British Upper Carboniferous Stratigraphy

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Chapter 10

Coal Measures of the Pennine Basin

This chapter covers the classic areas of Coal Measures of the Lancashire, Yorkshire and East Midlands coalfields (Figure 10.1). They are the thickest and most fully developed coalfields north of the Wales-Brabant Barrier, with up to 2000 m of Westphalian strata being present. They have also yielded abundant and diverse assemblages of non-marine bivalves (e.g. Eagar, 1946, 1947, 1951, 1952b, 1956), marine band faunas (e.g. Calver, 1968) and plant microfossils (e.g. Smith and Butterworth, 1967). The main drawback from a field geology standpoint is the very poor exposure, due to a combination of thick glacial deposits, and the extensive urbanization of the area. Despite this, the area has played a central role in the study of the Westphalian of Britain, and is generally regarded as the type-area for the Coal Measures Group. Furthermore, the area, particularly around Sheffield and Chesterfield, has been used by the IUGS Subcommission on Carboniferous Stratigraphy as the basis for defining the Langsettian, Duckmantian and Bolsovian stages (see Chapter 2).

Economically, these coalfields are among the most important in Britain, and were the driving-force behind the Industrial Revolution, at least in its middle and later phases. In 1857, they had a combined annual production of 21 million tons, representing virtually one-third of the entire UK production, and over 20% of that of the whole world (Hull, 1861). By the mid-1930s, it had gone up to 82 million tons per year, or 39% of the UK production (Bone and Himus, 1936), and by the 1950s it was over 100 million tons, or nearly half the UK production (Edwards and Trotter, 1954). The most recent figures (for 1990/91 – British Coal Corporation Annual Report) show a reduction in output to 48 million tons, forming 67% of the total UK production. A combination of exhaustion of the reserves and geological difficulties has seen a rapid decline in the Lancashire and South Yorkshire coalfields, but North Yorkshire and the East Midlands are the most important British coalfields.

Clay ironstones were also an important economic reserve in this area. They were worked as far back as Roman times and were a major industry in the medieval period (Edwards and Trotter, 1954). However, improved smelting technology introduced during the 19th century could not use such clay ironstones, and today all of the iron ore used in the area is imported.

Other economically important products of the Pennine Coal Measures are seat earths, particularly in the lower Westphalian where they are refractory and thus of use in the steel industry. Some of the other mudstones are also used for brickmaking.

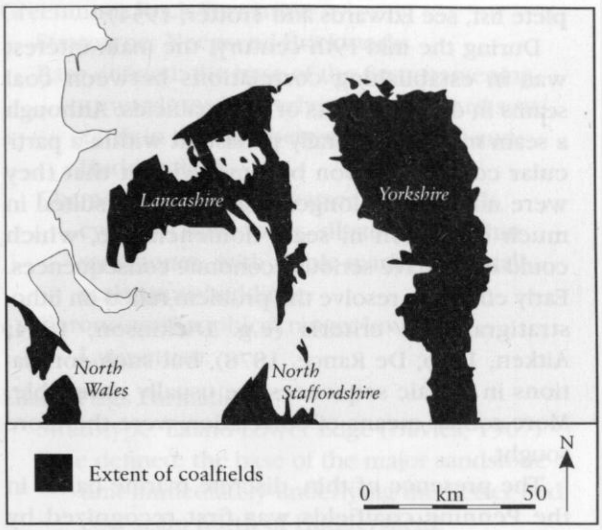

Figure 10.1 Coal Measures outcrop in the Pennine Basin, between the Wales-Brabant Barrier to the south and the Askrigg Block to the north. Based on Guion and Fielding (1988, fig. 13.1).

History of research

The history of geological investigations into the Pennine coalfields started in earnest in the early 19th century, and coincided with the rapid growth in the commercial exploitation of the coalfields. The work was initiated by William Smith, who prepared some of the earliest geological maps of the area (Edwards and Trotter, 1954), but the earliest published descriptions were by his colleagues and pupils, such as Farey (1811), Phillips (1832) and Looney (*in* Hall, 1836).

In contrast to South Wales, where the Geological Survey was active from a very early time through the activities of Henry De la Beche (see Chapter 4), the government's geological agency was relatively slow to take an interest in the Pennine coalfields; mapping did not start until 1850, 15 years after the Survey had been established. Eventually, however, a memoir for the entire Yorkshire Coalfield was produced by Green *et al.* (1878). During the 20th century, the Survey's work expanded considerably in the Pennine coalfields, involving re-mapping and the publication of descriptive memoirs, reflecting the wider significance of this area for Westphalian stratigraphy. A full list of the published memoirs is beyond the scope of this review, but it is worth mentioning some of the most recent which reflect much of the Survey's current thinking on the stratigraphy of these coalfields (Earp *et al.*, 1961; Smith *et al.*, 1967; Frost and Smart, 1979; for a more complete list, see Edwards and Trotter, 1954).

During the mid-19th century, the main interest was in establishing correlations between coal seams in different parts of the coalfields. Although a seam might be laterally persistent within a particular colliery, it soon became evident that they were not so over longer distances. It resulted in much confusion in seam nomenclature, which could often have serious economic consequences. Early efforts to resolve the problem relied on lithostratigraphical criteria (e.g. Dickinson, 1864; Aitken, 1866; De Rance, 1878), but such correlations in deltaic sequences are usually unreliable. More robust means of correlation were therefore sought.

The presence of thin, discrete marine bands in the Pennine coalfields was first recognized by Phillips (1832) and Looney *in* Hall (1836), and their potential for correlation was discussed by Binney (1841, 1860). The Geological Survey subsequently used them in their memoirs, and helped to confirm them as one of the most useful stratigraphical tools, in the lower and middle Westphalian. Further significant records by Culpin (1909, 1910), Edwards and Stubblefield (1948) and Goossens (1952) culminated in the major studies by Calver (1968, 1969a, 1969b), which brought together all of the distributional and faunal data available to establish a stratigraphically coherent palaeoecological and biostratigraphical model for these marine bands. There has also been some interest in the geochemistry of these bands, especially in the Yorkshire and East Midlands coalfields (e.g. Curtis, 1964; Spears, 1964).

Marine bands have been supplemented for stratigraphical work by non-marine bivalves. Although such bivalves are known throughout the Upper Carboniferous paralic belt of northern Europe, their stratigraphical role was pioneered in the Pennines coalfields. Their potential was first recognized by Binney (1860), and the first significant zonation proposed by Hind (1894–1905). As with the marine bands, progress with the non-marine bivalves was helped significantly by the work of the Geological Survey, who used them in their mapping of the coalfields. The most extensive documentation of these bivalves was by Trueman and Weir (1946–1968), who also established the currently accepted biozonal scheme. Most recently, there have been attempts to further refine the biostratigraphy by introducing what are in effect subzones ('faunal belts' – Calver, 1956; Eagar, 1956), and to examine the environmental effects on the morphological variation of these shells (e.g. Eagar, 1947, 1952a, 1956, 1960, 1987).

In contrast, plant macrofossils have been relatively little used for biostratigraphy here. Kidston (1890, 1892, 1893) made extensive but mostly unillustrated records of their distribution in these coalfields, and a number of specimens were figured in his 1923–1925 monograph, especially from the Barnsley Seam of Yorkshire (see also Kidston, 1888a, 1895, 1896). However, they have not been developed as stratigraphical tools in the same way as has happened in the South Wales and Bristol-Somerset coalfields.

In passing, it is worth noting the discovery by Binney (1862a, 1862b, 1866) of nodules in a Langsettian coal seam in Lancashire, which yielded exquisitely preserved plant fossils. These coal balls, as they became known, revolutionized Palaeozoic palaeobotany and resulted in numerous significant studies; however, their geological significance is limited, (see Phillips, 1980 for a review of the subject).

The coals of the Pennine coalfields are mostly of low rank, and thus are suitable for the preparation of fossil pollen and spores. The Yorkshire coalfield in particular saw some of the pioneering work on stratigraphical palynology of the British Coal Measures (e.g. Slater *et al.*, 1930; Slater and Eddy, 1932). However, major progress was not made until the 1950s and later, mainly through the work of Smith and Butterworth, whose work on these strata was incorporated in their 1967 monograph. In addition to their basic biostratigraphical work, Smith (1957, 1962) made major progress in the use of palynology for interpreting the palaeoecology of the coals. Recently, Turner and Spinner (1993) have also investigated the palynology of some of the clastic deposits, in an attempt to refine both the biostratigraphy and the palaeoecology.

Up until about the mid-1960s, most work on the Pennine coalfields was stratigraphical, in its simplest sense, i.e. trying to establish correlations. The sedimentology tended to be largely seen in terms of cyclothems, resulting from marine transgressions. While such a model works broadly for the lower Langsettian, for higher parts of the Westphalian it is less satisfactory, since they were formed in a middle to upper delta-plain setting. The first significant progress was made by Elliott (1968, 1969, 1974), who used facies analysis to interpret them in terms of switching subdeltas and floodbasin lake deposits, similar to those developed in the present-day Mississippi delta. This was then further developed by Scott (1978, 1979, 1984) who incorporated evidence of plant fossil distribution with the sedimentology, to try to establish an overall palaeoecological model for the swamps. The sedimentology of some of the sandstones has been investigated by Guion, including the large Langsettian sand body known as the Crawshaw Sandstone (Guion, 1971), and smaller sandstones that form wash-outs in some of the coal seams (Guion, 1984, 1987a, 1987b). A more complete historical review of sedimentological research on these beds is given by Guion and Fielding (1988).

Lithostratigraphy

The entire sequence covered in this chapter belongs to the Coal Measures Group. The junction between this group and the underlying Millstone Grit is not sharply marked lithologically, with a gradual change from the thick sandstones of the lower Yeadonian, through to the shale-dominated sequences of the middle Langsettian. For convenience, the boundary has been taken here to coincide with the base of the Subcrenatum Marine Band, thus coinciding with the base of the Westphalian Series.

The bulk of the Coal Measures in the Pennine coalfields, at least up to the middle Bolsovian, belongs to the Productive Coal Formation. Particularly in the Langsettian, however, there are a number of prominent fluvial sandstone bodies which merit formational status. Only those sandstone formations which are discussed in this chapter will be summarized below:

Productive Coal Formation (defined in South Wales – *q.v.*)

Crawshaw Sandstone Formation
- Stratotype: Ridgeway Quarry
- Base defined: the base of the major sandstone overlying the Subcrenatum Marine Band in the East Midlands Coalfield.
- Characteristic facies: cross-bedded sandstones.
- Chronostratigraphical range: basal Langsettian.

Wharncliffe Crags Formation
- Stratotype: Wharncliffe Crags
- Base defined: the base of the major sandstone overlying the Amaliae Marine Band in the Sheffield area.
- Characteristic facies: relatively pure, quartzitic sandstone with cross-bedding.
- Chronostratigraphical range: lower Langsettian.

Greenmoor Rock Formation
- Stratotype: Neepsend Brickworks
- Base defined: the base of the first coarsening-upwards cycle overlying the 80 Yard seat earth in the area between Sheffield and Huddersfield.
- Characteristic facies: coarsening-upwards cycles of mudstones, siltstones and thin sandstones, with ripple marks and small-scale cross-bedding.
- Chronostratigraphical range: lower Langsettian.

Elland Flags Formation
- Stratotype: Elland Lower Edge (Davies, 1967)
- Base defined: the base of the major sandstone unit immediately underlying the Better Bed coal seam north of Huddersfield.
- Characteristic facies: massive sandstones, sheet sandstones with cross-bedding, and channel-sandstones with erosive bases.
- Chronostratigraphical range: lower Langsettian.
- Comment: this is a lateral equivalent of the Greenmoor Rock Formation (*q.v.*).

Above the Cambriense Marine Band, red beds dominate many parts of the sequence (Trotter, 1952; Goossens and Smith, 1973). Lithostratigraphical names exist for at least some of these strata, such as the Ardwick Formation in Lancashire. However, there are virtually no exposures now available and so these are not included in this discussion.

Geological setting

The sites dealt with in this chapter represent the classic coal-bearing strata of the Pennine Basin. It is essentially the same geographical area as the Central Province of the Namurian (see Chapter 9). In the Namurian, the area was dissected into a series of separate depositional 'basins', formed as the result of basement faulting during the Dinantian. However, by the Westphalian, the influence of this faulting had declined considerably and the area formed a more or less coherent depositional basin (Figure 10.2).

Strictly speaking, the sequences in the English Midlands (Wyre Forest, South Staffordshire, Warwickshire coalfields) are also in the Pennine Basin. However, being marginal deposits, onlapping against the Wales-Brabant Barrier, they are quite different from the more 'basinal' deposits

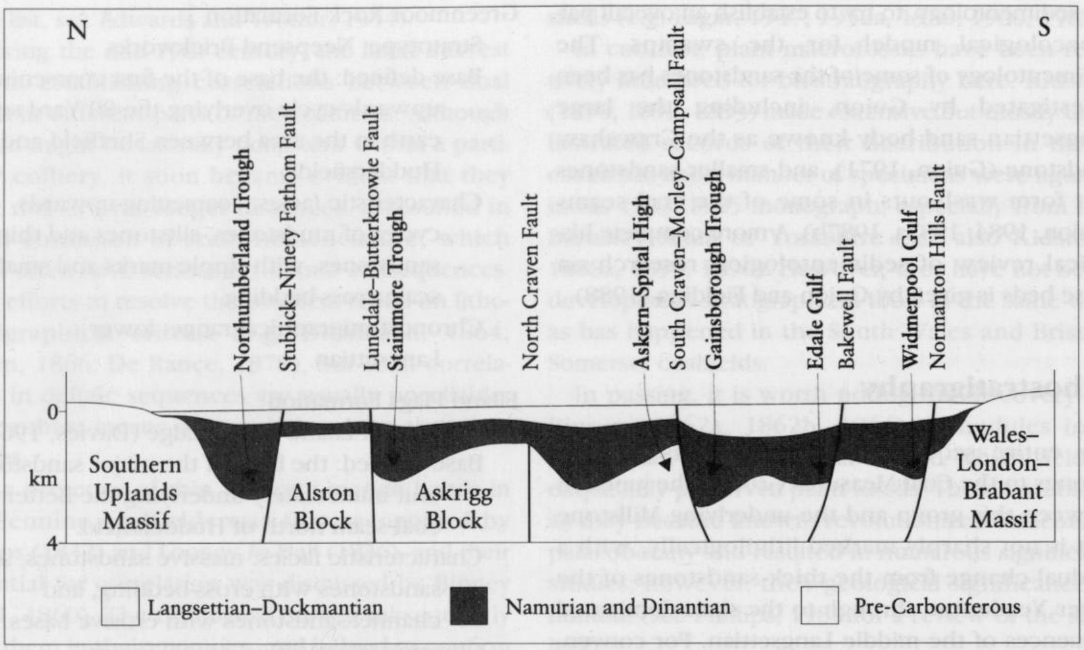

Figure 10.2 Relationship between the Coal Measures, Millstone Grit and Carboniferous Limestone in the Pennine Basin. Based on Guion and Fielding (1988, fig. 13.5).

seen in north Derbyshire, north Nottinghamshire, Yorkshire and Lancashire, and so have been dealt with separately (Chapter 7).

The northern margin of the Pennine Basin has been taken here to coincide with the North Craven Fault (i.e. the southern margins of the Askrigg Block). Some authors do not make this distinction, and refer to the entire area from the Wales-Brabant Barrier to the Southern Uplands as the Pennine Basin (e.g. Guion and Fielding, 1988). However, the deposits of these more northerly areas are rather different, and have been dealt with separately in Chapter 11.

The deposition in the area can be seen in terms of the interaction of two conflicting factors: (1) the flow of fluvial sediment from upland areas to the north (mainly from the Caledonian Highlands, and to a lesser extent the Southern Uplands and North Sea High); and (2) marine incursions periodically spreading in from the south-west and possible south-east. The result was a large, southwards-flowing fluvio-deltaic complex (Figure 10.3). For most of the time, the flow of fluvial sediment predominated, and the deposits seen in the Pennine coalfields represent a middle to upper delta-plain setting. Swamp deposits (including coals) and floodbasin lake fills (crevasse-splay and overbank floods) are the most common (e.g. Fielding, 1984a; Guion, 1987a). In the early Langsettian and late Duckmantian to early Bolsovian, however, marine influence became more important. The strata formed at these times represent lower delta-plain and delta-front deposits (Fielding, 1987), characterized by numerous marine bands (Calver, 1968), and channel-sandstones formed by elongate, river-dominated deltas (e.g. Crawshaw Sandstone – Guion, 1971).

What controlled the relative influence of the marine and non-marine environments is not clear. Eustasy probably had some effect, particularly in the detailed development of the marine bands (Calver, 1968; Ramsbottom, 1979a). However, it is unlikely that this alone could have generated the major progradation and retreat of the delta seen in the Pennine Basin. More likely, this large-scale movement of the delta was controlled by the balance of basin subsidence against the rate of sediment supply into the delta; increase the supply of sediment relative to the subsidence, then the delta expands, reduce it and it withdraws. Both basement subsidence and hinterland uplift were presumably controlled by tectonism, and may thus have been closely linked. Whether one or the other had the predominant effect on the sedimentation pattern is however, unclear.

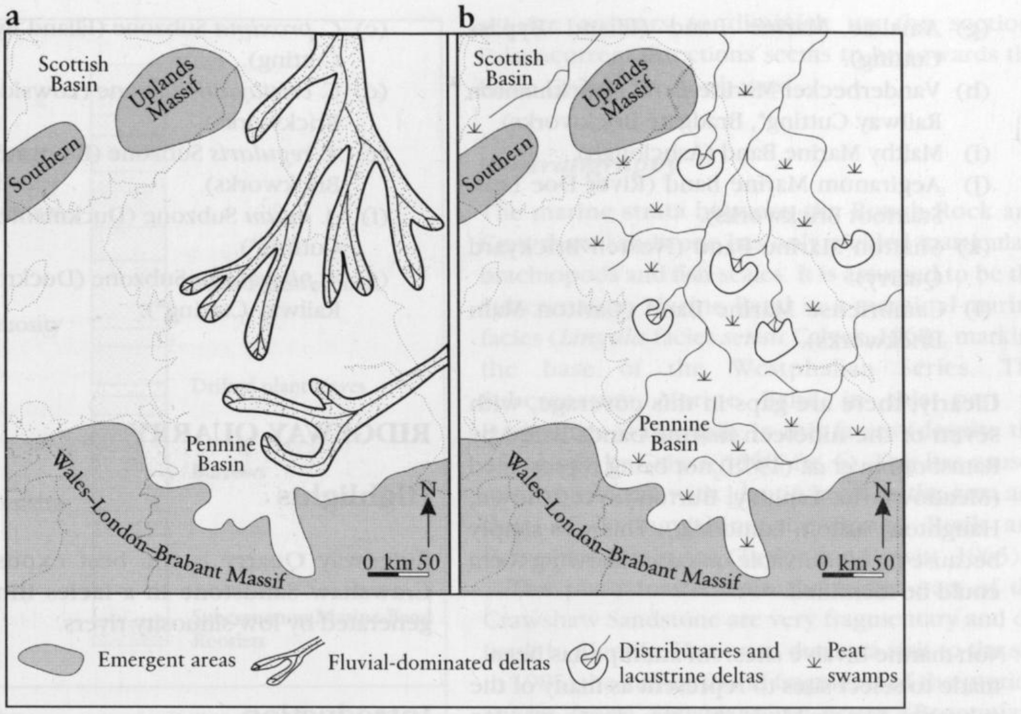

Figure 10.3 Generalized depositional models for the Pennine Basin Coal Measures. (a) Early Langsettian, lower delta-plain setting; (b) Late Langsettian to middle Duckmantian, middle to upper delta-plain setting. Based on Guion and Fielding (1988, fig. 13.8).

GCR site coverage

As mentioned in the opening paragraph of this chapter, exposure of these strata is on the whole poor. It has thus not been possible to build up a comprehensive network of GCR sites for the Westphalian of the Pennine Basin, in the same way as proved possible in South Wales (Chapter 4) and the Millstone Grit of the Central Province (Chapter 9). The coverage can be divided into the following categories:

1. Sedimentological sites. These are mainly controlled by what parts of the succession have been subjected to detailed sedimentological investigation.

   (a) Crawshaw Sandstone Formation and its associated strata (Ridgeway Quarry,Stannington Ruffs, Ambergate Quarry see Guion, 1971).
   (b) Wharncliffe Crags Formation (Wharncliffe Crags).
   (c) Greenmoor Rock Formation (Neepsend Brickworks – see Davies, 1966, 1967).
   (d) The interval between the Lower Mountain Mine and Bullion Mines coals (Ravenhead Brickworks – see Broadhurst, 1988; Broadhurst *et al.*, 1980).
   (e) Peel Hall Rock Formation (River Tonge, Mill Hill).

2. Marine band sites. The following have been selected wholly or in part because of the marine bands that they contain (the sites marked with a * are international boundary stratotypes, and are dealt with separately in Chapter 2).

   (a) Subcrenatum Marine Band (Little Don*).
   (b) Holbrook Marine Band (Honley Station Cutting, Goyt's Moss, Neepsend Railway Cutting).
   (c) Springwood Marine Band (Honley Station Cutting).
   (d) Honley Marine Band (Goyt's Moss, Ravenhead Brickworks).
   (e) Listeri Marine Band (Ravenhead Brickworks, Neepsend Railway Cutting).
   (f) Parkhouse Marine Band (Ravenhead Brickworks).

(g) Amaliae Marine Band (Elland Bypass Cutting).
(h) Vanderbeckei Marine Band (Duckmanton Railway Cutting*, Bradgate Brickworks).
(i) Maltby Marine Band (Ashclough).
(j) Aegiranum Marine Band (River Doe Lea*, Stairfoot Brickworks).
(k) Shafton Marine Band (Nostell Brickyard Quarry).
(l) Cambriense Marine Band (Carlton Main Brickworks).

Clearly, there are gaps in this coverage, with seven of the nineteen marine bands listed by Ramsbottom *et al.* (1978) not being represented (Meadowfarm, Langley, Burton-Joyce, Clown, Haughton, Sutton, Edmondia). This was simply because no conservable outcrops showing them could be identified.

3. Non-marine bivalve sites. An attempt has been made to select sites to represent as many of the subzones as possible in this, the classic area for non-marine bivalve biostratigraphy. However, the restricted outcrop has meant that only seven subzones are represented;

(a) *C. protea / C. fallax* Subzone (Little Don*, Honley Station Cutting, Goyt's Moss, Ravenhead Brickworks, Neepsend Railway Cutting).
(b) *C. extenuata* Subzone (Ravenhead Brickworks).
(c) *C. proxima* Subzone (Elland Bypass Cutting).
(d) *C. cristagalli* Subzone (Lowside Brickworks).
(e) *A. regularis* Subzone (Bradgate Brickworks).
(f) *A. ovum* Subzone (Duckmanton Railway Cutting*).
(g) *A. phrygiana* Subzone (Duckmanton Railway Cutting*).

RIDGEWAY QUARRY

Highlights

Ridgeway Quarry is the best exposure of the Crawshaw Sandstone in a facies thought to be generated by low-sinuosity rivers.

Introduction

A quarry at the end of Crich Lane (SK 358514), 1 km east of Ambergate, 4 km north of Belper, Derbyshire, shows the topmost Millstone Grit and lowermost Coal Measures, as developed in the southern part of the Notts-Derbyshire Coalfield. The geology has been described by Smart and Frost (1968), Guion (1971) and Frost and Smart (1979), and a log is provided by Guion and Fielding (1988).

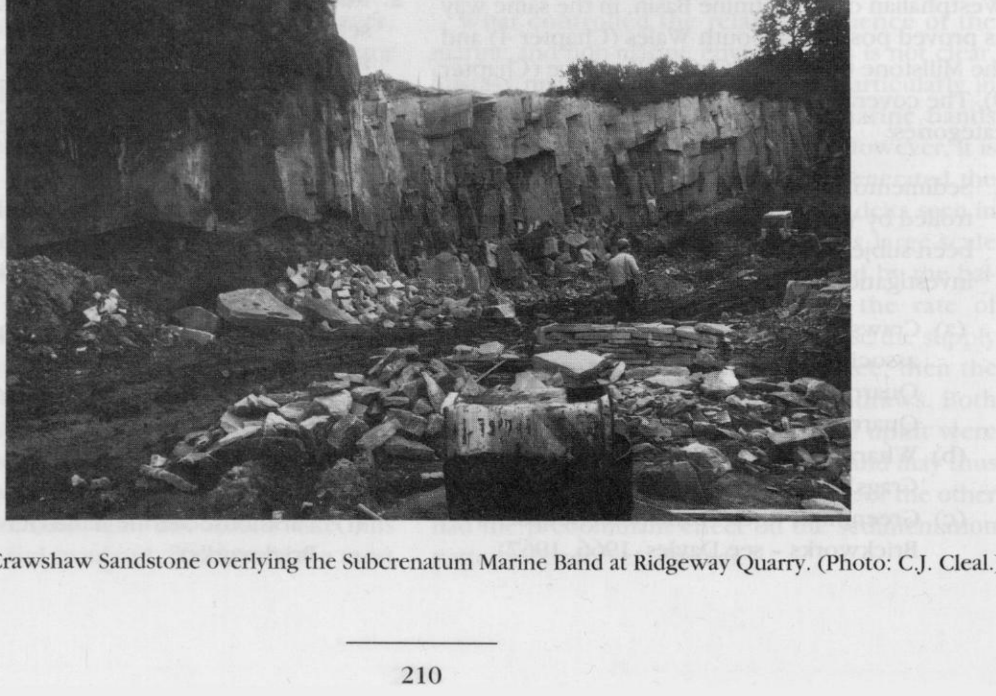

Figure 10.4 Crawshaw Sandstone overlying the Subcrenatum Marine Band at Ridgeway Quarry. (Photo: C.J. Cleal.)

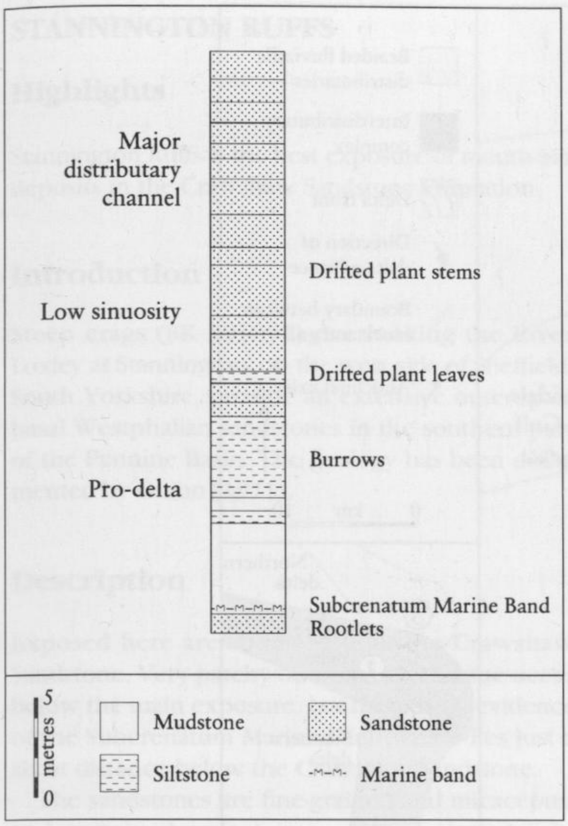

Figure 10.5 Section exposed at Ridgeway Quarry, showing the Crawshaw Sandstone overlying the Subcrenatum Marine Band. Based on Guion and Fielding (1988, fig. 13.9a).

Description

Lithostratigraphy

The exposed sequence here is about 34 m thick (Figures 10.4 and 10.5). At the base is about 1 m of medium to fine-grained sandstone with ripple-lamination, belonging to the Rough Rock Formation. These are overlain by a 10 m thick, coarsening-upwards interval of shales and siltstones. The lower part of this unit consists of dark, marine shales, which in turn are overlain by contorted shales, and then siltstones with burrows.

The rest of the succession belongs to the Crawshaw Sandstone Formation. It consists mainly of coarse-grained, cross-bedded sandstones, with a thin siltstone band containing plant remains about 2 m above the base. Guion (1971) has interpreted the Crawshaw Sandstone here as being the remains of transverse bars in low sinuosity rivers. The cross-bedding is planar to very broadly curved, and the set-size appears to diminish up the section. Palaeocurrent directions seems to be towards the Edale Gulf to the north-west.

Biostratigraphy

The marine strata between the Rough Rock and Crawshaw Sandstone has only yielded inarticulate brachiopods and fish scales. It is assumed to be the Subcrenatum Marine Band in a marginal-marine facies (*Lingula* facies *sensu* Calver, 1968), marking the base of the Westphalian Series. The Subcrenatum Marine Band in this part of Derbyshire is normally in this facies (despite the map given by Calver, 1968, fig. 6). This has caused major problems with identifying it in the area and thus of distinguishing the Rough Rock and Crawshaw Sandstone (Taylor and Howitt, 1965).

The plant fossils from the lower part of the Crawshaw Sandstone are very fragmentary and difficult to identify. However, during a visit to the site in 1985, the author found fragments of the pteridosperm frond *Karinopteris acuta* (Brongniart) Boersma, which is restricted to the upper *Pecopteris aspera* and the *Lyginopteris hoeninghausii* zones (middle Marsdenian to upper Langsettian).

Interpretation

The Crawshaw Sandstone is a major unit of arenaceous strata found over large areas of the south-eastern part of the Central Province. It has been studied in detail by Guion (1971) who interpreted it in terms of three discrete delta complexes, extending into the Edale Gulf (Figure 10.6). Two of the complexes are mainly represented by the deposits of low-sinuosity distributary channels, while the third is represented by delta-front deposits (see discussion below on Stannington Ruffs). Ridgeway Quarry is one of the best sites for showing the sedimentological features of the first of these facies, in particular the distinctive nature of the cross-bedding. It is also one of the few sites where the sandstones can be seen in relation to the Subcrenatum Marine Band, albeit in a facies lacking the index ammonoid. These two factors together make Ridgeway Quarry uniquely important for understanding the sedimentology and stratigraphical position of this formation.

The Crawshaw Sandstone is important as being the last of the major Millstone Grit style of delta complexes to be seen in the Central Province/

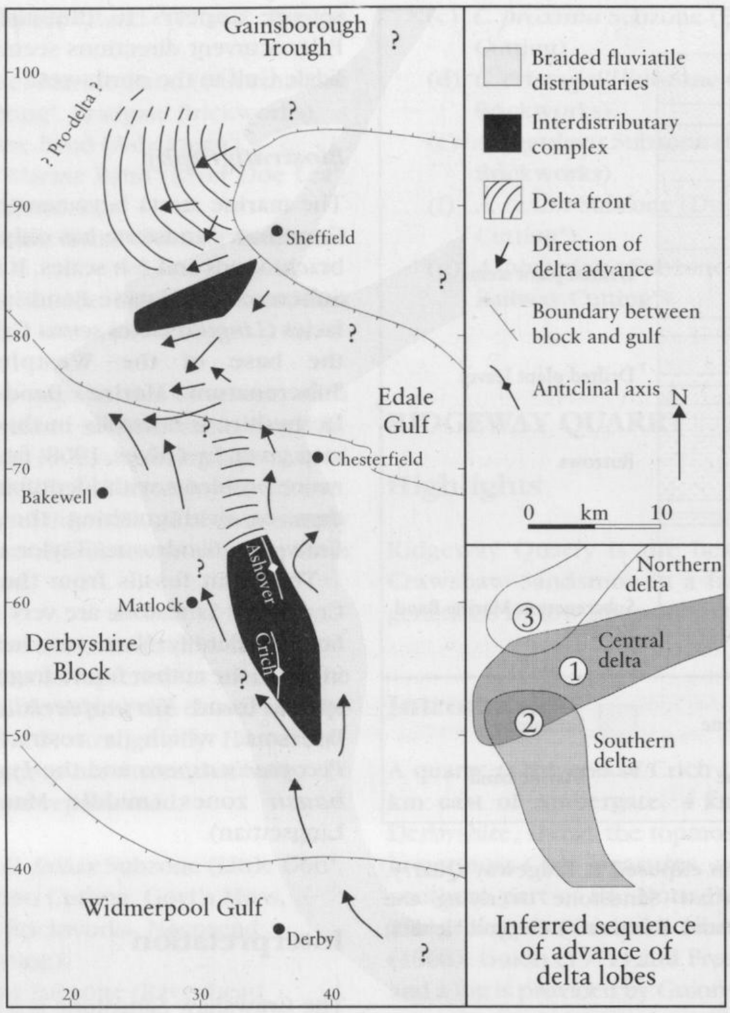

Figure 10.6 Generalized depositional patterns for the Crawshaw Sandstone Formation. Based on Guion (1971).

Pennine Basin. It is also of considerable economic significance, being responsible for some 70% of the oil production in the East Midlands Coalfield.

Similar slumping immediately above the Subcrenatum Marine Band has been identified elsewhere in the southern part of the Central Province, such as at Little Don, and the Goyt Syncline (Francis, 1967). It has also been recognized immediately above the Subcrenatum Marine Band on the South Crop of the South Wales Coalfield (e.g. Tenby-Saundersfoot Coast – see Chapter 4), which in turn has been correlated with the generation of the Farewell Rock on the North Crop of that coalfield. The distribution of this slumping all seems to point to tectonic movement in the earliest Langsettian, probably located somewhere within the Wales-Brabant Barrier. Whether it can be related to the formation of the immediately overlying Crawshaw Rock sandstones is for the moment a matter of speculation.

Conclusions

Ridgeway Quarry is an important exposure of sandstones known as the Crawshaw Rock, about 315 million years old. It lies at the very base of the Coal Measures in the Pennine Basin. The rocks seen here probably represent sands deposited by low-sinuosity rivers.

STANNINGTON RUFFS

Highlights

Stannington Ruffs is the best exposure of mouth-bar deposits in the Crawshaw Sandstone Formation.

Introduction

Steep crags (SK 305891) overlooking the River Loxley at Stannington, on the west side of Sheffield, South Yorkshire, provide an extensive outcrop of basal Westphalian sandstones in the southern part of the Pennine Basin. The geology has been documented by Guion (1971).

Description

Exposed here are about 12 m of the Crawshaw Sandstone. Very patchy outcrops of siltstone occur below the main exposure, but there is no evidence of the Subcrenatum Marine Band which lies just a short distance below the Crawshaw Sandstone.

The sandstones are fine-grained and micaceous, and contain abundant, comminuted plant debris. There is also some evidence of bivalve burrows (*Pelecypodichnus*). Trough cross-bedding is well developed, forming sets about 1 m thick, with gently curved basal erosive surfaces. There is also some ripple cross-lamination, particularly in the upper part of the beds. The sequence is thought to represent mouth-bar deposits of a major distributary system, and palaeocurrents suggest an overall flow from the north-east.

Interpretation

This is the most extensive exposure of the delta-front facies of the Crawshaw Sandstone Formation, a major fluvio-deltaic unit in the basal Langsettian of the southern Pennine Basin (Figure 10.6). Most exposures of the formation (e.g. Ridgeway Quarry) are in quite a different facies, formed by transverse bars in low-sinuosity rivers; the sandstones are much coarser and show mainly planar cross-bedding. Mouth-bar deposits such as seen at Stannington Ruffs are not normally preserved, being removed either by wave-action, or by the subsequent progradation of the delta. However, the Crawshaw delta appears not have migrated further west than this part of South Yorkshire, and wave-action in the basin into which it prograded (the Edale Gulf) was minimal. Together, these factors allowed the preservation of the mouth-bar deposits.

Conclusions

Stannington Ruffs is an important exposure of sandstones known as the Crawshaw Sandstone Formation at the base of the Coal Measures in the Pennine Basin. The particular rocks seen here represent mouth-bar deposits formed in a river delta, some 315 million years ago.

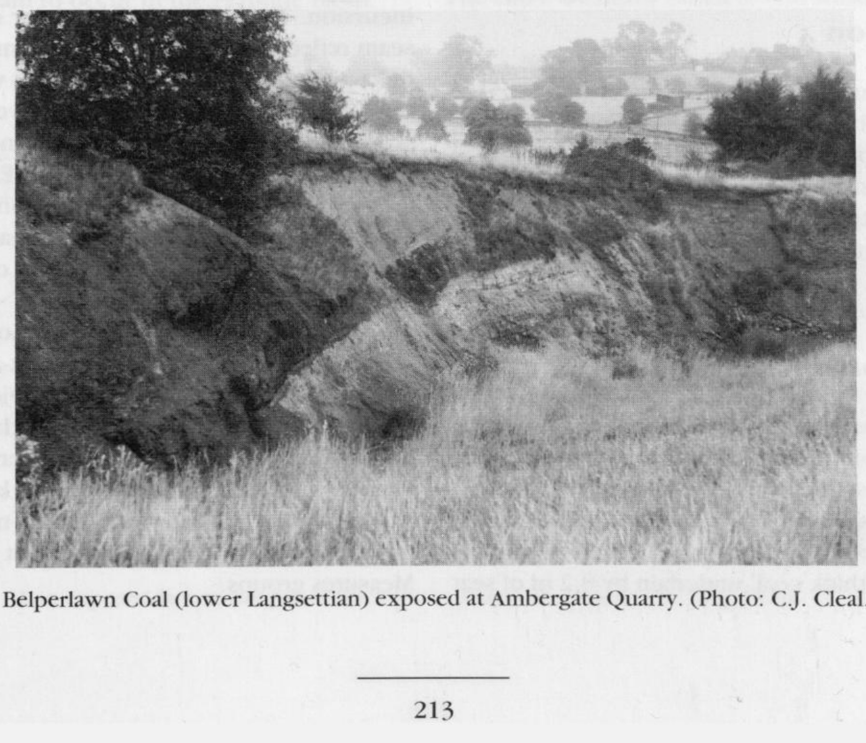

Figure 10.7 Belperlawn Coal (lower Langsettian) exposed at Ambergate Quarry. (Photo: C.J. Cleal.)

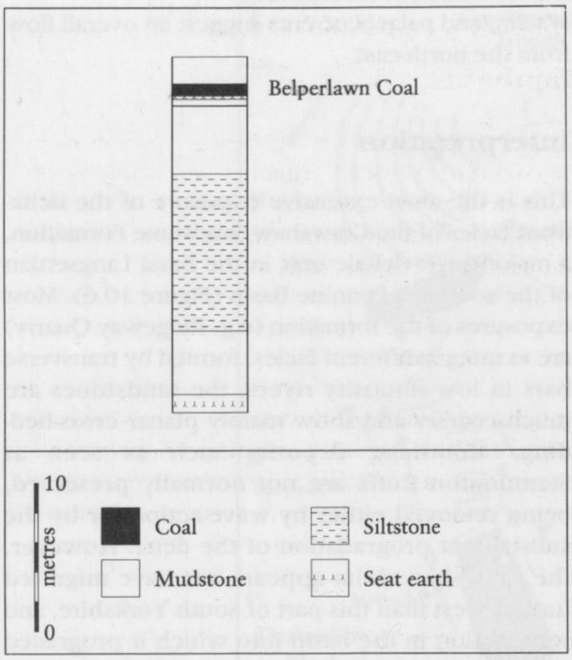

Figure 10.8 Section as originally exposed at Ambergate Quarry, drawn from a log given by Neves (1967, p. 46).

AMBERGATE QUARRY

Highlights

Ambergate Quarry is the best exposure of the Belperlawn Coal (Figure 10.7), which is the stratigraphically lowest widespread coal seam to occur in the Pennine Basin.

Introduction

This disused and partly infilled quarry (SK 359518) between Bullbridge and Ridgeway, 4 km north of Belper, Derbyshire, shows part of the basal Langsettian in the southern part of the Pennine Basin. The site is described by Neves (1967) and mentioned briefly in the memoir by Frost and Smart (1979).

Description

The site has been partly filled by tipping, but there remain approximately 3 m of section still visible (the original sequence as seen by Neves, 1967 is summarized in Figure 10.8). Mostly, it shows unfossiliferous, dark-grey mudstone. However, there is also a 0.85 m thick coal, underlain by 0.2 m of seat earth. This is the Belperlawn Coal, and is nearly at its thickest here; further east it thins and becomes poorer quality. Consequently, the seam has only been exploited commercially to any extent in a narrow belt extending some 10 km south from Bullbridge.

No fossils can be found here, other than possible palynomorphs from the coal. However, elsewhere in the area, Frost and Smart (1979) record fish fragments from the mudstones overlying the coal. This is thought to represent the Holbrook Marine Band.

Interpretation

This is the only site where the Belperlawn Coal can still be seen. It is one of the oldest seams in the Pennines coalfields, and is only marginally predated by the thin Pot Clay Coal of the upper Yeadonian (see discussion on the Little Don in Chapter 2). Coals also occur in this stratigraphical position elsewhere in the Pennine coalfields, where it is known variously as the Soft Bed (Yorkshire Coalfield) and Bassy Seam (Lancashire Coalfield); it is also probably the same as the Goyt Seam at Goyt's Moss. However, the Belperlawn Coal at Ambergate Quarry is by far the best exposure of this seam to be seen anywhere in the Pennine Basin.

It represents a relatively short period of peat development (perhaps no more than 6000 years, if the time-estimates of Broadhurst and France, 1986 are correct), that developed on the Pennine delta before it was flooded by the Holbrook marine incursion. The thin, relatively poor quality of the seam reflects the fact that it was formed in a lower delta-plain setting, where conditions were less conducive to the growth of the swamp vegetation than were present later in the Westphalian. The coal is a little thicker in this part of the East Midlands Coalfield because they developed on sands of the Crawshaw delta-lobe, that presumably provided a more stable basis for the growth of the swamp forest.

The Belperlawn/Bassy/Soft Bed/Goyt coal represents the first development of peat-accumulating swamp vegetation to occur over a wide geographical area in the Pennine Basin. It thus marks an important step in the gradual environmental change that occurred between the late Namurian and early Westphalian, and which is marked by the junction between the Millstone Grit and the Coal Measures groups.

Figure 10.9 Langsettian exposures at Neepsend Brickworks. (Photo: C.J. Cleal.)

Conclusions

Ambergate Quarry is the best exposure of a coal seam known as the Belperlawn Coal. It was formed about 315 million years ago, and is the oldest widespread coal seam to occur in the Pennine Basin.

NEEPSEND BRICKWORKS

Highlights

Neepsend Brickworks is the best site for showing the Greenmoor Rock Formation and is one of the few places where interdistributary bay tidal-flat deposits can be seen in the Langsettian of the Pennine Basin (Figure 10.9).

Introduction

This disused quarry (SK 353890) near Woodside, north Sheffield, South Yorkshire, exposes lower Langsettian deposits in the southern part of the Pennine Basin. The geology is described by Eden *et al.* (1957) and Davies (1965, 1966, 1967).

Description

The exposed sequence here is about 90 m thick (Figure 10.10). The lower 70 m belongs to the Greenmoor Rock Formation, and can be divided into three sedimentary cycles. At the base of each cycle are mudstones, followed by a sequence of alternating mudstones and siltstones. These siltstones show lenticular bedding thought to indicate current and wave action in shallow water. They also show a variety of trace fossils, such as *Arenicolites* burrows and *Limulicubichnus* limulid resting places (Figure 10.11). The siltstones are overlain by thin sandstones, less than 3 m thick. The latter are thinly bedded with small-scale trough

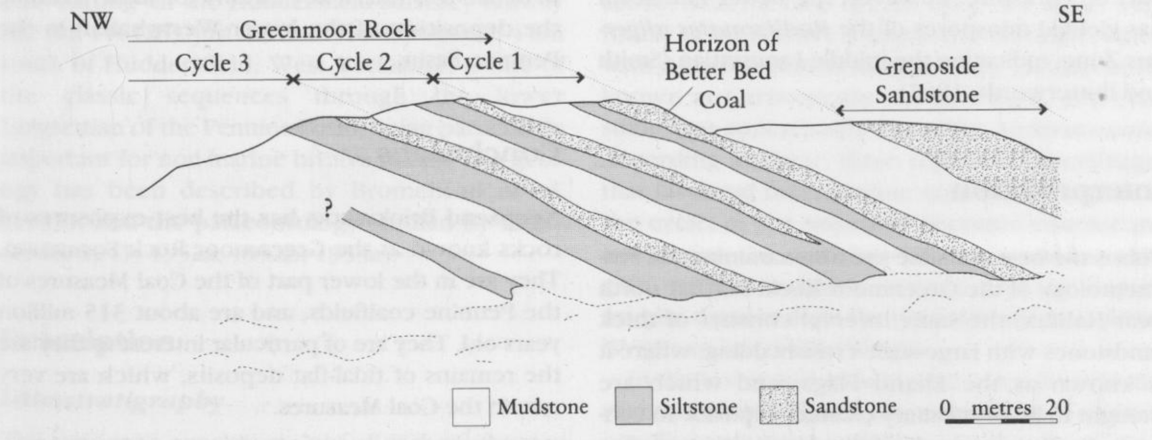

Figure 10.10 Main exposed face at Neepsend Brickworks. Based on Davies (1967, fig. 18.2).

Figure 10.11 Neepsend Brickworks GCR site. Xiphosurid trace fossil. (Photo: C.J. Cleal.)

cross-lamination, often developing into climbing ripples, which is thought to reflect fast deposition in a low-energy regime. The top of each cycle is marked by a seat earth, indicating emergent conditions. This is also supported by the fact that one of the sandstones also shows soft-sediment deformation structures, probably due to de-watering of the sediment.

The uppermost of these three thin sandstones is capped by a thin coal known as the Better Bed Seam, although it is not well seen here. There then follows 10 m of relatively featureless mudstone, capped by coarse sandstones of the Grenoside Sandstone Formation.

No fossils other than the traces mentioned above have been reported from here. Elsewhere in this part of Yorkshire, however, the Better Bed Seam has yielded miospores of the *Radiizonates aligerens* Zone, indicating the middle Langsettian (Smith and Butterworth, 1967).

Interpretation

This is the best available site for examining the sedimentology of the Greenmoor Rock. Further north near Halifax, the same interval consists of thick sandstones with large-scale cross-bedding, where it is known as the Elland Flags, and which are thought to be distributary channel deposits. In contrast, the Greenmoor Rock has been interpreted as tidal-flat deposits in a large interdistributary bay. Each cycle represents a crevasse-splay event, where the bay was flooded to form a lake, and was then progressively infilled by sediment introduced from the main distributary channel. Eventually the margins of the lake would be filled, forming tidal-flats that could be occupied by swamp vegetation. A useful account of sites showing the different facies in the Greenmoor Rock – Elland Flags complex is given by Davies (1967).

This type of lower delta-plain deposit is typical of much of the lower Westphalian of the Pennine Basin. However, most exposures tend to be in the sandstones formed in the distributary channel deposits, which are more resistant to erosion. This is one of the few sites where the sedimentology of the rather softer, tidal flat facies can be examined in detail. It is thus a key locality for understanding the deposition of the lower Westphalian in the Pennine Basin.

Conclusions

Neepsend Brickworks has the best exposures of rocks known as the Greenmoor Rock Formation. They are in the lower part of the Coal Measures of the Pennine coalfields, and are about 315 million years old. They are of particular interest as they are the remains of tidal-flat deposits, which are very rare in the Coal Measures.

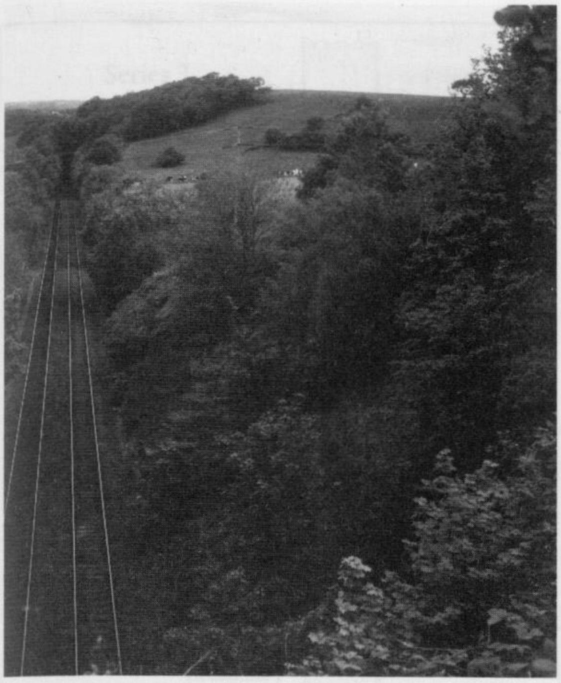

Figure 10.12 Classic exposure of marine bands and non-marine bivalve beds at Honley Railway Cutting, now badly overgrown. (Photo: C.J. Cleal.)

HONLEY STATION CUTTING

Highlights

Honley Station Cutting is a classic section through part of the lower Langsettian of the Pennine Basin, and is particularly important for the non-marine bivalve fossils (Figure 10.12).

Introduction

This cutting on the Huddersfield-Barnsley railway line (SE 146125), just north of Honley station, 4 km south of Huddersfield, West Yorkshire, is one of the classic sequences through the lower Langsettian of the Pennine Basin, being particularly important for non-marine bivalve fossils. The geology has been described by Bromehead *et al.* (1933), and the palaeontology studied by Eagar (1946, 1947, 1952a, 1952b, 1953a).

Description

Lithostratigraphy

The sequence consists mainly of dark mudstones and shales immediately overlying the Soft Bed Coal in the lower Productive Coal Formation (Figure 10.13). About 10 m of strata were documented by Eagar (1947), which he divided into three coarsening-upwards cycles. In an idealized section, there should be a marine band at the base of each cycle. At Honley, 'marine' fossils only occur at the base of the upper cycle, although the shale at the base of the middle cycle is very sulphurous, suggesting deposition under brackish or anoxic conditions.

Biostratigraphy

Marine bands

The sulphurous shales at the base of the middle cycle, although lacking fossils, are thought by Calver (1968) to be the Holbrook Marine Band. The shales at the base of the upper cycle are the Springwood Marine Band (also known as the Second Smalley Marine Band by Calver, 1968). They only yield *Lingula*, which is typical of this band in the southern part of Yorkshire. According to Calver, both marine bands only occur in the middle of the Pennine Basin.

It should be noted that the Honley Marine Band, which is the next highest in the scheme of Ramsbottom *et al.* (1978) does not occur in this, the classic Honley section.

Non-marine bivalves

Eagar (1947) investigated the bivalves from 19 narrowly defined beds within this section. They belong to what has become known as the *Carbonicola fallax–C. protea* Subzone (or 'faunal-belt'), which characterizes the lowermost Langsettian of the Pennine Basin. Eagar was able to correlate changes in the morphology of the shells with the three sedimentary cycles mentioned above. Near the base of each cycle, the shells were found to be relatively small and elongate, often with a curved ventral margin. They include forms known as *Carbonicola limax* Wright, and even some that superficially resemble *Anthraconaia*. According to Eagar, these represent assemblages that favoured more marine conditions. Higher in the cycle, as the sediment becomes coarser and less marine, the shells become larger and less elongate, with a straighter or even reflexed ventral margin; these include the typical forms of *C. fallax* Wright and *C. protea* Wright.

In the lower and middle parts of each cycle, the variation within a particular assemblage is continuous. Towards the top of the cycles, however, there is evidence of a bimodal distribution of the bivalves, with two groups being distinguishable by their relative growth patterns. Eagar (1952b) argued that this represented speciation within the assemblage, triggered by conditions becoming less marine.

The same general pattern can be identified in each of the three cycles, although it is only completely developed here in the middle one. Eagar nevertheless claims that each cycle has its distinctive faunal character, particularly in the upper part. In the lower cycle, these are characterized by *Carbonicola rectilinearis* Trueman and Weir, in the middle cycle by *C. discus* Eagar and *C. haberghamensis* Wright, and in the upper cycle *C. limax* Wright, *C. declinata* Eagar. This may reflect the migration of outside faunas into the area when conditions were at their least marine.

Eagar (1946) also used specimens from here in his study on the hinge structure of Westphalian non-marine bivalves. He found a wide range of structures in a completely gradational series, but which seemed to be totally independent of the gross morphology of the shell. There is some comparison with the structures described by MacLennan (1944) in *Carbonicola pseudorobusta* Trueman shells from higher in the Langsettian. However, they are clearly distinguishable from those of *Anthracosia* (the '*C. aquilina* group') in having a larger hinge-plate, with less prominent teeth in a higher position (see also comments by Trueman and Weir, 1951).

Interpretation

This is one of the best sites for showing the strata immediately overlying the Soft Bed and Bassy Mine coals of the Pennine Basin. The interval is relatively uniform over a wide area of the basin, such as at Goyt's Moss (see Eagar, 1952b, 1953a). However, Honley Railway Cutting is one of the best for showing the three sedimentary cycles, which is vital for a correct palaeoecological interpretation of the interval.

The site is particularly important as being where Eagar made his initial investigations into morphological variation of Westphalian non-marine bivalves, and where he developed his methodology for understanding these difficult fossils (Eagar, 1947). They had long been recognized to be important biostratigraphical tools (e.g. Dix and Trueman, 1937), but their extremely variable morphology made them difficult to use in practice. Two approaches had been tried. The most widely used

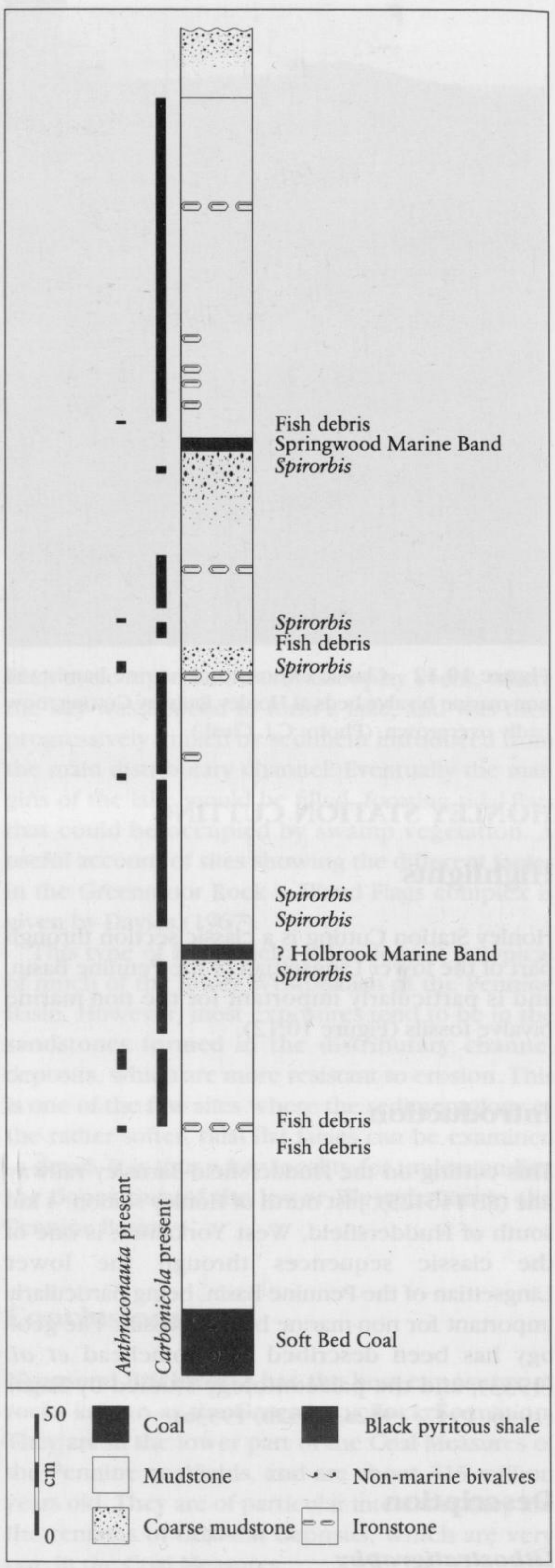

Figure 10.13 Sequence originally exposed at Honley Railway Cutting. Based on Eagar (1947, fig. 7c).

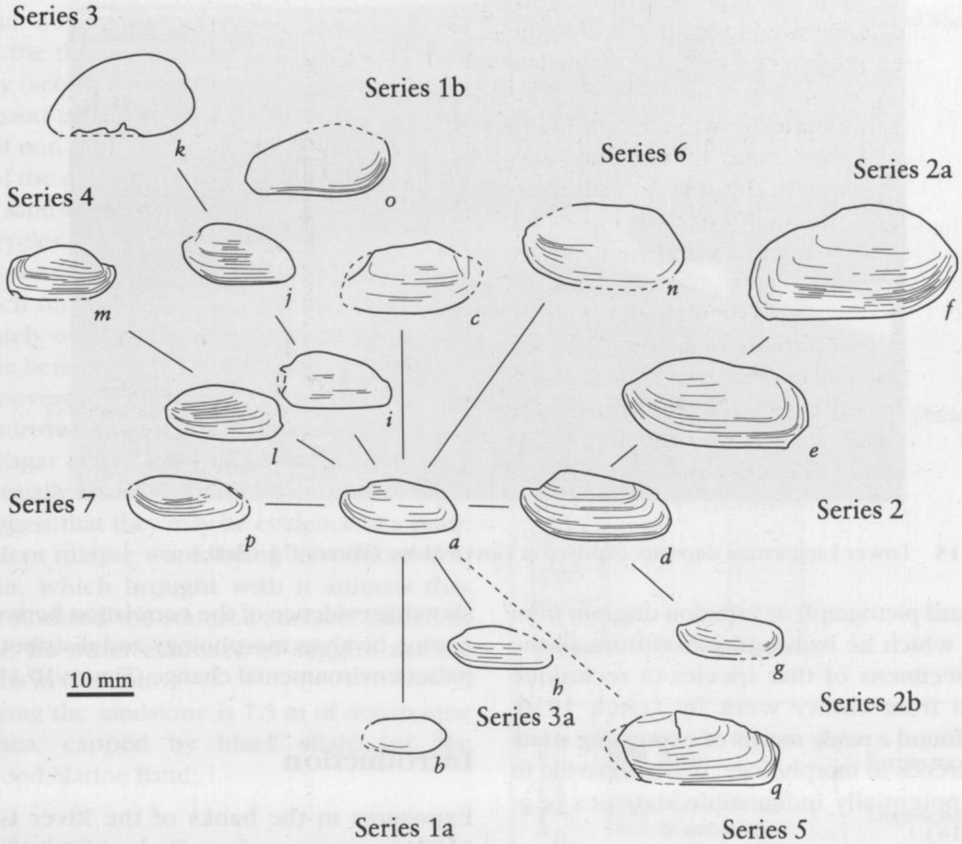

Figure 10.14 Example of the type of pictogram developed by Eagar to express the variation in non-marine bivalve shells. This one represents the assemblage from a 0.6 m thick mudstone immediately overlying the Holbrook Marine Band. Based on Eagar (1947, fig. 8).

was developed mainly by Trueman, who used a set of artificial form-species, each describing a very limited range of morphology (Trueman and Weir, 1946); the range of morphology of an assemblage would thus be expressed by the list of form-species. The drawback with this is that it produces very inflated taxonomic lists, and the names have little biological meaning. A second approach was more statistical, and involved the use of univariate and regression analyses on certain shell parameters such as length, height, etc. One of the best examples of this sort of study was by Leitch (1940). The resulting taxa had far more biological meaning, but unfortunately were not always easy to recognize in small assemblages, which thus limited their biostratigraphical utility. Also, and perhaps more significantly, the statistical techniques then available (essentially restricted to bivariate statistics) were not really adequate for providing an overall view of the variation of the shells. In recent years, the first attempts have been made to use multivariate methods (principle components and cluster analyses – Vasey and Bowes, 1985), but it will need considerably more work before the full potential of these powerful techniques will be achieved.

Eagar adopted aspects of both of the traditional approaches, while adding significant improvements of his own. For instance, he found that by only measuring shells from from a narrowly defined stratigraphical interval, only a few centimetres thick, the range of variation was dramatically reduced. He could then use the statistical approach to establish patterns of relative growth of the shells within each assemblage. He also found it valuable to identify accurately the lithology containing each assemblage, as it allowed at least some of the morphological variation of the shells to be correlated with environmental effects, and separated from the residual, possibly phylogenetic changes. By plotting the morphology of shells from each horizon

Figure 10.15 Lower Langsettian deposits exposed at Goyt's Moss. (Photo: C.J. Cleal.)

on a standard pictograph or variation diagram from a species, which he had synthesized from all the known specimens of that species (a technique developed from earlier work by Leitch 1936, 1940), he found a ready means of expressing stratigraphical trends in morphology, without having to resort to potentially indigestible statistics (e.g. Figure 10.14).

Eagar has used this methodology in other parts of the Westphalian with considerable success (e.g. Eagar, 1960, 1987). However, it was here in the lower Langsettian of Honley that the early breakthrough was made. It may thus be taken as the birth-place of Carboniferous non-marine bivalve palaeontology in its modern sense.

Conclusions

Honley Station Cutting is a classic exposure of fossiliferous Lower Coal Measures rocks, about 315 million years old. It was where some of the pioneering work was carried out on the influence of ecology on the morphology of freshwater bivalve shells, which has proved of great importance for using these fossils for establishing stratigraphical correlations of Coal Measures rocks.

GOYT'S MOSS

Highlights

Goyt's Moss is an important exposure of lower Langsettian in the Pennine Basin, in particular for showing evidence of the correlation between non-marine bivalves morphology and distribution, and palaeoenvironmental change (Figure 10.15).

Introduction

Exposures in the banks of the River Goyt (SK 018715), upstream from Derbyshire Bridge, 4 km WSW of Buxton, Derbyshire, show mainly shales of the lower Langsettian of the southern Pennine Basin. They are on the axis of the Goyt Syncline, one of a series of N-S trending structures that lie between Derbyshire Dome and the Cheshire Plain (Francis, 1967). The site was first described by Cope (1948). The field geology is described in detail by Eagar (*in* Broadhurst *et al.*, 1970) and Eagar and Broadhurst (1991), and the palaeontology has been dealt with by Eagar (1956), Hardy (1970b) and Eagar *et al.* (1985).

Description

Lithostratigraphy

A sequence about 18 m thick can be seen here (Figure 10.16). The lowest visible bed is a 1.5 m thick coal known as the Goyt's Coal, overlying about 1 m of seat earth. Although of poor quality, the coal has been worked in the past for lime burning, and there is a disused pit just to the west of the site. It is generally assumed to be the same as the Soft Bed/Bassy Mine coal seam that occurs extensively through the Pennine Basin.

There then follows about 4 m of non-marine mudstones, capped by a thin sulphurous marine mudstone. According to Eagar (1956), this is the lower of the three sedimentary cycles recognized at Honley (see above). In the north of the site, the marine band is conformably overlain by a further 12.5 m of non-marine mudstones, representing the middle of the cycles at Honley. This is in turn overlain by a sandstone, which cuts out the third of the Honley cycles.

In the southern part of the site, this sandstone cuts much further down into the sequence, and immediately overlies the lower marine band. The sandstone here is 0.2–0.3 m thick, and its erosional base is covered with horizontal or oblique 'U'-shaped burrows known as *Rhizocorallium* (Hardy, 1970b; Eagar *et al.*, 1985). Such trace fossils are more normally associated with marine strata. Eagar *et al.* suggest that they may be evidence of a pulse of turbulent marine water being introduced into the basin, which brought with it animals that briefly colonized the scoured surface. There is, however, no other evidence to suggest marine conditions in this unit.

Overlying the sandstone is 7.5 m of non-marine mudstones, capped by black shales of the Springwood Marine Band.

Biostratigraphy

Marine bands

Only two beds in this sequence contain unequivocal evidence of marine or brackish conditions. The shale 4 m above the Goyt's Seam has only yielded *Lingula*, *Orbiculoidea* and rare *Gastrioceras*. It is assumed to be the Holbrook Marine Band, and is the only known locality where this band yields ammonoids. The shale near the top of the section has *Lingula*, *Posidonia* and *Caneyella*, as well as indeterminable ammonoids, and is probably the Springwood Marine Band.

Non-marine bivalves

The interval of shales ranging for 4 m above the Goyt's Seam has yielded numerous shells. They are mostly *Carbonicola fallax* Wright, *C. rectilinearis* Trueman and Weir, *C. pilleolum* Eagar and *Curvirimula* sp. (Eagar *in* Broadhurst *et al.*, 1970), and are very similar to the assemblage reported from the lower cycle at Honley. However, there is also a 25 cm silty mudstone band containing *C.* aff. *protea* Wright and *C.* aff. *discus* Eagar, which is unknown elsewhere at this particular stratigraphical level.

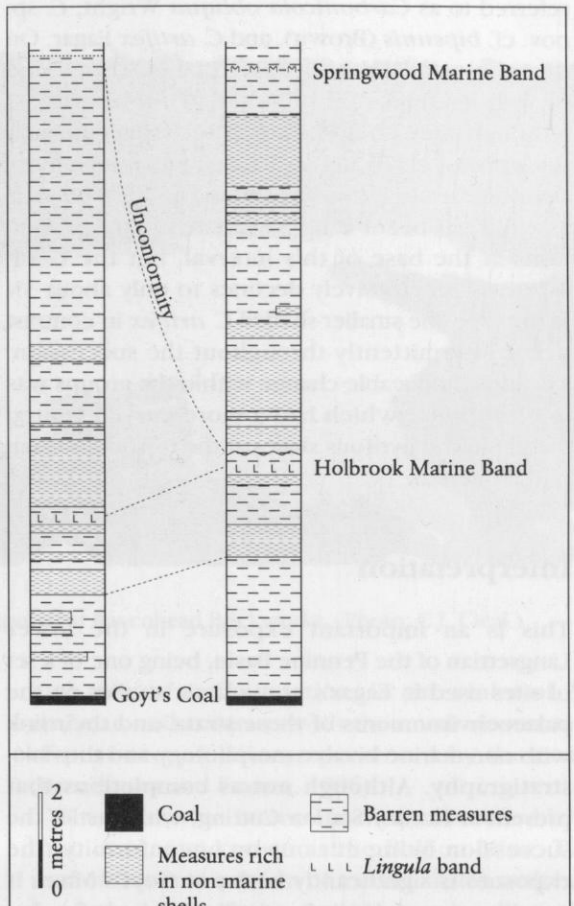

Figure 10.16 Sections through strata immediately overlying the Goyt's Coal at Goyt's Moss. Based on Eagar and Broadhurst (1991, fig. 7).

Immediately above the marine band, anthracosiaioid shells predominate, but then give way to *Carbonicola artifex* Eagar and *C.* aff. *declinata* Eagar (Eagar *in* Broadhurst *et al.*, 1970). This thus follows the general sequence seen in the lower part of the middle cycle at Honley. About 3.5 m above the marine band, very slightly coarser-grained strata have yielded *Anthraconauta* sp. and is thought to be the *C. discus* Band recognized elsewhere in the middle cycle; *C. discus* Eagar itself does not occur here, however.

The strata between the unconformable sandstone and the Honley Marine Band has also yielded diverse bivalve assemblages, and the 2.5 m of shale immediately above the sandstone has been studied in particular detail by Eagar (1956). He was able to recognize three major groups, which probably represent distinct biological species, and which he referred to as *Carbonicola obliqua* Wright, *C.* sp. nov. cf. *bipennis* (Brown), and *C. artifex* Eagar. On the whole, individual bedding planes were found to only contain one or other of these groups, although they could be so closely spaced that a thickness of only 1 cm of shale might contain more than one group. *C. obliqua* and *C.* cf. *bipennis* assemblages occur in approximately equal proportions at the base of this interval, but the *C.* cf. *bipennis* progressively declines to only about 3% at the top. The smaller-shelled *C. artifex* in contrast occur intermittently throughout the succession. The most noticeable change within the groups was in *C. obliqua*, which had a more curved ventral margin in the pyritous shales at the top and bottom of the interval.

Interpretation

This is an important exposure in the lower Langsettian of the Pennine Basin, being one of a set of sites used in Eagar's now classic studies on the palaeoenvironments of these strata, and their link with non-marine bivalve morphology and thus biostratigraphy. Although not as complete as that present at Honley Station Cutting, with part of the succession being cut out by unconformity, the exposure is significantly better at Goyt's Moss. It provides a useful adjunct to that site, confirming the widespread distribution of the lower and middle sedimentary and faunal cycles seen there. It also shows the cycle immediately underlying the Honley Marine Band, which is not visible at Honley Station Cutting. Although involving different species of bivalve, Eagar (1956) has been able to demonstrate similar trends in morphology in this higher cycle to those seen in the two cycles immediately overlying the Soft Bed-Bassy Mine. In particular, there seems to be a correlation between marine influence and the curvature of the ventral margin of the shells.

At many of the other sites showing the sequence immediately overlying the Soft Bed and Bassy Mine, it has been possible to correlate the changes in shell morphology with the grain size of the sediment. In the upper cycle at Goyt's Moss, however, the morphological changes observed in the upper cycle did not seem to be linked with any significant lithological change. It thus points to the potential of the non-marine bivalves for revealing environmental changes within the Productive Coal Formation which might not be recognizable using other means.

Conclusions

Goyt's Moss is an important exposure of Lower Coal Measures rocks in the Pennine Basin. They were deposited during what geologists call the Langsettian Age, about 310 million years ago, in the lower part of a river delta. The sequence consists of alternating marine and non-marine deposits, reflecting periodic floodings of this part of the delta, due to variations in sea-level. Evidence from here has proved to be of considerable importance for understanding the influence of these environmental changes on the freshwater bivalves that were living in the delta, and whose fossilized remains have proved to be of considerable importance to geologists for helping establish stratigraphical correlations.

RAVENHEAD BRICKWORKS

Highlights

Ravenhead Brickworks shows the best exposed sequence between the Honley and Parkhouse marine bands in the Pennine Basin, yielding both marine and non-marine faunas. It is also the best site for demonstrating the sedimentology of the lower delta-plain deposits of the lower Langsettian of this basin.

Introduction

This quarry (SD 515040) on the south-west side of Up Holland, 3 km ESE of Skelmersdale, Lancashire, used to be worked for shales and mudstones in the lower Langsettian of the Lancashire Coalfield (Figure 10.17). Although the site was abandoned some years ago and has been partly infilled, a considerable part of the original sequence can still be seen. The stratigraphy of the site has been described by Eagar (1951) and aspects of the sedimentology by Broadhurst *et al.* (1980) and Broadhurst (1988). A detailed account of the field geology is given by Eagar *in* Broadhurst *et al.* (1970).

Description

Lithostratigraphy

The complete sequence exposed here is 90 m thick. The lowest 7 m are a coarsening-upwards sequence of mudstones and shales, and correspond

Figure 10.17 Lower Langsettian lacustrine deposits exposed at Ravenhead Brickworks. (Photo: C.J. Cleal.)

to the third of the cycles overlying the Soft Bed at Honley. These are overlain conformably by a sandstone, which is 4.5 m thick in the northern part of the site, but thins southwards to less than 1 m.

The sandstone was reported to be immediately overlain in the northern part of the quarry by a thin seat earth, thought to mark the position of the Lower Foot Mine coal. However, this is no longer visible, and the sandstone is now seen to be succeeded by a 4 m coarsening-upwards cycle of mudstones and shales, which are brackish at the base and non-marine towards the top. A second cycle, this time 16 m thick, then follows, with marine shales at the base passing up into non-marine mudstones, and then 3 m of ganister. The cycle is completed by a complex of seat earths and coals, the latter including the Rambler Mine and Lower Mountain Mine.

Above the Lower Mountain Mine, there follows 21 m of alternating laminated sandstones and mudstones (Figure 10.18). The sedimentology of this part of the succession was examined in detail by Broadhurst *et al.* (1980), who argued that it represents floodbasin lake deposits, with the sandstones being crevasse splays. Within the sandstones, bivalve moulds and burrows were identified. From the distribution of these bivalve traces, it was concluded that each sandstone-mudstone couplet was one year's sedimentation, and thus that the sediment supply was controlled by a seasonal (monsoonal) cyclicity (see also Broadhurst, 1988). If this model is correct, it suggests an extremely high rate of sedimentation, in the realm of 30 cm/year, and contrasts with the much slower rate of peat accumulation represented by the coals (Broadhurst and France, 1986).

This lacustrine interval is then succeeded by a thin, dirty coal known as the Bullion Mine. The roof of this coal is 0.6 m of marine shales with bullions, the Listeri Marine Band known locally as the Bullion Mine Marine Band, which marks the base of another coarsening-upwards cycle. The cycle, which is some 27 m thick, consists of dark shales immediately overlying the marine band, passing up into flaggy shales, and then a flaggy sandstone known as the Inch Mine Rock. This is capped by 1.2 m of ganister, which has yielded some excellently preserved lycophyte rooting structures, and a streak of coal which is thought to be the Inch Mine Coal elsewhere in the coalfield.

The top part of the succession consists of 1.5 m of dark marine shales, passing up into 6 m of grey non-marine siltstones, with two well marked carbonate bands.

Biostratigraphy

Marine bands

Four marine or brackish bands have been identified in this sequence. The lowest immediately overlies the Lower Foot Mine coal. It has only yielded inarticulate brachiopods and cannot be correlated with any of the standard marine bands mentioned by Ramsbottom *et al.* (1978).

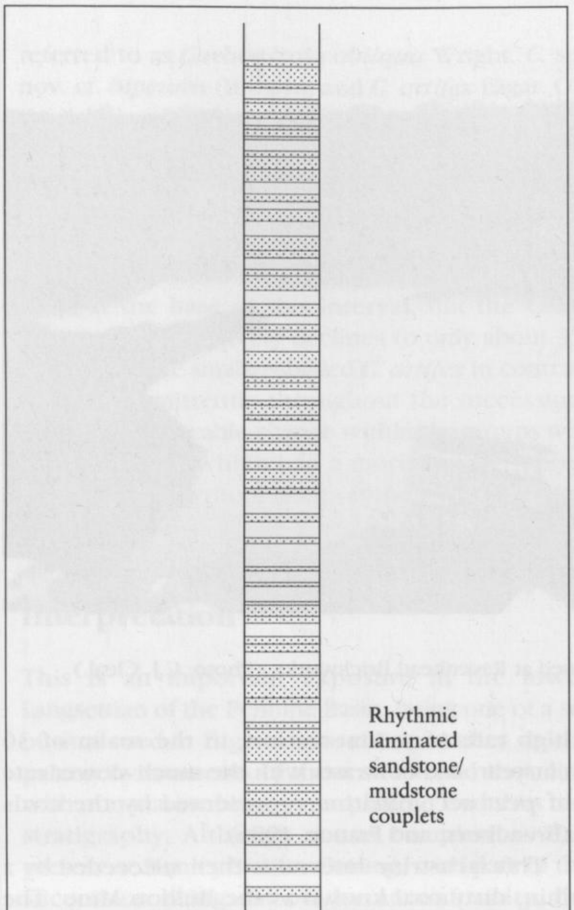

Figure 10.18 Part of the sequence above the Lower Mountain Mine visible at Ravenhead Brickworks, showing sandstone-mudstone couplets thought to represent seasonal deposits in a lacustrine environment. Based on Broadhurst (1988, fig. 19.3).

The marine shales 4 m above the Lower Foot Mine, and locally known as the Lower Foot Mine Marine Band, have yielded a more diverse assemblage belonging to the *Gastrioceras*/Pectinoid Facies of Calver (1968). There is no published species list for this site in particular, but Eagar *in* Broadhurst *et al.* (1970) mentions from the nearby Pimbo Lane Quarry *Gastrioceras* aff. *subcrenatum* (Frech), *Anthracoceras* sp., *Lingula* sp. and bivalves. The bed is thought to be the Honley Marine Band in the standard classification by Ramsbottom *et al.* (1978).

The carbonate concretions in the Bullion Mine Marine Band have yielded well preserved, three-dimensional ammonoids, including *Gastrioceras listeri* (Sowerby) and *G. circumnodosum* Foord (syns. *G. retrorsum* Chalmers and *G. normalis* Chalmers – see Ramsbottom and Calver, 1962) as well as the bivalves *Dunbarella papyracea*, *Posidonia insignis* and *Caneyella multirugata*. This is the widely distributed Listeri Marine Band, which is one of the most important stratigraphical marker-horizons in the Langsettian of the Pennine Basin.

The marine shales at the base of the topmost cycle preserved in this sequence has yielded no more than fish-scales and indeterminable organic debris. However, its position immediately overlying the Inch Mine indicates that it is what is locally known as the Inch Marine Band, and which is the Parkhouse Marine Band in the Ramsbottom *et al.* classification.

Non-marine bivalves

Well preserved bivalves occur at two principal levels. In the lower 7 m of the succession, a sequence of assemblages has been mentioned by Eagar *in* Broadhurst *et al.* (1970). In the lower part, there are elongate anthraconaioid shells, together with *Carbonicola declinata* Eagar and *C. limax* Wright. This is then replaced by assemblages containing *C.* aff. *fallax* Wright, *C.* aff. *pilleolum* Eagar and *C.* aff. *protea* Wright. There is a clear comparison here with the bivalves found in the third (i.e. uppermost) of the cycles recorded from Honley Station Cutting.

Eagar *in* Broadhurst *et al.* (1970) also mentions well preserved shells from immediately below the Honley Marine Band. A list of species is not mentioned from here, but from the nearby Pimbo Lane Quarry, Eagar records *Carbonicola obliqua* Wright, *C. limax* Wright, *C. artifex* Eagar, *C.* aff. *declinata* Eagar and *Curvirimula* sp. This is the characteristic assemblage of bivalves that has been found widely in the Pennine Basin from just below the Honley Marine Band (Eagar, 1956).

Traces of bivalves occur extensively in the alternating sequence of sandstones and mudstones between the Lower Mountain Mine and Bullion Mine coals (Broadhurst *et al.*, 1980). Shells are very rare, but Eagar *in* Broadhurst *et al.* (1970) reports *Carbonicola* aff. *extenuata* Eagar and *Anthraconaia* sp. from a siltstone immediately above the Lower Mountain Mine. This is an extremely low occurrence of the *extenuata*-type of *Carbonicola*, which rarely ranges below the Listeri Marine Band (Ramsbottom *et al.*, 1978).

Interpretation

This is the best exposure in the Pennine Basin of that part of the lower Langsettian between the Honley and Parkhouse marine bands. It includes a particularly good outcrop of the Listeri Marine Band, which is one of the most widely distributed of the Langsettian Marine Bands, second only to the Subcrenatum Marine Band. There are also diverse assemblages of non-marine bivalves of the *C. fallax-C. protea* Subzone, and what might be the lowest known occurrence of the *C. extenuata* Subzone.

This is also the best known site for showing the characteristic sedimentology of the lower Productive Coal Formation of the Pennine Basin. Much of the succession consists of a series of coarsening-upwards cycles, with marine or brackish strata at the base and often capped by a coal and/or seat-earth. They represent classic examples of the cyclothem, which for many decades was the main sedimentological model used to explain Westphalian deposition patterns in Europe. Although the cyclothem model has not proved satisfactory for explaining the middle and upper delta-plain deposits found higher in the Westphalian, it still generally holds good for the lower delta-plain deposits of the lower Langsettian.

Also present here are strata that were deposited by smaller-scale cycles in a lacustrine setting, producing varve-like couplets of sandstone and mudstone. Broadhurst *et al.* (1980) have argued that these beds demonstrate that a monsoonal cyclicity was controlling the flow of sediment into the delta, although the deltas themselves were probably subject to a more uniform climate. They also showed that the deposition of the clastics in this part of the sequence was extremely rapid (*c.* 30 cm/year). From this it would seem that, despite their relative thicknesses, the vast majority of time is represented by the coals rather than the clastic deposits. These observations made at Ravenhead Brickworks are clearly of vital importance for understanding the environment and deposition of the Productive Coal Formation, not only of the Pennine Basin, but throughout the belt of paralic basins of northern Europe.

Conclusions

Ravenhead Brickworks is the best exposure of rocks between the Honley and Parkhouse marine bands in the Lower Coal Measures of the Pennine Basin. The sequence includes both marine and non-marine strata, and is important for showing the patterns of deposition in a lower delta-plain setting during the early Langsettian, about 315 million years ago.

NEEPSEND RAILWAY CUTTING

Highlights

Neepsend Railway Cutting provides the most complete succession of lower Langsettian strata in the Pennine Basin, and demonstrates its lower delta-plain character.

Introduction

This cutting (SK 344896) along old Sheffield to Stocksbridge railway, between Parkwood Springs and Shirecliffe, 2 km north of the centre of Sheffield, shows the lower Langsettian sequence immediately above the Crawshaw Sandstone in the South Yorkshire area. The only detailed account of the geology is by Eden *et al.* (1957), although the site is also mentioned briefly by Love (1967).

Description

Lithostratigraphy

Over 100 m of lower Langsettian can be seen here (Fig. 10.19). The lowermost strata are sandstones from the upper part of the Crawshaw Formation. These are overlain by about 1 m of siltstone, followed by a seat earth and thin coal. This seam is locally known as the Coking Coal, although it is almost certainly the same as the Soft Bed Coal recognized elsewhere in Yorkshire.

The next highest coal seam in this area is that known locally as the Clay Coal (elsewhere known as the Middle Bed Coal). It cannot be seen in the cutting (Eden *et al.*, 1957 claim that it has been identified in other exposures in the immediate vicinity), but it is assumed that a ganister 9 m above the Coking Coal is its seat earth. Over much of the Pennine Basin, the sequence between the Coking and Clay coals (i.e. the Soft Bed and Middle Bed) can be divided into three coarsening-upwards cycles with a marine band at the base of each (cf. Honley Railway Cutting, Goyt's Moss). A similar cyclicity can also be recognized at Neepsend, although it is not as completely developed. The base of the lowest cycle is considered to be brackish, while the mudstones at the base of each of the upper two cycles are in fact fresh water, with non-marine bivalves (see below).

Above the level of the Clay Coal is another coarsening-upwards cycle, some 10 m thick. The top part of the cycle is marked by a thick ganister, which has been worked commercially in quarries very close to the cutting. It forms the seat earth of a 0.45 m thick coal (the Ganister Coal) which is a lateral equivalent of the Halifax Hard Bed of the Yorkshire Coalfield and the Union Seam of the Lancashire Coalfield. As well as being a useful stratigraphical marker, this seam is of interest in that elsewhere in the Pennine Basin it contains coal balls, that yield finely-preserved plant fossils. So far, no coal balls have been reported from this part of South Yorkshire. However, in the nearby ganister quarries, the shales immediately overlying the coal have yielded bullions containing marine shells.

The 50 m above this marine band can be divided into two coarsening-upwards cycles. The lower one is predominantly mudstone, with a 3 m thick sandstone and ganister at the top. In nearby quarries, the second cycle has been found to start with a brackish mudstone, but this has not yet been identified at Neepsend. It passes up through non-marine mudstones, and is capped by 9 m of sandstone. The latter is a widely-occuring interval unit over this part of the Pennine, and is known as the Loxley Edge Sandstone.

For about 5 m above the Loxley Edge Sandstone, exposure is not good here, except for some ribs of ganister. The next part of the succession to be well exposed is a fireclay, thin ganister and a coal smut, thought to be the Forty Yards Coal, and which Eden *et al.* (1957) estimate to be 4.8 m above the Loxley Edge Sandstone. The coal is overlain by a thin, pyritic mudstone and then dark shales. Elsewhere in the vicinity the shales in this position

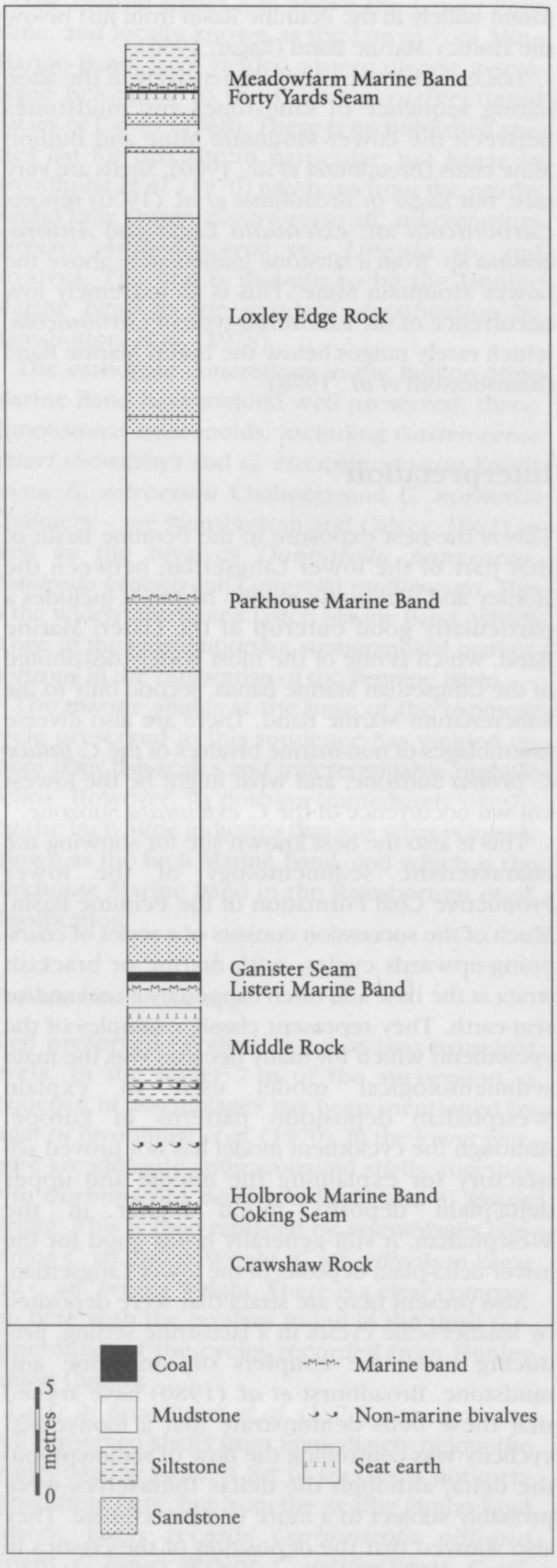

Figure 10.19 Sequence exposed along the Neepsend Railway Cutting. Drawn from descriptions given in Eden *et al.* (1957).

are black, and near Beauchief Hall have yielded fish fragments. However, no fossils have yet been found at Neepsend.

The marine band is overlain by siltstones, and then by a ganister, which is the highest bed exposed here and is thought to be the seat earth of the Norton Coal.

Biostratigraphy

Marine bands

Most of the levels assumed to be marine bands in the Neepsend sequence have produced no fossils or only fish fragments. Nevertheless, from their position in the sequence, the levels of the Holbrook, Parkhouse and Meadow Farm marine bands can be identified with reasonable certainty (see Fig. 10.19).

The only marine band to have been unequivocally identified here is the Listeri Marine Band, adjacent to the Ganister Coal. Eden *et al.* (1957) merely record 'traces of marine shells' from the cutting itself. However, from the tips of the nearby Parkwood Ganister Mine they obtained *Gastrioceras listeri* (Sowerby), *Dunbarella papyraceae* (Sowerby), *Caneyella multirugata* (Jackson) and *Anthracoceras* sp.

Non-marine bivalves

Eden *et al.* (1957) mention that bivalves could be found from two mudstones above the Coking Coal (in fact, these mudstones are probably lateral equivalents of the Springwood and Honley marine bands). However, they only provide a species list for the upper of the two mudstones: *Carbonicola* aff. *fallax* Wright, *C.* cf. *cristagalli* Wright, *Anthraconauta* spp. and *Naiadites* sp. This would seem to belong to the *C. fallax-C. protea* Subzone, indicating the basal Langsettian.

Interpretation

This is the most complete succession of lower Langsettian strata in the Pennine Basin, ranging from not far above the Subcrenatum Marine Band to above the Meadow Farm Marine Band. Parts of the succession are better exposed elsewhere (e.g. between the Coking and Clay coals – Honley Railway Cutting, between the Clay Coal and the Listeri Marine Band – Ravenhead Brickworks). However, nowhere else can the full sequence be seen as a whole.

The exposed sequence, consists of a set of coarsening-upwards cycles, with intervening 'marine' bands (in fact, often representing brackish or even fresh water conditions). In many cases, the coarse part of the cycle may only be siltstone, and just represent delta-front deposits. However, there are also examples of thicker sandstones, such as the Crawshaw and Loxley Edge sandstone, where the delta prograded more fully over the area. The whole sequence is typical of the type of lower delta-plain deposits that characterize the lower Langsettian of the Pennine Basin.

Conclusions

Neepsend Railway Cutting has the most complete sequence of rocks of early Langsettian age (about 312 million years old) in the Pennine Basin. It is possible to demonstrate here that these rocks were laid down in the lower part of a river-delta, which was subjected to periodic floodings by sea-water.

WHARNCLIFFE CRAGS

Highlights

Wharncliffe Crags is the type and best locality for the Wharncliffe Crags Formation, the remains of a localized braided river system in the lower Langsettian of the Pennine Basin.

Introduction

Crags (SK 300972) overlooking the River Don, east of Stocksbridge, 10 km NNW of Sheffield, South Yorkshire (Figure 10.20), are in sandstones of the Wharncliffe Crags Formation, a localized development in the Langsettian of the southern part of the Yorkshire Coalfield. There have been no published accounts of the site, and the following assessment is based on unpublished information supplied by P.D. Guion and H. Williams.

Description

The main crag exposes about 10 m of sandstone, representing the lower member of the Wharncliffe Crags Formation. About 2 m of the upper member can also be seen above the main crag, but the intervening argillaceous beds are not exposed.

The formation is characterized by relatively pure,

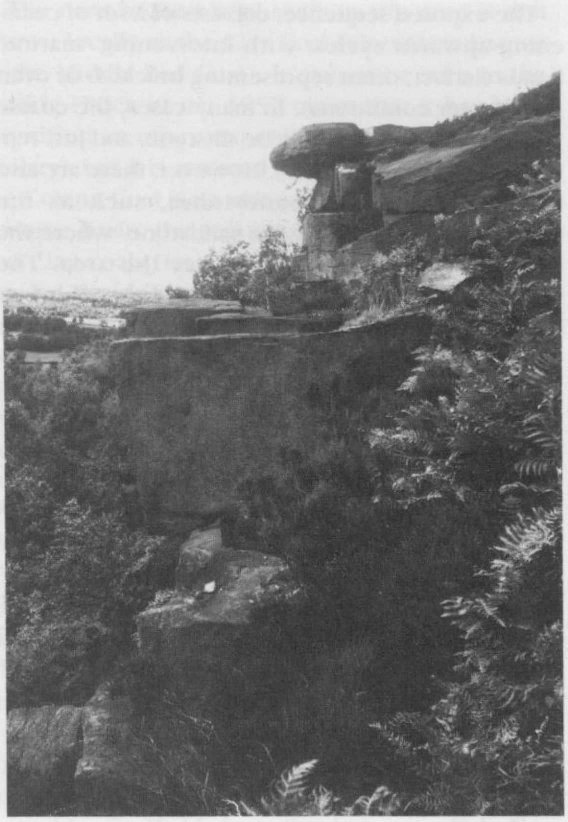

Figure 10.20 Wharncliffe Crags Formation exposed at its type locality. (Photo: C.J. Cleal.)

quartzitic sandstone. Pebble beds are absent, although some horizons with mud clasts can be seen. The dominant sedimentary structures are planar to gently trough cross-bedding, with sets up to 2 m thick. There are also soft-sediment deformation structures, particularly in the upper member and the upper part of the lower member. There is no evidence of either coarsening or fining upwards. Palaeocurrent indicators suggest that sediment transport was generally towards the south.

No fossils have been found at this site, but these sandstones are known to overlie the Amaliae Marine Band, and are thus lower Langsettian.

Interpretation

This is the type and best exposure of the Wharncliffe Crags Formation. It is a very localized deposit, restricted in development to the vicinity of Stocksbridge (Eden *et al.*, 1957). Laterally it is absent in the Sheffield area, and it also appears to rapidly die out to the north-west. It is probably the remains of a localized, low-sinuosity, braided fluvial system, transporting sediment southwards. It can thus be more closely compared with the Elland Flags Formation (Davies, 1966), except that it is on a much smaller scale. In contrast, the other major arenaceous formation in the lower Langsettian, the Crawshaw Rock, has an eastern and southern provenance (see Ridgeway Quarry and Stannington Ruffs).

Conclusions

Wharncliffe Crags is the best exposure of rocks of the Wharncliffe Crags Formation. These sandstones, which are about 310 million years old, are thought to be the remains of deposits laid down in a braided river system (i.e. a relatively straight river divided into many small, shallow, interlaced channels). This is in marked contrast to most of the other sandstones of the Coal Measures of the Pennine Basin, which were deposited by deeper, meandering rivers.

ELLAND BYPASS CUTTING

Highlights

Elland Bypass Cutting provides the best exposure of the Amaliae Marine Band in the Pennine Basin, and confirms its position relative to the *Carbonicola proxima* non-marine bivalve subzone.

Introduction

This cutting by the Elland Bypass (SE 119203), 5 km SSE of Halifax, West Yorkshire (Figure 10.21), is the remains of a disused claypit that worked refractory fireclays. There is no detailed description of the site in the literature, although the geology of the area is covered by Wray *et al.* (1930).

Description

Lithostratigraphy

The exposed sequence is about 30 m thick. The lowest beds are those immediately overlying the 48 Yard Coal, although the seam itself cannot be seen. The succession is dominated by mudstones with some thin coals and seat earths. There are also a number

Figure 10.21 Beds associated with the Amaliae Marine Band exposed at Elland Bypass Cutting. (Photo: C.J. Cleal.)

of sandstone bodies probably representing crevasse-splay deposits. Most of the mudstones are non-marine, and include one lacustrine interval. However, there is also a 5 cm thin band of black mudstone in the lower part of the sequence, which is of marine origin. The top of the succession is marked by 0.75 m of seat earth, which is thought to mark the position of the 80 Yard Band coal, although the seam itself is not normally present in this area.

Biostratigraphy

Marine bands

The thin marine band in the lower part of the succession contains the bivalve *Dunbarella*. From its position relative to the 48 Yard Coal, this is almost certainly the Amaliae Marine Band, also referred to as the Norton or Tonge's Marine Band by Calver (1968). According to Calver (1968), this band rarely contains anything other than this bivalve in the Yorkshire area, and only in a small area near Wigan and in North Devon does it develop into an ammonoid-bearing facies.

Non-marine bivalves

A band of mudstone 5.5 m below the level of the 80 Yard Band coal contains shells of the *Carbonicola proxima* Subzone. This is further evidence that these beds are in the lower Langsettian (upper *C. lenisulcata* Zone).

Interpretation

This is the best exposure of the Amaliae Marine Band in the Pennine Basin. It is more fully developed in Lancashire, particularly near Wigan (Earp and Magraw, 1955) where it contains ammonoids, but there are no permanent exposures in that area. Throughout the rest of the Pennine Basin, however, it is in the type of pectinoid facies seen here at Elland. While it has been identified at many other places in this facies in the Pennine Basin (Wray and Trueman, 1934; Eden, 1954; Smith *et al.*, 1967), this is the only place where it occurs in a large, surface exposure.

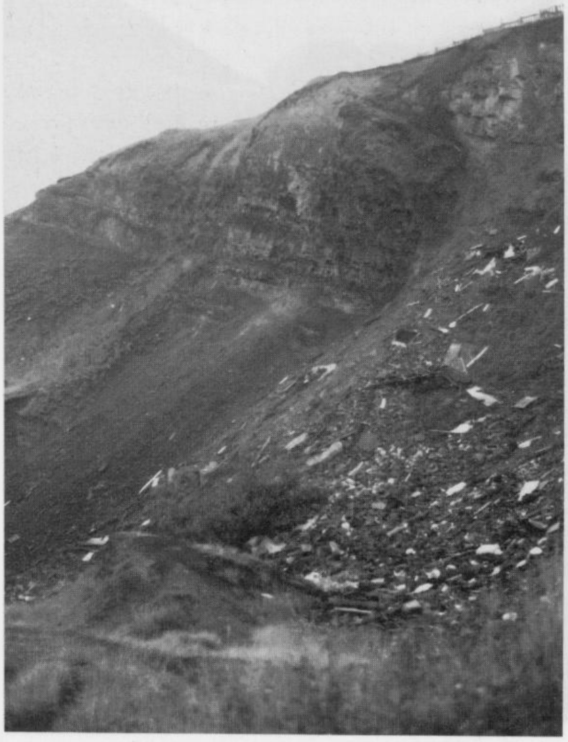

Figure 10.22 Lowside Brickworks GCR site. (Photo: C.J. Cleal.)

Significantly, the marine band can be seen here overlying a non-marine bivalve band, containing a *C. proxima* Subzone assemblage. In the standard sequence of subzones in the Pennine Basin, the Amaliae Marine Band is normally taken to mark the boundary between the *C. extenuata* and *C. proxima* subzones, and this agrees with the sequence observable at Elland.

Conclusions

Elland Bypass Cutting is the best exposure of shales of the Amaliae Marine Band in the Pennine Basin. The band represents one of the major intervals of flooding of the Coal Measures delta that occurred about 310 million years ago, and is an important marker-horizon that helps established detailed correlations between sequences of this age in different parts of north-western Europe. It is also possible here to relate this band to some fossils of freshwater bivalves, which have also proved important tools for establsihing detailed correlations.

LOWSIDE BRICKWORKS

Highlights

Lowside Brickworks is the best exposure yielding non-marine bivalves of the *Carbonicola cristagalli* Subzone of the *Anthraconaia modiolaris* Zone in the Pennine Basin (Figure 10.22).

Introduction

This abandoned brickworks (SD 942042) at Glodwick, on the east side of Oldham exposes upper Langsettian strata that yield abundant non-marine bivalves. Some details of the geology are given by Tonks *et al.* (1931), while an up-to-date field description is provided by Broadhurst *in* Eagar and Broadhurst (1991).

Description

Lithostratigraphy

The exposed sequence is about 20 m thick. The lowest 6 m consists of alternating sandstones and siltstones, thought to represent successive crevasse-splay or possibly overbank deposits filling a lacustrine basin. The highest sandstone in this sequence contains presumed lycopsid rootlets, and is thought to mark a period of emergence when a coal is often found in this area. This coal is locally known as the Oldham Great Seam, but is probably a lateral equivalent of the Trencherbone Coal elsewhere in the Lancashire Coalfield.

Overlying the Oldham Great Seam are about 10 m of lacustrine mudstone, with bands of sideritic clay-ironstone. These in turn are overlain by a fluvial sandstone. The sandstone here is only about 1 m thick, but Broadhurst *in* Eagar and Broadhurst (1991) reports that it becomes much thicker to the south-east. This, together with the presence of very well developed ripple cross-laminations, suggest that it may be a crevasse channel deposit.

Above this sandstone is a thin interval representing emergent conditions. The sandstone is overlain by a seat earth, which is badly weathered but sometimes shows evidence of rootlets. This is succeeded by the Blenfire Coal, which here occurs as three discrete leaves, overlain by mudstone.

The topmost part of the succession consists of another sandstone, known as the Blenfire Rock, which occurs over large parts of the Lancashire Coalfield. The base of the sandstone is clearly erosive, cutting down into the roof of the Blenfire

Coal, and in other parts of the coalfield cutting down into the coal itself. The Blenfire Rock shows well-developed trough cross-bedding and abundant mudstone clasts, which together with its strongly erosive base, indicate that it is a fluvial channel deposit.

Biostratigraphy

The only stratigraphically useful fossils reported from here are non-marine bivalves from between the Oldham Great and Blenfire coals, and include *Carbonicola cristagalli* Wright and *C. oslancis* Wright. These are diagnostic of the *C. cristagalli* Subzone (lower *A. modiolaris* Zone), indicating a position in the upper Langsettian. The shells are mostly preserved compressed flat, except in the ironstones where uncrushed specimens can be found. This suggests that the ironstone developed soon after deposition of the mudstone, before significant compaction occurred.

Interpretation

This is the best exposure in Britain of beds yielding bivalves of the *C. cristagalli* Subzone. The subzone is known from other coalfields in Britain (e.g. see Ramsbottom *et al.*, 1978, pl. 2) and is known from natural exposures in South Wales, such as on the Amroth Coast and Cwm Gwrelych (see Chapter 4). However, these deposits are most easily investigated at Lowside Brickworks, where the bivalves can be seen in their original lacustrine setting.

There are few well documented assemblages of this subzone from outside of Britain. The only notable exception is one from Limburg in The Netherlands, documented by van der Heide (1943).

The site is also of interest for showing a typical example of the upper Langsettian part of the Coal Measures in the Pennine Basin, including an equivalent of the Trencherbone Coal which occurs widely over the western part of the basin. It clearly demonstrates many of the typical lithologies of the Coal Measures found in this basin, including examples representing lacustrine, fluvial and emergent conditions. In particular, it shows the two main types of Coal Measures sandstone: the fluvial channel deposit with its trough cross-bedding and the crevasse channel deposit with ripple cross-bedding.

Conclusions

Lowside Brickworks shows a well exposed sequence of Coal Measures rocks of late Langsettian age (about 313 million years old). Its shows a range of rock types, representing deposits formed in lakes, river channels and swamps, the latter including coal deposits. It is the best site in Britain for yielding shells of the freshwater bivalves *Carbonicola cristagalli* and *C. oslancis*, which typically inhabited the lakes of this age, and whose remains are diagnostic of this particular level in the Coal Measures.

BRADGATE BRICKWORKS

Highlights

Bradgate Brickworks is one of the best exposures of typical Productive Coal Formation of the Pennine Basin (Figure 10.23) and the best site in Britain for yielding non-marine bivalves of the middle *A. modiolaris* Zone.

Introduction

The remains of this disused quarry (SK 413935), on the west side of Fenton Road, Bradgate, Rotherham, South Yorkshire, shows part of the middle Productive Coal Formation in the Pennine Basin. The site is mentioned by Mitchell *et al.* (1947), and the field geology as still visible is described by Spears (1967).

Description

Lithostratigraphy

The exposed sequence here is about 32 m thick (Figure 10.24). The base of the sequence is marked by the Joan Coal which, although not well seen now, was originally 45 cm thick. It is immediately overlain by about 1 m of black marine shales, now poorly exposed. The remaining 30 m or so consist mainly of shales, siltstones and thin sandstones. They are mostly distal or medial crevasse-splay deposits, although some of the shales are lacustrine, with non-marine bivalves (see below). There are also several minor coals representing emergent conditions. The thickest seam is at the top of the section, and is 35 cm thick. It is known as the

Figure 10.23 Bradgate Brickworks, exposing the Productive Coal Formation as developed in the Pennine Basin. (Photo: C.J. Cleal.)

Lidgett Coal, and occurs widely in the Yorkshire Coalfield (Ramsbottom *et al.*, 1978). No clear evidence of cyclicity in the sequence is present.

Biostratigraphy

Marine bands

Only one marine band is present in the sequence, immediately overlying the Joan Coal. It has only yielded inarticulate brachiopods (*Lingula*). However, the only marine band known to occur in this part of the Productive Coal Formation is the Vanderbeckei Marine Band (traditionally known in this region as the Clay Cross Marine Band) and is normally in the *Lingula* or at best pectinoid facies (Calver, 1968). It thus marks the junction between the Langsettian and Duckmantian stages.

Non-marine bivalves

As presently exposed, non-marine bivalves can be found at two horizons in this sequence: immediately above and 17 m above the Vanderbeckei Marine Band. Both horizons yield *Anthracosia aquilina* (Sowerby), *A. regularis* (Trueman) *sensu lato* and *Naiadites triangularis* (Sowerby). *A. regularis* in particular indicates the subzone of that name in the middle *A. modiolaris* Zone, i.e. topmost Langsettian to lowermost Duckmantian.

Spears (1967) mentions that assemblages of

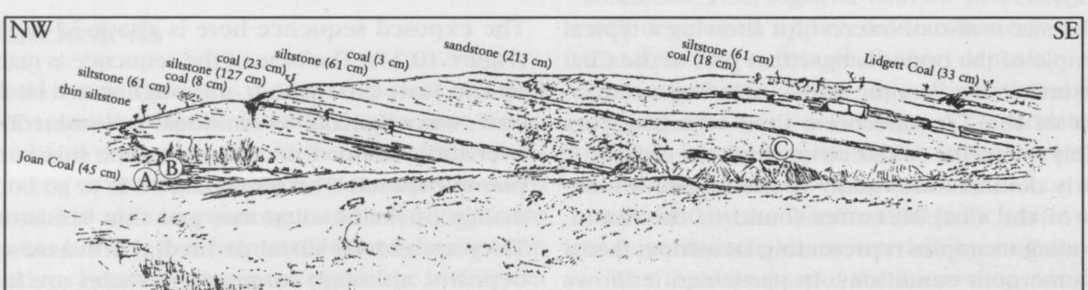

Figure 10.24 Sketch of face at Bradgate Brickworks, as recorded by Spears (1967, fig. 19.2).

Figure 10.25 Bradgate Brickworks GCR site. Close up of face, with hammer for scale. (Photo: C.J. Cleal.)

bivalves of similar composition had also been found from 3.3–6.4 m above the Lidgett Coal.

Interpretation

This is one of the best exposures of the middle part of the Productive Coal Formation in the Pennine Basin. The argillaceous nature of the strata tends to result in little natural outcrop being produced, and most man-made exposures tend to be infilled. In this particular case, however, part of the face has been retained after the quarry was restored (Figure 10.25).

The sequence here, dominated by shales and siltstones, with subsidiary thin, sheet sandstones, is typical of distal crevasse-splay deposits in an upper delta-plain setting (Fielding, 1984a). It is characteristic of the middle and upper Productive Coal Formation in the Pennine Basin, and thus of the economically most important coal-bearing strata in Britain. In contrast, the lower Langsettian deposits of the Pennine Basin (e.g. Goyt's Moss, Honley Station Cutting, Ravenhead Brickworks) were formed in a lower delta-plain setting, and show far clearer cyclicity between marine and non-marine strata (i.e. the classic cyclothems).

The non-marine bivalves from here have not been studied in detail, but the lists provided by Spears (1967) suggest that they are characteristic of the middle *A. modiolaris* Zone. If this interpretation is correct, this is the best British exposure for yielding this fauna.

Conclusions

Bradgate Brickworks is one of the best exposures of typical Late Carboniferous coal-bearing rocks in the Pennine Basin. It is also the best British site for fossil shells of freshwater bivalves, which belong to the middle *A. modiolaris* Zone, and indicate an age somewhere near the junction of the Langsettian and Duckmantian ages (i.e. between 305 and 310 million years old).

RIVER TONGE, MILL HILL

Highlights

The cliff on the River Tonge at Mill Hill is the best available exposure of the Peel Hall Rock (Figure 10.26), an important sandstone body in the Duckmantian of the Lancashire Coalfield.

Introduction

This cliff on west side of River Tonge (SD 725096), immediately north of the Tonge Bridge, Mill Hill, Bolton, Greater Manchester, shows sandstones in the lower Duckmantian of the Lancashire Coalfield. The only description of the geology is by Tonks *et al.* (1931).

Description

The cliff here exposes some 12 m of sandstone from the lower part of the Peel Hall Rock Formation, overlying grey mudstones. The sandstone, which is pale grey in colour and fine-grained, shows some cross-bedding. However, the two-dimensional nature of the face makes it impossible to determine a meaningful palaeocurrent direction.

The sandstones here contain no fossils, other than indeterminable plant fragments. At the type locality for the formation (Peel Hall Quarry, Little

Figure 10.26 Peel Hall Rock exposed at Mill Hill on the River Tonge. (Photo: C.J. Cleal.)

Hulton, Greater Manchester) there have been records of numerous casts of *Trigonocarpus* seeds (Tonks *et al.*, 1931, pl. 2), but these are of no biostratigraphical value.

The mudstones underlying the sandstone here were reported by Tonks *et al.* (1931) to contain bivalves, including *Anthracosia* cf. *phrygiana* (Wright). This suggests the subzone of the same name, indicating the lower Duckmantian.

Interpretation

This is the best exposure of the Peel Hall Rock, a fluvio-deltaic, arenaceous formation in the lower Duckmantian of the Lancashire Coalfield. It reaches a maximum of 45 m thick in this part of the coalfield, but thins rapidly to the south and eventually disappears at about Tyldesley. As well being an important fluvio-deltaic complex, the formation is of interest for providing of the distinctive *Trigonocarpus* 'nuts' found in many museum collections.

Conclusions

The River Tonge at Mill Hill is the best available exposure of a sandstone known as the Peel Hall Rock, about 305 million years old.

ASHCLOUGH

Highlights

Ashclough is considered the best exposure of the Maltby Marine Band in Britain.

Introduction

The cliff (SD 763063) on the southern side of the River Roch between Little Lever and Kearsley, 5 km SE of Bolton, Greater Manchester, provides a fine exposure of upper Duckmantian strata in the Lancashire Coalfield. The geology is described briefly by Tonks *et al.* (1931).

Figure 10.27 Maltby Marine Band exposed at Ashclough. (Photo: C.J. Cleal.)

Description

Lithostratigraphy

A full stratigraphical log for this section is not available, but about 100 m of strata are probably present. Most of the succession consists of mudstones and shales, and includes a thin coal known as the Ashclough Mine. There is also a band of sandy ironstone in the middle of the succession.

The topmost beds exposed are sandstones, which help maintain the face, and are known as the Nob End Rock. They were described by Tonks *et al.* (1931) as 'Sandstone with shaley bands' and, although forming a prominent feature here, are mainly restricted to this immediate part of the coalfield. They are separated from the underlying mudstones by a small fault, but according to Tonks *et al.* (1931) lie about 73 m above the Ashclough Mine.

Biostratigraphy

Marine bands

Just above the Ashclough Mine is a thin band of dark shale containing fish fragments. This is locally known as the Ashclough Marine Band which corresponds to the Maltby Marine Band in the classification of Ramsbottom *et al.* (1978).

Tonks *et al.* (1931) claimed to have located an exposure of another dark shale, this time above the Nob End Rock. They argued that this is the Dukinfield (i.e. Aegiranum) Marine Band. However, the outcrop cannot now be located.

Non-marine bivalves

Shales underlying the sandy ironstone in the middle of the succession have according to Tonks *et al.* (1931) yielded the following assemblage: *Anthracosia concinna* (Wright), *A. acutella* (Wright), *A.* cf. *aquilina* (Sowerby), *Anthraconaia librata* (Wright), *Anthracosphaerium (?) radiatum* (Wright) and *Naiadites* sp.

There are also records of '*C.*' cf. *blaydsii* (Brown) and '*C.*' cf. *nana* (Brown), but the taxonomy of these species is confused (Trueman and Weir, 1947). The assemblage clearly suggests the Lower '*similis-pulchra*' Zone, and the presence of *A. (?) radiatum* and *A. acutella* indicates the *A. atra* Subzone.

Interpretation

This is the only conservable outcrop of the Maltby Marine Band in Britain. It is one of the standard marine bands in the classification of Ramsbottom *et al.* (1978), which has played such an important role in establishing British Upper Carboniferous stratigraphy. Calver (1967) shows that it occurs extensively through the Pennine Basin, but mostly

Figure 10.28 Stairfoot Brickworks GCR site. Original exposure of Aegiranum Marine Band. Photographed during the visit to the site by the IUGS Subcommission on Carboniferous Stratigraphy, August 1981. (Photo: W. A. Wimbledon.)

in underground workings. Calver named it the Two Foot or Ashclough Marine Band, presumably because of the natural exposure. However, Ramsbottom *et al.* (1978) renamed it, because the only known occurrence of the marine band containing ammonoids was in the Maltby Colliery sinking (Edwards, 1952).

It is important as being the lowest of the marine bands in the interval of lower delta-plain deposits that characterize the upper Duckmantian and lower Bolsovian of this country. This interval represents the last occasion that marine conditions affected Britain until the Late Permian.

Conclusions

Ashclough is the best exposure in Britain of shales known as the Maltby Marine Band. This band, which is about 305 million years old, marks a time when the Coal Measures delta was flooded by a raising of the sea-levels. The resulting marine band is an important marker horizon, which has proved valuable for correlating rocks of this age over large parts of north-western Europe.

STAIRFOOT BRICKWORKS

Highlights

Stairfoot Brickworks is the best exposure of the Aegiranum Marine Band in the Pennine Basin.

Introduction

Stairfoot Brickworks (SE 381050) lies about 3 km ESE of Barnsley, South Yorkshire. Exposed here is the Aegiranum Marine Band, which is an index to the Duckmantian-Bolsovian stage boundary. The site was at one time proposed as the international stratotype for this stage boundary (Calver and Owens, 1977), although River Doe Lea subsequently became the designated site (see Chapter 2 for further details). The only description of the exposed section is in Ramsbottom (1981), although Spears (1967) gave a measured log of the same strata exposed in another part of the quarry (now no longer visible).

Description

Lithostratigraphy

When the quarry was active (up until the early 1980s), a considerable sequence above the sandstone known locally as the Oaks Rock could be seen here. However, only the marine band and its immediately adjacent strata can now be seen. The exposed marine band is 4 m thick, and consists mainly of black and blue-grey shales and mudstones. These overlie a thin, unnamed coal and its seat earth. Ramsbottom *et al.* (1974) state that this coal immediately underlying the marine band has a thin tonstein, but no mention of it was made by Ramsbottom (1981).

Biostratigraphy

Marine band

The upper and lower parts of the marine band only yield fish fragments and *Naiadites* bivalves. However, the middle part of the band has yielded an assemblage of ammonoids (including the index *Donetzoceras aegiranum* (Schmidt)), nautiloids, pectinoid bivalves, gastropods and crinoids. Although the stratigraphical context of these marine strata cannot now be seen, the presence of *D. aegiranum* makes it almost certain that this is the Aegiranum Marine Band, which is used to mark the Duckmantian-Bolsovian stage boundary.

Palynology

Thirty-two species of palynomorph were listed from this exposure in Ramsbottom (1981), and belong to the *Microreticulatisporites nobilis-Florinites junior* miospore zone. As pointed out by Riley *et al.* (1985), the Duckmantian-Bolsovian boundary does not correspond to a significant palynological change.

Interpretation

This is the best available exposure of the Aegiranum Marine Band (Figure 10.28) in the Pennine Basin, and is probably the best exposure of the band containing the index ammonoid anywhere in the world. It is one of the most widely occurring of the Westphalian marine bands of north-western Europe, occurring in Britain both north and south of the Wales-Brabant Barrier, as well as in Belgium, The Netherlands, northern France and northern Germany (a more detailed discussion on the distribution of this band can be found in Chapter 2). Its presence in any basin is important, as it allows the accurate placement of the Duckmantian-Bolsovian stage boundary.

Stairfoot Brickworks was at one time a candidate site for the international stratotype of the Duckmantian-Bolsovian stage boundary. It was eventually rejected as a stratotype because it was thought (in the middle 1980s) that there would be problems with its long-term conservation. However, the owners of the site (Yorkshire Brick Company) have now ensured that the site has a long-term future, making it the basis of a 'geological conservation site and teaching facility'. The conservation future of this site is now far better than it is for the formal stage boundary stratotype at Doe Lea, but it is probably unlikely that any move will be made to change the location of the official stratotype, at least in the immediate future.

The site is particularly good for the index ammonoid of the Aegiranum Marine Band. It was originally assigned to *Anthracoceras* by Schmidt (1925), a genus more typically found in the Namurian. Following a detailed study of the juvenile stages, however, Saunders *et al.* (1979) transferred the species to the more typically Westphalian genus *Donetzoceras*. Although this genus is also known from the Ukraine and North Africa, *D. aegiranum* itself is only known from the Aegiranum Marine Band in Europe.

Conclusions

Stairfoot Brickworks is the best exposure of the Aegiranum Marine Band in the Pennine Basin. It is an important stratigraphical marker horizon, representing the boundary between the Duckmantian and Bolsovian Stages. It was formed about 311 million years ago, when the river delta on which the coal swamps were formed was flooded by seawater.

NOSTELL BRICKYARD QUARRY

Highlights

Nostell Brickyard Quarry is the best exposure in Britain of the Shafton Marine Band, an important marker horizon in the middle Bolsovian of northern Europe (Figure 10.29). It is also the best surface exposure for middle Westphalian plant fossils in the Pennine Basin.

Introduction

This quarry (SE 403170) south of Nostell Priory, between Ackworth Moor Top and Crofton, 8 km ESE of Wakefield, West Yorkshire, shows shales and mudstones of the middle Productive Coal Formation in the Pennine Basin. The site was first mentioned by Culpin (1910), and an account of the stratigraphy and palaeontology provided by Edwards *et al.* (1940) and Barker and Whittle (1944).

Figure 10.29 Nostell Brickyard Quarry, as visible in the mid-1980s. (Photo: C.J. Cleal.)

Description

Lithostratigraphy

The exposed sequence here consists of 7.5 m of grey-blue mudstones. The lowest 2 m are brackish deposits, representing the upper part of the Shafton Marine Band. The remainder of the sequence are non-marine, presumably flood-plain deposits.

Biostratigraphy

Marine bands

The mudstones at the base of the sequence yield a shallow marine to brackish assemblage of fossils, including inarticulate brachiopods *Orbiculoidea* and *Lingula*, and fish scales such as *Rhizodopsis* (Barker and Whittle, 1944). Although not seen in this quarry, Edwards *et al.* (1940) report that in this area, these mudstones are immediately underlain by black shales, and include *Pterinopecten*, *Dunbarella* and occasional *Anthracoceras*. This is the Shafton Marine Band in an *Anthracoceras*/Pectinoid Facies, which is the typical development of this marine band in this part of the Yorkshire Coalfield (Calver, 1968).

Plant fossils

Barker *in* Barker and Whittle (1944) lists a diverse assemblage of plant fossils from the mudstones overlying the Shafton Marine Band. A fuller account of the palaeobotanical significance of this band is given in the 'Palaeozoic Palaeobotany' GCR volume. From a biostratigraphical standpoint, however, significant species include *Laveineopteris loshii* (Brongniart) Cleal *et al.*, *Alethopteris lonchitica* Sternberg, *Mariopteris sauveurii* (Brongniart) Zeiller, *Lobatopteris miltoni* (Artis) Wagner, *Sphenophyllum cuneifolium* Sternberg and *Annularia sphenophylloides* (Zenker) Gutbier. The assemblage clearly belongs to the middle or upper parts of the *Paripteris linguaefolia* Zone, and most likely to the *Laveineopteris rarinervis* Subzone as defined in Cleal (1991). This therefore suggests the middle Bolsovian.

Interpretation

This is the best exposure in Britain of the Shafton Marine Band, one of the key lithostratigraphical marker horizons in the Productive Coal Formation of northern Europe. It represents the penultimate marine incursion into the Pennine Basin in the Westphalian, and is a useful indication of the middle Bolsovian. According to Calver (1968), it is mainly restricted to the southern and central parts of the Pennine Basin, such as the Lancashire, Yorkshire, East Midland, North and South Staffordshire coalfields. Its fullest development is in the southern part of the Yorkshire Coalfield, such as here at Nostell, where it is in the *Anthracoceras*/Pectinoid Facies. According to Edwards *et al.* (1940), the band can reach a thickness of 7.9 m in this area, although in this quarry it is only about 3.5 m in total, the base not being seen.

The site is also of interest because of the plant fossils. The middle Productive Coal Formation of the Pennine Basin yields some of the most characteristic mid-Westphalian plant fossil assemblages in Britain, perhaps best exemplified by the so-called 'Barnsley Seam Flora' summarized by Kidston (1923–1925) and Crookall (1955–1975). There are currently no good surface exposures from where plant fossils can be collected from the mudstones associated with the Barnsley Seam. While the plant fossils from Nostell are marginally higher, stratigraphically, they include many of the characteristic taxa found near the Barnsley Seam.

Conclusions

Nostell Brickyard Quarry is the best British exposure of shales of the Shafton Marine Band. This is an important marker horizon in the middle Bolsovian (rocks about 311 million years old) of northern Europe. It is also the best place for plant fossils of this age in the Pennine Basin.

CARLTON MAIN BRICKWORKS

Highlights

Carlton Main Brickworks (Figure 10.30) shows the best exposure of the Cambriense Marine Band in Britain, and the last evidence of marine influence on the British environment, until the Late Permian.

Introduction

The quarry (SE 411081) for the brickworks south of Grimethorpe, 7 km ENE of Barnsley, South Yorkshire, exposes marine strata in the middle Productive Coal Formation of the Pennine Basin. It is mentioned by Spears (1967) and Calver (1968), and a detailed description is provided by Goossens and Bell (1969). Some of the fossils from here are figured (but not described) by Calver (1973).

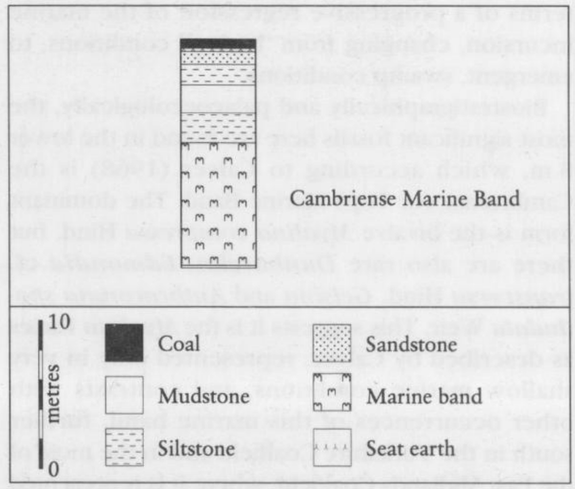

Figure 10.31 Section exposed at Carlton Main Brickworks. Drawn from descriptive log in Goossens and Bell (1969).

Figure 10.30 Carlton Main Brickworks. (Photo: C.J. Cleal.)

Description

The exposed sequence here is 15 m thick (Figure 10.31). The lower 8 m are black to dark grey mudstones and siltstones, representing the Cambriense Marine Band (see below). Most of the rest of the succession are pale grey mudstones and siltstones, representing non-marine flood-plain deposits, although there are also some darker grey mudstones and siltstones which are probably lacustrine deposits. The topmost 80 cm of the succession are a seat earth followed by interbedded shale and poor quality coal, thus representing emergent conditions. The section here can thus be seen in terms of a progressive regression of the marine incursion, changing from 'basinal' conditions, to emergent, swamp conditions.

Biostratigraphically and palaeoecologically, the most significant fossils here are found in the lower 8 m, which according to Calver (1968) is the Cambriense (or Top) Marine Band. The dominant form is the bivalve *Myalina compressa* Hind, but there are also rare *Dunbarella*, *Edmondia* cf. *transversa* Hind, *Geisina* and *Anthraconaia spathulata* Weir. This suggests it is the *Myalina* Facies as described by Calver, represented only in very shallow marine conditions, and contrasts with other occurrences of this marine band, further south in the Yorkshire Coalfield and in the most of the East Midlands Coalfield, where it is represented by deeper water, *Anthracoceras*/Pectinoid to Pectinoid facies (e.g. Edwards and Stubblefield, 1948; Goossens, 1952).

In the 2.8 m of strata above the marine band, Goossens and Bell (1969) mention 'non-marine' bivalves such as *Anthraconaia* and *Naiadites*. However, no species names were given. They probably represent an estuarine fauna, marking the first sign of reversion to non-marine conditions.

Interpretation

This is the best exposure of the Cambriense Marine Band in Britain, and yields fossils of the *Myalina* Facies. It is the highest of the marine bands found anywhere in the Upper Carboniferous of north-western Europe, and marks the withdrawal of marine influence from this area until the Late Permian. This environmental shift was symptomatic of the geomorphological changes occurring during the late Westphalian, resulting from the collision between the Laurasia and Gondwana palaeocontinents to form Pangea, and which is known as the Variscan Orogeny.

Conclusions

Carlton Main Brickworks is the best British locality for shales of the Cambriense Marine Band, about 305 million years old. This marine band represents the last evidence in this country of marine conditions until the Late Permian.