Chapter 12
Cumbria and the northern Pennines

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Carboniferous rocks within the Cumbria and northern Pennines region are bound by the Maryport–Stublick–Ninety Fathom Fault System, which forms the northern boundary of the Lake District and Alston blocks (Fig. 12.1). In the Pennines, the succession occupies the Alston and Askrigg blocks and the intervening Stainmore Trough, a broadly east-west trending graben. Carboniferous strata also flank the Lake District High, occurring at outcrop in north Cumbria, Furness and Cartmel (south Cumbria) and the Vale of Eden, and in the subsurface in west Cumbria. The Askrigg Block succession is separated from that of the Craven Basin (Chapter 11), to the south, by the Craven Fault System.

All of the stages of the Carboniferous, with the exception of the Stephanian, are present at outcrop. The oldest Tournaisian strata occur at outcrop along the flanks of the Lake District High and within the Stainmore Trough. They are represented by alluvial and peritidal deposits (Ravenstonedale Group), and locally associated with volcanic rocks (Cockermouth Volcanic Formation of north Cumbria). The Ravenstonedale Group is diachronous, occurring later on the structural highs, with deposition during Chadian times on the Askrigg Block and Holkerian times on the Alston Block. The Ravenstonedale Group is overlain by upper Tournaisian to upper Visean platform carbonate rocks (Great Scar Limestone Group), which initially developed on the flanks of the Lake District High, but by late Asbian times extended across the entire region (Mitchell 1978). Mixed shelf carbonate and deltaic deposits became established across the region during the late Visean and Namurian (Yoredale Group). In the southern part of the region (the Askrigg Block) fluvio-deltaic deposits of the Millstone Grit Group range throughout the Namurian, a condensed equivalent of the succession present within the Craven Basin to the south (Chapter 11).

Westphalian strata occur at outcrop toward the west (West Cumbria Coalfield) and east (Durham Coalfield) of the region, with small outliers also in the Askrigg Block area south of Masham and the Stainmore Outlier (Fig. 12.1). The Westphalian strata are dominated by fluvio-lacustrine deposits (Pennine Coal Measures Group), with subsequent deposition of upper Westphalian red-bed alluvial deposits (Warwickshire Group) preserved in the West Cumbria Coalfield.

The lithostratigraphical nomenclature is that of Waters *et al.* (2007) and Dean *et al*. (2011).

Tournaisian

The Ravenstonedale Group was deposited extensively across the region within an epicontinental basin as alluvial fan, fluvio-deltaic, marginal marine and peritidal deposits (Holliday *et al*. 1979). The group shows a marked diachroneity, with earliest Tournaisian deposition occurring within basinal areas flanking the Lake District High (Fig. 12.2, Cols. 1-3). The earliest deposits occur locally within the Stainmore Trough (Fig. 12.2, Col. 6 $^{\wedge O1}$), comprising dolostone and dolomitic limestone interbedded with calcareous mudstone and sandstone of the Pinskey Gill Formation, which

contains miospores (Johnson & Marshall 1971; Holliday *et al*. 1979) and conodonts (Varker & Higgins, 1979) indicative of a Tournaisian (mid-Courceyan) age. The Ravenstonedale Group is dominated by alluvial fan deposits within linked basins, recognised as the Marsett Formation. This formation generally rests unconformably upon pre-Carboniferous rocks, except within the Stainmore Trough, where it lies unconformably upon the Pinskey Gill Formation. Miospore assemblages from a number of sites including Cockermouth (Fig. 12.2, Col. 1 ^1; Mitchell 1978), Furness (Col. 3 ^1; Rose & Dunham 1977) and Ravenstonedale (Col. 6 ^2; Holliday *et al*. 1979) all indicate a CM Zone, Tournaisian age for the Marsett Formation.

In the Stainmore Trough (Fig 12.2, Col. 6) the Marsett Formation is overlain conformably by the Stone Gill Limestone Formation. The latter comprises limestone, sandstone and mudstone with calcretes, desiccation structures and evaporite pseudomorphs (Holliday *et al*. 1979) which indicate deposition in a quiet, nearshore to peritidal restricted marine environment. Considered to be Tournaisian in age by Holliday *et al*. (1979), the upper part has a Pu Zone miospore assemblage ^3. A similar succession is evident along the southern flank of the Askrigg Block (Fig. 12.2, Col. 4), in which dolostones and anhydrites of the Stockdale Farm Formation (ungrouped) were deposited in alluvial plain and marginal marine flats. The topmost 11 m of the formation contain the typical Tournaisian foraminifers O1 *Endothyra danica*, *Lugtonia monilis*, *Palaeospiroplectammina mellina* and *Spinoendothyra mitchelli* (Arthurton *et al*. 1988). The equivalent, though more carbonate-dominated, Martin Limestone Formation (Great Scar Limestone Group) of Furness, Cartmel and Kendal was also deposited within a nearshore to peritidal, restricted marine environment, with barrier beach complexes, tidal flats and restricted lagoons (Rose & Dunham 1977; Johnson *et al*. 2001). The lowermost, less fossiliferous part of the formation is of Tournaisian age. In the Stainmore Trough (Fig. 12.2, Col. 6) the carbonate-dominated Great Scar Limestone Group was deposited during the late Tournaisian within a nearshore to peritidal, restricted marine environment as the Coldbeck Limestone Formation. The top of the Algal Band of Garwood (1913), which is present at the top of the Coldbeck Limestone and within the Martin Limestone formations is considered to represent the base of the Visean (Mitchell 1972).

Visean

The deposition of the Ravenstonedale Group on the Askrigg Block occurred following early Visean sea-level rise, with the succession located marginal to the more open marine conditions present in the Stainmore Trough at the time. The Raydale Borehole [SD 9026 8474] (Fig. 12.2, Col. 5) proved a dolostone succession, the Raydale Dolostone Formation, with a miospore assemblage of Chadian age ^1 (B. Owens, pers. comm. reported in Waters *et al*. 2007). Biostratigraphy of the borehole suggests a possible Chadian age for the interbedded limestone, dolostone, sandstone and siltstone of the Penny Farm Gill Formation ^2 (see Dunham & Wilson 1985). On the Alston Block, deposition of the Marsett Formation occurred during the Holkerian (Fig. 12.2, Col. 7).

Much of the Visean succession is dominated by deposition of platform carbonate rocks of the Great Scar Limestone Group. The presence of the foraminifer *Eoparastaffella* sp. and coral *Dorlodotia pseudovermiculare* indicates that the upper part of the Martin Limestone Formation (Fig. 12.2, Cols. 2 O*1 & 3 O*2) ranges into the

Visean (Rose & Dunham 1977; Barclay *et al*. 1994), continuing deposition seen during the Tournaisian. The equivalent succession within the Stainmore Trough (Fig. 12.2, Col. 6) comprises packstone of the Scandal Beck Limestone Formation.

The Arundian succession of the Stainmore Trough (Fig. 12.2, Col. 6) commences with the Breakyneck Scar Limestone Formation, comprising packstone or grainstone with mudstone/siltstone interbeds. The early Arundian age of the limestones (George *et al*. 1976; Mitchell 1978; Millward *et al*. 2003), is determined from a rich coral fauna including *Palaeosmilia murchisoni* and *Siphonodendron martini*, the productoid *Linoprotonia* sp. and costate spiriferoids *4. On the Askrigg Block (Fig. 12.2, Col. 5) the broadly equivalent biosparite of the Tom Croft Limestone Formation contains the corals *Koninckophyllum* sp. and *Michelinia megastoma,* and the brachiopod *Delepinea carinata* *3**.** The Ashfell Sandstone Formation extends above both of these formations. Fossils from the thin limestone beds within the Ashfell Sandstone Formation contain the corals *Diphyphyllum smithi* and *Siphonodendron martini* of late Arundian age (Fig. 12.2, Col. 5 *4; Dunham & Wilson 1985). The base of the peloidal grainstone of the Red Hill Limestone Formation of south Cumbria (Fig. 12.2, Col. 3) and interbedded calcarenite, micrite, mudstone and sandstone of the Chapel House Limestone Formation of the Askrigg Block (Col. 4) is coincident with the Chadian/Arundian boundary. In both cases they unconformably overlie Tournaisian strata. The Red Hill Limestone Formation contains the corals *Koninckophyllum* sp., *Michelinia megastoma* and *Palaeosmilia murchisoni*, of early Arundian age *3 (Rose & Dunham 1977); it corresponds to the '*Camarophoria isorhyncha'* subzone of Garwood (1913). The overlying Dalton Formation contains three informal divisions corresponding approximately to Garwood's (1913) '*Chonetes carinata* Subzone', *'Clisiophyllum multiseptatum* Band', and 'Gastropod Beds', in ascending order. The characteristic Arundian brachiopod *Delepinea carinata* occurs at the base *4, whereas the upper part of the formation has the first appearance of *Siphonodendron martini* in south Cumbria (Rose & Dunham 1977).

The Kilnsey Formation of the southern margin of the Askrigg Block, near Settle (Fig. 12.2, Col. 4) contains foraminifers diagnostic of an Arundian to Holkerian age. The lower part of the formation contains the characteristically Arundian brachiopod *Delepinea carinata* and foraminifers *Ammarchaediscus bucullentus*, *Rectodiscus* sp. and *Tubispirodiscus (=Uralodiscus) settlensis* *O2 (Arthurton *et al*. 1988). In the upper part of the formation species of the coral *Lithostrotion* s.s. (cerioid), which is not recorded below the base of the Holkerian (Mitchell 1989) and other corals and foraminifers indicate a Holkerian age *O3 (Arthurton *et al*. 1988). The upper part of the formation shows a northward transition to the mainly packstone and grainstones of the Fawes Wood Limestone Formation of the Askrigg Block (Fig. 12.2, Col. 5) and the packstone, grainstone and micrite beds of the Ashfell Limestone Formation of the Stainmore Trough (Col. 6). Within the Ashfell Limestone Formation the characteristic Holkerian brachiopod *Davidsonina carbonaria* is found in the Orton and Ravenstonedale area *5 (Pattison 1990), with the 'Bryozoa band' of Garwood (1913) occurring at the top of the formation. The lower part of the Fawes Wood Limestone Formation contains distinctive Holkerian fossil assemblages with the corals *Lithostrotion minus* and *Siphonodendron sociale* and brachiopod *Davidsonina carbonaria* *5 (Dunham & Wilson 1985). Although it is lithologically similar to the Ashfell Limestone Formation, the upper limit of the Fawes Wood Limestone

Formation is taken at a lower stratigraphical level. In the Furness and Cartmel area (Fig. 12.2, Col. 3), the Park Limestone Formation contains a coral/brachiopod assemblage indicative of a Holkerian age [*5] (Rose & Dunham 1977). The lower lithostratigraphical boundary seen in the Holkerian Stratotype at Barker Scar (See Chapter 2; George *et al*. 1976) is 4.2 m lower than the Arundian/Holkerian substage boundary (see Johnson *et al*. 2001, pp. 60–61). It should be noted that Riley (1993) stated that it seems likely that a considerable non-sequence is developed at Barker Scar and that the stratotype will require relocation.

The Frizington Limestone Formation of Barclay *et al*. (1994) crops out in north and west Cumbria and occurs in the subsurface at Sellafield (Fig. 12.2, Cols. 1 & 2). The presence of the foraminifer *Pojarkovella nibelis* in the Sellafield boreholes (Barclay *et al*. 1994) indicates the Cf5 Zone [O2] (Holkerian) age. Palaeokarst surfaces in the upper part of the formation (Fig. 12.2, Col. 2) indicate that periodic emergence preceded a period of non-deposition during late Holkerian and early Asbian times.

The Potts Beck Formation, present in the Stainmore Trough (Fig. 12.2, Col. 6) comprises mainly packstone with the corals *Axophyllum* sp., *Dibunophyllum bourtonense*, *Palaeosmilia murchisoni*, *Siphonodendron junceum*, *S. martini*, and the brachiopods *Daviesiella llangollensis* and *Gigantoproductus* sp. of latest Holkerian to early Asbian age [*6]. The Stainmore Trough contains the basal Asbian Stratotype at Little Asby Scar (see Chapter 2; George *et al*., 1976). Faunal analysis of this section places the Holkerian/Asbian boundary above the base of the formation (Ramsbottom 1981). The wackestone and porcellaneous micrite of the Garsdale Limestone Formation of the Askrigg Block (Fig. 12.2, Col. 5 [*6]), also of late Holkerian to early Asbian age, contain the equivalent of Garwood's (1913) 'Bryozoa Band', including the brachiopods *Pleuropugnoides pleurodon*, *Productus garwoodi*, *Punctospirifer scabricosta*, *Leiopteria lunulata* and ostracods. This 'Bryozoa Band' also occurs near the base of the Melmerby Scar Limestone Formation (Turner 1927) on the Alston Block (Fig. 12.2, Col. 7). The presence of *P. garwoodi* in the lower part of the Sixth Limestone at Rowrah (Ramsbottom 1955) indicates that the Holkerian/Asbian boundary occurs within, and not at the base of the Eskett Limestone Formation of north and west Cumbria (Fig. 12.2, Col. 1 [*2]).

The rhythmically bedded limestones of the Knipe Scar Limestone Formation of the Stainmore Trough (Fig. 12.2, Col. 6) is of late Asbian age [*7], with the coral *Siphonodendron pauciradiale,* and brachiopods *Davidsonina septosa* and *Delepinea* sp. (Pattison 1990). Within the equivalent Danny Bridge Limestone Formation of the Askrigg Block (Fig. 12.2, Col. 5) fossils contain *D. septosa* and typically, *S. martini* and a late Asbian assemblage of foraminifers [O*7] (see Dunham & Wilson 1985, p. 22). The Asbian succession of the Alston Block and southern flank of the Askrigg Block is dominated by the Melmerby Scar Limestone and Malham formations, respectively. The Rookhope Borehole [NY 9375 4278] located on the Alston Block includes an interbedded conglomerate, sandstone, mudstone and limestone, interpreted as part of the Ravenstonedale Group, resting unconformably upon the Weardale Granite. Limestone within this succession include foraminifers typical of the Cf6γ Subzone (Cózar & Somerville 2004). The overlying Melmerby Scar Limestone Formation also contains foraminifers typical of a latest Asbian age (Cózar & Somerville 2004). The Malham Formation passes southward into the Cracoe Limestone Formation, the

'Marginal Reef Limestones' of Arthurton *et al*. (1988), a succession of boundstone to packstone and wackestone that accumulated as an apron reef along the southern shelf margin of the Askrigg Block, south of the Middle Craven Fault. An Asbian (B_2) age for the reef succession is determined from ammonoid assemblages (Arthurton *et al*. 1988; Fig. 12.2, Col. 4 [+4]) and P_{1a} foraminifers including stellate archaediscids and *Howchinia bradyana* [O5] (Strank in Arthurton *et al*. 1988). In Furness and Cartmel (Fig. 12.2, Col. 3), the Urswick Limestone Formation corresponds almost exactly to the *'Lower Dibunophyllum Subzone'* of Garwood (1913). Fossils are relatively prolific and contain the corals *Dibunophyllum bourtonense, Lithostrotion* spp., *Palaeosmilia murchisoni, Siphonodendron* spp., and the brachiopod *Gigantoproductus maximus,* and, towards the top of the unit, *D. septosa* [*6] (Rose & Dunham 1977).

Succeeding the Great Scar Limestone Group, the Yoredale Group extends across much of the region. The Tyne Limestone Formation, of Asbian age, is present as a single member (the Wintertarn Sandstone Member) in the Stainmore Trough (Fig. 12.2, Col. 6), east Cumbria and the Askrigg Block. The overlying Alston Formation, broadly of Brigantian (to Pendleian) age, occurs in all but north Cumbria (Fig. 12.2, Col. 1), where platform carbonate deposition of the Eskett Limestone Formation (Great Scar Limestone Group) persisted. On the Alston Block (Fig. 12.2, Col. 6), the base of the Alston Formation is taken at the base of the Peghorn Limestone [O*2], the base of which at Janny Wood, on the east bank of the River Eden near Kirkby Stephen was taken by George *et al*. (1976) as the basal stratotype for the Brigantian Substage. The substage is defined by the incoming of the characteristic corals, brachiopods, foraminifers and conodonts listed in Chapter 2 (George *et al*. 1976). Riley (1993) indicated that some of these overlap with distinctive Asbian fauna. The *Girvanella* Band of Garwood (1913) almost coincides with the base of the Brigantian and can be traced extensively across the region (Burgess & Mitchell 1976), including Furness, where the Alston Formation was formerly known as the Gleaston Formation (Dean *et al*. 2011). The Hardraw Scar Limestone of the Askrigg Block (Fig. 12.2, Col. 4) overlies mudstone containing *Goniatites sphaericostriatus* of P_{1c} age [+6] (Dunham & Stubblefield 1945). The Scar Limestone of Teesdale on the Alston Block (Fig. 12.2, Col. 7) is overlain by mudstone with the ammonoids indicative of the P_{2a} subzone [+3], whereas the overlying Five Yard Limestone contains ammonoids of the P_{2a} subzone on Great Dun Fell (Dunham 1990).

Namurian

The base of the Namurian Regional Stage is taken a few metres below the base of the Great Limestone Member (Dunham 1990), the uppermost limestone of the Alston Formation (see Chapter 13). At Fountains Fell, on the Askrigg Block (Fig. 12.2, Col. 5) this limestone (formerly the Main Limestone) overlies mudstone with *Cravenoceras (=Emstites) leion* [+8] (Arthurton *et al*. 1988). Above this the Yoredale Group is represented by the Stainmore Formation, which ranges throughout the early Namurian (Pendleian to ?early Kinderscoutian) in the Stainmore Trough and Alston Block (Fig. 12.2, Cols. 6 & 8). On the Askrigg Block (Fig. 12.2, Col. 5) the equivalent early Namurian succession above the Great Limestone lacks development of Yoredale-type cyclothems. It is represented by the Millstone Grit Group, equivalent to the much thicker fluvio-deltaic succession present to the south of the Craven Fault System in the Craven Basin (Chapter 11).

The Stainmore Formation is distinguishable from the underlying Alston Formation by a decrease in the number and thickness of limestone beds. Sandstone units are typically fine to medium grained, and locally show evidence of deposition within a marine environment. Locally, fluvial, locally pebbly, coarse-grained sandstone bodies with markedly erosive bases and ribbon-like geometries occur within the succession (Dunham 1990, fig. 5), probably representing feeder channels to the lower part of the Millstone Grit Group present on the Askrigg Block (Fig. 12.2, Col. 5) and within the Craven Basin to the south (Chapter 11).

Few of the diagnostic ammonoid-bearing marine bands found in the Craven Basin have been recorded within the Stainmore Formation north of the Craven Fault System, making correlation of successions problematical (Ramsbottom *et al*. 1978, fig. 9). Mudstone associated with the Mirk Fell Ironstone of Tan Hill (Fig. 12.2, Col. 5), which forms the local base of the Silsden Formation (Millstone Grit Group) contain *Cravenoceras cowlingense* of E_{2a} age $^{+9}$ (Hudson 1941). The equivalent level has been correlated with the Cockhill Marine Band of the Greenhow area of the southern part of the Askrigg Block (Dunham & Stubblefield 1945) and the Lower Felltop Limestone of the Alston Block (Fig. 12.2, Col. 8; Dunham 1990), within the Stainmore Formation.

The *Homoceras beyrichianum* ($H_{1b}1$) Marine Band is recorded by Wilson (1960) in the Masham area of the Askrigg Block (Fig. 12.2, Col. 5 $^{+10}$), indicating the presence of strata of Chokierian age. However, no strata of Alportian age have been recorded on the Askrigg Block (Ramsbottom *et al*. 1978). In the Woodland Borehole [NZ 0910 2770], located on the southern flank of the Alston Block, the Chokierian – Alportian interval has been assigned to a 16 m-thick mudstone succession, the upper limit marked by the occurrence of the Kindercoutian ammonoid *Homoceras henkei* and some 14 m higher in the succession by *Reticuloceras* sp. (Mills & Hull 1968), characteristic of the R_{1b} Zone (Fig. 12.2, Col. 8^{+1}). Early Kinderscoutian strata are also recorded in the Stainmore Outlier with the ammonoid *Vallites henkei* (R_{1a}) in association with the influx of the miospore *Crassispora kosankei* recorded by Owens & Burgess (1965) in the Mousegill Marine beds of the KV Biozone (Fig. 12.2, Col. 6 $^{+\wedge 8}$).

The upper part of the Namurian succession (Kinderscoutian to Yeadonian age) is distinguished by an absence or presence of only thin limestones and the occurrence of thick, often pebbly, coarse-grained sandstone. These fluvial sandstone bodies have historically been mapped as First and Second Grit (Ramsbottom *et al*. 1978, fig. 9). The First Grit occurs above the R_{1b} Zone mudstones in the Woodland Borehole (Mills & Hull 1968), indicating a late Kinderscoutian age, whereas the Second Grit is partly Marsdenian, but mainly Yeadonian in age (Dunham 1990). However, the correlation of such a simple stratigraphy for a complex of channel sandstones is now questioned (Dean *et al*. 2011). They probably represent feeder channels for the fluvio-deltaic succession of the Millstone Grit Group, found on the Askrigg Block (Fig. 12.2, Col. 5). This Millstone Grit Group succession is greatly condensed compared with the succession present to the south of the Craven Fault System (see Chapter 11).

The Winksley Borehole [SE 2507 7151], located on the Askrigg Block contains both the *Cancelloceras cancellatum* and *C. cumbriense* marine bands (Fig. 12.2, Col 5 $^{+11}$).

C. cf. *cumbriense* of probable G_{1b} Zone is also recorded by Owens & Burgess (1965) in the Swinstone Middle Marine Band of the Stainmore Outlier (Fig. 12.2, Col. 6 $^{+9}$). In the West Cumbrian Coalfield (Fig. 12.2, Col. 1) a large non-sequence occurs within the Stainmore Formation in which strata of Chokierian to Marsdenian age are absent (Akhurst *et al*. 1997). The type locality of the Yeadonian ammonoid *C. cumbriense* occurs within the mudstone beds at Bigrigg [NY 0010 1305] (Fig. 12.2, Col. 1 $^{+3}$), above this hiatus (Eastwood *et al*. 1931).

Westphalian

During the Langsettian to early Bolsovian, the grey, mudstone-dominated fluvio-lacustrine deposits (Pennine Coal Measures Group) were deposited across the region. The Pennine Coal Measures Group crops out in the Cumbrian Coalfield of west and north Cumbria and the Durham Coalfield to the east of the region (Fig. 12.1). In north Cumbria the succession has been extensively secondarily reddened and evidence of the presence of Pennine Coal Measures has come from biostratigraphical analysis (Eastwood *et al*. 1968). Small outliers of Westphalian strata occur at Stainmore (Fig. 12.2, Col. 6) and Kirkby Malzeard (Fig. 12.1). During the late Bolsovian and Asturian (Westphalian D), red, mudstone- and sandstone-dominated alluvial successions (Warwickshire Group) may have been widespread, but are now only recorded in the Cumbrian Coalfield (Fig. 12.2, Col. 1; Fig. 12.3). Inversion of the basin during end Carboniferous deformation may have resulted in the erosion of much of the Warwickshire Group.

The Subcrenatum Marine Band, which defines the base of the Langsettian Substage and Pennine Lower Coal Measures Formation, has been recorded in the Cumbrian Coalfield (Fig. 12.2, Col. 1 $^{+4}$) about 6 m below the Harrington Four Foot Coal (Taylor 1961; Fig. 12.3), not above as indicated by Ramsbottom *et al.* (1978). In north Cumbria, this marine band is absent and strata of the Lenisulcata Chronozone have not been recognised (Eastwood *et al*. 1968). Diagnostic ammonoid fauna are also absent in the Durham Coalfield, although the marine band is inferred to occur at a marine horizon including productoids, proved in the Middle Stotfold Borehole [NZ 4501 2987] (Smith & Francis 1967). A *Lingula* band occurs at the level of the Subcrenatum Marine Band in the Winksley Borehole, near Kirkby Malzeard (Dunham & Wilson 1985) and in the Stainmore Outlier (Owens & Burgess 1965).

In the northern part of west Cumbria, the lowermost part of the Pennine Lower Coal Measures of the Lenisulcata Chronozone contains the Honley, Listeri, Amaliae and Langley marine bands (Fig. 12.3). However, around Whitehaven the Harrington Four Foot Rock occupies this part of the succession (Taylor 1961; Akhurst *et al*. 1997). In the Durham Coalfield (Fig.12.2, Col. 6; Fig. 12.3) only the probable Listeri Marine Band with foraminifers ^{O10} (Smith & Francis 1967; Ramsbottom *et al*. 1978) and Amaliae Marine Band with *Lingula mytilloides* are recorded (Mills & Hull 1976). None of these four marine bands or any strata of proved Lenisulcata Chronozone age have been recorded in north Cumbria (Eastwood *et al*. 1968). The general absence of non-marine bivalves prevents determination of the location of the base of the Communis Chronozone in this region. In the upper part of the Pennine Lower Coal Measures, the base of the Modiolaris Chronozone occurs at the Top Busty Coal in the Durham Coalfield and is inferred at the Lickbank Coal in west and north Cumbria (Ramsbottom *et al*. 1978) (Fig. 12.3).

The base of the Vanderbeckei Marine Band defines the bases of the Duckmantian Substage and the Pennine Middle Coal Measures Formation. The marine band is evident in the region as a *Lingula* band. The base of the Lower Similis-Pulchra Chronozone is taken at the Main Coal, in west Cumbria, and Maudlin Coal in the Durham Coalfield (Fig. 12.3) (Ramsbottom *et al*. 1978). The Maltby, Clown, Haughton and Sutton marine bands occur in the upper part of the formation in Durham (Fig. 12.3; Ramsbottom *et al*. 1978), mainly represented by *Lingula* bands. In west Cumbria, only the Haughton Marine Band has been proved (Taylor 1961).

In the Stainmore Outlier a Langsettian to Duckmantian succession, up to strata of the Lower Similis–Pulchra Chronozone are recorded (Ford 1955; Owens & Burgess 1965). The 300 m thick succession is closely comparable with that present in the Durham Coalfield. The probable equivalent of the Listeri Marine Band is recorded within this succession (Ramsbottom *et al*. 1978).

The upper part of the Pennine Middle Coal Measures Formation contains four marine bands developed in the Durham Coalfield, the Aegiranum, Edmondia, Shafton and Cambriense marine bands (Ramsbottom *et al*. 1978; Smith 1994) evident as *Lingula* bands. In west Cumbria, only the Aegiranum and Cambriense marine bands have been proved (Taylor 1961). The base of the Aegiranum Marine Band, with the definitive ammonoid *Donetzoceras aegiranum,* defines the base of the Bolsovian Substage. This upper part of the formation occurs within the Upper Similis-Pulchra Zone. The top of the Pennine Middle Coal Measures is now defined at the top of the Cambriense Marine Band and only a thin development of the Pennine Upper Coal Measures Formation is present in west Cumbria and Durham (Fig. 12.2, Cols. 1 & 8; 12.3).

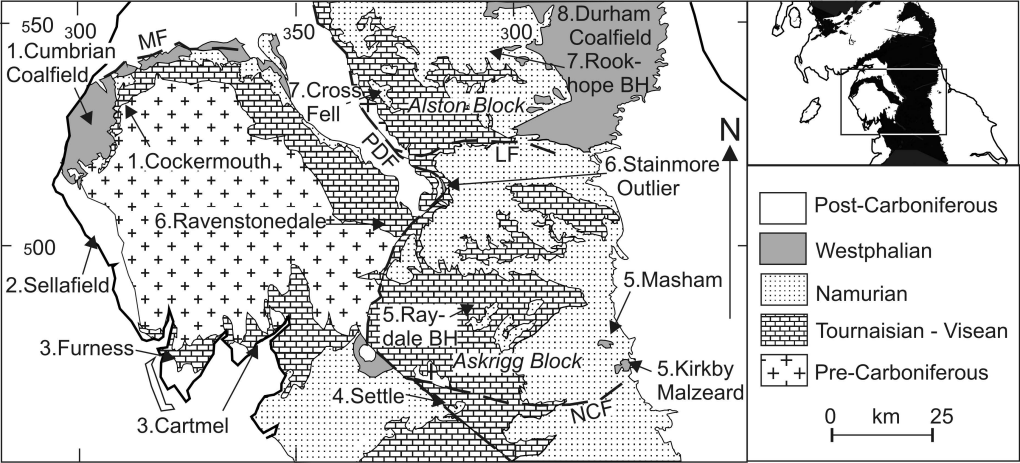
In west Cumbria, the Pennine Coal Measures Group is overlain unconformably by reddened fluvial sandstones of the upper Bolsovian to lower Asturian Whitehaven Sandstone Formation (Warwickshire Group), with the non-marine bivalve *Anthraconauta phillipsii* (Eastwood *et al*. 1931) (Fig. 12.2, Col. 1 $^{\sim 5}$). The unconformity cuts down to the Aegiranum Marine Band or, locally older strata (Akhurst *et al*. 1997). With palaeocurrents from the north-east, the basal Bransty Cliff Sandstone Member cannot be equated on lithological grounds with equivalent strata from the Canonbie Coalfield (Jones *et al*. 2010; see Chapter 13). The upper part of the formation, the Millyeat Member, is dominated by interdistributary or lacustrine deposits, including *Spirorbis* limestones (Akhurst *et al*. 1997).

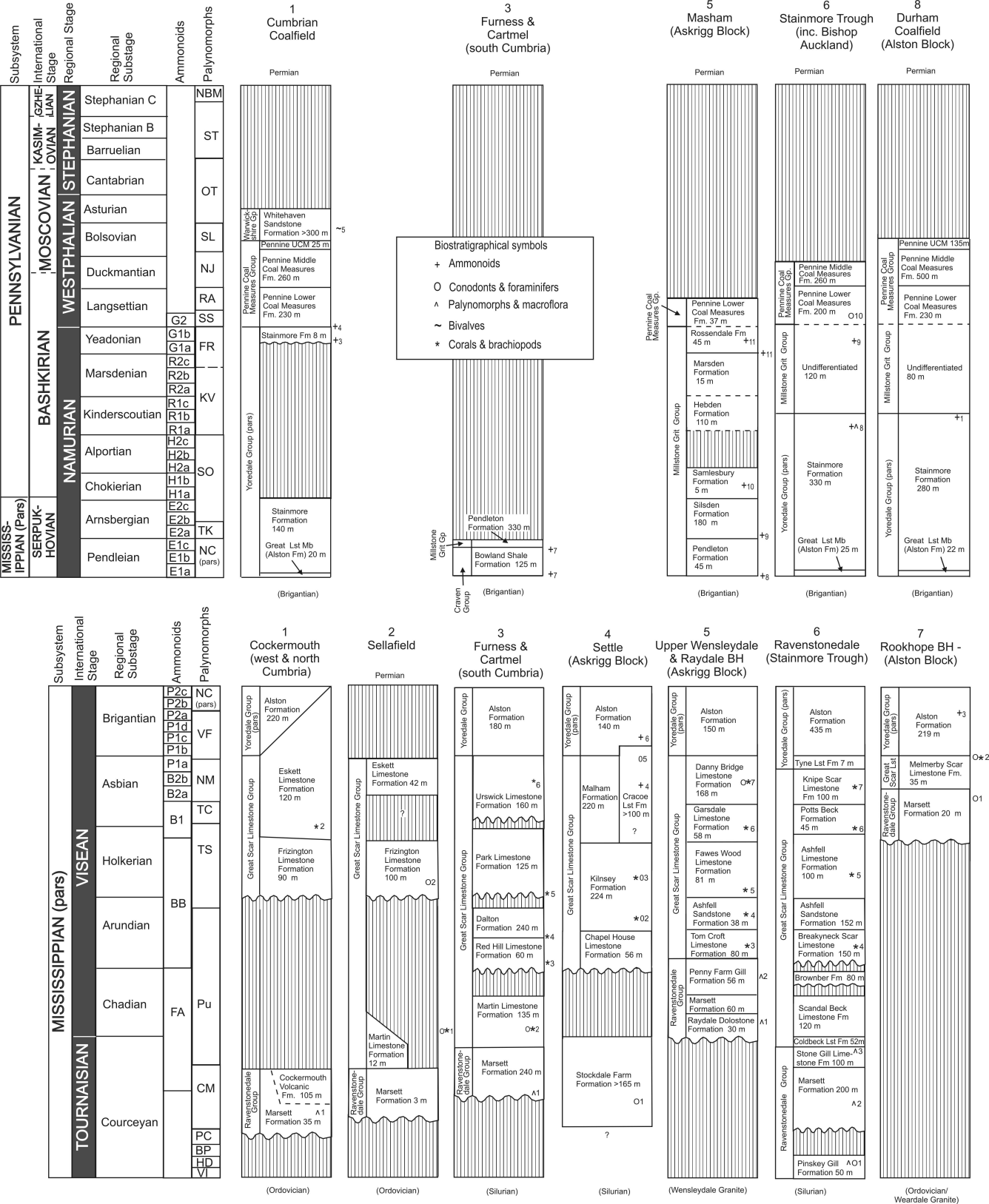
Fig. 12.1. Geological map showing the distribution of Carboniferous strata from Cumbria and the north Pennines, adapted from IGS (1979). LF- Lunedale Fault; MF- Maryport Fault; NCF- North Craven Fault System; PDF- Pennine–Dent Fault System.

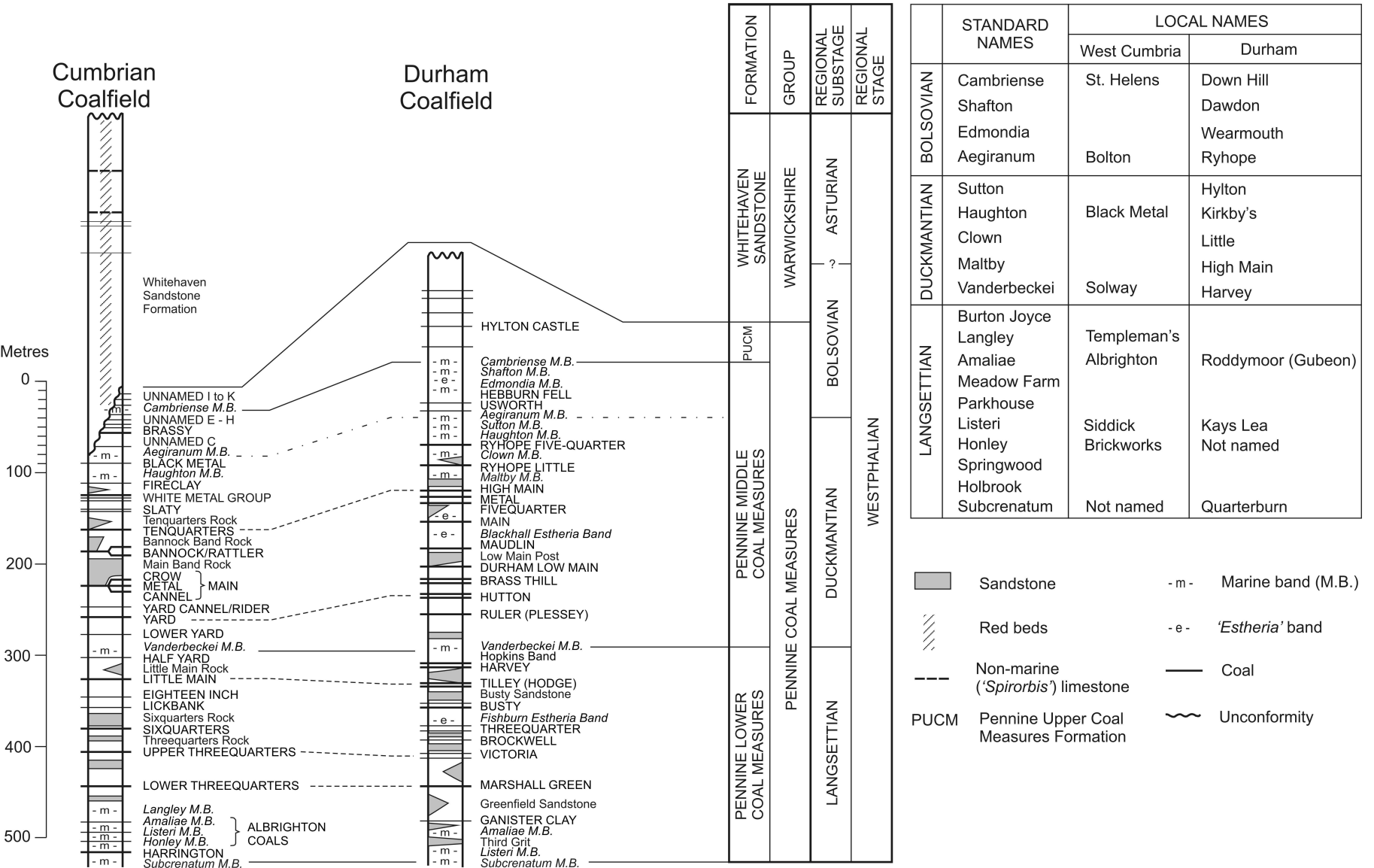
Fig. 12.2. Correlation of Carboniferous successions in Cumbria and the north Pennines. The nomenclature is that of Waters *et al*. (2007) and Dean *et al*. (2011), with details from the following publications: Col. 1 from Eastwood *et al*. (1968) and Taylor (1961); Col. 2 from Akhurst *et al*. (1997); Col. 3 from Rose & Dunham (1977) and Johnson *et al*. (2001); Col. 4 from Arthurton *et al*. (1988); Col. 5 from Dunham &

Wilson (1985); Col. 6 from Dunham & Wilson (1985), Ford (1955) and Owen & Burgess (1965); Col. 7 from Dunham (1990); Col. 8 from Smith & Francis (1967).

Fig. 12.3 Correlation of Westphalian strata, showing named coals, sandstones and marine bands modified from Ramsbottom *et al*. (1978), based upon Taylor (1961) for the West Cumbrian Coalfield and Smith & Francis (1967) for the Durham Coalfield.


550
300
1.Cumbrian Coalfield
MF
350
300
8.Durham Coalfield
7.Rook-hope BH
7.Cross Fell
Alston Block
PDF
LF
N
1.Cockermouth
6.Stainmore Outlier
6.Ravenstonedale
500
2.Sellafield
5.Masham
5.Ray-dale BH
3.Furness
Askrigg Block
5.Kirkby Malzeard
4.Settle
NCF
3.Cartmel
Post-Carboniferous
Westphalian
Namurian
Tournaisian - Visean
Pre-Carboniferous
0 km 25


Subsystem
International Stage
Regional Stage
Regional Substage
Ammonoids
Palynomorphs
PENNSYLVANIAN
MISSISSIPPIAN (Pars)
BASHKIRIAN
MOSCOVIAN
KASIMOVIAN
GZHELIAN
NAMURIAN
WESTPHALIAN
STEPHANIAN
SERPUKHOVIAN
Stephanian C
Stephanian B
Barruelian
Cantabrian
Asturian
Bolsovian
Duckmantian
Langsettian
Yeadonian
Marsdenian
Kinderscoutian
Alportian
Chokierian
Arnsbergian
Pendleian
G2
G1b
G1a
R2c
R2b
R2a
R1c
R1b
R1a
H2c
H2b
H2a
H1b
H1a
E2c
E2b
E2a
E1c
E1b
E1a
NBM
ST
OT
SL
NJ
RA
SS
FR
KV
SO
TK
NC (pars)
1 Cumbrian Coalfield
Permian
Warwickshire Gp
Whitehaven Sandstone Formation >300 m
Pennine UCM 25 m
Pennine Coal Measures Group
Pennine Middle Coal Measures Fm. 260 m
Pennine Lower Coal Measures Fm. 230 m
Stainmore Fm 8 m
Yoredale Group (pars)
Stainmore Formation 140 m
Great Lst Mb (Alston Fm) 20 m
(Brigantian)
3 Furness & Cartmel (south Cumbria)
Permian
Biostratigraphical symbols
+ Ammonoids
O Conodonts & foraminifers
^ Palynomorphs & macroflora
~ Bivalves
* Corals & brachiopods
Pendleton Formation 330 m
Millstone Grit Gp
Bowland Shale Formation 125 m
Craven Group
(Brigantian)
5 Masham (Askrigg Block)
Permian
Pennine Coal Measures Gp.
Pennine Lower Coal Measures Fm. 37 m
Rossendale Fm 45 m
Marsden Formation 15 m
Hebden Formation 110 m
Millstone Grit Group
Samlesbury Formation 5 m
Silsden Formation 180 m
Pendleton Formation 45 m
(Brigantian)
6 Stainmore Trough (inc. Bishop Auckland)
Permian
Pennine Coal Measures Gp.
Pennine Middle Coal Measures Fm. 260 m
Pennine Lower Coal Measures Fm. 200 m
Millstone Grit Group
Undifferentiated 120 m
Yoredale Group (pars)
Stainmore Formation 330 m
Great Lst Mb (Alston Fm) 25 m
(Brigantian)
8 Durham Coalfield (Alston Block)
Permian
Pennine UCM 135m
Pennine Coal Measures Group
Pennine Middle Coal Measures Fm. 500 m
Pennine Lower Coal Measures Fm. 230 m
Millstone Grit Group
Undifferentiated 80 m
Yoredale Group (pars)
Stainmore Formation 280 m
Great Lst Mb (Alston Fm) 22 m
(Brigantian)
MISSISSIPPIAN (pars)
TOURNAISIAN
VISEAN
Brigantian
Asbian
Holkerian
Arundian
Chadian
Courceyan
P2c
P2b
P2a
P1d
P1c
P1b
P1a
B2b
B2a
B1
BB
FA
NC (pars)
VF
NM
TC
TS
Pu
CM
PC
BP
HD
VI
1 Cockermouth (west & north Cumbria)
Yoredale Group (pars)
Alston Formation 220 m
Great Scar Limestone Group
Eskett Limestone Formation 120 m
Frizington Limestone Formation 90 m
Ravenstonedale Group
Cockermouth Volcanic Fm. 105 m
Marsett Formation 35 m
(Ordovician)
2 Sellafield
Permian
Great Scar Limestone Group
Eskett Limestone Formation 42 m
Frizington Limestone Formation 100 m
Martin Limestone Formation 12 m
Ravenstonedale Group
Marsett Formation 3 m
(Ordovician)
3 Furness & Cartmel (south Cumbria)
Yoredale Group
Alston Formation 180 m
Great Scar Limestone Group
Urswick Limestone Formation 160 m
Park Limestone Formation 125 m
Dalton Formation 240 m
Red Hill Limestone Formation 60 m
Martin Limestone Formation 135 m
Ravenstonedale Group
Marsett Formation 240 m
(Silurian)
4 Settle (Askrigg Block)
Yoredale Group (pars)
Alston Formation 140 m
Great Scar Limestone Group
Malham Formation 220 m
Cracoe Lst Fm >100 m
Kilnsey Formation 224 m
Chapel House Limestone Formation 56 m
Stockdale Farm Formation >165 m
?
(Silurian)
5 Upper Wensleydale & Raydale BH (Askrigg Block)
Yoredale Group (pars)
Alston Formation 150 m
Great Scar Limestone Group
Danny Bridge Limestone Formation 168 m
Garsdale Limestone Formation 58 m
Fawes Wood Limestone Formation 81 m
Ashfell Sandstone Formation 38 m
Tom Croft Limestone Formation 80 m
Ravenstonedale Group
Penny Farm Gill Formation 56 m
Marsett Formation 60 m
Raydale Dolostone Formation 30 m
(Wensleydale Granite)
6 Ravenstonedale (Stainmore Trough)
Yoredale Group (pars)
Alston Formation 435 m
Tyne Lst Fm 7 m
Great Scar Limestone Group
Knipe Scar Limestone Fm 100 m
Potts Beck Formation 45 m
Ashfell Limestone Formation 100 m
Ashfell Sandstone Formation 152 m
Breakyneck Scar Limestone Formation 150 m
Brownber Fm 80 m
Scandal Beck Limestone Fm 120 m
Coldbeck Lst Fm 52m
Ravenstonedale Group
Stone Gill Limestone Fm 100 m
Marsett Formation 200 m
Pinskey Gill Formation 50 m
(Silurian)
7 Rookhope BH - (Alston Block)
Yoredale Group (pars)
Alston Formation 219 m
Great Scar Lst
Melmerby Scar Limestone Fm. 35 m
Ravenstonedale Group
Marsett Formation 20 m
(Ordovician/ Weardale Granite)



	STANDARD NAMES	LOCAL NAMES	
		West Cumbria	Durham
BOLSOVIAN	Cambriense	St. Helens	Down Hill
	Shafton		Dawdon
	Edmondia		Wearmouth
	Aegiranum	Bolton	Ryhope
DUCKMANTIAN	Sutton		Hylton
	Haughton	Black Metal	Kirkby's
	Clown		Little
	Maltby		High Main
	Vanderbeckei	Solway	Harvey
LANGSETTIAN	Burton Joyce		
	Langley	Templeman's	
	Amaliae	Albrighton	Roddymoor (Gubeon)
	Meadow Farm		
	Parkhouse		
	Listeri	Siddick	Kays Lea
	Honley	Brickworks	Not named
	Springwood		
	Holbrook		
	Subcrenatum	Not named	Quarterburn

Sandstone

Red beds

Non-marine ('*Spirorbis*') limestone

PUCM Pennine Upper Coal Measures Formation

-m- Marine band (M.B.)

-e- '*Estheria*' band

Coal

Unconformity