoparastaffella* Cf4β Subzone occurs some 9.7 m above the base of the Embsay Limestone Member (Riley 1990) in the Skipton Anticline [O1] (Fig. 11.2, Col. 3). Holkerian (Cf5 Zone) foraminiferal assemblages are recognised above the Chaigley Limestone Member in the west [O3] (Fig. 11.2, Col. 2) and above the Twiston Sandstone Member (Riley 1990) in the east of the basin [O2] (Col. 3).

The pelagic porcellanous wackestone of the Hodderense Limestone Formation was deposited in the sediment-starved Craven Basin during late Holkerian times. An ammonoid assemblage, including *Bollandoceras hodderense,* is indicative of the upper part of the *Bollandites-Bollandoceras* Zone (Aitkenhead *et al*. 1992) in the Lancaster Fells [+3] and Bowland [+4] sub-basins (Fig. 11.2, Cols. 1 & 2). The formation is absent in the Skipton Anticline (Fig. 11.2, Col. 3) due to the unconformity below the base of the Pendleside Limestone Formation. The widespread limestone turbidites and debris flows of the Pendleside Limestone Formation range from late Holkerian to early Brigantian age. The earliest *Neoarchaediscus* foraminiferal Zone occurs near the base of the formation (Fig. 11.2, Col. 2), with the subzones Cf6α-γ recorded [O5] (Aitkenhead *et al*. 1992). The Bowland Shale Formation ranges from late Asbian to

early Pendleian. An ammonoid assemblage indicative of the P_{1a} to top of P_2 [+4] was recorded by Earp (1955) from the Bowland Forest Tunnel (Fig. 11.2, Col. 1). In the Clitheroe area (Fig. 11.2, Col. 2) the lower part of the formation includes ammonoid assemblages from the B_{1a} Subzone [+6] (Earp *et al*. 1961). In the Settle area (Fig. 11.2, Col. 3) the base of the formation is highly diachronous, ranging from B_2 to P_{1c} Zones [+3] (Arthurton *et al*. 1988). In the Croxteth No.1 Borehole (Fig. 11.2, Col. 8) the formation is of P_2 age (Macgraw & Ramsbottom 1956). A period of non-deposition or erosion is suggested by the absence of Bowland Shale Formation strata of Brigantian age in the Wessenden and Roddlesworth boreholes (Fig. 11.2; Evans & Kirby 1999).

The Craven Group includes a widespread unconformity at the base of the Hodder Mudstone Formation, present at the base of the locally developed Limekiln Wood Limestone, Phynis Mudstone, Hetton Beck Limestone and Embsay Limestone members (Fig. 11.2). The unconformity is marked by irregular erosive surfaces, an abrupt lithological change and significant overstep of the underlying Clitheroe Limestone Formation (Riley 1990). Unconformities at the base of the Twiston Sandstone Member and Pendleside Limestone Formation (Fig. 11.2, Col. 3) are restricted to the northern margins of the basin and are localised to syndepositional anticline axes.

Namurian

During the early Pendleian the hemipelagic mudstone of the Bowland Shale Formation extended across the region. The influx of the fluvio-deltaic deposits (Millstone Grit Group) into the Central Pennine Basin complex is markedly diachronous, occurring initially in the north during the Pendleian (Fig. 11.2, Cols. 1, 3 & 7), but not reaching the southwestern parts of the region until Marsdenian times (Fig. 11.2, Col. 8). The thickest development of Namurian strata is in the northwest of the region, with c. 2700 m present in the Lancaster Fells area, of which about 70% of the total thickness was deposited during the Pendleian and Arnsbergian substages. The Pendleian and Kinderscoutian successions of the Millstone Grit Group are each characterised by prodeltaic ramp turbidites, overlain by a major siltstone-dominated slope unit that is, in turn, overlain by fluvio-deltaic sandstone. The intervening Arnsbergian–Chokierian succession represents a comparatively sand-poor interval, with small deltas present in the north of the region, deepening southwards into the hemipelagic mudstone-dominated Samlesbury Formation. By mid-Mardenian time deltaic sediments largely filled the basin, typically forming coarsening-upwards cycles with regionally extensive marine bands at the base, and passing up to non-marine mudstones and siltstone, which in turn is overlain by sheet-like delta-top sandbodies. Plant macrofossils are generally rare in these deposits, the few available records having been summarised by Dix (1933) and Lacey (1952).

The *Cravenoceras (=Emstites) leion* ($E_{1a}1$) and *Cravenoceras brandoni* ($E_{1b}1$) marine bands are found widely in the north of the region within the Bowland Shale Formation (Fig. 11.2, Cols. 1 [+5] & 3 [+4]), the former also being recorded in the Croxteth No.1 Borehole [SJ 40316 94266] [+2] (Fig. 11.2, Col. 8; Macgraw & Ramsbottom 1956). The *Cravenoceras malhamense* ($E_{1c}1$) Marine Band is well developed in the west of the region (Fig. 11.2, Cols. 1 [+5], 3 [+4] & 7 [+4]), where it forms the uppermost marine band within the Bowland Shale Formation (Price *et al*. 1963; Brandon *et al*. 1998).

The *Cravenoceras cowlingense* ($E_{2a}1$) and *Cravenoceratoides edalensis* ($E_{2b}1$) marine bands are well developed within the Silsden Formation in the northwest (Fig. 11.2, Cols. 1 [+6] & 3 [+5]). The *Nuculoceras stellarum* ($E_{2c}1$) Marine Band is recorded in the Silsden Formation at Hole Brook [+5] (Price *et al*. 1963) (Fig. 11.2, Col. 7).

The *Isohomoceras subglobosum* ($H_{1a}1$) and *Homoceras beyrichianum* ($H_{1b}1$) marine bands are well developed in the northwest of the region (Fig. 11.2, Cols. 1 [+7] & 3 [+6]) and the west, most notably in the Samlesbury Bottoms section (Moore 1930) (Fig. 11.2, Col. 7 [+6]), both within the Samlesbury Formation. The latter marine band is also recorded in the Croxteth No.1 Borehole [+3] (Fig. 11.2, Col. 8) in the southwest, within the Bowland Shale Formation. Alportian ammonoids are generally not recorded in the region, suggesting the presence of a widespread non-sequence. The *Hudsonoceras proteum* ($H_{2a}1$) Marine Band is present in the Samlesbury Bottoms section (Moore 1930; Price *et al*. 1963) (Fig. 11.2, Col. 7 [+7]). The *Homoceras undulatum* ($H_{2b}1$) Marine Band has been recorded from the Lancaster Fells (Brandon *et al*. 1998; Fig. 11.2, Col. 1 [+8]).

The *Hodsonites magistrorum* ($R_{1a}1$) Marine Band occurs at the base of the Hebden Formation in the north of the region near Ilkley (Stevens *et al*. 1953; Fig. 11.2, Col. 3 [+7]), and in the west at Samlesbury Bottoms (Moore 1930; Fig. 11.2, Col. 7 [+8]). The *Reticuloceras eoreticulatum* ($R_{1b}1$) Marine Band is recorded in the Lancaster Fells (Brandon *et al*. 1998; Fig. 11.2, Col. 1 [+9]) and Heywood No.1 Borehole [SD 83851 08976], which in the latter is immediately overlain by the Parsonage Sandstone. Marine bands of the *Reticuloceras reticulatum* (R_{1c} Zone) are complexly associated with the thick turbiditic succession of the Mam Tor Sandstones and Shale Grit, with the Grindslow Shales slope succession of the south of the region (Fig. 11.2, Col. 4) and with the more extensive fluvial Kinderscout Grits. The last unit is commonly subdivided into a Lower and Upper Kinderscout Grit, with the mudstone unit separating the two sandstones containing a *Lingula* band referred to as the Butterly Marine Band.

The *Bilinguites gracilis* ($R_{2a}1$) and *Bilinguites bilinguis* (R_{2b}) marine bands are present over much of the region within a mudstone-dominated succession at the base of the Marsden Formation (Fig. 11.2, Col. 1 [+10], Col. 3 [+8], Col. 4 [+1], Col. 5 [+2], Col. 7 [+9]). However, in the Croxteth No.1 Borehole (Fig. 11.2, Col. 8) these two marine bands occur within the upper part of the Bowland Shale Formation [+4], the base of the Millstone Grit Group occurring at the base of the possible equivalent of the Fletcher Bank Grit of R_{2b} age. The *Bilinguites superbilinguis* ($R_{2c}1$) Marine Band is a regionally important marker horizon within the predominantly sheet-like delta-top sandstones of the upper part of the Marsden Formation (Fig. 11.2, Col. 3 [+8], Col. 5 [+2], Col. 6 [+1] Col. 7 [+9]).

The Rossendale Formation is marked by an extensive lower mudstone-dominated succession with the *Cancelloceras cancellatum* ($G_{1a}1$) and *C. cumbriense* ($G_{1b}1$) marine bands (Fig. 11.2, Col. 1 [+11], Col. 3 [+9], Col. 4 [+2], Col. 5 [+3], Col. 7 [+10]). In the Rossendale area (Fig. 11.2, Col. 6 [+2]) these marine bands are overlain by the sandstone-dominated Lower and Upper Haslingden Flags, respectively, both of which have a western provenance (Collinson & Banks 1975). In other areas, the *C. cumbriense* Marine Band is overlain by the Rough Rock Flags, derived from the north. Overlying both the Upper Haslingden Flags and Rough Rock Flags is the

Rough Rock, a major fluvial sandstone sheet, also derived from the north (Bristow 1988).

Westphalian

During the Langsettian to early Bolsovian, grey, mudstone-dominated fluvio-lacustrine deposits (Pennine Coal Measures Group) were laid down across the region. During the late Bolsovian and Asturian (Westphalian D), red, mudstone- and sandstone-dominated alluvial successions (Warwickshire Group) may have been widespread, but they are now only recorded in the northwest (Fig. 11.2, Col. 1) and southwest (Fig. 11.2, Col. 4) of the region. Inversion of the basin during late Carboniferous deformation resulted in the erosion of much of the Warwickshire Group. The formation of the north–south trending Pennine Anticline isolated the outcrop into the Lancashire Coalfield (Fig. 11.2, Cols. 5, 6, 7 & 8; Fig. 11.3a) and Yorkshire Coalfield (Fig. 11.2, Cols. 3 & 4; Fig. 11.3b). In addition to the area of Westphalian outcrop shown in Fig. 11.1, the Pennine Coal Measures of the Yorkshire Coalfield extend eastwards beneath Permo-Triassic strata. Much new information has become available from recent coal workings in the Selby Coalfield, but also from hydrocarbon exploration data in the Hatfield, Gainsborough and South Humber fields. In the north of the region, the small Ingleton Coalfield (Fig. 11.2, Col. 1; Fig. 11.3b) is faulted against the Askrigg Block across the South Craven Fault. The thickest development of Westphalian strata, up to 2000 m, is in the Lancashire Coalfield.

The base of Subcrenatum Marine Band defines the base of the Langsettian Substage and Pennine Lower Coal Measures Formation. The lower part of this formation, up to the Pasture Coal of Lancashire (Fig. 11.3a) and 80 Yard Coal of Yorkshire (Fig. 11.3b) and equating with the non-marine bivalve Lenisulcata Chronozone, is marked by numerous marine bands and thin coals, with micaceous sandstones of a similar northern provenance as the sandstone bodies of the underlying Millstone Grit Group (Chisholm *et al*. 1996; Hallsworth & Chisholm 2000). In the Lancashire (Fig. 11.2, Col. 5 $^{+4}$, Col. 6 $^{+3}$, Col. 7 $^{+11}$, Col. 8 $^{+5}$) and Yorkshire (Fig. 11.2, Col. 3 $^{+10}$, Col. 4 $^{+3}$) coalfields, only the Subcrenatum and Listeri marine bands commonly contain thick-shelled ammonoids, whereas the Holbrook, Springwood, Honley, Parkhouse, Meadow Farm and Amaliae marine bands commonly include *Lingula*, marine bivalves and anthracoceratid ammonoids (Wilson & Chisholm 2004). The Listeri Marine Band in these coalfields is of particular palaeobotanical significance as this marine transgression resulted in the formation of the plant petrifactions (‘coal balls’) in the underlying coal seam, which transformed our understanding of the coal forest ecosystems (Galtier 1997). Within the Ingleton Coalfield (Fig. 11.2, Col. 1 $^{+12}$; Fig. 11.3b) the Subcrenatum, ?Honley, Listeri and Amaliae marine bands are recorded (Ford 1954). The lower part of the non-marine bivalve Communis Chronozone, between the Pasture and Arley coals of Lancashire (Fig. 11.3a) and 80 Yard and Better Bed coals of Yorkshire (Fig. 11.3b), includes the Langley and Burton Joyce Marine bands in the west of the Lancashire Coalfield and shows micaceous sandstone of northern provenance and greenish, weakly micaceous sandstone of western provenance (Chisholm *et al*. 1996; Hallsworth & Chisholm 2000). The Better Bed Coal also marks the introduction of the ‘typical’ early Westphalian macrofloras, a level recognised biostratigraphically as the base of the *Laveineopteris loshii* Subzone (Cleal 2005). The upper part of the non-marine bivalve Communis and lower part of the Modiolaris chronozones are devoid of marine bands, but include thick coals and sandstone units that are mainly of western provenance.

The base of the Vanderbeckei Marine Band defines the bases of the Duckmantian Substage and the Pennine Middle Coal Measures Formation (Fig. 11.2, Col. 3 [+11], Col. 4 [+4], Col. 5 [+5], Col. 7 [+12], Col. 8 [+6]). The marine band is considered to be represented in the Ingleton Coalfield (Fig. 11.2, Col. 1 [+13]; Fig. 11.3b) by a *Lingula* band above the Four Feet Coal (Ramsbottom *et al*. 1978). The lower part of the formation, between the Vanderbeckei and Maltby marine bands consists of thick coal seams and sandstone of western provenance (Hallsworth & Chisholm 2000; Hallsworth *et al*. 2000) but is devoid of further marine bands. These beds yield the most diverse and well-preserved adpression floras from the British Westphalian Stage, notably those associated with the Barnsley Main Coal of the Yorkshire Coalfield (Fig. 11.3b; Wray 1932; Cleal 2005) from where many of the specimens figured in Kidston's (1923-1925) classic monograph on Carboniferous floras originated. The Maltby and overlying Haughton and Sutton marine bands occur within the non-marine bivalve Lower Similis-Pulchra Chronozone. The upper part of the formation, within the Upper Similis-Pulchra Chronozone, includes four regionally developed marine bands, the Aegiranum, Edmondia, Shafton and Cambriense marine bands (Aitkenhead *et al*. 2002) proved in parts of the Lancashire (Fig. 11.2, Col. 5 [+6], Col. 7 [+13], Col. 8 [+7]) and Yorkshire (Fig. 11.2 Col. 4 [+5]) coalfields. This part of the succession is absent in the Ingleton Coalfield (Fig. 11.2, Col. 1). The base of Aegiranum Marine Band defines the base of the Bolsovian Substage and the top of the formation is defined at the top of the Cambriense Marine Band. Throughout this marine-influenced part of the succession, there is a progressive decline in the diversity of the macrofloras (Cleal 2005), which is in marked contrast to the pattern seen in South Wales (Chapter 5; Cleal 2007). In the Yorkshire Coalfield the late Duckmantian and Bolsovian succession is dominated by thicker and coarser sandstones with palaeocurrents towards the west but ultimately sourced from the south (Hallsworth & Chisholm 2000; Hallsworth *et al*. 2000).

The Pennine Upper Coal Measures Formation (Fig. 11.2, Cols. 4, 5 & 8; Fig. 11.3a & b), includes strata of the non-marine bivalve Phillipsii Chronozone. The formation is devoid of marine bands but contains common estheriid bands and sandstone bodies derived from the southeast (Hallsworth & Chisholm 2000; Hallsworth *et al*. 2000). These changes in sedimentation patterns were also accompanied by declining diversities in the macrofloras (Cleal 2005).

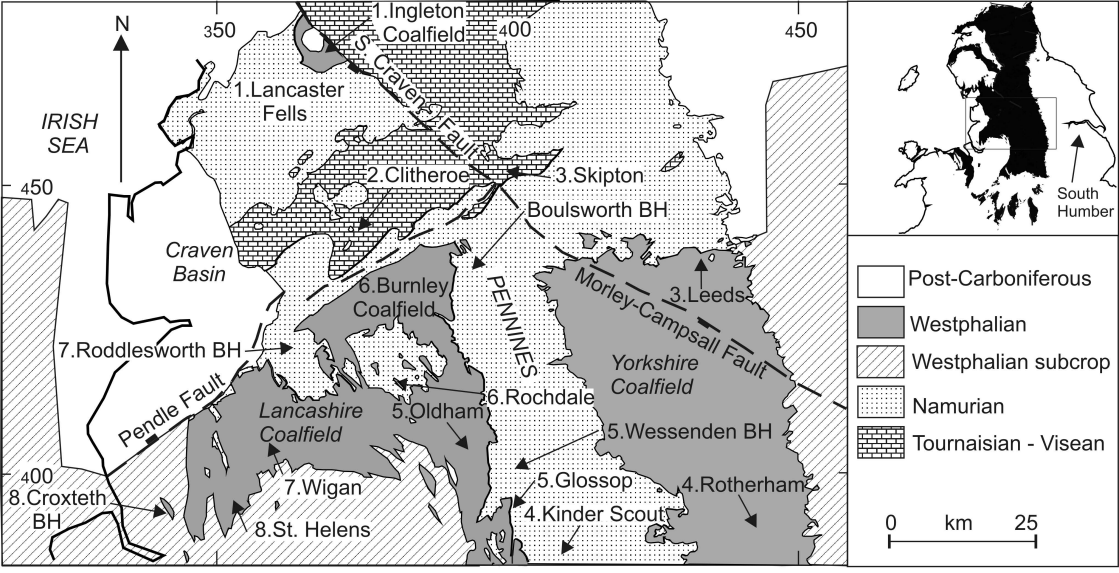
In south-west Lancashire there is a conformable transition from the grey, coal-rich Pennine Coal Measures Group into the overlying red, coal-poor Warwickshire (former Ardwick) Group (Fig. 11.2, Cols. 5 & 8). However, in the Ingleton Coalfield (Fig. 11.2, Col. 1[~14]) the base of the group, of the Phillipsii Chronozone, rests unconformably upon strata of the Pennine Middle Coal Measures Formation (Modiolaris Chronozone) (Ford 1954). The base of the Etruria Formation occurs at a lower stratigraphical level in the west of the Lancashire Coalfield (e.g. St. Helens compared with Stockport/Manchester in Fig. 11.3a). The overlying Halesowen Formation comprises grey and varicoloured mudstone and siltstone with thin coal and distinctive *Spirorbis* limestone.

Figures

Fig. 11.1. Geological map showing the distribution of Carboniferous strata of the Craven Basin and southern Pennines, adapted from IGS (1979).

Fig. 11.2. Correlation of Carboniferous successions in the Craven Basin and southern Pennines. The nomenclature is that of Waters *et al*. (2007; 2009), with details from the following publications: Col. 1 from Ford (1954) & Brandon *et al*. (1998); Col. 2 from Earp *et al*. (1961); Col. 3 from Waters (2000) and Cooper & Gibson (2003); Col. 4 from Stevenson & Gaunt (1971) and Aitkenhead et al. (2002); Col. 5 from Wessenden No. 1 Borehole and Aitkenhead et al. (2002); Col. 6 from Aitkenhead et al. (2002); Col. 7 from Riley (1993b) and Aitkenhead et al. (2002); Col. 8 from Macgraw & Ramsbottom (1956) and Aitkenhead et al. (2002).

Fig. 11.3. Correlation of Westphalian successions with the nomenclature that of Waters *et al*. (2007; 2009). Details modified from the following: a) Lancashire Coalfield. Burnley Coalfield- Aitkenhead et al. (2002); Stockport/Manchester- Aitkenhead et al. (2002); Wigan Coalfield- Aitkenhead et al. (2002); St. Helens- Aitkenhead et al. (2002). b) Ingleton and Yorkshire coalfields. Ingleton Coalfield- Ford (1954); Bradford-Leeds- Waters (2000) and Cooper & Gibson (2003); Sheffield-Rotherham- Aitkenhead et al. (2002); South Humber- Brigg Borehole.


N
350
400
450
450
400
IRISH SEA
1.Ingleton Coalfield
S. Craven Fault
1.Lancaster Fells
2.Clitheroe
3.Skipton
Boulsworth BH
Craven Basin
6.Burnley Coalfield
PENNINES
Morley-Campsall Fault
3.Leeds
7.Roddlesworth BH
Pendle Fault
Yorkshire Coalfield
Lancashire Coalfield
5.Oldham
6.Rochdale
5.Wessenden BH
5.Glossop
4.Rotherham
4.Kinder Scout
7.Wigan
8.Croxteth BH
8.St. Helens
South Humber
Post-Carboniferous
Westphalian
Westphalian subcrop
Namurian
Tournaisian - Visean
0
km
25