British Upper Carboniferous Stratigraphy

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Chapter 11

Northern England

The area dealt with in this chapter lies between the Pennine Basin and the Southern Uplands Massif (Figure 11.1). It mainly covers present day Northumberland, Durham and Cumbria, although (despite the name generally given to the area) it also extends into the southernmost parts of Scotland. It is in effect a northern continuation of the Central Province/Pennine Basin, and some authors do not distinguish between them. However, there are a number of distinctive characters of the depositional regime in these northern areas, both in the Namurian and the Westphalian, and so they have been allocated a separate chapter in this review.

One great advantage that Northern England has over the Pennine Basin, from a geological standpoint, is the better exposure. This is mostly because of the existence of coastal sites, which provide some of the best exposures of Namurian and Westphalian strata in Britain. Inland, particularly in the urbanized areas of Northumberland and Durham, exposure is less good. However, in some of the more rural and rugged areas, such as Stainmore, there are numerous stream and river sections.

The Northumberland-Durham Coalfield in particular has been of considerable economic importance in the past. In 1857, it produced nearly 16 million tons of coal, which was 24% of the total UK production (Hull, 1861). In 1929, it reached a maximum of 52.5 million tons, or 20% of the UK production (Bone and Himus, 1936). In contrast, the Cumberland Coalfield has been much less productive, its annual production in 1856 being merely 0.8 million tons, rising to 2.4 million tons in the 1920s and 1930s. The Stainmore, Midgeholm and Canonbie coalfields have never supplied much more than local needs. Today, deep mining activity in all of these areas has all but stopped, except for parts of the Northumberland-Durham Coalfield, where the 7 remaining deep-mines produced in 1990/91 8.9 million tons or 12% of the UK production (British Coal Corporation Annual Report), and where there is some potential for developing the undersea extensions of the coalfields.

Also important for the early industrialization of the area were the clay ironstones found in the Coal Measures. However, they were replaced by the Lower Carboniferous haematite ores of west Cumbria as the main supply of local ore. Refractory and brick clays have also been exploited in the area.

History of research

In addition to the areas of Upper Carboniferous outcrop discussed in detail below, there are also a

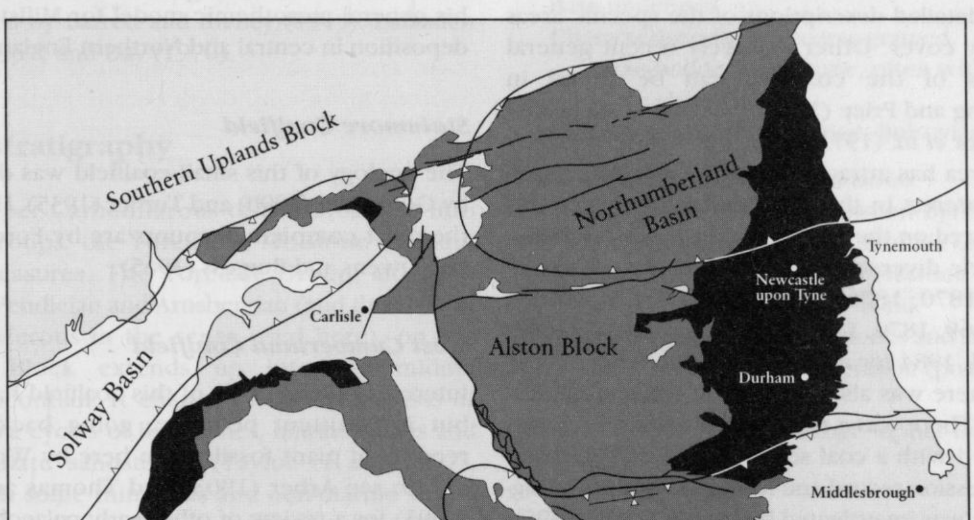

Figure 11.1 Upper Carboniferous of the Northern England area (including southernmost Scotland). Based on Taylor *et al.* (1971, fig. 13).

number of smaller coalfields, most notably the Ingleton and Midgeholm coalfield. There are no GCR sites in these coalfields, and therefore no historical account of them will be given. However, further information on them can be found in Trotter and Hollingworth (1932) and Ford (1954).

Northumberland-Durham Coalfield

Interest in the Upper Carboniferous geology of the area seems to have started in earnest in the early 19th century. The earliest substantive account of the coalfield was given by Winch (1817). During the remainder of the century, a whole string of general accounts of its geology were published, reflecting the economic activity of the area (e.g. Buddle, 1831a, 1831b; Hall, 1854; Hurst, 1860; Lebour, 1878; Brown, 1888; Murton, 1892). Surprisingly, however, the Geological Survey were not particularly active here, at least from the point of view of the publication of memoirs (although some geological maps were issued at this time). Major memoirs dealing with parts of the coalfield did not appear until well into the 20th century, the earliest being by Carruthers *et al.* (1930) and Fowler (1936). Most recently, there have been three memoirs by Smith and Francis (1967), Day (1970) and Land (1974), which provide valuable background information on the area as a whole, as well as detailed descriptions of the specific areas that they cover. Other relatively recent general accounts of the coalfield can be found in Armstrong and Price (1954), Magraw *et al.* (1963) and Taylor *et al.* (1971).

The area has attracted considerable palaeontological interest In the 19th century, much of this was centred on the unusual deposits at Newsham, with their diverse vertebrate assemblages (e.g. Atthey, 1870, 1876, 1877; Hancock and Atthey, 1868, 1869, 1870, 1871; Kirkby and Atthey, 1864; see Boyd, 1984 for a review of more recent literature). There was also some early palaeobotanical interest. There was a record of *in situ* tree-stumps associated with a coal seam (Wood, 1831), while the adpression record and its biostratigraphical significance was investigated by Howse (1857, 1890), Kidston (1922) and Bolton (1926). However, from a biostratigraphical point of view, by far the most important contributions were by Hopkins (1928, 1929, 1930, 1933, 1934, 1935), whose studies on the non-marine bivalves and marine bands did much to unravel the stratigraphical correlations of the coals within the coalfield, and with other areas, principally the Pennine Basin. This work was subsequently continued by Tonks (1939), Burnett (1947) and Pollard (1966, 1969).

Another aspect of the geology of the coalfield that attracted early interest centred on the age and nature of the red beds in the upper part of the succession. Hutton (1831) and Sedgwick (1835) argued that they were Permian, but Howse (1857) used palaeobotanical evidence to show that they had to be Carboniferous in age. More recently, the coloration of the upper beds in the coalfield have been investigated by Anderson and Dunham (1953).

The extensive coastal exposures of these deposits have resulted in a number of sedimentological investigations, including Sorby's (1852) pioneering work on cross-bedding in sandstones, and Lebour and Smythe (1906) examined a sandstone-filled wash-out. However, the detailed sedimentological investigation of the coalfield has only recently been undertaken, largely through the efforts of Fielding (1984a, 1984b, 1986), Haszeldine (1981, 1983a, 1983b, 1984a) and Haszeldine and Anderton (1980).

In contrast to the Coal Measures, the Millstone Grit of this area has attracted relatively little interest, other than the Geological Survey memoirs. One of the earliest significant contributions was by Hull (1968), while some borehole evidence is covered by Mills and Hull (1969) and Neves (1969). Despite the relative paucity of evidence from here, Ramsbottom (1977) was able to incorporate it in his general mesothemic model for Millstone Grit deposition in central and Northern England.

Stainmore Coalfield

The geology of this small coalfield was discussed by Goodchild (1890) and Turner (1935). However, the most complete accounts are by Ford (1955) and Owens and Burgess (1965).

West Cumberland Coalfield

Interest in the geology of this coalfield has a long but intermittent pedigree, going back to the records of plant fossils from here by Woodward (1729; see Arber (1903) and Thomas and Cleal (1993) for a review of other early palaeobotanical records from here). Sedgwick (1835, 1836, 1842) dealt with the sandstones in the upper part of the Carboniferous, which he then erroneously considered to be Permian in age. However, an understanding of the general stratigraphy of the coalfield did not develop significantly until the end of the 19th century, and developed along two distinct lines. Firstly, there were studies by local geologists, mainly linked with coal mining activities (e.g. Kendall, 1883, 1895, 1896; Russell, 1895). Secondly, the Geological Survey commenced mapping the area in 1892 and, although the memoirs were not published for nearly another four decades (Eastwood, 1930; Eastwood *et al.*, 1931), the maps provide a valuable guide to the then known geology of the coalfield.

Arber (1903), while reviewing the palaeobotany of the coalfield, also provided a useful summary of the stratigraphical background. Later reviews have been by Taylor (1961, 1978; see also Taylor *et al.*, 1971). Most recently, Thomas and Cleal (1993) have returned to the problem of the stratigraphy of the sandstones in the upper part of the coalfield (known as the Whitehaven Sandstone), using palaeobotanical evidence.

Canonbie Coalfield

The first account of the geology of this coalfield was by Gibsone (1861) and Binney (1863). However, the first complete account did not appear until Peach and Horne's (1903) paper describing the Geological Survey's mapping of the area. As part of this mapping project, considerable numbers of plant fossils were collected and subsequently described by Kidston (1903a, 1903b). Most recently, memoirs dealing with the area have been produced by Barrett and Richey (1945), Lumsden *et al.* (1967) and Day (1970).

Lithostratigraphy

The Upper Carboniferous of this area falls into three groups: the Yoredales, Millstone Grit and Coal Measures. The Yoredale Group, although mainly Pendleian and Arnsbergian (and thus Lower Carboniferous in the sense used here), on the Alston Block extends up into the middle Kinderscoutian. It characteristically consists of repetitive cycles of limestones, marine shales and subordinate sandstones (Taylor *et al.*, 1971), although some thin coals and non-marine shales occur throughout the group. The numerous limestone beds in this group are individually named (e.g. Whitehouse Limestone), but there is as yet no satisfactory formational classification.

The rest of the Namurian belongs to the Millstone Grit Group. Compared with the the Central Province, it is significantly condensed. For instance, in the Northumberland Trough the entire Chokierian to Yeadonian is only some 70 m thick, and in the Stainmore Trough about 140 m thick; this contrasts with 650 m for Lancashire and 935 m in the Edale Gulf (thickness taken from Ramsbottom *et al.*, 1978). It is not surprising, therefore, that only two grit formations can be recognized in Northern England, which in ascending order are known as the First Grit Formation and Second Grit Formation.

As in the Pennines, the boundary between the Millstone Grit and Coal Measures can be conveniently drawn at the base of the Subcrenatum Marine Band, thus making it coincident with the Namurian-Westphalian boundary. In the Northumberland-Durham Coalfield (also the Stainmore and Midgeholm coalfields), the entire Coal Measures Group belongs to the Productive Coal Formation. It differs somewhat from the classic development of this formation in South Wales and the Pennines, in being more arenaceous. It nevertheless contains numerous coals and mudstones, and has a similar chronostratigraphical range, and so it has been decided not to establish a separate name.

In the Cumberland and Canonbie coalfields, however, the upper parts of the Coal Measures are in quite different facies, justifying the recognition of the following formations:

Whitehaven Sandstone Formation
- Stratotype: Saltom Bay, Cumberland Coalfield
- Base undefined.
- Characteristic facies: coarse-grained, cross-bedded sandstone, often with large shale clasts.
- Chronostratigraphical range: Bolsovian.

Canonbie Red Sandstone Formation
- Stratotype: River Esk, between Byreburnfoot and Canonbie Bridge, Canonbie Coalfield
- Base defined: base of thick sandstone overlying the Cambriense Marine Band.
- Characteristic facies: sandstones and shales, with red or purple coloration (possibly secondary).
- Chronostratigraphical range: upper Bolsovian to Westphalian D.

Geological Setting

The area dealt with in this chapter is in effect a northern extension of the Central Province and Pennine Basin, but which is characterized by more condensed succession, often in rather different facies. In the Viséan and lower Namurian, the area could be subdivided into a series of east-west trend-

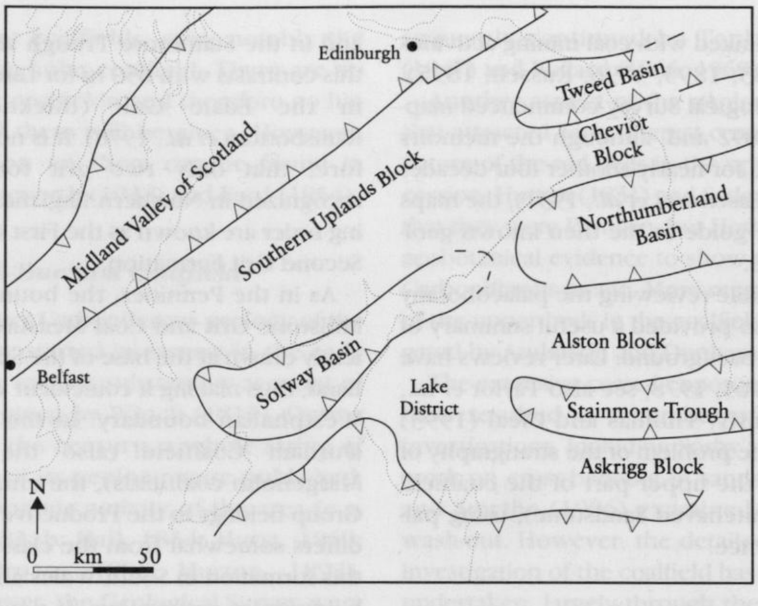

Figure 11.2 Distribution of main basins in Northern England in the Late Carboniferous. Based on Johnson (1984, fig. 1).

ing basins - from south to north, the Stainmore, Northumberland and Tweed troughs (Figure 11.2). These were separated from each other by the Askrigg, Alston and Cheviot blocks, which were probably produced by the presence of basement granites (Johnson, 1984). By the mid-Namurian, the distinction between the basins had all but disappeared, but the effects of the basement granites can still be seen, in the more condensed successions present throughout Northern England.

The lower Namurian is characterized by cyclical limestone and non-marine clastic deposits, known as the Yoredales. The cyclicity is thought to have been the result of the movement of delta lobes, due to either tectonic movement or to purely sedimentary processes within the delta (Leeder and Strudwick, 1987). Within the basinal areas, the Yoredale style of deposition had disappeared by the end of the Arnsbergian, but on the blocks it persisted into the Kinderscoutian.

Most of the Upper Carboniferous part of the Namurian of Northern England is in a condensed Millstone Grit facies. The condensed sequences point to the reduced subsidence, probably resulting from the existence of basement granites. The reduced subsidence also limited the number of marine incursions that occur here. This is important, as it has meant that the marine bands are not as useful for fine stratigraphical work here as they have proved in the Central Province (see Chapter 9). There has been little detailed sedimentological work on the Millstone Grit of this area, but it is likely that the grits were the result of sheet deltas, similar to those seen in the Central Province.

The Westphalian sees a change to delta-plain conditions. It clearly represents a continuation of the delta-complex that formed the deposits of the Pennine Basin; the sedimentological studies by Fielding (1984a, 1984b, 1986) have demonstrated that, especially with the flood-plain facies-associations, there is an essential similarity with coeval deposits in the central part of the Pennine Basin (e.g. Elliott, 1968, 1969). However, much of the Coal Measures of Northern England have a much higher proportion of sandstone than their equivalents further south. Furthermore, recent sedimentological work suggests that many of these sandstones were formed in relatively high-energy, braided channels, that cut down into the flood-plain deposits, and were thus probably in a more proximal position in the delta-complex (Haszeldine and Anderton, 1980). A more proximal position is also supported by the reduced number of marine bands present and the fact that, where they do occur, they are often little more than *Lingula* bands.

Higher in the Westphalian, sandstones form an even higher proportion of the succession, and coal virtually disappears (e.g. Whitehaven and Canonbie Red formations). These presumably represent fluvio-deltaic deposits derived from the Southern Uplands Block to the north, although they have not yet been subjected to detailed sedimentological investigation.

GCR site coverage

The core of the coverage lies in the coastal sites, that demonstrate long successions: Howick to Seaton Point for the Millstone Grit, Tynemouth to Seaton Sluice, and Cresswell and Newbiggin Shore for the Productive Coal Formation, Saltom Bay for the Whitehaven Sandstone and Byre Burn. In view of its biostratigraphical significance, particularly for palynological studies, a section through the Millstone Grit of the Stainmore Trough has also been included (Mousegill Beck).

In addition to these, Crag Gill was selected to demonstrate the persistence of the Yoredales on the Alston Block. Wear River Bank was chosen for its considerable palaeontological interest, yielding remains including insects, xiphosurids and fish. Finally, Jockie's Syke was chosen for showing the Canonbie Red Sandstone Formation, as well as being the only British site still yielding middle Westphalian D plant fossils.

MOUSEGILL BECK

Highlights

Mousegill Beck provides the best section through the Millstone Grit of the Stainmore Trough, a sedimentary basin that lay between the Askrigg and Alston blocks in Northern England.

Introduction

This tributary of Argill Beck (NY 825129–NY 837124), 4 km ESE of Brough, Cumbria, shows a complete sequence through the Namurian of the Stainmore Trough, an area of downwarp during the Late Carboniferous, that lay between the Askrigg and Alston blocks (Figure 11.2). The geology was mentioned by Goodchild (1890) and Turner (1935), but the most detailed accounts are to be found in papers by Ford (1955) and Owens and Burgess (1965).

Description

Lithostratigraphy

Exposed along this stream is a virtually complete succession through the Namurian of the Stainmore Trough, from the Pendleian up into the lower Westphalian. However, this account will only deal with the Upper Carboniferous (Chokierian to Yeadonian) part of the Namurian here. These strata are some 140 m thick (Figure 11.3).

The base of the Upper Carboniferous is taken to be at about 2.5 m above the Peasah Wood Limestone. The lowest unit is about 39 m thick, and consists of two fining-upwards cycles, with sandstone at the base and passing up through siltstones into brackish/marine mudstones. The mudstones at the top of the first cycle are thin and brackish. Those at the top of the second cycle, however, form an 18 m thick interval called the Mousegill Marine Beds. They are of much more marine character, consisting predominantly of shales and thin limestones, although there is also a thin coal.

Above the Mousegill Marine Beds are 54 m of shales and sandstones, that may be interpreted in terms of three coarsening-upwards cycles. From marine or brackish mudstones, each cycle passes up through siltstones into sandstones, which is then capped by a thin coal or seat earth. The coal or seat earth is then overlain by the next marine or brackish mudstone. The cycles are probably the result of small-scale deltas prograding into a shallow marine basin.

The third of these cycles is incomplete, there being no coal or seat earth. Instead, it is capped by a marine mudstone, known as the Swinstone Bottom Marine Band. This seems to mark a change in style of sedimentation, with alternating marine mudstones and thick cross-bedded sandstones indicating a pronounced change from deeper-water marine to delta-top fluvial channel deposits. In addition to the Swinstone Bottom Marine Band, this part of the succession also includes the Swinstone Middle and Swinstone Top marine bands. The latter marks the top of the Namurian in this succession (see below).

Biostratigraphy

Marine bands

Most of the so-called marine bands in this sequence contain little more than *Lingula* and *Planolites*, and are thus difficult to relate on faunal grounds with the marine bands found in the classic succession of the Central Province. There have been attempts to correlate the *Lingula* bands with the Pennines marine bands, but this has sometimes caused confusion. For instance, the Cancellatum Marine Band was correlated by Taylor *et al.* (1971) with one of the *Lingula* bands between the Mouse Gill and Swinstone Bottom marine bands, by Owens and Burgess (1965) with the Swinstone

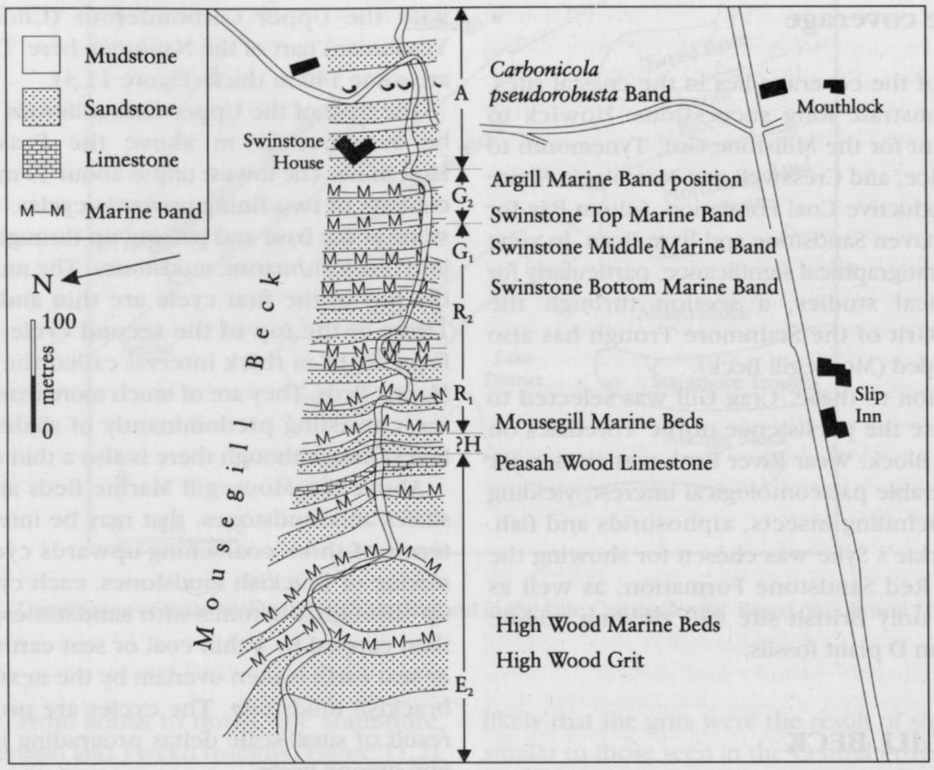

Figure 11.3 Millstone Grit exposed along Mousegill Beck. Based on Owens and Burgess (1965).

Bottom Marine Band and by Ramsbottom *et al.* (1978) with the Swinstone Middle Marine Band. There is not even any unequivocal faunal evidence as to the position of the Namurian-Westphalian boundary. It is widely believed that the Swinstone Top Marine Band is a correlative of the Subcrenatum Marine Band, but the index ammonoid has not been found here.

In fact, only two horizons have yielded diagnostic marine faunas. Firstly, the Mousegill Marine Beds have yielded *Vallites henkei* (Schmidt), which is generally taken as an index of the *R. circumplicatile* Subzone (Owens and Burgess, 1965), and secondly, the Swinstone Middle Marine Band, which contains a much more diverse fauna including the ammonoid *Cancelloceras* cf. *cumbriense* (Bisat), and thus correlates with the middle Yeadonian Cumbriense Marine Band of the Central Province.

Palynology

The details of the palynology of this sequence are described by Owens *in* Owens and Burgess (1965), who prepared microfossils from 12 horizons between the Mousegill Marine Beds and the Swinstone Top Marine Band. The lowest Upper Carboniferous sample that he had was from immediately below the Mousegill Marine Beds, where he recognized a significant influx of *Crassispora kosankei* (Potonié and Kräusel) Bhardwaj. Such an influx is generally taken to mark the base of the *C. kosankei–G. varioreticulatus* Zone, which is a good index to the base of the Kinderscoutian Stage. This is in full agreement with the faunal evidence found in these marine beds (see above).

Broadly similar assemblages were identified for about 20 m above the Mousegill Marine Beds. However, from there upwards, the assemblages changed, to include taxa such as *Dictyotriletes varioreticulatus* Neves, *Secarisporites lobatus* Neves, *S. remotus* Neves and *Cirratriradites ornatus* Neves. This is characteristic of the *R. fulva–R. reticulatus* Zone, indicating the upper Marsdenian to Yeadonian.

Interpretation

This is the best exposure of Millstone Grit in the Stainmore Trough. Exposures are limited to stream sections in this small area near Brough, known as the Stainmore Outlier. Alternative outcrops can be found along Argill Beck and Hocker Gill, but Mousegill Beck provides by far the most complete and well exposed succession.

The sequence is typical of the Namurian in Northern England, north of the Central Province. For one thing, it is much more condensed – for instance, the Chokierian to Yeadonian of the Rossendale area is about 1200 m thick, in contrast to about 140 m at Mousegill Beck. Also, the Stainmore succession is typically poor in ammonoids, again contrasting sharply with the more basinal sequences of the Central Province.

This scarcity of ammonoids is one of the reasons why there have been so many difficulties in establishing the exact chronostratigraphical position of the Stainmore sequence. Owens and Burgess (1965) clearly demonstrated the value of palynological biostratigraphy in such sections where the marine faunas are poor or absent, but this did not solve all of the problems. For instance, although Ford's (1955) postulated stratigraphical gap of Arnsbergian to Langsettian appears to be exaggerated, there may nevertheless be a gap below the Mousegill Marine Beds incorporating the Chokierian and Alportian. It has become widely quoted that Owens and Burgess regard the interval between these marine beds and the underlying Peasah Wood Limestone as representing these two stages (e.g. Ramsbottom *et al.*, 1978), but there is no biostratigraphical evidence to support this; it would be just as acceptable to have a non-sequence somewhere between these two marine units. Also, palynology has not been able to resolve the problem of the detailed correlations of the 'marine' bands in the upper part of the Namurian here, and the location of the Marsdenian-Yeadonian boundary.

Conclusions

Mousegill Beck is the best locality for examining rocks of the Millstone Grit, as found in an area of deposition known as the Stainmore Trough. The site is particularly important for fossil pollen and spores, which have proved of considerable value in establishing the age of the rocks (about 315–325 million years old).

HOWICK TO SEATON POINT

Highlights

The coastal exposures between Howick and Seaton Point provide the best exposure of the unconformity between the Yoredales and Millstone Grit in the northern Northumberland Basin.

Introduction

Coastal exposures (NU 262173–NU 264125) 2 km east of Longhoughton, near Alnwick, Northumberland, show the Millstone Grit of the Northumberland Trough, lying unconformably on Yoredale limestones. The site has been described by Carruthers *et al.* (1930). Much of the sequence exposed is in the Lower Carboniferous Yoredale limestones, so that the following account is restricted to the Millstone Grit part of the succession.

Description

Problems of faulting, particularly in the southern part of the site, makes it difficult to establish a total thickness for the succession, but it is likely to be at least 125 m. It consists of three sandstone units, 15, 18 and 75 m thick in ascending order, separated by shale/siltstone units about 3 m thick. The lowest sandstone is a fine-grained, coarsening-upwards unit. The other two are coarser, sometimes pebbly sandstones, with cross-bedding and ripple-lamination, generally more typical of the Millstone Grit of the Central Province to the south (see Chapter 9).

Mapping of the area described by Carruthers *et al.* (1930) demonstrated that the base of the Millstone Grit here is unconformable, and this is supported by indirect biostratigraphical evidence (see below).

Interpretation

This is the best site for showing the relationship between the Millstone Grit and the underlying Yoredales in the northern part of the Northumberland Trough. It shows particularly well the change from the limestone-dominated to the sandstone-dominated facies, reflecting the progressive withdrawal of marine influence from the area.

The size of the stratigraphical gap between the Yoredales and Millstone Grit in this part of Northumberland is difficult to determine, and this site provides little direct evidence on the point. However, the highest part of the Yoredales seen along this stretch of coast lies just above the Upper Foxton Limestone, which Ramsbottom *et al.* (1978) correlated with the middle Arnsbergian Castlecary Limestone in the Kincardine Basin of Scotland. According to borehole evidence reviewed by Hull (1968), the base of the Millstone

Grit throughout most of Northumberland is in the middle Kinderscoutian. Consequently, the stratigraphical gap here probably represents the upper Arnsbergian, Chokierian, Alportian and lower Kinderscoutian.

Conclusions

Between Howick and Seaton Point can be seen the best exposures of the junction between the rock units known as the Yoredales and Millstone Grit in the northern Northumberland Basin. There is evidence that there is a time-gap of about 4 million years between the two rock units.

CRAG GILL

Highlights

Crag Gill shows the best section through the Namurian on the Alston Block, and includes one of the highest known marine limestones in the Carboniferous of north-western Europe.

Introduction

This stream (NZ 027236) between Eggleston and Woodland, 8 km ESE of Middleton in Teesdale, County Durham, exposes Namurian rocks on the Alston Block, an area of reduced subsidence that separated the Stainmore and Northumberland troughs. Details of the geology can be found in Mills and Hull (1976).

Description

The full sequence as exposed along Crag Gill is 49 m thick, but only the upper 25 m is Upper Carboniferous and thus dealt with here. The lowest Upper Carboniferous strata are 11 m of alternating mudstones and deltaic sandstones, together with one thin limestone. These are overlain by a 28 cm thick grey, impure limestone – the Whitehouse Limestone, for which this is the type locality.

The Whitehouse Limestone is overlain by 2 m of basinal mudstones with abundant marine fossils (see below). There then follows thick sandstones, which mark the base of the Millstone Grit on this part of the Alston Block. Two sandstones can be seen in this section, the lowest is only 3 m thick, and is relatively fine grained, the higher one, however, is much coarser and massive, and is known as the First Grit, which can be up to 22 m thick, although only 8 m are visible here.

The thin, unnamed limestone below the Whitehouse Limestone has yielded an abundant brachiopod fauna, together with the bivalves *Sanguinolites* sp. (Mills and Hull, 1976). This is not biostratigraphically diagnostic. However, the same bed in the nearby Woodland Borehole has yielded the ammonoid *Vallites henkei* (Schmidt) (Mills and Hull, 1969), indicating the *R. circumplicatile* Zone (lower Kinderscoutian). As the underlying Grindstone Limestone is thought to be upper Arnsbergian, there seems to be a non-sequence somewhere in the intervening succession.

The Whitehouse Limestone here has yielded only a limited range of fossils, mainly crinoid debris and *Productus* sp., but in the Woodland Borehole *Reticuloceras stubblefieldi* Bisat and Hudson has been found, indicating the *R. nodosum* Zone (middle Kinderscoutian). At Crag Gill, this ammonoid species occurs in the mudstones immediately overlying the limestone. It occurs together with bryozoa (*Fenestella*, *Rhombopora*), echinoderms (*Archaeocidaris*), brachiopods (*Crurithyris*, *Productus*, *Rugosochonetes*), gastropods (*Coleolus*, *Euphemites*), bivalves (*Aviculopecten*, *Euchondria*, *Palaeoneilo*, *Paleyoldia*), cephalopods (*Catasroboceras*) and arthropods (*Dithyrocaris*). There are also fragments of zaphrentids which, although they have so far proved specifically unidentifiable, are of interest as one of the youngest occurrences of this coral-type.

Interpretation

This is the best exposure of the upper Yoredale and lower Millstone Grit groups on the Alston Block. The Namurian sequence developed on the Alston Block is more condensed compared with those of the Stainmore and Northumberland troughs (Taylor *et al.*, 1971, pl. 7). Also, the Yoredale facies extends to rather higher stratigraphical levels, with the Whitehouse Limestone of middle Kinderscoutian age; in the trough successions, Yoredale limestones do not extend above the Arnsbergian.

A somewhat more complete succession has been reported from the nearby Woodland Borehole (Mills and Hull, 1969). For instance, the stratigraphical interval between the Grindstone and Whitehouse limestones is 38 m thick in the borehole, but only 21 m along Crag Gill. However, whether this represents a non-sequence between the Arnsbergian and Kinderscoutian at Crag Gill, or is simply a function of the relatively poor exposure of this part of the succession here, is not totally clear.

Although it has not been subjected to a detailed taxonomic study, the Whitehouse Limestone fauna is important as being the youngest shelf-limestone assemblage known from the Carboniferous of north-western Europe. In fact, apart from the Zechstein deposits of the Upper Permian, it is the oldest marine limestone deposit in the entire Palaeozoic of north-western Europe. It thus holds considerable potential importance for understanding the decline in marine influence in the Late Carboniferous and Permian in this part of Laurasia/Pangea, which resulted from the geographical changes caused by the Variscan earth movements.

Conclusions

Crag Gill is the best exposure of rocks of Namurian age (about 320 million years old) on the Alston Block in Northern England. The marine limestone is amongst the youngest known in the Carboniferous of north-western Europe.

TYNEMOUTH TO SEATON SLUICE

Highlights

Tynemouth to Seaton Sluice provides the best exposure of Duckmantian in Northern England, and the best continuous succession through much of that stage anywhere in Britain. It can be demonstrated here that the depositional environment was different from that present in the Pennine Basin to the south, being subjected to periodic high-energy conditions. The site has also several important fossil localities, including the famous Whitley Bay non-marine bivalve site.

Introduction

These are coastal exposures (NZ 373693–NZ 345760) extending for about 9 km NNW of the mouth of the River Tyne, Tyne and Wear and

Figure 11.4 Typical exposures of the Productive Coal Formation exposed at Hartley Cliff, 160 m S of Crag Point, Tynemouth to Seaton Sluice GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (L630).

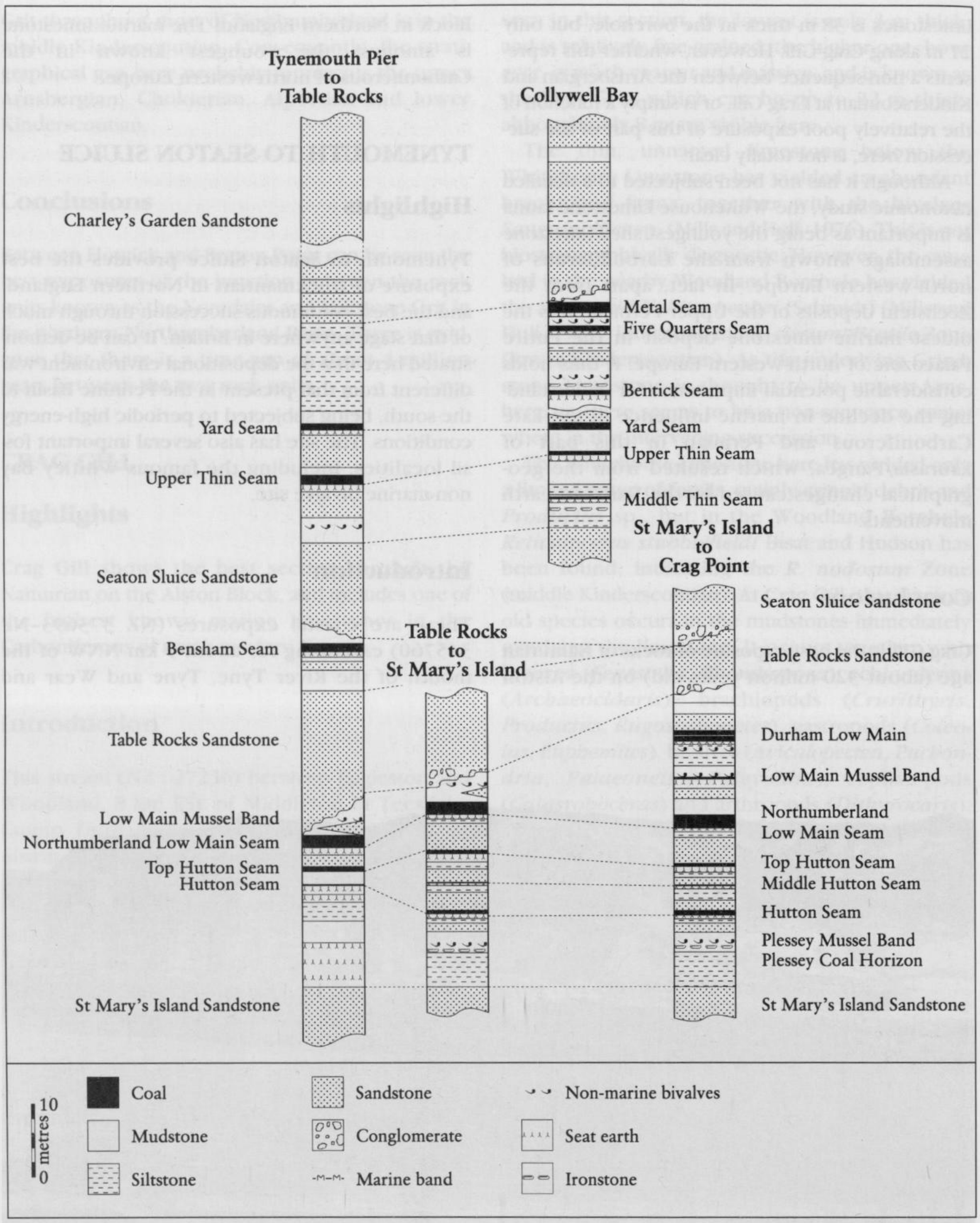

Figure 11.5 Sequence of Duckmantian strata seen along the coast between Tynemouth and Seaton Sluice. Reconstructed from information given in Jones (1967).

Northumberland. They are some the finest natural exposures of Westphalian strata in Britain (Figure 11.4). It shows a continuous succession of Duckmantian strata, folded into a periclinal structure known as the Whitley Dome. It was the subject of the pioneering sedimentological work by Sorby (1852), and more recently by Haszeldine and Anderton (1980) and Haszeldine (1981, 1983a, 1983b, 1984a). The general field geology has been described by Absalom and Hopkins (1926), Jones (1967) and Land (1974).

Description

Lithostratigraphy

A succession of about 145 m thick is represented here (Figure 11.5). The exposures are at least partly along strike, thus providing some evidence of lateral variation of the strata. The lowest beds seen are massive, cross-bedded sandstones, known as the St Mary's Island Sandstone. The base of this unit is not seen here, but from nearby boreholes and shafts it has been shown to be about 6 m thick (Land, 1974). It is part of an elongate sandstone body, 2–4 km wide, that extends north-west from St Mary's Island.

There follows 39 m of coal-bearing strata, which include the Hutton, Northumberland Low Main and Durham Low Main coal seams. Between the St Mary's Island Sandstone and the Bottom Hutton are lacustrine mudstones marking the position of the Plessey Seam. Further north in Northumberland, the Plessey seam is one of the most important coals and has been worked over 7 km out to sea. As is shown by Land (1974, fig. 35), however, it rapidly thins to the south and in this particular section has completely disappeared. The Hutton Seam, in contrast, has its main development to the south, and was commercially exploited near Newcastle-upon-Tyne and South Shields, but at their locality it has thinned to less than 0.4 m thick. There are also two thin seams a short distance above the Hutton referred to by Jones (1967) as the Middle and Top Hutton. According to Land (1974), these are very localized deposits, only known here. However, the shales between the Hutton and Middle Hutton seams are of interest as they contain ironstone nodules, and are at the same level as the famous fossiliferous ironstone deposits found near Crawcrook. Finally, there is a 12 cm thick coal some 5 m above the Northumberland Low Main coal, known as the Whitley Seam. Although this coal is of no commercial significance, its roof is an ironstone (the Whitley Ironstone) which was worked in the neighbourhood in the 18th century. The roof also contains well-preserved bivalve fossils, and hence is sometimes referred to as the Low Main Shell Bed.

The two 'Low Main' seams are more fully developed near Tynemouth; the Northumberland Low Main Seam is 1.7 m thick, and the Durham Low Main Seam 1.2 m thick. Both have been extensively worked in this area and, although their exposure on the coast is rather poor, Jones (1967) claimed that they could be uncovered by digging along the foreshore. The nomenclature of these seams has caused considerable problems, the 'Low Main' coals mined in Northumberland and Durham were traditionally regarded as the same seam, but Armstrong and Price (1954) showed that the Durham coal is stratigraphically higher and equated with the Five Quarter Seam of the Northumberland sequence (Jones, 1967 still persisted with the old nomenclature). To further complicate matters, in the Newcastle-upon-Tyne area the name Five Quarters Seam has been used for what is now called the Northumberland Low Main. These nomenclatural difficulties have been largely resolved by Land (1974).

The sedimentology of the interval between the Northumberland Low Main and Durham Low Main as exposed here have been described in detail by Haszeldine (1981, 1984a). He interpreted it in terms of three facies associations.

1. Lacustrine association. This refers to coarsening-upwards successions, representing the progressive in-fill of a lake. In the lower part are black mudstones with ironstone bands that pass up into alternating dark and pale grey, slightly coarser-grained mudstones. These are in turn overlain by coarsening-upwards rippled siltstones and fine sandstones.
2. Flood-plain association. This consists mainly of coals, seat earths, and epsilon cross-bedded siltstones. They represent emergent conditions that developed when the lake had silted-up.
3. Deltaic association. This includes various types of sandstone, representing bar and channel-fills of the deltas that supplied sediment and water into the lake. Such small-scale deltas may also be referred to as crevasse channel and splay deposits.

Haszeldine's model has been slightly modified following subsequent work by Fielding (1984a, 1984b, 1986), based mainly on artificial exposures that allowed more three-dimensional observations to be made. Nevertheless, the essence of the model remains intact as a means of interpreting much of the British middle Westphalian coal-bearing deposits, in terms of the infill of lakes formed in floodbasins by small-scale deltas or crevasse-splays.

The laminated lacustrine shales that immediately overlie the Northumberland Low Main seam are lateral equivalents of the well-known cannely shales found at Newsham, and which contain numerous vertebrate fossils (Andrews *in* Land, 1974; Boyd, 1984).

Above this interval of coal-bearing strata is a 20 m thick sandstone unit known as the Table Rocks Sandstone. The lower part of the formation is conglomeratic, and the base is erosive; in the northern part of the site it lies some 6.5 m above the Durham Low Main, while in the more southerly exposures near Table Rocks it has almost cut down as low as the Northumberland Low Main. Another distinctive feature of this unit is that the underlying strata are disturbed, which Lebour and Smythe (1906) interpreted as the result of thrusting. Land (1974) instead argued that the sandstone was a washout and that the underlying beds had suffered contemporaneous disturbance during or just before its deposition. However, it is not a localized channel washout, having been identified over large areas of the Northumberland-Durham Coalfield (Land, 1974, fig. 45).

There have been nomenclatural problems with the Table Rocks Sandstone, due at least in part to its diachronous base. Jones (1967) referred to the outcrops near Hartley Bay as the Lower Crag Point Sandstone, but Land (1974) has shown that they are in fact the same as the Table Rocks Sandstone. The Upper Crag Point Sandstone is in fact the Seaton Sluice Sandstone, and will be discussed below.

In much of the site, the Table Rocks Sandstone are overlain by 8.6 m of mudstones, thin sandstones and the 0.6 m thick Bensham coal. This is another economically important coal seam worked extensively in this area (Land, 1974, fig. 47), whereas further north it splits into two leaves.

The interval containing the Bensham Seam is in turn overlain by 12–14 m of sandstone (in the northernmost part of the site the sandstone cuts down through this coal and lies directly on top of the Table Rocks Sandstone). Jones (1967) variously called this the Brown's Point Sandstone, the Upper Crag Point Sandstone and the Seaton Sluice Sandstone, depending on where it outcropped. However, Land (1974) argued that it was all part of the same diachronous unit, which he referred to as the Seaton Sluice Sandstone. The sedimentology of this sandstone has been studied in detail by Haszeldine and Anderton (1980) and Haszeldine (1981, 1983a, 1983b, 1984a), who demonstrated that it was probably the remains of laterally migrating medial bars deposited in a low-sinuosity, braided river system.

Above the Seaton Sluice Sandstone sees another return to coal-bearing strata, which is best seen in the northern part of the site near Seaton Sluice. The sequence is described in detail by Jones (1967) and Land (1974). The former noted that the evidence for the traditional naming of the seams in this section was far from conclusive, and they were revised later by Land. To clarify the apparent discrepancy between the stratigraphical logs provided in these two descriptions, the two schemes of seam nomenclature are correlated as follows:

Coal Seam Names (Jones, 1967)	Coal Seam Names (Land, 1974)
—	Middle Thin
Bottom Yard	Upper Thin
Top Yard	Yard
Bottom Grey (or Stone)	Bentick
Top Grey (or Metal)	Five Quarters
High Main	Metal

The general consensus now seems to be that Land's identifications are the correct ones, and that the High Main Seam, one of the most important in the coalfield, does not crop out here. Of the seams that do occur, only two are economically important, the Yard and Metal seams (0.8 and 1.2 m thick respectively).

The stratigraphically highest Carboniferous strata exposed here are about 22 m of mainly purple-stained sandstones. They are named the Charley's Garden Sandstone, after the prominent stack of that name between Collywell Bay and Seaton Sluice (Figure 11.6). The formation is conglomeratic at the base, including mud- and coal-clasts, reflecting its erosive base that scoured into the coal-bearing strata. Cross-bedding suggests sediment transport was in a broadly southerly direction. The colouring of the sandstone is thought to be due to staining from the overlying Permian beds (Anderson and Dunham, 1953).

Biostratigraphy

Non-marine bivalves

The lowest biostratigraphical evidence here comes from a thin band of ironstone overlying the level thought to equate with the Plessey Seam, and known as the Plessey Mussel Band. Jones (1967) mentions that they are not seriously compressed, but he does not give a species list, nor does Hopkins (1929, 1930) or Land (1974). However, from other localities in the vicinity, Land lists taxa

Figure 11.6 Charley's Garden, Tynemouth to Seaton Sluice GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (L637).

of the *Anthracosia ovum* Subzone, indicating the basal Duckmantian.

The next highest bivalves comes from the so-called Low Main Shell Bed, which in fact is the roof of the Whitley Seam. Historically, the most important exposure of this band is in Whitley Bay, where it yields *Anthracosia beaniana* King, *A. phrygiana* (Wright) and *A.* cf. *ovum* Trueman and Weir; it will almost certainly be the provenance of the historical specimens found in many museums labelled as 'Whitley Bay'. Most significantly, it is the type locality for *A. beaniana*, which in turn is the type species of *Anthracosia*, one of the most important genera of non-marine bivalves from the middle Westphalian of northern Europe.

The same Low Main Shell Bed also occurs near Crag Point. Here, it does not yield *A. beaniana*, but includes the remainder of the species found at Whitley Bay, together with *Anthraconaia salteri* (Leitch), *Anthracosphaerium* aff. *radiatum* (Wright), *A.* aff. *turgidum* (Brown), *A.* cf. *propinquum* (Melville) and *Naiadites quadratus* (Sowerby). From the assemblages described from both of these localities, the Low Main Shell Bed would seem to belong to the *A. phrygiana* Subzone, in the topmost part of the *A. modiolaris* Zone.

Land (1974) lists a fauna from about 4.5 m above the Low Main Shell Bed at Crag Point. It contains a very similar *A. phrygiana* assemblage, particularly with respect to the *Anthracosia* species (except *A. beaniana* is absent).

In an offshore borehole, Land (1974) reports the roof of the Bensham Seam to contain bivalves of the *Anthracosia caledonica* Subzone, thus marking the lowest part of the 'Lower *similis-pulchra*' Zone. However, the stratigraphically lowest horizon in these coastal exposures to yield this subzone is above the Seaton Sluice Sandstone, in a thin cannel above the Middle Thin Seam; Land reports from here *Anthraconaia pulchella* Broadhurst, *Anthracosia faba* (Wright), *A. simulans* Trueman and Weir, *A.* cf. *caledonica* Trueman and Weir and *Naiadites productus* (Brown).

The highest level to yield bivalves is just above the Bentick Seam, from where Land (1974) records *Anthraconaia* cf. *pumila* (Salter), *Anthracosia aquilinioides* (Tchernyshev), *A. caledonica?* Trueman and Weir, *A. simulans* Trueman and Weir, *A.* cf. *planitumida* (Trueman), *Anthracosphaerium turgidum* (Brown) and *Naiadites productus* (Brown). This again almost certainly belongs to the *A. caledonica* Subzone.

Arthropods

From the mudstones above the Hutton Seam have been found fragments of a crustacean that has been variously named *Pygocephalus* and *Anthrapalaemon* (Rhodes and Wilson, 1957; Jones, 1967; Land, 1974). It has been found at two separate points in the site, near Brierdene and at Cullercoats. Also, Jones states that the same crustacean occurs in the Phoenix Brickworks at Crawcrook, which is also just above the Hutton coal.

In addition to this crustacean, estheriid arthropods have been found in the Low Main Shell Bed and in the cannel above the Middle Thin Seam.

Plant macrofossils

From the same horizon that yielded the crustacean remains mentioned above, Jones (1967) mentions plant 'species' *Pecopteris, Neuropteris, Alethopteris, Sphenopteris, Annularia* and *Calamites*. This assemblage has not been documented in detail, but is probably similar to that listed from the Phoenix Brickworks at Crawcrook by Kidston (1922). From its lower Duckmantian position, it would be expected to belong to the '*Neuropteris*' *hollandica* Subzone of the *Lonchopteris rugosa* Zone.

Interpretation

This is one of the finest exposures of Westphalian strata in Britain, showing much of the Duckmantian. Most exposures of these beds tend to be inland and thus usually of limited extent. This restricts their value, especially for sedimentological studies, which thus have to rely on temporary, man-made exposures which do not allow repeat observations to be made. The only other extensive coastal exposures are in Pembrokeshire, but these are mainly lower Westphalian. The only well-exposed Duckmantian strata in Pembrokeshire is at Amroth Coast, which is limited to the basal part of the stage (see Chapter 4). Also, the Pembrokeshire sequences suffer from more severe tectonic deformation, distorting both sedimentological structures and the fossils, as well as causing difficulties in establishing a continuous stratigraphical succession.

The type of sedimentological work such coastal exposures allow is exemplified by the studies of Haszeldine and Anderton (1980) and Haszeldine (1981, 1983a, 1983b, 1984a) on the Seaton Sluice Sandstone. They have argued that this is one of a number of distinctive sandstone bodies found in the Northumberland-Durham Coalfield, and thought to represent the deposits of relatively short-lived, braided rivers. According to their model, these braided river systems were the result of intervals of tectonic uplift and erosion of the sedimentary source areas (mainly the Southern Uplands and North Sea High) causing a sudden discharge of sediment into the delta. They contrast with the rather lower energy, meandering river systems that characterize the Pennine Basin further south. Haszeldine and Anderton (1980) suggest that this may reflect the more proximal, slightly elevated position of the Northern England area relative to the Pennine Basin, an idea which seems to be supported by the evidence from the marine bands (Calver, 1968).

The site is also of considerable palaeontological interest. It is the best surface outcrop for yielding non-marine bivalves of the upper *A. modiolaris* and lower 'Lower *similis-pulchra*' zones, many of which are preserved three-dimensionally in ironstone. In particular, the historically important 'Whitley Bay' site (Low Main Shell Bed) is here, from where much material was collected in the 19th century, including the types of the stratigraphically significant genus *Anthracosia* King.

From the list of form-genera mentioned by Jones (1967), there is also considerable palaeobotanical potential here; if the assemblage from above the Hutton Seam is as diverse as it suggests, it will be the best lower Duckmantian palaeoflora known (at least from surface outcrop) from anywhere in Britain.

The ironstones from above the Hutton Seam also have much potential for palaeozoological work. They have already yielded crustacean remains. As it is the same stratigraphical level as the famous palaeontological deposits at the Phoenix Brickworks, Crawcrook, Ryton, it would not be unreasonable to anticipate further faunal discoveries.

Conclusions

Tynemouth to Seaton Sluice is the most extensive exposure of rocks of Duckmantian age (about 313 million years old) in north-western Europe. It is possible to study here in great detail the depositional environments represented by these rocks. There are also several important fossil localities here, including the famous Whitley Bay non-marine bivalve site.

WEAR RIVER BANK

Highlights

Wear River Bank is one of the most important Upper Carboniferous palaeontological sites in Northern England, yielding insects, non-marine bivalves, xiphosurids, ostracods, fish and plants.

Introduction

This section on the north bank of the River Wear (NZ 362579), 3 km west of Sunderland, Tyne and Wear, which is sometimes known alternatively as Claxheugh, is one of the very few exposures of upper Westphalian strata in the Northumberland and Durham Coalfield. The most recent description of the geology of the site is by Trechmann and Woolacott (1919). In addition, aspects of the palaeontology of the site have been covered by Kirkby (1864, 1867), Stobbs (1905b), Woodward (1918), Bolton (1921-1922) and Armstrong and Price (1954).

Description

Lithostratigraphy

The main part of this exposure shows 5.2 m of Carboniferous strata. Most of the section consists of shaley sandstone, light yellow-brown in the lower part, more grey towards the top. About 2 m above the base, however, is about 1 m of shales and siltstones with ironstone nodules, which is the fossiliferous band.

To the west, this main part of the section is limited by two faults, on the downthrow side of which are about 9 m of shaley sandstone. These are thought to be the same as the upper sandstone in the main part of the face. About 20 m further west again, another fault has brought down yellow sandstone, thought to be Permian.

Biostratigraphy

Non-marine bivalves

Stobbs (1905b) and Trechmann and Woolacott (1919) record abundant shells of *Anthraconauta phillipsi* (Williamson). However, Calver *in* Armstrong and Price (1954) argued that these shells were only homeomorphs of *A. phillipsi*, and in fact belong to *Naiadites* (this view was supported by Trueman and Weir, 1960). Associated with them were *Naiadites* aff. *daviesi* Dix and Trueman and *N.* aff. *elongata* Hind *non* Dawson (syn. *N. hindi* Trueman and Weir). Such an assemblage is typical of the upper part of the 'Upper similis-pulchra' Zone, indicating the lower Bolsovian.

Estheriids

Kirkby (1864) established the species, *Ancyclus vinti*, based on some small shells from here. He was unable to establish their affinities, but Hind (1899) regarded them as non-marine bivalves, and transferred them to *Carbonicola vinti* (Kirkby) Hind. Bolton (1915) subsequently argued that they were the young fry of *Anthraconauta phillipsi*, a view supported by Trechmann and Woolacott (1919). Most recently, however, Calver *in* Armstrong and Price (1954) has interpreted them as estheriid shells of the genus *Euestheria*.

Insects

Insect wings were first recorded from here by Kirkby (1867). The best preserved specimen was identified by Trechmann and Woolacott (1919) as *Eoblattina mantidioides* Goldenberg (they attribute this identification to Kirkby, although he does not use that name in his 1867 paper). Bolton (1922) re-described the fossil and showed that Kirkby's illustration was inaccurate. Nevertheless, he confirmed the identification, although he transferred the species to the blattoid genus *Phylomylacris*.

A second specimen was identified by Trechmann and Woolacott (1919) as *Lithomylacris kirkbyi* Woodward. Bolton (1921) lists this specimen in the introduction of his monograph, but does not describe it in the systematic section.

Plant macrofossils

Kidston *in* Trechmann and Woolacott (1919) listed the following species from here. *Paripteris gigantea* (Sternberg) Gothan (in fact, probably *P. pseudogigantea* (Potonié) Gothan), *Calamites suckowii* Brongniart, *Lepidodendron simile* Kidston, *'Lepidophyllum' triangulare* Kidston and *Sigillaria discophora* (König) Kidston. The assemblage is not biostratigraphically diagnostic.

Other groups

Fish fragments are abundant in the ironstones. Calver *in* Armstrong and Price (1954) list a *Diplodus* tooth, together with several types of scale (*Elonichthys, Rhabdoderma, Rhadinichthys, Rhizodopsis*, indet. palaeoniscid).

Woodward (1918) described a well-preserved limulid from here as *Belinurus trechmanni*. Other arthropods include ostracods (*Geisina*).

Interpretation

This is one of the classic palaeontological sites in the Upper Carboniferous of Northern England. Its full potential has still to be developed, but already a wide variety of animal and plant fossils have been found here. Of particular interest is the presence of insect fossils, which are generally very rare, particularly in surface exposures. Durden (1984) referred the assemblage to his Portbarnettian 'Provincial Insect Age'. The best known assemblages of this 'age' are from the Dunkard Basin of west Pennsylvania, USA (Handlirsch, 1906), while there are also well documented examples from France and Germany (Pruvost, 1919; Guthörl, 1934). In Britain, the only other localities mentioned by Durden as yielding insects of this 'age' are the roof-shales of the Swansea Two Feet and Graigola coals of South Wales, which in fact are stratigraphically much higher than this Durham site (upper Westphalian D – Cleal, 1978).

Also significant is Calver's work (*in* Armstrong and Price, 1954) on the bivalves from here. *Anthraconauta phillipsi* is one of the key species for recognizing the upper Bolsovian in northern Europe, and he demonstrated that certain naiaditids in the lower Bolsovian could develop homeomorphs of this species.

Conclusions

Wear River Bank is one of the most important sites in Britain for fossils of Late Carboniferous age (these are just about 311 million years old). So far, there have been found here the remains of insects, non-marine bivalves, xiphosurids, ostracods, fish and plants.

CRESSWELL AND NEWBIGGIN SHORE

Highlights

Cresswell and Newbiggin Shore is the best exposure of upper Duckmantian strata in Northern England.

Introduction

The coast near Newbiggin-by-the-Sea (NZ 304855–NZ 301872, NZ 315879–NZ 311897, NZ 302916–NZ 292942), Northumberland, provides extensive exposure of the upper part of the Coal Measures in the Northumberland-Durham Coalfield. The only published account of the geology visible here is by Fowler (1936).

Description

Lithostratigraphy

As pointed out by Fowler (1936), the strata are much faulted here, and so far there has been no attempt to assemble the individual fault blocks into a coherent succession. The stratigraphically lowest beds, which are exposed at Snab Point, consist of about 5 m of hard, sandy shales with ironstone nodules, overlain by 2.5 m of sandstone. In the upper part of the shaley interval are two coals, each about 0.3 m thick, and below the lowest of the coals, the shales are lacustrine with shells (see below). This part of the succession is thought to be some 60 m above the High Main Coal.

South of this, towards Lyne Sands, a buff coloured sandstone is faulted against the shales of Snab Point. The sandstone is strongly cross-bedded, and presumably represents a fluvial channel complex. From evidence in nearby boreholes, Fowler (1936) calculates that the sandstone is 91.5 m (300 ft) above the High Main Coal.

The southern part of the site, near Newbiggin, shows a sequence some 30 m thick. Its relation to the sandstone mentioned in the previous paragraph cannot be seen, exposure being hidden by the Lyne Sands, but it is likely that there is a intervening fault. According to Fowler (1936) they lie 146 m (480 ft) above the High Main Coal. These strata can be seen in terms of three incomplete coarsening-upwards cycles. Each is marked by a seat earth and thin coal at the base (the thickest coal recorded here is 55 cm thick), overlain by carbonaceous or lacustrine shales. These then pass up through sandy shales into a thick sandstone, which is then overlain by the seat earth and coal of the next cycle. The sandstones vary from 3.5 to 9.1 m thick. The lowest sandstone is coarse-grained and shows marked cross-bedding with many pebbly bands, while the uppermost one seen (known as the North Seaton or Woodhorn Sandstone) is more of a medium-grained and quartzitic. The succession is probably the result of a series of small-scale deltas or crevasse-splays infilling a subsiding lake.

Biostratigraphy

There is relatively little published biostratigraphical evidence from this site. The Geological Survey map for the area marks the presence of a number of marine bands, including the Aegiranum Marine Band, but there is no published account of the evidence on which this is based. If correct, however, it indicates that the succession is of upper Duckmantian to early Bolsovian age.

Fowler (1936) records '*Carbonicola*' shells from above the lowest coal in the sequence near Newbiggin. No species are mentioned, but it may be assumed that they would belong to the *Anthracosia atra* Subzone.

From the shales below the coals at Snab Point, Fowler (1936) reports another assemblage of bivalves. This time he does provide a list of species, including *Carbonicola* cf. *acuta* (Sowerby), *C.* aff. *oslancis* Wright, *Anthracosia* aff. *aquilina* (Sowerby) and *A.* aff. *concinna* (Wright). Such an assemblage would seem to indicate a position somewhere in the *A. modiolaris* Zone, contradicting the field evidence. However, Trueman and Weir (1946–1968) have revised many of these species, such as *C. acuta* and *A. aquilina*, and have shown that many of the earlier records of them have been in error. The Snab Point assemblage is in clear need of review.

Interpretation

The geological interest of this site has still to be developed. However, it contains considerable potential for investigating the sedimentology of the upper part of the Coal Measures of North England. It lies a short distance above the strata exposed at Tynemouth to Seaton Sluice (discussed above), for which it provides a contrasting view of the Westphalian sedimentology of this area. In particular, there is little evidence of the thick, down-cutting sandstones that characterize the lower strata. Also there is the presence of marine bands. Together, this suggests that these higher beds represent a time when basin subsidence did not significantly outpace sediment infill, and sometimes outstripped it.

Amroth Coast in Pembrokeshire exposes strata of similar age (see Chapter 4). However, until these Northumberland strata have been more thoroughly investigated it is impossible to make any sort of coherent comparison.

Conclusions

Cresswell and Newbiggin Shore is the best exposure of rocks of late Duckmantian age (about 312 million years old) in Northern England.

SALTOM BAY

Highlights

Saltom Bay provides the best exposure of the Whitehaven Sandstone, a distinctive sequence of fluvial deposits in the middle Westphalian of the Cumberland Coalfield.

Introduction

The coastal cliffs (NX 962165) just west of Whitehaven, Cumbria, are in effect the type locality for the Whitehaven Sandstone Formation. The geology is briefly discussed by Eastwood *et al.* (1931).

Description

Approximately 50 m of coarse-grained, cross-bedded sandstones are exposed here. They are mainly grey-purple in colour, sometimes tending to brown. A characteristic feature is the presence of lags of large, red-shale clasts.

Interpretation

This is the best exposure of the Whitehaven Sandstone, a mid-Westphalian arenaceous formation of the Cumberland Coalfield. There have been no studies on the formation since the work of Kendall (1896), Arber (1903) and Eastwood *et al.* (1931), other than the account based on borehole evidence provided by Taylor (1961). There remain significant difficulties in its interpretation, not least in establishing its exact boundaries. For instance, at least some of the strata referred to by Arber (1903) as Whitehaven Sandstone in fact belong to the underlying Productive Coal Formation (Eastwood *et al.*, 1931). Taylor (1961) has argued that there are no clear-cut lithological characteristics that serve to identify the Whitehaven Sandstone, and that it should thus be abandoned as a stratigraphical concept. However, his arguments are not totally convincing and are, rather, an argument for establishing a more coherent lithostratigraphical classification for the Cumberland Coalfield.

Kendall (1896) and Eastwood *et al.* (1931) argued that the sandstone was unconformable on the Productive Coal Formation. However, Kidston *in* Eastwood *et al.* (1931) reported plant fossils from the sandstones which indicated the 'Blackband subdivision of the Staffordian Series' (or what would be called the *Alethopteris serlii* Subzone in the classification of Cleal, 1991); this is not significantly older than the highest strata of the Productive Coal Formation here (*Lobatopteris rarinervis* Subzone of Cleal, 1991 – Thomas and Cleal, 1993).

Trotter (1953) claimed that the 'red' coloration of the Whitehaven Sandstone was primary, but Taylor (1961) argued that it is variable in occurrence, and thus probably of secondary, perhaps Triassic, origin. However, it is difficult to reconcile a secondary origin for the reddening with the presence of *Spirorbis* limestones (e.g. Brockbank, 1891). There would seem to be a clear similarity with the reddened Etruria Formation in the English Midlands, whose coloration was of penecontemporaneous origin, due to a relatively low water-table (Besly and Turner, 1983).

Conclusions

Saltom Bay is the best exposure of the Whitehaven Sandstone, a distinctive sequence of river deposits, about 310 million years old, in the Cumberland Coalfield.

BYRE BURN

Highlights

Byre Burn is the best exposure of the upper beds in the Productive Coal Formation of the Canonbie Coalfield, and contains abundant plant fossils which have considerable biostratigraphical potential.

Introduction

Exposures along the burn and the adjoining River Esk (NY 389778–NY 397783), from Byreburnfoot to the Byreburnside viaduct, 2 km north of Canonbie, Dumfries and Galloway, Scotland, show Duckmantian strata in the Canonbie Coalfield. The site is described briefly by Peach and Horne (1903) and Lumsden *et al.* (1967), and plant fossils are described by Kidston (1903a, 1903b).

Description

Lithostratigraphy

The site offers a faulted strike section through part of what Peach and Horne (1903) refer to as the Byre Burn Group. This corresponds to the upper of the two subdivisions of the Productive Coal Formation in the Canonbie Coalfield (the lower one is Peach and Horne's Rowanburn Coal Group). A detailed log of the exposed section has never been published. However, Peach and Horne provide the log of a nearby borehole which passed through essentially the same succession, which proved to be about 55 m thick.

The succession consists predominantly of grey mudstones, seat earths and coals, with only subsidiary sandstones. Three of the coals were worked here, under the names (in ascending order) Lime, Three-Quarter and Main coals. According to Lumsden *et al.* (1967), the Three-Quarter and Main coals correspond to the Seven Foot and Black Top coals in their standard classification of seams in this coalfield.

The upper part of the succession shows some evidence of red coloration. Whether this is secondary alteration or pene-contemporaneous is not clear, but it suggests that it is not far below the junction with the Barren Red Formation, as exposed at Jockie's Syke.

Biostratigraphy

Lumsden *et al.* (1967) refer to a grey mudstone exposed here, which contains juvenile shells of *Anthracosia* and *Anthraconaia*. They compared it with a similar fauna found elsewhere in the coalfield below the Archerbeck Coal.

Kidston (1903a, 1903b) described numerous plant fossils from three localities along Byre Burn. Unfortunately, only one specimen was figured (a cordaite seed *Cordaicarpus cordai* Geinitz). The list gives a number of species (e.g. *Lyginopteris hoeninghausii* (Brongniart) Potonié, *Paripteris gigantea* (Sternberg) Gothan) that suggest the Langsettian, while others (e.g. *Alethopteris grandinii* (Brongniart) Göppert) indicate the Westphalian D. The assemblages are in clear need of revision.

Interpretation

This is the only good exposure of the upper part of the Productive Coal Formation in the Canonbie

Coalfield. The exact stratigraphical position of these strata cannot yet be fixed by biostratigraphical criteria (see above), but circumstantial evidence suggests they are upper Duckmantian. The fact that there is potential for more refined biostratigraphical work here, using plant macrofossils, as well possibly as non-marine bivalves and even palynology, makes this site of considerable significance.

Conclusions

Byre Burn is the best exposure of rocks of the younger part of the Canonbie Coalfield, about 310 million years old. They contain abundant fossils of plants and freshwater bivalves, which, although in need of revision, are of considerable potential value in establishing the age of the strata.

JOCKIE'S SYKE

Highlights

Jockie's Syke is the best available locality for *Lobatopteris micromiltoni* Zone plant macrofossils in Britain.

Introduction

Exposures in this small stream (NY 424756) (also known as Baxton Gill) that runs into Liddel Water, 8 km north-east of Longtown, Cumbria, show upper Westphalian red beds in the Canonbie Coalfield. The geology has been described by Peach and Horne (1903), Barrett and Richey (1945) and Day (1970). Plant macrofossils from here have been dealt with by Kidston (1903a, 1903b).

Description

Lithostratigraphy

There is no published log for the section and the full thickness has not been determined. The exposed strata are red and purple sandstones alternating with red mudstones and shales. They belong to the 'Red Sandstone Group' of Peach and Horne (1903), and which have been renamed here the Canonbie Red Sandstone Formation.

Biostratigraphy

Non-marine bivalves

Day (1970) recorded *Anthraconauta phillipsi* (Williamson) and *A. tenuis* (Davies and Trueman) from the shales here, and Weir *in* Trueman and Weir (1960, pl. 32, fig. 25) figured an example of the latter. This suggests the *A. tenuis* Zone, which ranges from the topmost Bolsovian to the Cantabrian.

Plant macrofossils

The most complete description of these fossils is by Kidston (1903b). He had specimens from four distinct locations within the site, although no significant difference between the assemblages can be discerned. The only figured specimens are of the lycophyte stem *Lepidodendron fusiforme* (Corda) Unger, which is of little biostratigraphical significance. However, he also records a number of other taxa that are more significant biostratigraphically. There has been no detailed revision of this assemblage in recent years, other than the comments provided by Cleal and Thomas (1995 – *Palaeozoic Palaeobotany of Great Britain* GCR volume). Following the latter comments, the assemblage probably includes *Annularia stellata* (Sternberg) Wood, *Cyathocarpus* aff. *arborescens* (Brongniart) Weiss, *Neuropteris ovata* Hoffmann, *N. flexuosa* Sternberg, *Macroneuropteris scheuchzeri* (Hoffmann) Cleal *et al.*, *Alethopteris ambigua* Lesquereux and *A. grandinioides* Kessler. If this interpretation of Kidston's assemblage is correct, it appears to belong to the *Lobatopteris micromiltoni* Subzone (lower *L. vestita* Zone in the classification of Cleal, 1991). This indicates the middle Westphalian D.

Other groups

In addition to the above, Day (1970) recorded the estheriid species: *Anomalonema defretinae* (Novojilov), and the ostracods *Carbonita salteriana* (Jones) and *C. pungens* (Jones and Kirkby). Calver *in* Day (1970) claims that the first of these is characteristic of the *A. tenuis* bivalve zone.

Also mentioned from here are the shark egg-capsule *Palaeoxyris* sp., and the insect wing *Mylacris similis* Handlirsch.

Interpretation

This is the most important exposure of the red beds that form the upper part of the Coal Measures in the Canonbie Coalfield. There are other exposures of these strata, in particular along the Liddel Water near its junction with Archerbeck. However, Jockie's Syke is the only place where biostratigraphically significant plant fossils occur, and which fix the beds as middle Westphalian D. It demonstrates that the Canonbie Red Sandstone Formation is not merely a lateral equivalent of the Whitehaven Sandstone, which occurs at the top of the Coal Measures in the nearby Cumberland Coalfield (see Saltom Bay), since the latter is Bolsovian. It is also stratigraphically different from the upper Westphalian D red beds of the English Midlands, known as the Keele Formation.

Gibsone (1861), in the earliest account of the coalfield, claimed that these red beds were Permian. Binney (1863), in contrast, thought that they were at least partly Upper Carboniferous, based on the presence of *Spirorbis* in some thin bands of limestone, but such evidence is far from conclusive. Not until the discovery of the plant fossils was their position as Upper Carboniferous finally confirmed (Kidston, 1903a, 1903b).

Plant macrofossils of this age are rare in Britain. Only in South Wales are there reliable records of *L. micromiltoni* Subzone plant macrofossils, from the Swansea Member in the western part of the main coalfield, and these were all collected from underground exposures (Cleal, 1978). Throughout the rest of Britain, strata of this age are missing, at least partly due to the effects of Leonian tectonics.

Conclusions

Jockie's Syke is the best British site for plant fossils of the *Lobatopteris micromiltoni* Zone. Plant fossils of this age (about 310 million years old) have proved to be of considerable value in establishing detailed stratigraphical correlations.