British Upper Carboniferous Stratigraphy

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Chapter 9

Millstone Grit of the Central Province

The Central Province refers to the complex of depositional basins lying between the Wales–Brabant Barrier to the south and the Askrigg Block to the north (Figure 9.1). It is the thickest development of Millstone Grit in Britain, with a maximum thickness of over 180 m near Burnley and Skipton, and outcrops over an area of more than 4000 m. Much of the strata is relatively resistant to erosion, resulting in rugged scenery most typically represented by the moorland and hills of the High Peak between Sheffield and Manchester; names such as Kinder Scout and Edale are as well known to the hiker and rock-climber as they are to the geologist. Such scenery is well suited to producing good outcrop, and has attracted many geologists to the area. Furthermore, fossils occur abundantly, particularly in the marine bands which have yielded biostratigraphically sensitive ammonoids and conodonts. The non-marine parts of the sequence also contain fossils, although, except for the palynomorphs, have been subject to relatively little investigation. The combination of good exposure and good biostratigraphical control has meant that it is the classic area for the study of the Namurian, and most of the Namurian stage boundary stratotypes have been designated here (see Chapter 2).

The strata are of little direct economic importance. At one time, the sandstones were used to produce mill-wheels (hence the name). This industry has now effectively disappeared, although the remains of discarded wheels can still be seen in parts of the Peaks. The sandstones are still being used as aggregates, paving and building-stones, albeit on a smaller scale than previously, and have produced some of the characteristic architecture of cities such as Sheffield, Leeds and Manchester. Perhaps its most important economic role today is in water-supply, the larger valleys in the Millstone Grit being particularly well suited to damming. The resulting reservoirs, such as Ladybower, Derwent and Woodhead, are the major suppliers of water to a number of the northern industrial cities.

History of research

A number of local scholars, such as Martin Lister and John Michell, took note of the geology of the Pennines in the 17th and 18th centuries (Edwards and Trotter, 1954). The term Millstone Grit itself seems to have been coined in the late 18th century by Whitehurst (1778) for a sandstone in the south of the area (probably what is now known as the Ashover Grit). As elsewhere in England, however, major progress did not occur until William Smith started mapping the area in the early 19th century. Smith's pupil John Farey published the first geological account of the Millstone Grit in 1811, noting for the first time that it occurred between the Carboniferous Limestone and Coal Measures. However, for many years the definitive statement was by Smith's nephew John Phillips, whose 1836 book remained the standard reference until the Geological Survey started their work some decades later.

The Survey's first detailed analysis of the Millstone Grit was by Hull and Green (1864), the results of which were incorporated into a series of memoirs (e.g. Hull and Green, 1866; Green *et al.*, 1878). These works contained the first coherent attempts to subdivide the Millstone Grit, based on the four major grit-intervals, the lowest now known as the Kinderscout Grit, and the highest as the Rough Rock. In Derbyshire, these were underlain by what was called the 'Yoredale Series', then thought to be equivalents of the strata of the same name in the Northern Province (see Chapter 11). As pointed out by Hind (1899), however, the true Yoredales of the Northern Province are significantly older than these beds in Derbyshire and so, following detailed stratigraphical work by Jackson (1923, 1925b, 1926, 1927), the currently used subdivisions of Edale Shales, Mam Tor Sandstones, Shale Grit and Grindslow Shales was introduced.

Up until the 1920s, much of the stratigraphical work on the Millstone Grit had a lithostratigraphical basis. However, it rapidly became clear that such work in isolation had serious limitations, due to problems in correlating the geographically impersistent grits. The turning point came with the first attempts at biostratigraphy using ammonoids by Bisat (1924, 1928). For the first time, it was possible to establish accurate correlations throughout the Central Province, and for the pattern of sandstone distribution to be seen against an independent stratigraphical framework. Further discoveries of ammonoids and their associated marine fossils continued to refine the biostratigraphy (Hudson, 1936, 1945; Bisat and Hudson, 1943; Hudson and Cotton, 1943; Hodson, 1957), and allowed the Geological Survey to pursue their mapping programme armed with an accurate means of correlation (e.g. Bromehead *et al.*, 1933; Edwards *et al.*, 1950; Stephens *et al.*, 1953; Eden *et al.*, 1957; Earp *et al.*, 1961; Smith *et al.*, 1967; Evans *et al.*, 1968; Stevenson and Gaunt, 1971). The results of the work are well summarized in the detailed stratigraphical scheme published by Ramsbottom

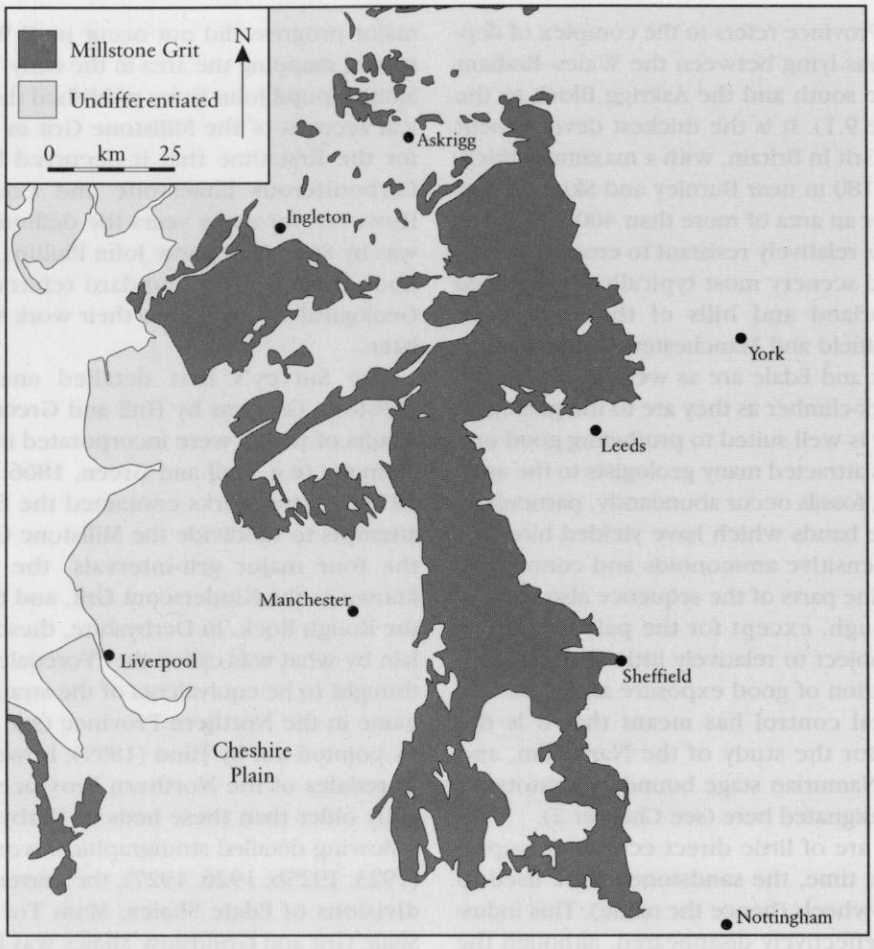

Figure 9.1 Millstone Grit outcrop of the Central Province, between the Wales–Brabant Barrier to the south and the Askrigg Block to the north. Based on Edwards and Trotter (1954, fig. 2).

(1966; see also Ramsbottom *et al.*, 1978).

One of the most interesting results of the integration of the sandstone distribution with the ammonoid biostratigraphy has been the development of the so-called 'Mesothem Model', mainly by Ramsbottom (1977). This attempted to interpret the broad pattern of sedimentation observable in the Millstone Grit of the Central Province in terms of eustatic sea-level changes, controlled possibly by Milankovich cyclicity. The significance of this would be that the cyclicity should also be recognizable at a regional if not global level, with important consequences for long range stratigraphical correlations. The evidence in the Millstone Grit of the Central Province has been reviewed by Holdsworth and Collinson (1988). They found clear evidence of small-scale cyclicity, which they believe was produced by sea-level changes, but evidence of the type of the large-scale cyclicity in Ramsbottom's model was less certain. For instance, the mesothem boundaries did not always seem to coincide exactly with the faunal changes, as required by the Ramsbottom model. However, there does seem to be a larger-scale pattern of cyclicity than Holdsworth and Collinson's 'minor cycles' and, whether or not they are called 'mesothems', they need to be explained. Ramsbottom's controversial ideas have provided one of the most lively subjects for debate in Carboniferous stratigraphy, and the evidence from the Central Province Millstone Grit has played a central role.

The most recent developments in geological investigation of these strata have been in the field of sedimentology. Early investigations by Sorby (1859) and Gilligan (1920) looked at the petrography of the rocks in order to establish details such as provenance. However, real progress did not occur until facies analysis was applied to the problem, pioneered by Trotter (1951). The Kinderscout Grit and its underlying sediments have attracted

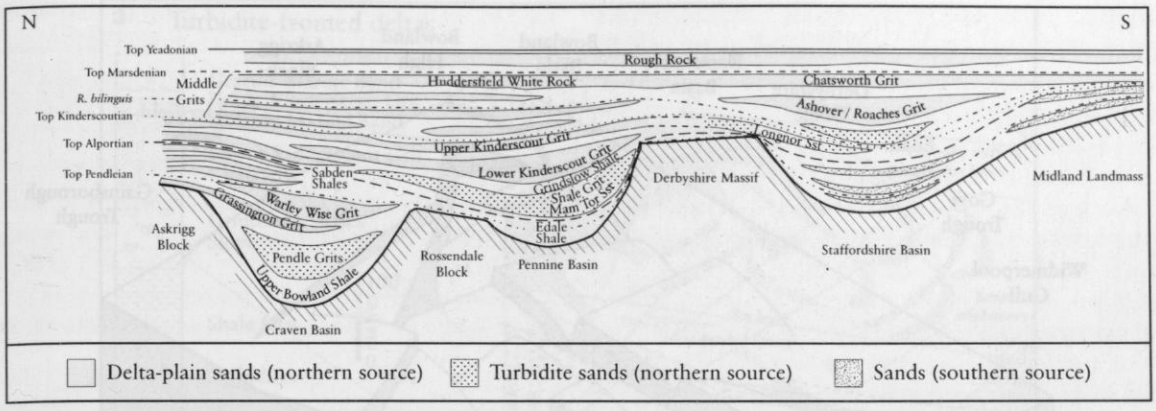

Figure 9.2 The distribution of major sandstone bodies in the Millstone Grit of the Central Province. Based on Collinson (1988, fig. 9.5).

some of the most intense interest (Allen, 1960; Walker, 1964b, 1966a, 1966b; Collinson, 1968, 1969, 1970; McCabe, 1975, 1977, 1978) and is now modelled as a turbidite-fronted delta. However, there has also been work on the Rough Rock (Shackleton, 1962; Heath, 1975; Miller, 1986; Bristow, 1988), the Chatsworth and Ashover grits (Mayhew, 1967a, 1967b) and the Haslingden Flags (Collinson and Banks, 1975; Bristow, 1988). A useful summary of the evidence is provided by Collinson (1988).

Lithostratigraphy

As pointed out above, establishing a coherent lithostratigraphical scheme for these strata has presented serious problems, largely because of the impersistence of many of the main sandstone bodies (see for instance Figure 9.2). Even at the level of group, there is not a uniform classification for use throughout the Central Province, particularly in the lower part of the Millstone Grit.

The scheme used in this chapter is based partly on that used by the British Geological Survey, as summarized by Edwards and Trotter (1954). Four subgroups are recognized as the main divisions (Edwards and Trotter recognized a further two subgroups in the Pendleian and Arnsbergian parts of the Millstone Grit, but this lies outside the remit of this volume). Within each subgroup, the main grits or sandstones are recognized as formations; except in the lower part of the sequence, the shales are not normally named. In some cases, the grits occur as two discrete leaves, and these are recognized as members. As far as the authors are aware, no formal stratotypes have been designated for these lithostratigraphical units.

Edale Shales Subgroup

Base defined: base of shales immediately above the Warley Wise Grit Formation in the Craven Basin; elsewhere at the base of Millstone Grit.

Characteristic facies: marine shales with subsidiary mainly turbiditic sandstones.

Major formations: Edale Shales (Edale Basin), Sabden Shales (Craven Basin).

Comments: This is referred to by Edwards and Trotter as the Middleton Grit Group. However, this grit occurs only in the very north of the Central Province and is totally atypical of the lithologies found elsewhere in this interval. The Edale Shales are a far more typical development, and so its name has been adopted for the subgroup, as in Moore (1967).

Kinderscout Subgroup

Base defined: base of first major turbiditic sandstone above the Edale Shales Subgroup.

Characteristic facies: turbiditic shales and sand stones in the lower part, fluvio-deltaic sandstones in the upper part.

Major formations: Kinderscout Grit over much of province; Mam Tor Sandstone, Shale Grit and Grindslow Shale (Edale Basin); Longnor and Blackstone Edge sandstones (Staffordshire Basin); Cobden Sandstone and Todmorden Grit (Craven Basin).

Middle Grit Subgroup

Base defined: base of shale immediately above the Kinderscout Grit and its lateral equivalents.

Characteristic facies: shales, both marine and non-marine; feldspathic, often cross-bedded sandstones.

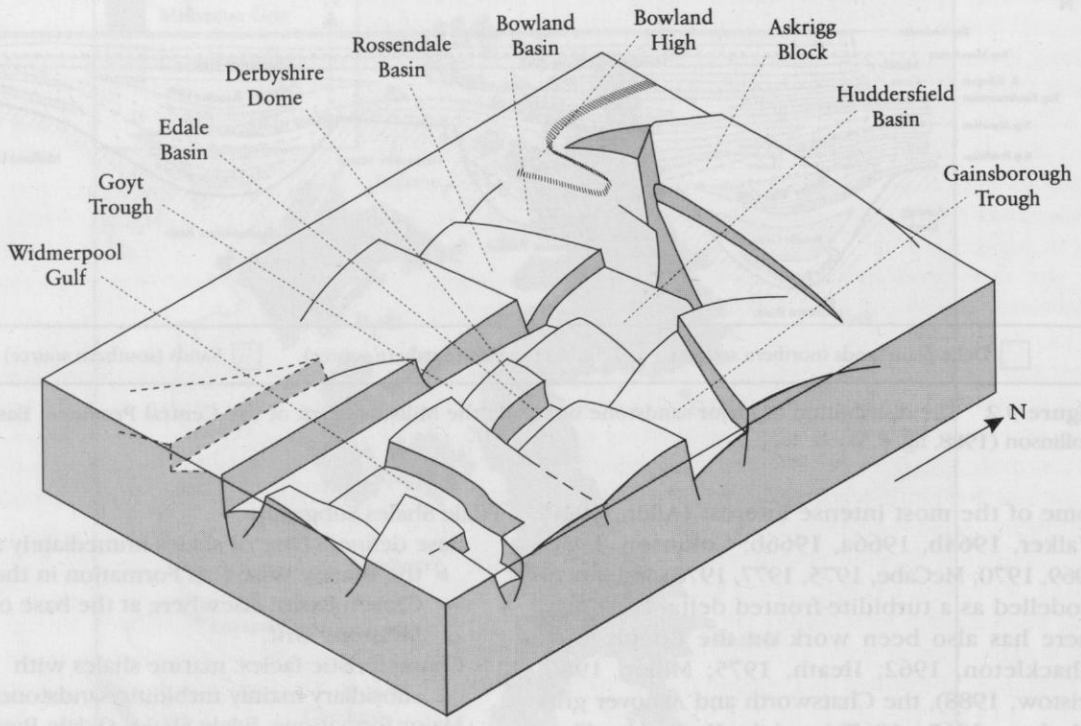

Figure 9.3 The relationship between individual basins in the Central Province during the middle Namurian. Based on Lee (1988, fig. 8.8).

Major formations: Chatsworth and Ashover grits over much of province; Roaches Grit (Staffordshire Basin); Alum Crag, Revidge, Hazel Greave and Holcombe Brook grits (Craven Basin); Huddersfield White Rock (Huddersfield Basin).

Rough Rock Subgroup

Base defined: base of shale immediately above the Chatsworth Grit, Huddersfield White Rock and Holcombe Brook Grit formations.

Characteristic facies: mainly non-marine shales with some thin coals and seat earths, and only occasional marine intercalations; fine to medium-grained sandstones.

Major formations: Rough Rock over much of province; Haslingden Flags (Craven Basin).

Geological setting

The Central Province is the remains of a broad area of sag between the Wales–Brabant Barrier to the south and the Askrigg Block and Lake District High to the north (Figure 9.2). Based on seismic data, Lee (1988) has shown that in the early to middle Namurian it comprised of a set of separate fault-bounded basins, the result of lithospheric extension and thinning (see also Leeder and McMahon, 1988). The most important of these were those first established in the Dinantian, namely the Staffordshire Basin, the Widmerpool Gulf, the Edale Basin, the Huddersfield Basin and the Craven Basin (Figure 9.3). These basins had a marked influence on sediment distribution in the Kinderscoutian and before, but by the late Marsdenian sedimentary patterns had become more uniform over the Central Province, with the possible exception of the Craven Basin.

The Millstone Grit of this area may be seen as comprising two major facies associations. The first consists of mainly fine-grained (shale, siltstones) basinal deposits. Salinity levels within the basin appear to have varied; at some levels conditions were fully marine, resulting in the stratigraphically important marine bands, whilst at others conditions were non-marine, and sometimes even emergent. This variation has been seen in terms of cyclical eustatic changes (Holdsworth and Collinson, 1988), but there is also a clear long-term reduction in marine influence, culminating in strata that are very similar to the Coal Measures in the

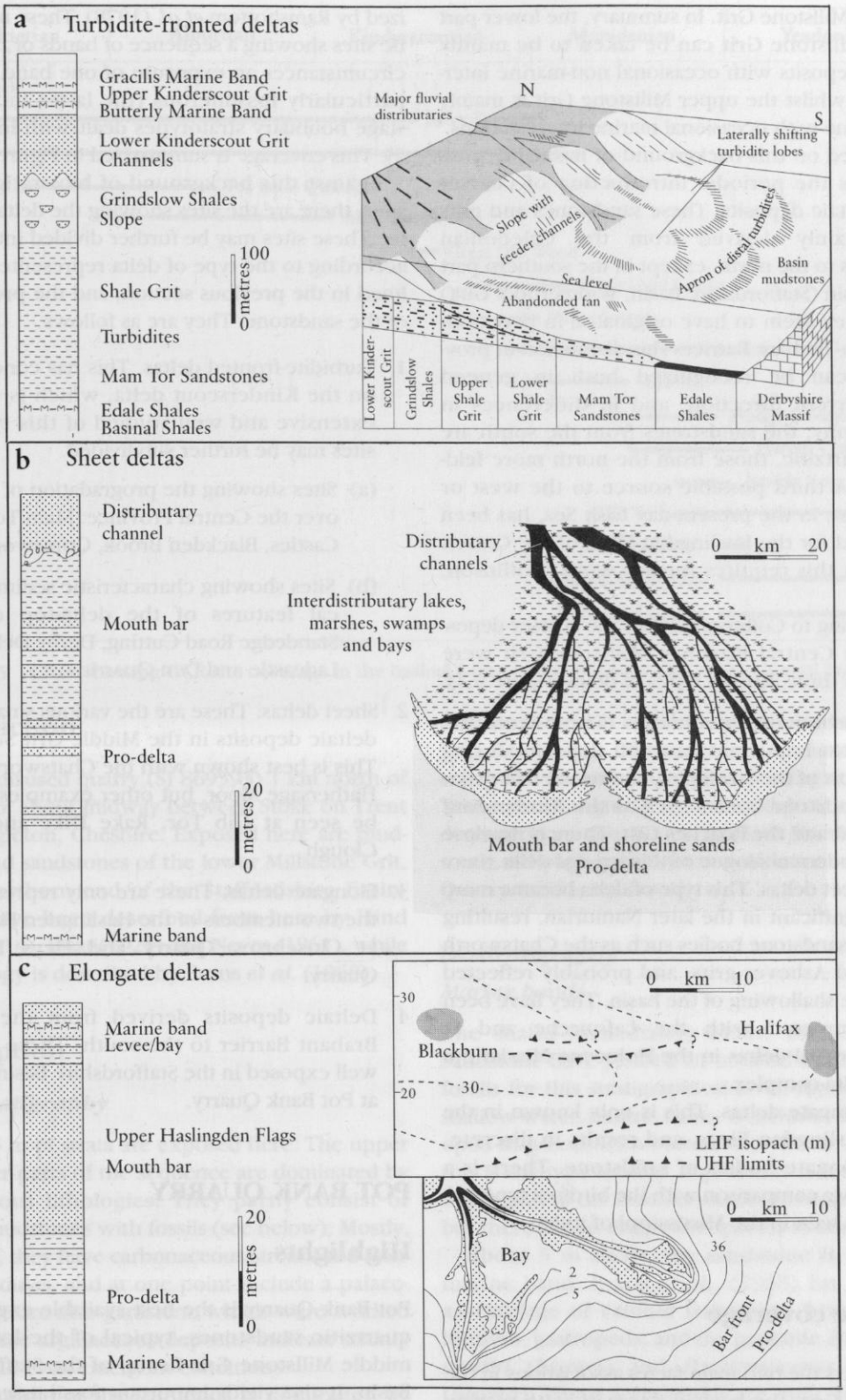

Figure 9.4 The three main types of deltaic sedimentation recognizable in the Millstone Grit of the Central Province. Based on Collinson (1988, fig. 9.4).

topmost Millstone Grit. In summary, the lower part of the Millstone Grit can be taken to be mainly marine deposits with occasional non-marine intercalation, whilst the upper Millstone Grit is mainly non-marine with occasional marine intercalations.

Imposed on this background of basinal deposition, was the periodic introduction of coarser fluvio-deltaic deposits. These sandstones and grits were mainly derived from the Caledonian Highlands to the north, except in the southern part of the basin (Staffordshire Basin, Widmerpool Gulf) where they seem to have originated in part from the Wales–Brabant Barrier. This distinction in provenance can be recognized both in general palaeocurrent direction, and in differences in petrography; the sandstones from the south are more quartzitic, those from the north more feldspathic. A third possible source to the west or north-west, in the present-day Irish Sea, has been postulated for the Haslingden Flags of the Craven Basin but this requires further work (Collinson, 1988).

According to Collinson (1988) the coarser deposits of the Central Province Millstone Grit were formed in three distinct types of delta (Figure 9.4).

1. Turbidite-fronted deltas. These were the most important basin-fill deposits during most of the Namurian, and resulted in major sandstone bodies such as the Kinderscout Grit and the Roaches Grit. There is no close modern analogue of this type of delta.
2. Sheet deltas. This type of delta became more significant in the later Namurian, resulting in sandstone bodies such as the Chatsworth and Ashover grits, and probably reflected the shallowing of the basin. They have been compared with the Lafourche and St Bernard deltas in the Holocene Mississippi delta-complex.
3. Elongate deltas. This is only known in the Haslingden Flags, and results in discrete, elongate bodies of sandstone. There is a close comparison with the birdfoot-type deltas seen in the Mississippi of today.

GCR site coverage

This reflects the two main facies associations in the Millstone Grit: the basinal deposits with marine bands, and the deltaic deposits. The basinal deposits are represented by a sequence of sites showing the standard succession of marine bands, summarized by Ramsbottom *et al.* (1978). These may either be sites showing a sequence of bands or, in certain circumstances an exposure of one band which is particularly fossiliferous (the latter include the stage boundary stratotypes dealt with in Chapter 2). This coverage is summarized in Figure 9.5.

Against this background of biostratigraphical sites, there are the sites showing the deltaic deposits. These sites may be further divided into groups according to the type of delta represented, as outlined in the previous section, and the provenance of the sandstone. They are as follows.

1. Turbidite-fronted deltas. This has concentrated on the Kinderscout delta, which is the most extensive and well studied of this type. The sites may be further subdivided.
   (a) Sites showing the progradation of the delta over the Central Province: Mam Tor, Alport Castles, Blackden Brook, Crimsworth Dean.
   (b) Sites showing characteristic sedimentological features of the delta-top deposits: Standedge Road Cutting, Derby Delf Quarry, Ladcastle and Den Quarries.
2. Sheet deltas. These are the various smaller-scale deltaic deposits in the Middle Grit Subgroup. This is best shown with the Chatsworth Grit at Hathersage Moor, but other examples can also be seen at Gib Tor, Rake Dike and Hodge Clough.
3. Elongate deltas. These are only represented in the two members of the Haslingden Flags, seen at Closebrow Quarry and Heys Britannia Quarry.
4. Deltaic deposits derived from the Wales–Brabant Barrier to the south. These are only well exposed in the Staffordshire Basin, such as at Pot Bank Quarry.

POT BANK QUARRY

Highlights

Pot Bank Quarry is the best available exposure of quartzitic sandstones, typical of the lower and middle Millstone Grit Group of the Staffordshire Basin. It also yields important fossil assemblages, and has included the types of some important Chokierian and Alportian species.

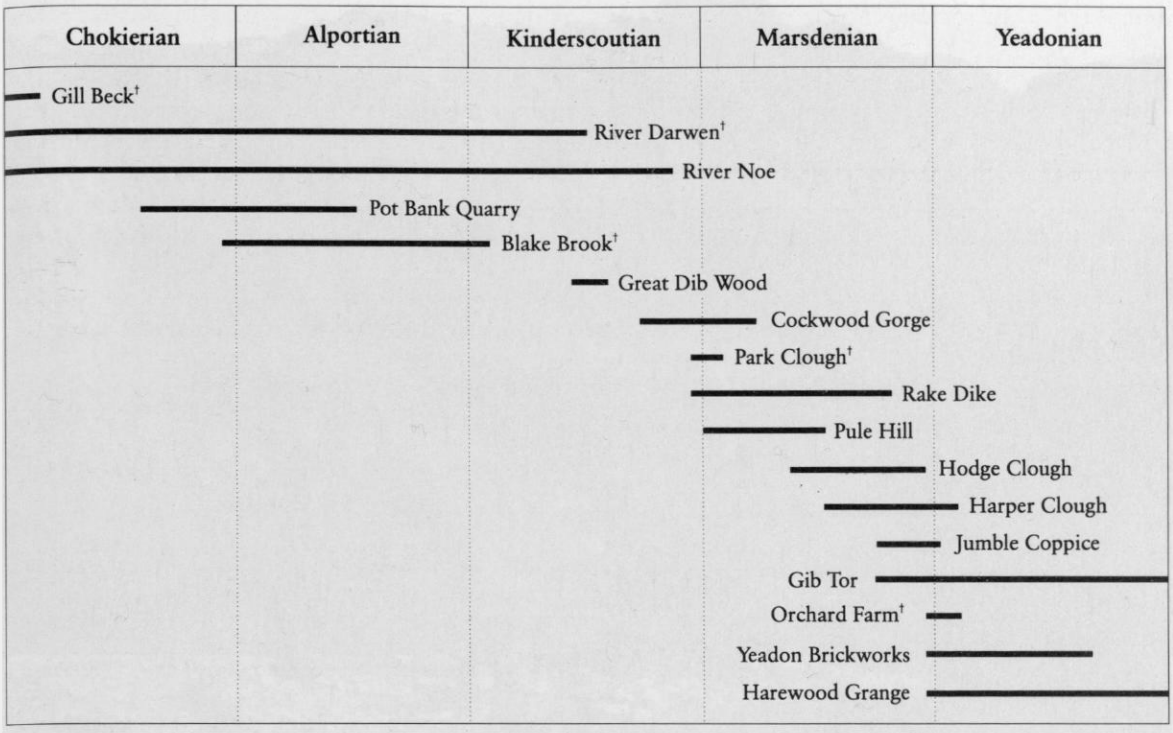

Figure 9.5 Chart showing GCR site coverage in the basinal facies of the Millstone Grit in the Central Province.

Introduction

This is a disused quarry (SJ 869593) 1 km north of Mow Cop, about midway between Stoke on Trent and Congleton, Cheshire. Exposed here are mudstones and sandstones of the lower Millstone Grit, at the northern end of the Staffordshire Basin. Fossils have been described from here by Hind (1910, 1914), Bisat (1924) and Neves (1961), while the geology is described by Evans *et al.* (1968).

Description

Lithostratigraphy

About 25 m of strata are exposed here. The upper and lower parts of the sequence are dominated by argillaceous lithologies. They partly consist of marine mudstones with fossils (see below). Mostly, however, they have carbonaceous streaks and ironstone nodules, and at one point include a palaeosol. There are also ganisters, which were worked here. These argillaceous deposits indicate mainly littoral and even emergent conditions.

The middle of the sequence is dominated by sandstones, and belongs to the Lum Edge Sandstone Formation. They are characteristically fine-grained, quartzitic sandstones, with parallel-bedding as the main sedimentary structure (Figure 9.6). They often contain plant fragments, and at one point include stigmarian rooting structures. These are thought to represent deltaic sediments derived from the Wales–Brabant Barrier to the south, although palaeocurrent evidence at Pot Bank Quarry itself is equivocal.

Biostratigraphy

Marine bands

The shales immediately below the Lum Edge Sandstone have yielded an unusual assemblage of fossils for this stratigraphical level, representing a shallow-water, marine fauna. It includes the brachiopod *Rugosochonetes hindi* Muir-Wood, for which this is the type locality. It probably belongs to the upper part of the *Homoceras beyrichianum* Zone, but there are no diagnostic species to confirm this.

About 5 m above the sandstone is a second marine band. Evans *et al.*, (1968) list a diverse assemblage of crinoid fragments, brachiopods, bivalves, gastropods, and the goniatite *Homoceras smithi* (Brown) and *Hudsonoceras proteum* (Brown). These ammonoids are indicative of the lower Alportian Proteum Marine Band.

Hind (1914) described some ammonoids from here as *Pericyclus divaricatus*, but which

Figure 9.6 Proteus Marine Band and underlying quartzitic sandstones of the lower Millstone Grit of the Staffordshire Basin at Pot Bank Quarry. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (L247).

Ramsbottom (1958) later renamed as *Homoceras undulatum*. This would suggest a level in the middle Alportian, and thus higher stratigraphically than the marine band mentioned in the previous paragraph. However, no such marine band is exposed today.

Palynology

The palynology of the marine shales yielding *H. proteus* (Brown) was studied by Neves (1961). Several new species were described from here: *Acanthotriletes baculatus*, *Neoraistrickia inconstans*, *Mooresporites trigallerus*, *Dictyotriletes tuberosus* and *Proprisporites laevigatus*. Some of these (*A. baculatus*, *M. trigallerus*, *D. tuberosus*) were only found in marine shales, and were thought to represent a quite different vegetational community to that represented in the coals. The assemblage belongs to what is now known as the *L. subtriquetra-K. ornatus* Zone.

Interpretation

This is the best exposure of the upper Chokierian and lower Alportian in the Staffordshire Basin. A similar section is shown in the Alportian stratotype at Blake Brook, but exposure is considerably better here, and the Alportian part of the sequence is less condensed. Pot Bank Quarry also seems to yield a more diverse assemblage of animal macrofossils, although the Blake Brook assemblage has yet to be described in detail. On the other hand, no conodonts have been reported from Pot Bank Quarry, nor does it show the upper part of the Alportian stage.

A feature particularly well seen here is the nature of the sandstones, which are southerly derived quartzites, known locally as 'crowstones'. This is typical of the lower and middle Namurian of both the Staffordshire Basin and the Widmerpool Gulf (Falcon and Kent, 1960; Collinson, 1988), and contrasts with the northerly derived feldspathic sandstones of the Pennine and Craven basins (i.e. the classic 'Millstone Grit'). The Staffordshire sandstones are thought to represent small-scale deltaic

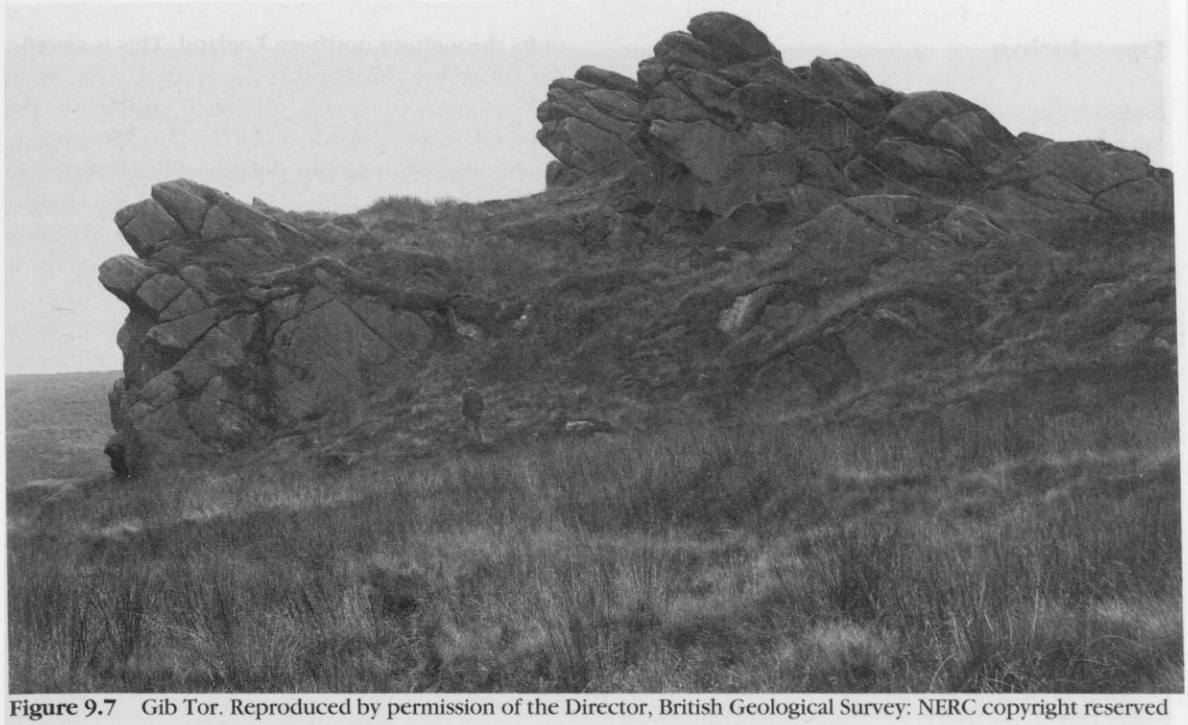

Figure 9.7 Gib Tor. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (L1241).

or turbiditic deposits derived from the Wales-Brabant Barrier (Holdsworth, 1963; Bolton, 1978). Unlike the feldspathic deposits, which were probably derived from the extensive Caledonian Highlands, the deltas spreading out from the much smaller Wales–Brabant Barrier were never able to fill the basin. Thus, until the late Kinderscoutian to early Marsdenian, sedimentation in most of the Staffordshire Basin and Widmerpool Gulf tended to be dominated by mudstones, with only relatively small-scale arenaceous intercalations. At least near Congleton, however, the mudstones are not basinal, but frequently reflect littoral or emergent conditions, which according to Hodson (1959) is a result of the close proximity of the Wales–Brabant Barrier.

Conclusions

Pot Bank Quarry is the best site for seeing the type of sandstone, known locally as crowstone, that characterizes the lower and middle Millstone Grit in Staffordshire. They represent sands deposited in the delta of a river flowing from the south, about 320 million years ago, that brought sediment down from an upland area that extended across parts of the English Midlands (the so-called Wales–Brabant Barrier). They are different in composition from the same-aged rocks found further north in Yorkshire and Lancashire, which are probably the remains of sands deposited by southerly-flowing rivers, and derived from the Caledonian Highlands in northern Scotland.

GIB TOR

Highlights

Gib Tor is the best exposure of the upper Millstone Grit in the Staffordshire area, and demonstrates that this area had become integrated into the main depositional basin of the Central Province. It also provides fine examples of shales showing contorted bedding, possibly the result of penecontemporaneous slumping (Figure 9.7).

Introduction

Exposures along Black Brook (SK 012643–SK 021648), on Goldsitch Moss, about 9 km NNE of Leek, Staffordshire, show the upper part of the Millstone Grit Group in the north Staffordshire area. The only paper describing aspects of the geology of the site is by Cope (1946), although Higgins (1975) makes a passing mention of conodonts found in some of the shales.

Description

Lithostratigraphy

There is no measured log available for this section, but it is probably about 250 m thick. Three major sandstone units can be seen, in ascending order the Roaches Grit, Chatsworth Grit and Rough Rock formations. They are coarse, feldspathic grits, with well developed trough-cross bedding and an erosive base. Palaeocurrent evidence suggests a northerly origin for the sediment. They are thus in the typical facies of the Millstone Grit deltaic sandstones, found throughout the rest of the Central Province.

Each of these arenaceous units is overlain by an interval of more argillaceous strata. Immediately overlying the sandstone are black marine shales. These coarsen upwards into siltstones, and are eventually overlain by the next unit of deltaic sandstone. A characteristic feature of the shales immediately above the marine band is that they are often contorted (Cope, 1946).

Biostratigraphy

There has been no published palaeontological work on this site, other than a mention by Higgins (1975) that conodonts occur in the marine bands (no species were listed). However, the lowest of the marine bands is known to yield *Bilinguites superbilinguis* Bisat, whilst the top one contains *Gastrioceras subcrenatum* (Frech). The middle band is thought to be the Cancellatum Marine Band. The sequence thus ranges from the upper Marsdenian to the lower Langsettian.

Interpretation

This is the best available section through the uppermost Millstone Grit in the Staffordshire area. The sequence exposed at Orchard Farm only shows that part of the succession immediately adjacent to the Cancellatum Marine Band, although it has yielded a greater diversity of fossils from that band.

The upper Millstone Grit of Staffordshire, which is so well seen here, does not differ significantly from coeval strata elsewhere in the Central Province (e.g. at Yeadon Brickworks); the northerly derived feldspathic grits of the Rough Rock and Chatsworth Grit formations (the latter sometimes alternatively known as the Huddersfield White Rock Formation) occur as fairly uniform units throughout northern England. This is significant, since it indicates that the Staffordshire Basin had ceased to be a separate entity by the Yeadonian, and possibly even the late Marsdenian. This contrasts with the position in the early and middle Namurian, such as seen at Pot Bank Quarry, where there is evidence of a quite discrete Staffordshire Basin, being filled by quartzitic sediment from the Wales–Brabant Barrier.

The contorted shales overlying the marine beds can be seen in a number of other localities in Staffordshire (Cope, 1946), but Gib Tor is by far the best. The origin of these structures is still far from clear and they have not been studied in recent years. Cope regarded them as due to tectonic deformation, quoting a variety of lines of evidence such as listric surfaces, bedding plane slickensides, and the absence of erosional truncation. Perhaps most significant, however, was his discovery that the fold axes of the contortions were parallel to the structural axes of the regional folding. In the Langsettian of Pembrokeshire (e.g. at Tenby–Saundersfoot see Chapter 4) there are similar contorted beds just above a marine band, which are now thought to be the result of penecontemporaneous, seismically-triggered slumping of the sediment down a palaeoslope. If the the regional structural axes were already controlling the palaeoslope directions in the late Namurian in the Staffordshire Basin, a sesimic origin for these contorted beds would seem highly likely.

Conclusions

Gib Tor is the best exposure of rocks in the upper part of the Millstone Grit in the Staffordshire area. These rocks, which are just over 310 million years old, include three major sandstones (the Roaches Grit, Chatsworth Grit and Rough Rock) which have been identified over large areas of the northern Midlands and north England, and are the remains of river sands that had been brought down from the Caledonian Highlands in present-day northern Scotland. They differ from the lower part of the Millstone Grit in Staffordshire, which was formed by rivers flowing from the south, and thus reflects a major switch in drainage pattern in the area. Gib Tor also has some fine examples of shales showing contorted bedding, possibly the result of seismic movements shortly after the rocks were deposited.

Figure 9.8 Section on the east bank of the River Noe, 320 m NNE of Fulwood Holmes, exposing Edale Shales (Millstone Grit) with bullions containing the ammonoid *H. subglobossum*. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (L210).

RIVER NOE

Highlights

This is the type and best known locality for the Edale Shales Formation, an interval of highly fossiliferous shales of Chokierian to Kinderscoutian age (Figure 9.8).

Introduction

The bed of the River Noe (SK 091858–SK 110847), near Edale, Derbyshire, is one of the classic exposures of Millstone Grit basinal shales in the the central Pennines Basin. The first detailed description was given by Jackson (1923), and was further studied by Hudson and Cotton (1943, 1945). More recent descriptions are given by Ramsbottom *et al.*, (1967) and Stevenson and Gaunt (1971).

Description

Lithostratigraphy

The sequence represented here is 180 m thick, of which the upper 60 m are Upper Carboniferous (Chokierian to Kinderscoutian). It consists mainly of shales and mudstones of the Edale Shales Formation, for which this is the type section. Two main facies can be recognized: (1) dark grey to black shales, with thin impure limestones or bands of calcareous nodules (bullions) near the base; and (2) soft, medium to light grey shales and mudstones, showing iron staining. This is the basinal mudstone facies described by Collinson (1988), and represents sediments deposited in quiet, relatively deep-water conditions. The alternating facies are thought to reflect variations in water salinity, which in turn was controlled by eustatic changes (Ramsbottom, 1977; Holdsworth and Collinson, 1988).

At the top of the section are sandstones of the Mam Tor Formation. This formation is better seen at Mam Tor and will be discussed further in the next site report.

Biostratigraphy

Ammonoids

Although Chokierian strata are exposed here, and marine bands of this age are seen in the nearby Crowden Brook, no assemblages representing the *H. subglobosum* or *H. beyrichianum* zones have been reported from the River Noe section. In contrast, three bands have been identified here, each yielding ammonoids of the three Alportian zones: the *H. proteus*, *H. undulatum* and *H. prereticulatus* zones.

The Kinderscoutian is also represented here by three bands yielding ammonoids. However, only the uppermost of the three has yielded an index species for one of the zones, namely *Reticuloceras reticulatum* (Phillips), indicating the upper Kinderscoutian.

Conodonts

These have been described by Higgins (1975) from a horizon in the lower Chokierian here, and referred to as sample ED3. A second sample (ED4) from higher in the stage yielded no specimens. Important components were hindeodellids, comprising about half the reported assemblage. Stratigraphically more significant, however, is the presence of declinognathodids, especially *D. inaequalis* (Higgins), *D. lateralis* (Higgins and Bouckaert) and *D. noduliferus* (Ellison and Graves), since these species do not occur below the mid-Carboniferous boundary (Higgins, 1982).

Interpretation

This is the type and by far the best exposure of the Edale Shales Formation. They are fine-grained, basinal deposits, characteristic of the lower Namurian (Pendleian to lower Kinderscoutian) of the Edale Basin. They can be compared with the Sabden Shales Formation of the Craven Basin, as for instance at the River Darwen site (see Chapter 2). However, the Sabden Shales are replaced by northerly derived deltaic sediments rather earlier than the Edale Shales; the former also tend to be more fossiliferous. In the Staffordshire Basin, although some basinal mudstone successions can be seen (e.g. Blake Brook), the same interval has significantly more deltaic sandstones, this time derived from a southerly source (presumably the Wales–Brabant Barrier).

Conclusions

This is the most important locality for rocks known as the Edale Shales Formation. The shales, which are about 315 million years, are the remains of marine muds deposited in front of a large river delta that was progressively spreading southwards at this time. The shales contain abundant fossils of marine organisms, including shells of ammonite-like animals called ammonoids, which allow the rocks to be dated with considerable accuracy.

MAM TOR

Highlights

Mam Tor is the type locality for the Mam Tor Formation, an interval of turbidite deposits derived from the large fluvial deltas further north.

Introduction

A landslip scar (SK 130836) on the south-east side of Mam Tor, 2.5 km west-north-west of Castleton, Derbyshire, provides a spectacular exposure of part of the lower Millstone Grit Group as developed in the Central Province (Figure 9.9). The lower part of the section has been described by Jackson (1927), and the turbidites in the upper part are dealt with in detail by Allen (1960). Other, shorter accounts can be found in Collinson and Walker (1967) and Stevenson and Gaunt (1971).

Description

The lower part of the section belongs to the Edale Shales. Three blocks of shales were described by Jackson (1927), although Stevenson and Gaunt (1971) regard only one of these as *in situ*. This was 18 m of shales with thin siltstone and ironstone ribs, belonging to the basinal mudstone facies of Collinson (1988). They were probably deposited in quiet, relatively deep-water conditions.

Above the Edale Shales are about 120 m of alternating couplets of sandstones and shales belonging

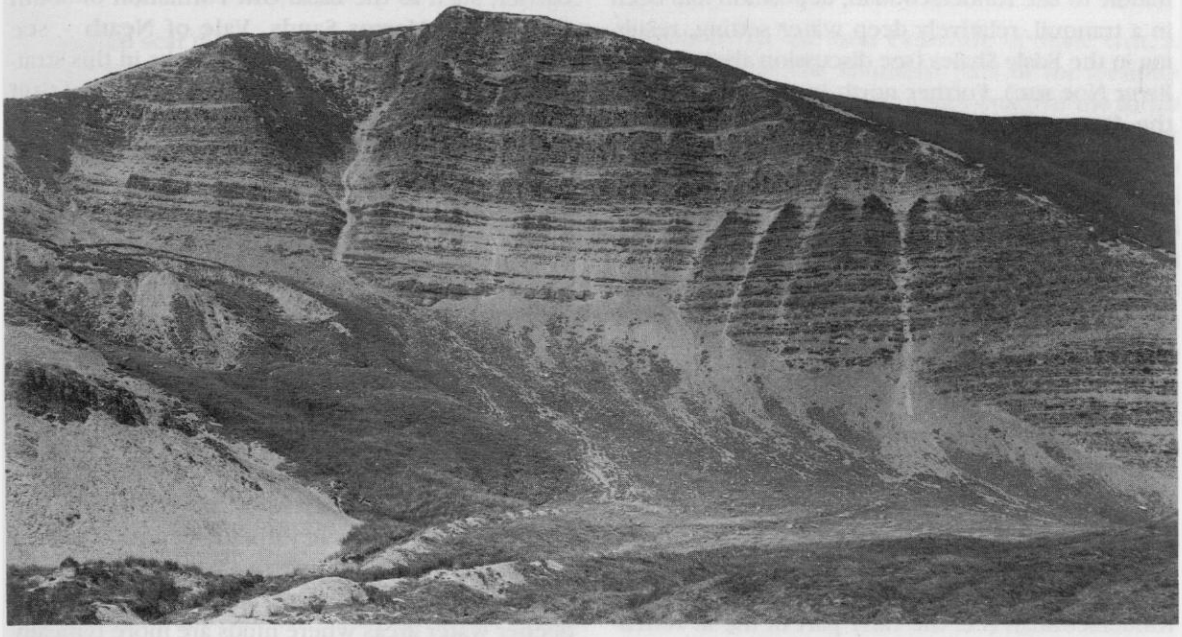

Figure 9.9 Mam Tor Formation (Millstone Grit) exposed at Mam Tor. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (L211).

to the Mam Tor Formation, the lowest part of the Kinderscout Grit Subgroup. The base of each unit is marked by a prominent sandstone with an erosive base and showing a variety of different sole-markings and bottom structures. In the lower 30 m of the formation, these sedimentary structures give a palaeocurrent direction of roughly ENE/WSW, changing to almost N/S at higher levels. Also present in many of the sandstones are penecontemporaneous deformation structures, including convolute bedding, crumpled bedding and slump-ball structures. This prominent sandstone then fines upwards through finer laminated sandstones, siltstones, mudstones and eventually black paper-shales. This type of fining-upwards sequence is typical of distal turbidite deposits. These particular examples are thought to be the result of turbidity currents that originated on the submarine slope of a large delta lying to the north (Allen, 1960; Walker, 1966a; Collinson, 1970).

The only biostratigraphical evidence here is based on marine fossils from the Edale Shales Formation. Jackson (1927) found assemblages belonging to the *E. bisulcatum* (Arnsbergian), *H. proteus* (Alportian) and *R. circumplicatile* (Kinderscoutian) zones in the loose blocks in the base. As this is part of a large landslip, however, it is impossible to be certain how they fit in with the *in situ* parts of the section. The *in situ* block yield limited assemblages from several horizons, included *Reticuloceras* sp., *Vallites* sp., *Caneyella* sp. and *Dunbarella rhythmica* (Jackson), which according to Jackson indicate the *R. nodosum* Zone (middle Kinderscoutian).

From the main part of the landslip scar, the shales immediately underlying the Mam Tor Formation have yielded *Reticuloceras reticulatum* Bisat, *Dunbarella* sp. and *Posidoniella* sp. This clearly belongs to the lower part of the *R. reticulatum* Zone (upper Kinderscoutian). The Mam Tor Formation itself yields few fossils other than bivalves and indeterminable plant fragments. However, from its regional setting, the entire formation probably belongs to the upper Kinderscoutian.

Interpretation

This is the best and most typical exposure of the Mam Tor Formation, and is normally taken as the type section. It is a variable unit; Stevenson and Gaunt (1971) report that only 1.5 km to the east the sandstones have become much thinner and less frequent, while elsewhere the sandstones develop into mappable units.

The Mam Tor beds are thought to be an interval of turbidites in the southern part of the Central Province, and mark a significant change in the sed-

imentary regime. Between the Pendleian and the middle to late Kinderscoutian, deposition had been in a tranquil, relatively deep water setting, resulting in the Edale Shales (see discussion above on the River Noe site). Further north in the basin, and in the Craven Basin, deposits of this age are the remains of Mississippi-sized deltas being produced by large river systems flowing from Caledonian Highlands to the north. During the Namurian, these deltas prograded steadily southwards, but did not reach the southern parts of the Central Province such as the Edale Basin until the very late Kinderscoutian. However, in these more southern areas, the deltas were prefaced by pulses of sands being reworked from the delta front by turbidity currents, the earliest of which produced the Mam Tor Formation. The Mam Tor section not only provides a fine exposure of these turbidites, which have allowed detailed sedimentological analysis (e.g. Allen, 1960), but also establishes the time of the sedimentary change as early Late Kinderscoutian (i.e. the early part of the *R. reticulatum* Zone time).

The nearest comparison with the Mam Tor beds is the Pendle Grit Formation of the Craven Basin and the Longnor Sandstone of the Staffordshire Basin, both being turbidites. However, they occupy different stratigraphical positions, the Pendle Grits being Pendleian and the Longnor Sandstone topmost Kinderscoutian. Elsewhere in Britain, the lower *R. reticulatum* Zone is mainly represented by deltaic sandstones derived from the Caledonian Highlands, such as the Lower Kinderscout Grit of the Craven Basin, or from the Wales–Brabant Barrier, such as the Basal Grit Formation of South Wales (e.g. Marros Sands, Vale of Neath – see Chapter 4). There are basinal deposits in this stratigraphical position, such as in the Widmerpool Gulf (Falcon and Kent, 1960) and in the central part of the South Wales Basin (e.g. Barland Common). However, these are all in basinal mudstone facies, with no evidence of clastic turbidites.

Conclusions

Mam Tor is the most important exposure of rocks of the Mam Tor Formation, which are about 315 million years old. They are alternating beds of sandstones and shales deposited in a marine setting, near the foot of a large river delta. The sandstones are thought to represent turbidite deposits, formed when sediment from the delta was disturbed, possibly by seismic movement, and flowed down into deeper water areas where muds are more typically deposited.

ALPORT CASTLES

Highlights

Alport Castles is the best exposure of Shale Grits, as developed in the southern part of the Pennine Basin.

Figure 9.10 Alport Castles GCR site. Exposures of Millstone Grit. (Photo: R.A. Cottle.)

Introduction

A landslip scar (SK 142914) on the south-west side of Birchenlee Pasture, 12 km ESE of Glossop, Derbyshire provides a large exposure of the Shale Grit Formation of the southern Pennines Basin (Figure 9–10). The geology has been described by Walker (1966a).

Description

About 120 m of strata are exposed here, 115 m of which belong to the Shale Grit. The latter formation consists in essence of numerous mudstone/siltstone–sandstone couplets. The mudstone/siltstone components are typical of the basinal facies of this part of the Millstone Grit, and can be compared with similar deposits such as at Mam Tor (see above), except that there are no fossils.

The sandstones are of two types, which Walker (1966a) referred to as Facies A and Facies C. The main difference is bed thickness, the former being 60 cm thick, the latter anything from 60 cm to 3m thick. Also, Facies C can sometimes be in the form of large channels, although small-scale channelling also occurs in Facies A. Alport Castles is particularly good for showing sedimentary structures in these sandstones units, including sole structures, graded bedding and parallel lamination. Ripple lamination is also sometimes visible, confined to the top part of a sandstone bed. Both sandstone types have been interpreted as turbidites, Facies A being the distal deposits and Facies C the proximal deposits (Walker, 1966a).

The Facies A sandstones dominate the lower half of the Shale Grit, and Facies C the upper half (compare Blackden Brook). In fact, Facies C is totally absent from the lower beds at Alport Castles and would thus be difficult to separate from the underlying Mam Tor Formation.

An unusual lithology present in the upper Shale Grit here are beds of pebbly mudstones, found adjacent to channels. Walker (1966a) believed these to have resulted from gravels falling on to and sinking into soft mud.

The top 15 m seen at Alport Castles are mudstones and a broad sandstone-filled channel, belonging to the Grindslow Shales. They compare closely with the more complete sequence visible at Blackden Brook.

Interpretation

This is by far the best exposure of Shale Grit, as developed in the southern part of the Pennine Basin. Another section through much of the formation occurs at Blackden Brook, but the sedimentology is not so well shown there. In particular, the sedimentary structures within the sandstones are well seen at Alport Castles. This is important, as the combination of erosive bases with sole structures, graded bedding, parallel-lamination through most of the bed, but ripple-cross lamination at the top, all fit into the classic Bouma Model for turbiditic deposits (Bouma, 1962; see also Walker, 1986). As well as being important for understanding the geological history of this part of Britain during the mid-Namurian, as part of the progradation of the Kinderscoutian delta over the area, this site documents one of the best examples of Late Palaeozoic turbidite deposits in north-western Europe.

Conclusions

Alport Castles is one of the most important exposures of rocks of the Shale Grits, which are about 315 million years old. The site has particularly well developed structures in the rocks that show that they were formed by turbidity currents. These currents were generated when seismic movement disturbed sediment in a shallow marine setting (in this case on the front of a river delta), which then rolled down along the sea-bottom into deeper water where the sediment was re-deposited. Alport Castles is one of the best Late Palaeozoic (250–410 million years old) examples of such deposits in north-western Europe.

BLACKDEN BROOK

Highlights

Blackden Brook has the best known sequence of Shale Grit and Grindslow Shale formations in its type area, and shows the transition from basin to delta top conditions as the Kinderscout delta progrades southwards.

Introduction

This small tributary (SK 115884–SK 130893) of the River Ashop descending from Edale Moor, 6 km NNW of Castleton, Derbyshire, exposes a fine

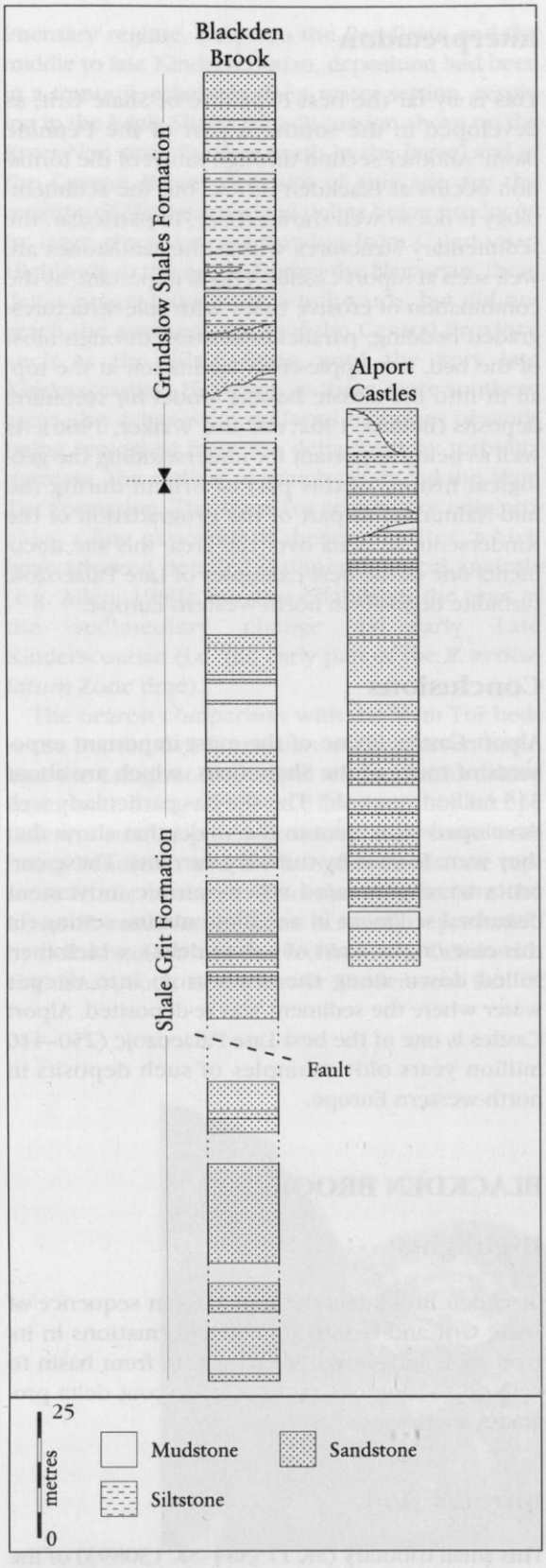

Figure 9.11 Shale Grit and Grindslow Shale formations exposed at Blackden Brook and Alport Castles. After Walker (1966a).

section between the Mam Tor sandstones and the Kinderscout Grit. The geology here has been dealt with by Jackson (1927), Walker (1966a, 1966b) and Collinson (1969, 1970).

Description

The exposed sequence here is about 300 m thick, and belongs mostly to the Shale Grit and Grindslow Shales formations (Figure 9.11). Near the top are pebbly grits of the Kinderscout Formation, but as these beds are seen better at other localities (e.g. Standedge Road Cutting), they will not be dealt with further here.

Jackson (1927) proposed the names Shale Grit and Grindslow Shales, based on sequences in this part of north Derbyshire. It can often be difficult to separate them and Walker (1966a) proposed that they should be united under a single name, the Alport 'Group'. However, most authors continue to recognize the separation.

The Shale Grit beds are 210 m thick here. The base of the formation is not exposed in the brook, but the general field relationships suggest that the lowest exposed strata lie not far above the Mam Tor beds. Particularly in the lower part of the formation, distal turbidite sandstones, identical to those of the Mam Tor Formation, form a prominent part of the succession; these are referred to by Walker (1966a) as Facies A. However, sandstone units, referred to as Facies C by Walker (1966a), become increasingly important going up through the Shale Grit beds (the base of the lowest Facies C sandstone is taken as the base of the Shale Grit Formation). Like Facies A, these units are fining-upwards and have an erosive base, often with sole structures. The main distinguishing feature is the thickness of the Facies C beds (60 cm thick), and that occasionally they show a channel morphology. Collinson and Walker (1967) claim that there are some cases of Facies C beds grading laterally into Facies A beds, and the genesis of the two types are clearly closely related. According to Walker (1966a), the Facies A represents more proximal turbidites, formed in submarine fans immediately in front of the fluvial delta front.

The Shale Grit Formation also includes some beds of mudstone, over 60 cm thick, but these argillaceous units form a less prominent part of the sequence than in the Mam Tor Formation. According to Walker (1966a), they represent basinal mud deposits, formed during quiet intervals between the activities of the turbidity currents.

The overlying Grindslow Shales Formation is much finer grained. The lower 60 m is dominated by mudstones, with some turbidite deposits. Very near the base, the turbidites are thin beds of sandstone, but more typically they occur as large, sandstone-filled channels. According to Collinson (1970) this part of the Grindslow Shales was formed on the delta front or slope. The finer sediment was deposited below wave base from suspension, escaping any significant reworking, but which was periodically cut by channels caused by turbidity currents.

The upper part of the Grindslow Shales is superficially similar to the lower beds described in the previous paragraph, with large sandstone-filled channels in an otherwise fine-grained sequence. However, the finer-grained parts of the sequence are siltstones and show evidence of extensive burrowing. There are also bands showing ripple cross-lamination, which Collinson (1970) interpreted in terms of traction current activity. The channels are larger than in the lower part of the formation, and are filled with coarser and 'cleaner' sandstones, showing no evidence of grading. The upper part of the Grindslow Shales is thus taken to be deposits of the distal part of the delta top; the siltstones being interdistributary bay deposits, and the sandstones fluvial channel deposits (Collinson, 1970).

No fossils have been found here, but work by Jackson (1927), Bisat and Hudson (1943) and Hudson and Cotton (1943, 1945) indicate that that Shale Grit and Grindslow Shale formations lie between the Reticulatum and Gracile marine bands. The entire sequence thus belongs to the middle part of the upper Kinderscoutian.

Interpretation

This is the best exposure of the Shale Grit and Grindslow Shale formations in its type area. The best alternative site is probably the Grindsbrook section on the other side of Edale Moor (Collinson and Walker, 1967), but this does not show such a complete succession of the Shale Grit, nor the upper, delta top facies association of the Grindslow Shale. An extensive exposure of Shale Grit can be seen at Alport Castles, showing some details not visible here, but it does not expose the Grindslow Shale.

The sequence at Blackden Brook clearly reveals the transition from distal turbidites, to proximal turbidites/submarine fan deposits, to delta front, and eventually to delta top deposits. When seen together with the nearby River Noe and Mam Tor sites, it is possible to chart the progressive southwards progradation of the Kinderscout delta over this part of the Pennine Basin. Such turbidite-fronted deltas are the major type of basin-fill in the Central Province during the Namurian (Collinson, 1988), and other examples of the migration of such a delta over an area are known in the Pendleian of the Craven Basin (Baines, 1977) and the Marsdenian of the North Staffordshire Basin (Jones, 1980). However, this example from the Kinderscoutian of the southern Pennine Basin is on the whole better exposed, and has certainly been the subject of far more intensive investigation.

Conclusions

Blackden Brook is the best known exposure of rocks of the Shale Grit and Grindslow Shale formations. These rocks, which are about 318 million years old, are the remains of sediments that formed as a large river delta (known to geologists as the Kinderscout delta) migrated southwards over this area.

STANDEDGE ROAD CUTTING

Highlights

Standedge Road Cutting provides the most complete and well exposed sequence through the Kinderscout Grit, including both upper and lower members, and the intervening Coreticulatum (Butterly) Marine Band.

Introduction

This cutting (SE 018095–SE 023098) along the A62 road, 3 km south-west of Marsden, West Yorkshire, provides an extensive section through the Kinderscout Grit Formation, as developed in the Pennine Basin, and not far (*c.*15 km north) from the type area of Kinder Scout. The best description of the site is to be found in Stevenson and Gaunt (1971).

Description

Lithostratigraphy

Exposed here are about 120 m of mainly

arenaceous strata belonging to the Kinderscout Grit. Five cycles can be recognized, consisting of coarse conglomeratic grits at the base, fining-upwards into flaggy fine-grained sandstones and siltstones. The lower parts of each cycle often show cross-bedding, whilst the upper beds are mainly flat-bedded. Trails, burrows, and casts and adpressions of stems such as *Calamites* occur commonly in the flaggy beds.

Between each sandstone cycle is a bed of dark grey shales, sometimes associated with a seat earth and thin coal. Between the upper two cycles there is also a thin marine band, known as the Butterly Marine Band (see below), which serves to divide the Kinderscout Grit into two members.

These beds have long been recognized to be fluvial in origin, probably derived from the north (Trotter, 1951; Holdsworth, 1963; Collinson, 1968; McCabe, 1975, 1977). According to Collinson (1988) they were formed on the top of an extensive, turbidite-fronted delta system that prograded southwards over the Central Province during the middle Namurian (the so-called Kinderscout Delta), and represent major distributary channels that were rapidly filled by sand during flood-events. After the channel was filled, there followed an interval of emergent conditions allowing some vegetation to become established and even peat-development to occur, although in at least one case the quiescent period was disrupted by a marine incursion.

Biostratigraphy

The Coreticulatum (Butterly) Marine Band, which divides the upper and lower Kinderscout Grit, is a persistent feature over large areas of the Central Province. In some areas, such as just north of Manchester, the band contains ammonoids of the *Reticuloceras coreticulatum* Subzone, which indicates the uppermost Kinderscoutian. Here, however, the assemblage is restricted to marine bivalves and brachiopods. The nature of the exposure at Standedge hinders any large-scale collecting, but nearby Red Brook Clough as yielded an extensive assemblage, including *Lingula mytilioides* Sowerby, *Orbiculoidea nitida* (Phillips), *Aviculopecten dorlodoti* Delepine, *Edmondia josepha* De Koninck, *Retispira undata* (Etheridge), *Sanguinolites ovalis* Hind and *S. tricostatus* (Portlock) (see Wray, 1929; Ramsbottom *in* Stevenson and Gaunt, 1971).

Interpretation

This is one of the most complete and easily accessible sections through the Kinderscout Grit in the Pennine Basin, and shows details of the sedimentology particularly well. The nearest comparison is with exposures near Kinder Scout itself, such as in the upper reaches of Grindsbrook near Edale (Collinson and Walker, 1967). However, these do not show the full sequence through the Kinderscout Grit as is seen at Standedge. The upper part of the Crimsworth Dean sections also passes through the entire Kinderscout Grit, but the exposure is far less complete and is disrupted by faults.

This is the last member of a sequence of sites representing the gradual southwards progradation of the Kinderscout Delta over the Pennines Basin; the others are River Noe (basinal deposits), Mam Tor and Alport Castles (turbidites), and Blackden Brook (delta front deposits). It is one of the best exposed and studied examples of a large turbidite-fronted delta of any geological age in Britain, and is of great significance for understanding how such sequences are generated in a general context, as well as being important for understanding the geological evolution of this part of Britain during the Carboniferous.

Conclusions

Standedge Road Cutting shows the most complete succession through an interval of rocks known as the Kinderscout Grit, which is one of the thickest sandstone units in the Millstone Grit of the Pennines. It represents deposits formed in a large river delta (often referred to as the Kinderscout delta), that extended southwards over the area about 318 million years ago. The grit typically consists of two discrete beds of coarse sandstone, separated by marine shales known as the Butterly Marine Band, all of which can be seen at Standedge.

CRIMSWORTH DEAN

Highlights

Crimsworth Dean is the best site for demonstrating the progradation of the Kinderscout Delta across the eastern part of the Pennine Basin during the Kinderscoutian.

Crimsworth Dean

Introduction

Exposed along this stream near Hebden Bridge (SD 988292–SD 994325), 20 km west of Bradford, West Yorkshire, are sandstones and shales belonging to the Todmorden, Hebden Bridge and Kinderscout Grit formations. They are on the western margins of the Central Province, not far from the positive area known as the Rossendale Block. Fossils from here were recorded by Bisat and Hudson (1943) and the geology described by Wray *et al.* (1930), Stephens *et al.* (1953) and McCabe (1975, 1977).

Description

Lithostratigraphy

The sequence here is only incompletely exposed and is disrupted by small faults, but is probably about 200 m thick. The faulting has caused some confusion as to the exact sequence and the identity of some of the sandstone units, particularly towards the top of the section. The most recent analysis of the field evidence is by McCabe (1975), and his conclusions form the basis of the following summary.

The lower part of the section belongs to the Todmorden Formation and consists mainly of shales with a single sandstone in the upper part known as the Todmorden Grit; the latter is thought to be the equivalent of the Caley Crags Grit of Wharfedale (Ramsbottom, 1977). They are believed to represent deep water, basinal muds together with a turbiditic sandstone (McCabe, 1975), and thus compare with the Edale Shales and Mam Tor formations in the Edale Gulf (see accounts of River Noe and Mam Tor earlier in this chapter).

The Todmorden Grit is overlain by an interval of shales and siltstones, thought by McCabe to be delta slope deposits, and thus similar to the Grindslow Shales Formation of the Edale Basin. These are in turn overlain by thick sandstones of the Kinderscout Grit Formation. As elsewhere, the latter is divided into two distinct leaves, separated by shales, in this case *c.*30 m thick.

Biostratigraphy

Only marine animal fossils have been reported from here. Three marine bands have been identified in the Todmorden Formation, below the grit (Bisat and Hudson, 1943). They all contain essentially similar assemblages, dominated by *Reticuloceras reticulatum* (Phillips) and *Vallites striolatum* (Phillips). The uppermost band, from just below the Todmorden Grit, yields *Hudsonoceras ornatum* (Ford and Crick).

The Hebden Bridge Formation includes only one marine band, although the fine preservation of the fossils in limestone bullions in the lower part of the band makes it of some interest. The goniatites identified from here include *Reticuloceras reticulatum* (Phillips) and *Vallites striolatum* (Phillips), and probably belong to the upper part of the *R. reticulatum* Zone.

In the shales separating the two sandstone members of the Kinderscout Grit Formation, Stephens *et al.* (1953) report *Reticuloceras coreticulatum* Bisat, indicating the topmost subzone of the Kinderscoutian.

Interpretation

This is the best exposure for demonstrating the progradation of the Kinderscout Delta over the eastern part of the Central Province. It can be compared with the sequence of sites demonstrating the same event in the Edale Gulf (River Noe, Mam Tor, Blackden Brook, Alport Castles), where the same transition from basinal deposits, through turbidites and delta slope deposits to delta top deposits can be observed. The fact that the sequence can be observed at a single site, rather than having to be pieced together from four geographically separated locations, gives Crimsworth Dean some advantage. Also, the latter has rather better biostratigraphical control, particularly in the upper part of the section. However, exposure is never as good as in the Edale sites, and the problem of faulting makes it difficult to be certain that the sequence has been correctly reconstructed. Nevertheless, it is of considerable interest to be able to demonstrate that the delta evolved in the same way at the same time over relatively wide areas of the Pennine Basin.

Conclusions

Crimsworth Dean is an important exposure of part of the Millstone Grit in Yorkshire. It is one of the few places where the whole history of the progressive migration of the Kinderscout Delta over the area about 314 million years ago can be charted at a single locality.

DERBY DELF QUARRY

Highlights

Derby Delf Quarry provides one of the best exposures of giant cross-bedding in the Kinderscout Grit Formation, and has been important for showing that it was formed mainly as transverse bars in a large river system.

Introduction

This disused quarry (SE 017160) on the north side of Booth Wood Reservoir, 11 km west of Huddersfield, West Yorkshire, provides a laterally extensive exposure of sandstones of the Kinderscout Grit Formation, as developed in the central part of the Central Province. The geology is described by McCabe (1975, 1977).

Description

The exposed sequence is 40 m thick, and consists mainly of sandstones. There is no biostratigraphical control, but mapping by McCabe (1975) has demonstrated that they belong to the Kinderscout Grit Formation, and most likely to the lower member.

Two facies were identified here by McCabe (1975, 1977). The most spectacular has very large-scale cross-bedding, which has been referred to by McCabe as 'giant cross beds'. Such 'giant cross beds' were defined by McCabe as having sets at least 3 m thick, although at Derby Delf they are 34 m or more thick. The sandstones in this facies are generally coarse, often with small pebbles and granules, and occasional ferruginous horizons.

The second facies was referred to as undulatory bedded sandstones, and occurs in the lower part of the sequence here, separated from the facies with 'giant cross beds' by an erosion surface. The individual beds vary markedly in thickness along their length, usually in the range of 10–20 cm. The beds are coarse-grained and massive, except for some cross-lamination on the western side of certain bed undulations.

Interpretation

This is a unique site for demonstrating features of the sedimentology of the Kinderscout Grit, in particular the association between the 'giant cross beds' and undulatory beds facies. The type of large-scale cross-bedding visible here has been known in the Kinderscout Grit for a long time and was interpreted as being generated in delta lobes, advancing in response to eustatic sea-level changes (Collinson, 1968, 1969). However , McCabe (1975, 1977) noted that there are no fine-grained, pro-delta type deposits associated with the sandstones, and also that the undulatory beds are atypical of deltaic sequences. He instead interpreted the Kinderscout Grit as being deposited in large fluvial channels, probably as transverse bars in a braided river setting; the cross-bedded units represent the body of the bars, whilst the undulatory beds are the remains of sand ribbons formed as bar-front spurs. McCabe argued that the bars were probably attached to the sides of the bank, although Collinson (1988) maintained that some may also have been mid-channel forms. Their progressive migration downstream resulted in the characteristic large-scale cross-bedding.

The size of river required to generate such deposits in the way suggested by McCabe is considerable. Channel widths of up to 2 km and depths of 40 m have been suggested. If correct, it confirms the scale of the fluvio-deltaic system that was responsible for the deposition of the Millstone Grit Group in the basins of the Central Province.

Conclusions

Derby Delf Quarry is the best exposure of giant cross-bedding in the Kinderscout Grit Formation, in rocks which are about 318 million years old. They suggest that the rocks were formed in a large river system, with channels up to possibly 40 m deep.

LADCASTLE AND DEN QUARRIES

Highlights

Ladcastle and Den Quarries is the best available exposure showing a succession of channel-fills in the Kinderscout Grit, demonstrating that they are the result of large-scale bedform migration.

Introduction

Disused quarries (SD 994059) on the west side of the Huddersfield Manchester railway line at

Upper-mill, 8 km east of Oldham, Greater Manchester, provide extensive exposures in the lower member of the Kinderscout Grit Formation. The geology is described by McCabe (1975).

Description

Exposed is a sequence about 30 m thick, consisting primarily of coarse sandstones. Three main facies are recognizable. The most distinctive are sandstones showing the 'giant cross beds' as defined by McCabe (1975, 1977), up to 12 m thick. Of particular interest here is the presence of small, internal cross-beds (intrasets of Collinson, 1968), suggesting current flow up, down and along the foreset slopes.

These cross-bedded units are associated with more massive, coarse-grained, more pebbly sandstones. They mostly underlie the 'giant cross beds' facies with a sharp, near horizontal contact, but sometimes the two pass laterally into one another. McCabe (1975) interprets them as trough deposits of large bedforms, with the change from the 'giant cross beds' facies representing a readjustment to changes in water flow.

The third facies are fine sandstones and siltstones, with parallel and ripple lamination. They are thought to be overbank and crevasse-splay deposits formed between the distributary channels.

According to McCabe (1975), the sequence can be interpreted in terms of the successive erosion and infilling of four separate channels. In each case, the infill follows the same general pattern. At the base of the channel is a unit of massive, coarse-grained sandstone, which is overlain by an interval of sandstones showing the 'giant cross beds'. This in turn is overlain by a unit of inter-channel deposits, the top of which is marked by an erosion surface.

Interpretation

This site clearly has to be seen in the same context as Derby Delf (see above). The 'giant cross beds' are not as well developed as at Derby Delf, where they are more than 34 m thick. Also, the undulatory bedded sandstones, representing the deposits of the bar spurs, are not visible here. However, the inter-channel deposits, not seen at Derby Delf, are well preserved. Furthermore, instead of part of just one channel-fill being present, as in most other exposures of these strata, a succession of four discrete channel-fills can be identified. This is important for confirming that they were formed by large-scale bedform migration, in this case probably migrating transverse bars in a large, braided river system (McCabe, 1975, 1977), rather than delta-lobe deposits as previously thought.

Conclusions

Ladcastle and Den Quarries is an important site for showing depositional structure within the Kinderscout Grit. It confirms that these rocks are the remains of large river deposits, formed about 318 million years ago.

GREAT DIB WOOD

Highlights

Great Dib Wood is the only good exposure of the Otley Shell Bed, a source of unusually well preserved marine fossils, including some of the youngest known trilobites in Britain.

Introduction

A natural cliff (SE 199443) on the south side of Great Dib Wood, 1 km south of Otley, West Yorkshire exposes the Otley Shell Bed, a localized fossiliferous deposit in the middle Namurian of Wharfedale, just south of the Askrigg Block. The geology has been described by Stephens *et al.* (1953) and Walker (1964b).

Description

Lithostratigraphy

About 26 m of strata are exposed here. Most of the sequence consists of sandstone, the lower 10 m belonging to the Addlethorpe Grit and the upper 10 m the Caley Crags Grit. Both are coarse, well bedded sandstones, with thin mudstones and seat earths. Between the two major sandstone units is the interval of limestones, thin sandstones and uncompacted mudstones known as the Otley Shell Bed.

Biostratigraphy

The shell bed has yielded an extremely diverse assemblage of marine animal fossils, including articulate and inarticulate brachiopods (*Lingula*, *Orbiculoidea*, *Chonetes*, *Spirifer*, *Crurithyris*, *Productus*), bivalves (*Dunbarella*, *Aviculopecten*,

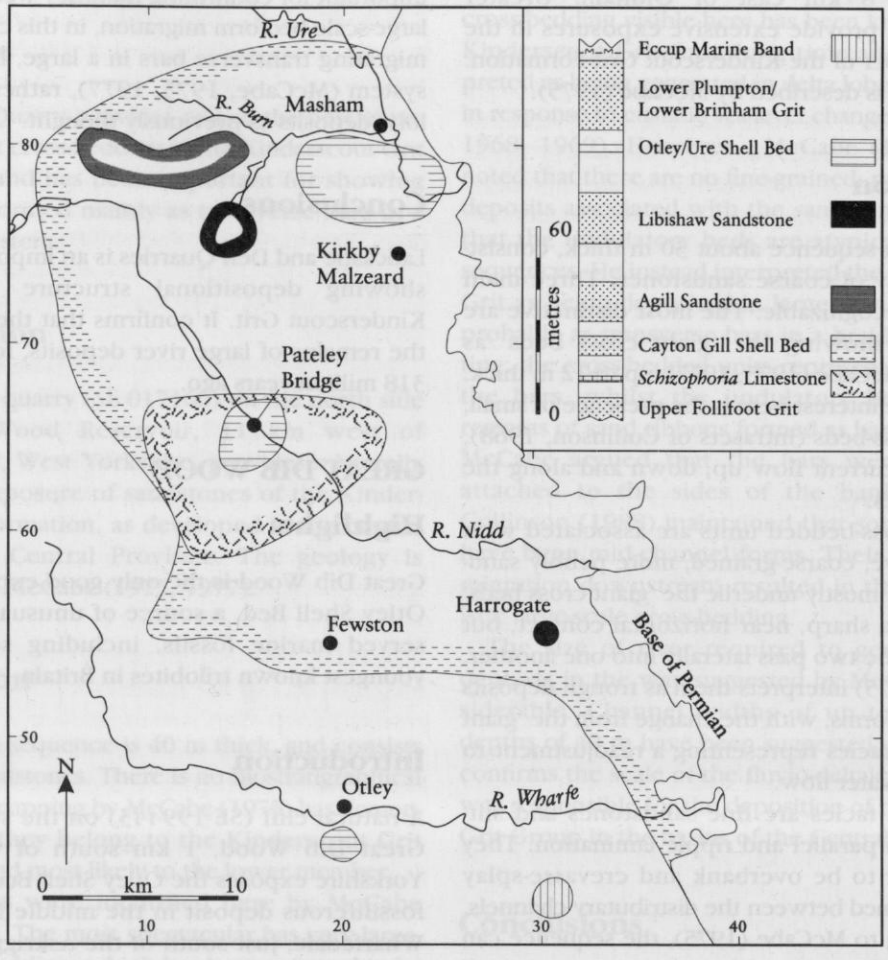

Figure 9.12 Geographical distribution of some of the localized shell beds in the Kinderscoutian of the Central Province. Based on Ramsbottom *et al.* (1974, fig. 30).

Allorisma, *Palaeolima*), gastropods (*Nauticopsis*, *Zygopleura*, *Hesperiella*, *Phymatifer*), trilobites, ostracods, corals, polyzoa and fish fragments. There are also numerous ammonoids of the *Reticuloceras nodosum* Zone.

The site is mentioned in Higgins' (1975) study of the conodonts of the Millstone Grit of northern England, and referred to as site K11. However, no taxa are listed from here.

The preservation of the shelly fossils is particularly good, since the sediment has been subjected to relatively little compaction. This is thought to have been a consequence of the early cementation of the unit.

Interpretation

This is the only good exposure of the Otley Shell Bed, whose aerial distribution seems to be restricted to the immediate vicinity of The Chevin at Otley (Figure 9.12). It has an unusual lithology for the British Millstone Grit, whose marine bands are usually more laminated and darker in colour, representing relatively anaerobic conditions. The Otley bed, in contrast, seems to represent fully aerobic conditions, in a shallow, open-marine setting. The closest comparison is with the Cayton Gill Shell Beds, in the lower Kinderscoutian of the Harrogate area (Fox-Strangeways, 1908).

The fossil fauna has not yet been the subject of a comprehensive monographic treatment, and so its full significance has yet to be established, beyond the fine quality of the preservation. One point of interest that has already been revealed, however, is the presence of trilobites, this being one of the stratigraphically highest assemblages to have yielded such arthropods at surface in Britain.

Conclusions

Great Dib Wood is the only good exposure of an interval of limestones, thin sandstones and mudstones, known as the Otley Shell Bed. The rocks are about 315 million years old, and are a source of unusually well preserved marine fossils, including some of the youngest known trilobites in Britain.

COCKWOOD GORGE

Highlights

Cockwood Gorge is the best available, continuous sequence through the upper Kinderscoutian and lower Marsdenian. It has also provided important fossil bivalves, that were probably ancestral to the non-marine bivalves of the Coal Measures.

Introduction

This section along Sabden Brook (SD 747341–SD 750350), between Cock Bridge and Parkhead, 7 km north of Accrington, Lancashire, shows an almost complete sequence from the lower Kinderscout Grit to the Revidge Grit, as developed in the Craven Basin. The geology of the site is described by Earp *et al.* (1961), whilst aspects of the palaeontology are dealt with by Eagar (1977).

Description

Lithostratigraphy

The sequence here is about 180 m thick. The lower part of the section is in coarse sandsdtones, thought to be the lower member of the Kinderscout Grit Formation (Earp *et al.*, 1961). This is overlain by about 19 m of mainly shales and thin sandstones, one of the latter being gainster-like and overlain in turn by a thin coal. The shales are dark grey to black, and include two marine bands with limestone bullions.

There then follows 40 m of medium to coarse sandstones, belonging to the upper member of the Kinderscout Grit. It is a typical development of this member, with occasional coarse, pebbly horizons, and showing a variety of bed forms, including massive, cross-bedded and flaggy.

The succeeding 110 m see a return to more argillaceous strata. They can be divided into two discrete cycles. Both have marine shales at the base, the lower one 15 m thick and with abundant limestone bullions, the upper one only 0.1 m thick. Above each marine band, the cycles fine upwards from fine grey, carbonaceous sandstones, through siltstones into shales. The more sandy units often include compressed plant stems.

The top of the section passes up into a coarse-grained, pebbly sandstone with an erosive base, belonging to the Revidge Grit Formation.

Biostratigraphy

Biostratigraphically diagnostic fossils have only been reported from the four marine bands (Hodson, 1942; Earp *et al.*, 1961). The lowest band, immediately above the lower Kinderscout Grit, yields *Reticuloceras reticulatum* (Phillips), *R. davisi* Bisat and *Dunbarella speciosa* (Jackson), while the upper one yields *Reticuloceras coreticulatum* Bisat, *R. reticulatum*, *Vallites striolatum*, *Posidonia obliquata*, *P. minor*, *Pseudocatastropoceras rawsoni*, *Anthracoceratites* sp. and turreted gastropods. On the face of it, the lower of these bands suggests the *R. reticulatum* Subzone. However, the Reticulatum Marine Band containing this subzone normally occurs below the lower Kinderscout Grit, whereas the marine band at Cockwood Gorge is above it. Instead, the record of *R. reticulatum* probably refers to the so-called 'late form' of that species, which is often associated with *R. coreticulatum* Bisat. It is, therefore, possible that the two marine bands between the leaves of the Kindserscout Grit both belong to the *R. coreticulatum* Subzone.

The 15 m of marine strata overlying the Kinderscout Grit can be divided into two parts. The lower part contains a diverse assemblage of shallow marine bivalves, including *Sanguinolites variabilis* M'Coy, Cf.*Sanguinolites* sp., *Aviculopecten* aff. *delepinei* Demanet and *Modiolus* sp. The *Sanguinolites* have been studied in detail by Eagar (1977), who has shown a continuous range in shell morphology similar to that found in the non-marine *Carbonicola* of higher strata. Eagar argued that the non-marine bivalves, that are so abundant in the Coal Measures, originated from *Sanguinolites* ancestors probably some time in the late Kinderscoutian.

The upper part of these marine strata contains a deeper-water assemblage, including *Bilinguites gracilis* Bisat (both 'early' and 'late' forms), *Caneyella rugata*, *Anthracoseratities deansi*, *Dunbarella speciosa* (Jackson) and *Orthoceras* sp.

(Hodson, 1942; Earp *et al.*, 1961). It clearly belongs to the *B. gracilis* Zone, normally taken to mark the base of the Marsdenian Stage. In this case, however, it is not clear whether the stage boundary should be placed at the base of the ammonoid-bearing interval, or at the base of the entire marine unit.

The topmost marine band is only very thin due to much of the horizon being slumped out, but has yielded the goniatite *Bilinguites bilinguis* (Salter), thus indicating middle Marsdenian.

Interpretation

This site provides an important, more or less complete section through the upper Kindserscoutian and lower Marsdenian of the Central Province. Other sites demonstrate parts of the sequence. For instance, the Coreticulatum Marine Band can be seen at Crimsworth Dean, and the Gracilis and Bilinguis marine bands at Park Clough, Rake Dike and Pule Hill. However, this is the only place where the sequence can be observed as a whole. The cyclicity in the fine-grained strata above the Kinderscout Grit is of particular interest, demonstrating the essentially shallow-water nature of much of these deposits, and thus contrasting with the marine-basinal deposition seen lower in the Millstone Grit. Also of interest is that it shows aspects of these strata specific to the Craven Basin, in particular the Revidge Grit and how it relates to the underlying Kinderscout Grit.

This has also proved to be one of the best sites for studying the marginal marine bivalves found in the Millstone Grit. The diverse assemblage found here is ideally suited to the morphometric-type study undertaken by Eagar (1977), and has provided vital data for understanding how the non-marine *Carbonicola* assemblages of the lower Westphalian evolved from their *Sanguinolites* marine ancestors.

Conclusions

Cockwood Gorge shows the best available, continuous sequence through rocks of late Kinderscoutian to early Marsdenian age (about 315 million years old) in northern England. The site has yielded important fossil shells of bivalves, that were probably ancestral to the freshwater bivalves that formed a major component of the faunas of the later Coal Measures swamp forests.

RAKE DIKE

Highlights

Rake Dike shows an important fossiliferous sequence through the Marsdenian Stage.

Introduction

This is one of the classic, fossiliferous sequences through the Marsdenian Stage. The geology of the site, which lies along a stream (SE 094048–SE 112058) running into Brownhill Reservoir, 11 km south of Huddersfield, West Yorkshire, is described by Green *et al.* (1878) and Bromehead *et al.* (1933). The biostratigraphy is discussed by Bisat (1920, 1924) and Ramsbottom (1969a).

Description

Lithostratigraphy

About 150 m of Millstone Grit are exposed here, ranging from the top part of the Kinderscout Grit to the base of the Huddersfield White Rock. It represents sediments deposited near the southern margins of the Huddersfield Basin. The Kinderscout Grit is not fully exposed, but a borehole drilled as part of the reservoir construction revealed about 75 m of the formation (Bisat, 1924). It includes both coarse, massive grits and finer grained, flaggy sandstones. There are also some shale partings, including one which is 9 m thick; although it has not yielded fossils, it is thought that this thick shale is a correlative of the Coreticulatum Marine Band, and thus marks the division between the upper and lower members of the Kinderscout Grit. A thin coal was reported from the top part of the formation.

The overlying 120 m consist of alternating sandstones and marine shales. There are three main sandstone bands in this part of the succession, known in ascending order as the Readycon Dean Grit, Heydon Rock and Beacon Hill Flags. The former is a coarsening upwards unit with burrowing in the upper part and an eroded top; the others are fine-grained flaggy units. They all probably represent small-scale sheet deltas, of the type described by Collinson (1988).

The top of the section is marked by a thick sandstone. It is poorly exposed here, although the base is clearly marked by a line of springs along the hillside. Its field relationships clearly point to it being the Huddersfield White Rock Formation.

Biostratigraphy

Only marine fossils have been reported from this locality to date. The lowest occurrences are in the shales between the Upper Kinderscout Grit and the Readycon Dean Grit. The commonest fossil is the ammonoid *Bilinguites gracilis* Bisat, which was first described from this locality by Bisat (1924) as *R. reticulatum* (Phillips). From an exposure of the same bed at nearby Holm Wood Dyke, Bromehead *et al.* (1933) also reported *Dunbarella* sp. and *Posidoniella* sp.

The shales both below and above the Heydon Rock yield the ammonoid *Bilinguites bilinguis* (Salter), and thus belong to the zone of that name. This was also described for the first time from this locality by Bisat (1924), as *R. reticulatum* (Phillips) mut. β.

The shales above the Beacon Hill Sandstone yield a more brackish assemblage, restricted to inarticulate brachiopods (*Lingula, Orbiculoidea*). By comparing them with the sequence in nearby Ramsden Clough, Bisat (1920) argued that the shales probably belong to the *Bilinguites superbilinguis* Zone.

Interpretation

This is one of the best exposed sections through the Marsdenian Stage in Britain, and includes fossil faunas representing two of the three included zones. It is also in what Bisat (1924, 1928) regarded as the type area for the stage. Ramsbottom (1969a) went further, to propose Rake Dike as a potential stratotype, but it is not an ideal candidate, as the level which would have defined the stage base (the marine shale yielding *B. gracilis* Bisat) is not well exposed. Consequently, the section at Park Clough, although not showing such a complete section, was chosen by the ICCS as the officially recognized Marsdenian stratotype (Ramsbottom, 1981).

There is some comparison with sections in South Wales, particularly on the north crop of the coalfield (e.g. Vale of Neath, see Chapter 4). Both have similar sequences of marine bands, and have sandstones representing similar southwards prograding deltas. However, they were formed in quite different palaeogeographical settings, and represent sediments with totally different provenances the Wales–Brabant Barrier for South Wales and a positive area somewhere to the north for the Pennines.

Although much of the section consists of marine shales, there are three sandstone bands, which probably represent sheet delta deposits. They are characteristic of the Marsdenian in the Central Province, and contrast with the larger-scale, turbidite-fronted deltas found lower in the Millstone Grit (e.g. the Kinderscout delta).

Conclusions

Rake Dike shows an important sequence of fossiliferous rocks of Marsdenian age (just over 317 million years old). Ammonoids are particularly abundant here.

HODGE CLOUGH

Highlights

Hodge Clough provides the most complete and fossiliferous sequence through the upper Marsdenian Stage in western and central Europe, and has yielded fossil faunas representing all of the known biostratigraphical units in this interval.

Introduction

A typical sequence through the upper Marsdenian of the Rossendale Basin is exposed along a small tributary of the River Irwell (SD 785193), about 4 km SSE of Haslingden, Lancashire (Figure 9.13). The geology is described by Wright *et al.* (1927) and Ramsbottom (1969a).

Description

Lithostratigraphy

The exposed sequence here is 50 m thick. At the base are 20 m of fine-grained sandstone, capped by a seat earth and thin coal. It is known as the Helmshore Grit Formation, and is a good example of deposits formed in a sheet delta environment as described by Collinson (1988).

The coal above the Helmshore Grit is in turn overlain by about 25 m of mainly argillaceous strata, and includes several marine bands (see below). Towards the top of this part of the sequence, the beds become more silty and include hard ribs of what Wright *et al.* (1927) called siliceous ironstones.

The rest of the sequence is rather poorly exposed, but includes some thin ganister-like sandstones which may correlate with the Hazel Greave Grit Formation further east, and shales which include two marine bands.

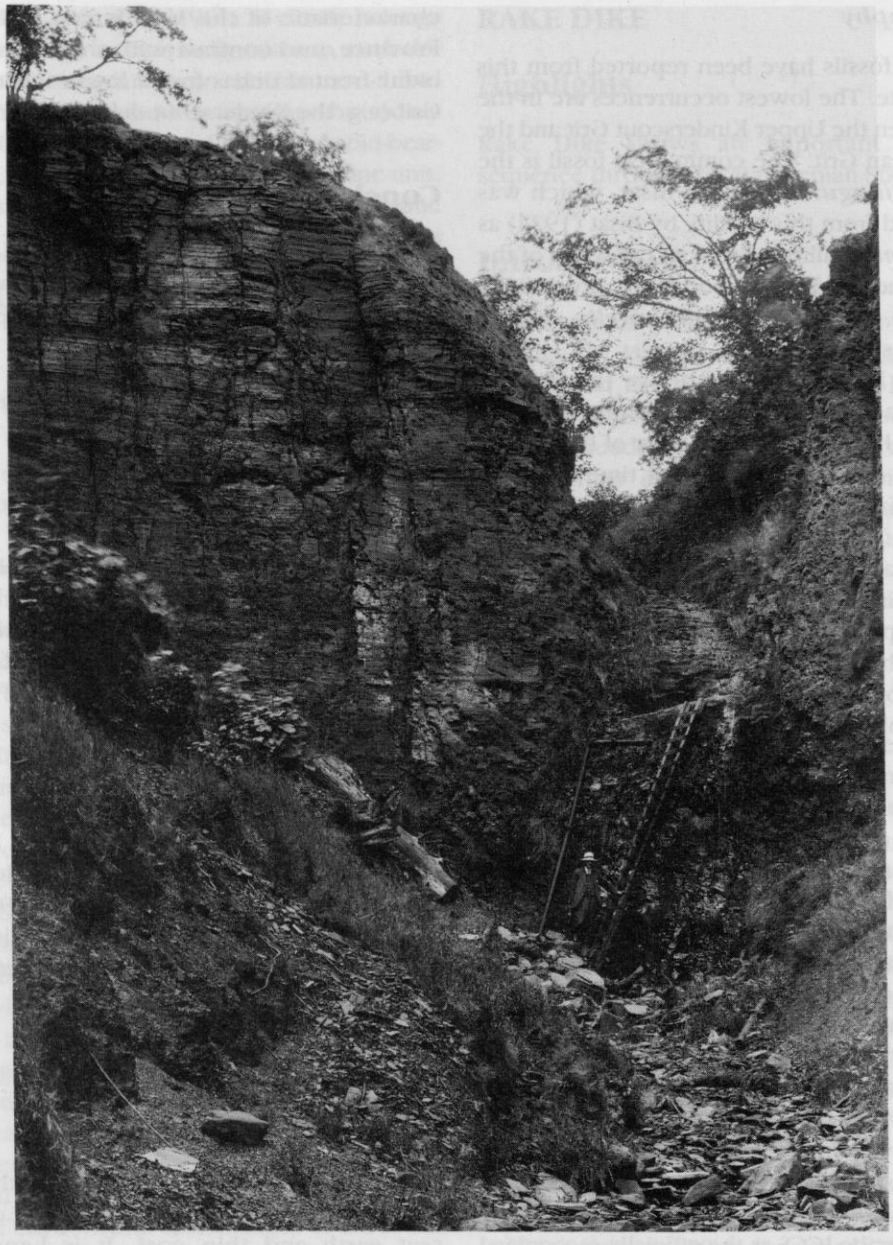

Figure 9.13 Hodge Clough. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A2523).

Biostratigraphy

This site has yielded marine animal fossils from four discrete marine bands. The lowest band, a short distance above the Helmshore Grit Formation, has yielded *Bilinguites bilinguis* (Salter) (*Reticuloceras reticulatum* mut. β *sensu* Wright *et al.*, 1927) and *B. eometabilinguis* (Ramsbottom), and thus the lower subzone of the *B. bilinguis* Zone. Fourteen metres above this, Ramsbottom (1969a) records ammonoids including *B. metabilinguis*, which this time indicate the upper subzone of the *B. bilinguis* Zone.

In the poorly exposed shales at the very top of the section, Ramsbottom (1969a) has reported two closely-spaced marine bands containing fossil faunas belonging to the *Bilinguites superbilinguis* and *Verneuilites sigma* subzones.

Interpretation

This site should be seen in conjunction with Rake Dike (see above), since together they provide an almost complete section through the Marsdenian

Stage of the Central Province. As pointed out by Ramsbottom (1969a), no other site shows such a complete and fossiliferous section through the upper Marsdenian as Hodge Clough. Only the topmost Marsdenian is absent, and this does not include any significant marine horizons. Nowhere in Britain can all the major marine bands be seen at a single locality (cf. Tenby–Saundersfoot, Vale of Neath, see Chapter 4), while sections in western and central Europe suffer from much poorer exposure.

Conclusions

Hodge Clough is the best exposure of fossiliferous upper Marsdenian rocks in western and central Europe (just over 316 million years old).

PULE HILL

Highlights

Pule Hill is the best known exposure of the Gracilis and Bilinguis marine bands in Europe.

Introduction

This stream section and disused quarry (SE 033103), 2 km SW of Marsden, 10 km WSW of Huddersfield, West Yorkshire, shows part of the upper Millstone Grit of the Huddersfield Basin (Figure 9.14). The palaeontology, which is the main interest here, has been described by Bisat (1924).

Description

Lithostratigraphy

The exposed sequence here is about 50 m thick. The lower 20 m are shales, mainly medium to dark grey, but with two darker bands representing marine deposits. The overlying strata are massive or coarsely cross-bedded sandstones, belonging to the Pule Hill Grit Formation. This is almost certainly a lateral equivalent of the Heyden Rock Formation to the south, and is probably part of a sheet-delta complex that prograded over the Huddersfield Basin from the north during the middle Marsdenian.

Biostratigraphy

Both marine bands here are reported to contain *Anthracoceras* sp., *Dunbarella* sp. and *Caneyella* sp. In addition, the lower one yields *Bilinguites gracilis* (Bisat), while the upper one contains *Bilinguites bilinguis* (Salter). The lower band is thus interpreted as the Gracilis Marine Band and the upper band as the Bilinguis Marine Band.

This the type locality for both *B. bilinguis* (Salter) and *B. gracilis* (Bisat).

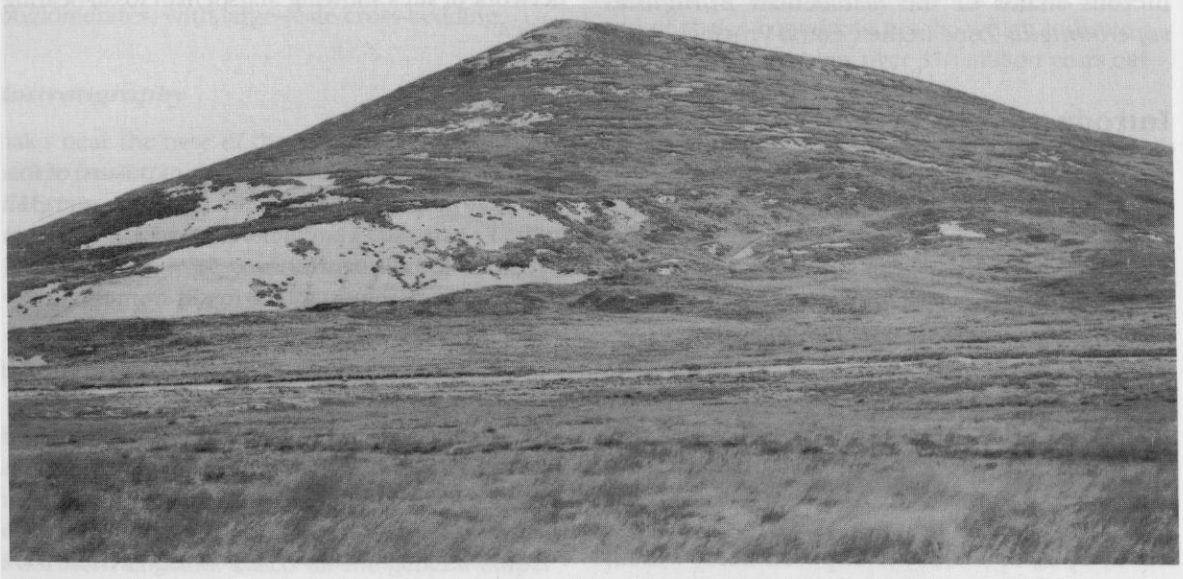

Figure 9.14 Pule Hill. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A4559).

Interpretation

This is historically the best known section through the lower Marsdenian (Ramsbottom, 1981), and was in effect the type for the stage base when it was first proposed by Bisat (1928). It has subsequently been shown that the lowest part of the marine band yielding *B. gracilis* (Bisat) is absent here, and so the stratotype section was moved to Rake Dike and then finally Park Clough. Nevertheless, Pule Hill provides the most extensive known surface exposure of both this and the overlying Bilinguis Marine Band anywhere in Europe. This, together with the fact that it is the type locality for two biozonal index species, makes it a site of considerable palaeontological significance.

Conclusions

Pule Hill is an exposure of marine shales of Marsdenian age (just over 317 million years old). The shales, known as the Gracilis and Bilinguis marine bands have been identified over large areas of Europe, but Pule Hill was where they were first described in detail and is still the most extensive natural outcrop.

JUMBLE COPPICE

Highlights

Jumble Coppice is an excellent exposure of fossiliferous shales of the Marsdenian *Bilinguites superbilinguis* Zone in the Central Province.

Introduction

This an exposure on the left bank of Heathy Lea Brook (SK 268721), on the northern edge of Chatsworth Park, 11 km west of Chesterfield, Derbyshire. Exposed here are the shales that lie between the Chatsworth Grit and Ashover Grit formations. The geology is described by Smith (1967) and Smith *et al.* (1967).

Description

Lithostratigraphy

About 10 m of shales are exposed here, which, from their field relationships, clearly lie between the Chatsworth and Ashover grits. They are mostly medium to dark grey, but there are also two layers of almost black shales, one at the base of the exposed section, and the other 5.5 m higher. These darker layers are marine bands.

Biostratigraphy

The fossil faunas of the two marine bands are listed by Smith *et al.* (1967). The lower band contains *Bilinguites superbilinguis* Bisat, *Homoceratoides fortelirifer* Ramsbottom, *Cancelloceras* spp., *Dunbarella speciosa* Jackson and *Caneyella* sp. This clearly belongs to the *B. superbilinguis* Subzone. The upper band has yielded a fauna of the *Verneuilites sigma* Subzone, including *V. sigma* (Wright), *Cancelloceras* sp., *Dunbarella* sp. and *Caneyella rugata* Jackson. Thus, both subzones of the Marsdenian *B. superbilinguis* Zone (R_{2c} in the traditional classification) are represented here.

Interpretation

This locality is a good example of upper Marsdenian shales belonging to the *B. superbilinguis* Zone, and has yielded faunas of both of its component subzones. It duplicates the upper part of the sequence seen at Hodge Clough, but is much better exposed and is more fossiliferous. Rake Dike also shows the lower part of the zone, but only the lower subzone, and then only as a brackish assemblage with inarticulate brachiopods. This site is thus of considerable importance for completing the network of sites showing Marsdenian fossil-bearing shales.

Conclusions

Jumble Coppice has an important exposure of fossiliferous shales of Marsdenian age, just over 317 million years old. They belong to what geologists refer to as the *Bilinguites superbilinguis* Zone, and are particularly important for fossils from the lower part of the zone.

HATHERSAGE MOOR

Highlights

Hathersage Moor shows the Chatsworth Grit Formation in its fullest development, together with a shale containing an upper Marsdenian fossil fauna.

Introduction

Exposures along and near Burbage Brook (SK 255820, SK 260815, SK 262815, SK 267812) 12 km SW of Sheffield, South Yorkshire, are in one of the classic areas for the Millstone Grit of northern England, famous for its rock climbing as well as the geology. These particular exposures show part of the Chatsworth Grit Formation and underlying shales. The geology is described by Eden *et al.* (1957) and Mayhew (1967a, 1967b).

Description

Lithostratigraphy

The full thickness of the succession here is difficult to determine from direct observation because of the discontinuous exposure, but is probably about 100 m. The lower strata are medium to dark grey, marine or brackish shales, with thin ribs of ferruginous siltstones and some ferruginous nodules. These are poorly exposed, but elsewhere in the vicinity lower strata are about 10 m thick (Mayhew, 1967a).

The shales are overlain by the Chatsworth Grit Formation (known locally as the Rivelin Grit). The formation consists of two arenaceous members, the lower one 15 m thick and the upper one 60 m thick, separated by a thick shale unit. The lower member consists of flaggy, fine-grained sandstones with thin shale interbeds. The upper member is also flaggy and fine grained at the base, but the rest of it consists mainly of coarse sandstones and sandy conglomerates, with large-scale cross-bedding.

Biostratigraphy

Shales near the base of the sequence have yielded marine fossils, including the ammonoid *Verneuilites sigma* (Wright) and the bivalve *Posidonia* cf. *insignis* (Jackson). It clearly belongs to the *D. sigma* Subzone, indicating the topmost Marsdenian.

Interpretation

This is an important exposure of the Chatsworth Grit Formation. The formation represents one of the best known examples of the type of sheet delta deposit, that characterizes the upper Millstone Grit of northern England. Based on the general model described by Collinson (1988), the lower member and basal part of the upper member probably represent mouth bar deposits, and the rest of the upper member the remains of distributary channel deposits.

The distribution of the Chatsworth Grit is discussed by Mayhew (1967a, 1967b), Ramsbottom *et al.* (1978) and Collinson (1988). It occurs throughout the Central Province, except on the southern margins near the Wales–Brabant Barrier, and seems to be the lowest part of the Millstone Grit in the province not to have been strongly influenced by the Dinantian palaeobathymetry (Figure 9.2). Mayhew (1967a, fig. 13.2) shows that the formation is most fully developed in this part of South Yorkshire. In particular, the lower member is only developed along a 15 km stretch of its outcrop, between Stanage Edge and Chatsworth. There are numerous exposures within this belt, but Hathersage Moor is one of the best, and the only one where it can be directly related at surface to a biostratigraphically diagnostic marine band.

In South Wales, strata of the same age are mainly basinal shales or littoral deposits of the Bishopston Formation (e.g. Tenby–Saundersfoot Coast) or Middle Shales Formation (e.g. Vale of Neath). Large-scale deltaic deposition is not seen until the upper Yeadonian to lower Langsettian, with the development of the Farewell Rock Formation.

Conclusions

Hathersage Moor is the best available exposure of sandstones from the upper Millstone Grit, known as the Chatsworth Grit Formation. It also includes a band of shales containing fossils, which indicate a late Marsdenian age, just over 310 million years old.

HAREWOOD GRANGE

Highlights

Harewood Grange has the most complete sequence through the Yeadonian Stage in the Central Province of northern England. It includes diverse assemblages of marine fossils and plant microfossils, together with an important non-marine bivalve assemblage.

Introduction

This site is a section along Hipper Sick stream (SK 312682), a tributary of the River Hipper, 100 m NE

of Harewood Grange, 8 km WNW of Chesterfield, Derbyshire. It shows an essentially continuous section through the Yeadonian of the Central Province. An account of the geology is given by Smith (1967) and Smith *et al.* (1967), and Neves (1961) has studied the palynology.

Description

Lithostratigraphy

The complete sequence here is about 50 m thick. The lower part consists of medium-grained ferruginous and calcareous sandstones, called the Redmire Flags Formation. This is a relatively localized development of deltaic sandstones, known only from this part of Derbyshire. A little to the north, it becomes a more massive unit, possibly representing the channel deposits of the delta, but in these more southerly outcrops it consists of soft, flaggy sandstones, widely used as a walling-stone. They probably represent shallow water sands, although they are rooted and contain plant fragments, and so must have been fully emergent.

The overlying 40 m are medium to dark grey shales with siltstone ribs and occasional ferruginous nodules. There are also two bands of black shale, representing marine bands. At the very top of this interval, the shales are lacustrine.

Above these shales are about 3 m of micaceous, siltstones and fine-grained sandstones, of the Rough Rock Formation. It is clearly a very condensed development of the formation, and it totally dies out only a few hundred metres to the south-west.

There follows a gap of about 3 m in the section. It is probably where the Pot Clay Coal occurs, as the next exposed part of the sequence are dark marine shales of the Subcrenatum Marine Band. This is in turn followed by Westphalian sandstones of the Crawshaw Sandstone Formation.

Biostratigraphy

Marine bands

The lowest marine band in this section is an interval of black shales immediately overlying the Redmire Flags. It has yielded the goniatites *Cancelloceras crencellatum* Bisat and *Agastrioceras carinatum* (Frech), and the bivalve *Posidonia* aff. *insignis* (Jackson). Although the index ammonoid has not been found, it is assumed that this is the Cancellatum Marine Band (Smith *et al.*, 1967), and thus marks the base of the Yeadonian Stage.

Some 10 m higher is the Cumbriense Marine Band. In addition to the index ammonoid, it has yielded *Aviculopecten* aff. *losseni* (von Koenen), *Caneyella multirugata* (Jackson) and palaeoniscid fish scales.

At the very top of the section, above the Rough Rock, is the Subcrenatum Marine Band, also known locally as the Pot Clay Marine Band. It has yielded *Gastrioceras subcrenatum* (Frech), *Anthracoceratites* sp., *Homoceratoides* sp., *Posidonia insignis* (Jackson), *P.* cf. *gibsoni* Salter, *Dunbarella papyraceae* (Sowerby) and *Caneyella multirugata* (Jackson), together with mollusc spat, conodonts and fish scales (Smith *et al.*, 1967). It marks the top of the Yeadonian Stage, and thereby the junction between the Namurian and Westphalian series.

Non-marine bivalves

These are only known at this locality from immediately below the Rough Rock. The assemblage includes *Anthraconaia angulosa* Pastiels, *Carbonicola exporrecta* Eagar, *C.* cf. *protea* Wright, *C.* cf. *rhomboidalis* Hind and *Naiadites* sp. The first two species in particular are characteristic upper Namurian elements.

Palynology

Neves (1961) stated that he prepared palynological samples from the Cancellatum, Cumbriense and Subcrenatum marine bands here, as well as the lacustrine shale containing non-marine bivalves, and he has referred to it as his Locality 12. However, he did not specify the taxa found at each horizon, except for those for which this is the type locality. They are :

(1) *Acanthotriletes? pilus*, *Secarisporites lobatus*, *Stenozonotriletes triangulus* and *Convolutispora laminosa* from the Cancellatum Marine Band; and

(2) *Abrenisoporites beeleyenis, Triquitites nodosu, Cirratriradites ornatus, Knoxisporites semiradiatus, Punctatisporites pseudopunctatus, Ibrahimispores brevispinosus* and *I. magnificus* from the lacustrine band.

Interpretation

This is the best exposed sequence through the Yeadonian Stage in the Central Province of northern England. It not only shows the lower part

of the stage containing the Cancellatum and Cumbriense marine bands, as can also be seen at Yeadon and Orchard Farm, but also shows the higher strata including the *Carbonicola exporrecta* lacustrine band, the Rough Rock, and eventually up into the Subcrenatum Marine Band. The Cancellatum Marine Band in particular is not as well developed here as at other localities, but nowhere else can the rest of the stage be so clearly seen. It thus represents the stratigraphically highest of the sequence of sites selected to demonstrate the basinal shale deposits of the Millstone Grit of the Central Province.

The site has also proved important for developing a palynological zonation for the upper Namurian, principally through the work of Neves (1961). The Cancellatum and *C. exporrecta* bands in particular have yielded diverse and well preserved pollen/spore assemblages, including the types of many species (see above).

Conclusions

Harewood Grange shows the most complete sequence of rocks of Yeadonian age (just over 316 million years old) in northern England. It yields abundant fossils, particularly of marine animals such as the ammonoids, and of non-marine bivalves. The site has also proved important for fossil pollen and spores.

YEADON BRICKWORKS

Highlights

Yeadon Brickworks is the eponymous site for the Yeadonian Stage, and is of importance for understanding the evolution of the chronostratigraphical classification of the Namurian Series.

Introduction

The disused brickworks (SE 193407) and the adjacent railway cutting, 9 km NNE of Bradford, West Yorkshire, is the original type and eponymous locality for the Yeadonian Stage, as proposed by Hudson (1945; see also Hudson, 1936; Edwards *et al.*, 1950; Stephens *et al.*, 1953; Ramsbottom, 1969a). Although it is no longer the official stratotype, it provides an excellent exposure through much of the lower part of the stage, as well as being of historical significance.

Description

Lithostratigraphy

The combined sequence demonstrated in the railway cutting and quarry is about 30 m thick. It is mostly shales in the lower part, passing up into flaggy shales near the top, thought to be the Rough Rock Formation. The argillaceous part of the sequence contains two marine shales (the Cancellatum and Cumbriense marine bands see below), but near the base there is a ganister-like seat earth.

Biostratigraphy

The lowest of the marine bands mentioned above, which immediately overlies the seat earth, contains *Lingula* in the lower part, but higher up has yielded a diverse assemblage of marine fossils. According to Stephens *et al.* (1953), it includes *Cancelloceras cancellatum* (Bisat), *Anthracoceras* sp., *Agastrioceras carinatum* (Frech), *Bilinguites superbilinguis* Bisat, *Homoceratoides divaricatus* Cope, *Posidonia* sp., *Caneyella multirugata* (Jackson) and *Dunbarella elegans* Jackson. *B. superbilinguis* Bisat occurs in the lower part of this ammonoid-bearing interval, and *A. carinatum* (Frech) in the upper part. However, there is no evidence of *Branneroceras branneroides* (Bisat) that occurs in the lower part of the Cancellatum Marine Band in certain other localities such as Orchard Farm.

The upper of the two marine bands has yielded a more restricted assemblage but is nevertheless diagnostic of the Cumbriense Marine Band. Species reported by Stephens *et al.* (1953) include *Cancelloceras cumbriense* Bisat, *Cancelloceras. crencellatum* Bisat, *Orthoceras* sp., *Anthracoceras* sp., *Aviculopecten* cf. *losseni* (von Koenen) and *Dunbarella elegans* Jackson.

Interpretation

This sites provides an excellent section through the Yeadonian of the Central Province, showing both of the principal marine bands. For many years it was acknowledged as the effective stratotype for the stage. However, Ramsbottom (1969a) demonstrated that the basal part of the Cancellatum Marine Band is missing here, with a more complete succession being present at Orchard Farm. As the base of this marine band was to mark the base of

the Yeadonian in its stratotype section, this omission was critical and resulted in this site not being selected as the official stratotype. Nevertheless, the site remains of considerable interest for upper Namurian stratigraphy in Britain.

Conclusions

Yeadonian Brickworks is historically important as being where the geological time-interval known as the Yeadonian Age (about 316 million years old) was first defined.

HARPER CLOUGH, SMALLEY DELF AND CLOSEBROW QUARRIES

Highlights

Harper Clough, Smalley Delf and Closebrow Quarries together provide the best known sequence through the upper Marsdenian and lower Yeadonian of the Craven Basin, and includes examples of the unusual Haslingden Flags deposits, thought to represent birdfoot-delta deposits.

Introduction

Three disused quarries (SD 717317, SD 720320, SD 718314) between Great Harwood and Blackburn, Lancashire, provide an almost complete sequence through the upper Marsdenian and lower Yeadonian, as developed in the Craven Basin. The geology is described by Wright *et al.* (1927).

Description

Lithostratigraphy

The combined sequence exposed in these old quarries is some 200 m thick. At the base are two thick sandstones separated by a shale, which belong to the Revidge Grit Formation. They are both coarse-grained units, and the upper one has an intraformational conglomerate at the base. There are a variety of sedimentary structures, including different types of ripples, cross-bedding and sole marks, as well as large casts of plant stems. This all suggests fluvial-channel, probably point-bar style deposition.

Above the Revidge Grit is a thick unit of shales, with siltstone ribs and occasional ironstone nodules. There are also numerous seat earths and at two levels the development of coal, suggesting that they are flood-plain deposits subject to periodic emergence.

Above this are about 3 m of flaggy micaceous sandstone, representing the Helmshore Grit Formation. It is a very condensed development of this formation, which further to the south and west thickens to up to 30 m. Of interest here, however, is the presence on the upper surface of the formation of a cast of an arborescent lycophyte stump (? *Lepidodendron*) showing the radially arranged *Stigmaria* rooting structures (Figure 9.15). This is further evidence of emergence in this interval, and that swamps were able to develop on the deltas.

Above the Helmshore Grit are more shales, with siltstone ribs and thin beds of flaggy sandstone. Unlike the shales between the Revidge and Helmshore grits, however, there is less evidence of emergent conditions, and at one level (1.5 m above the Helmshore Grit) there are shales representing a marine band. They thus represent a reversion to shallow water and possibly even at times basinal sediments, more typical of the argillaceous deposits lower in the Millstone Grit.

The next part of the succession cannot be seen here, but from other nearby exposures probably includes the Hazel Greave Grit, Brooksbottom Sandstone and Holcombe Brook Grit (Wright *et al.*, 1927). The next highest visible stratum here is a thin coal known as the Holcombe Brook Coal, which normally overlies the grit of the same name. There then succeeds a series of shales. Near the base of this interval, the shales are dark, and at one level contain fossils of the Cancellatum Marine Band. Above the marine band the shales show a evidence of penecontemporaneous slumping (Williamson, 1953), similar to that seen at the same level further south in Staffordshire (e.g. Gib Tor). The succeeding shales become much paler in colour, possibly indicating a transition to deltaic flood-plain deposits.

The top part of the sequence here belongs to the lower member of the Haslingden Flags. They consist of 3.5 m of massive white quartzitic sandstone, known locally as 'lonkey', overlain by flaggy, fine-grained sandstone. The exposure exhibits a number of sedimentary structures, with some bedding faces being covered in ripple-marks, trace-fossils and plant debris. It is very much a local development of the Lower Haslingden Flags, which disappears 2 km to the south. The formation is in

Figure 9.15 Upper Millstone Grit of the Craven Basin exposed at Harper Clough, including the famous *Stigmaria* rooting system. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A2646).

itself a relatively local development, extending in a narrow belt, at most only about 30 km wide, between Blackburn and Halifax. It is thought to be the remains of anb elongate, birdfoot-type delta, similar to that seen at the mouth of the Mississippi River today, and is unique in the deltas that formed the Millstone Grit in the Central Province (Collinson and Banks, 1975; Collinson, 1988).

Biostratigraphy

As stated above, there are two marine bands exposed in this sequence. The lowest, just above the Helmshore Grit, was reported by Wright et al. (1972) to yield *Bilinguites bilinguis* and is probably the Eometabilinguis Marine Band (middle Marsdenian). The marine band above the Holcombe Brook Coal yields *Bilinguites superbilinguis* (Bisat) and *Cancelloceras cancellatum* (Bisat), and is probably the Cancellatum Marine Band (Yeadonian).

Interpretation

This is the best exposed sequence through the upper Marsdenian and lower Yeadonian in the Craven Basin. This part of the Millstone Grit is well exposed elsewhere in the Central Province, in particular in the Huddersfield Basin (e.g. Rake Dike, Pule Hill) and Edale Basin (e.g. Jumble Coppice, Hathersage Moor), but the Craven Basin shows a number of distinct features. These include the Revidge Grit and Helmshore Grit formations, and perhaps most significantly the birdfoot-delta-type deposits of the Haslingden Flags Formation. The nearest comparison is with the sequence developed in the Rossendale Basin, which lies south of the Craven Basin, separated by the Pendle Monocline (i.e. the uplifted part of the Rossendale Block Lee, 1988). Here, sandstone units have been identified as being the same as the Helmshore Grit and Hazel Greave Grit formations, although otherwise the sequence follows that present in the more typical parts of the Central Province.

There have been attempts to integrate at least part of the Craven Basin sequence with that found in the rest of the Central Province. For instance, it has been suggested by Ramsbottom (1977) that the Hazel Greave and Holcombe Brook grits are lateral extensions respectively of the Ashover and Chatsworth grits, seen in the Edale Basin. Although there is at least an approximate time-correlation

between these deposits, there is little sedimentological evidence to support them being the remains of the same deltaic depositional unit. As the Craven Basin seems to have been subject to its own discrete bathymetric controls, the sandstone units probably represent separate parts of the overall delta complex.

It is significant that a major part of the shales here are non-marine, flood-plain deposits. Marine deposits are present, but are limited in vertical extent. This contrasts with the lower parts of the Millstone Grit, where marine shales are significantly more abundant. It can be seen as marking the transition between a mainly marine sequence with intermittent non-marine, deltaic incursions, and a predominantly delta-plain succession with intermittent marine incursions; in other words, the transition from typical Millstone Grit to typical Coal Measures.

The progressive environmental change occurring in the late Namurian is further indicated here by the presence of *in situ* remains of arborescent lycopsids, evidence of swamp vegetation on the Millstone Grit deltas. Coals occur at many levels through the Millstone Grit, including in these quarries, but they are invariably thin and there is no clear evidence as to whether they are the remains of arborescent swamp vegetation, or of herbaceous, scrub vegetation. The presence of clastic swamps (*sensu* Gastaldo *et al.*, 1989) in the Millstone grit is a clear preface to the more extensive coal-forming swamps that develop on these deltas later in the Westphalian.

Conclusions

Harper Clough, Smalley Delf and Closebrow Quarries are amongst the best exposures in northern England of rocks of late Marsdenian and early Yeadonian age (just over 310 million years old). They include examples of the Haslingden Flags, thought to represent deposits formed in the destinctive type of dissected, birdfoot-delta.

HEYS BRITANNIA QUARRIES

Highlights

Heys Britannia Quarries are the best available exposures in the Haslingden Flags, a unique development in the Millstone Grit of the Central Province, having been formed in a birdfoot-type delta.

Introduction

These extensive workings, 3 km south of Bacup, Lancashire (SD 872202), are in the upper part of the Haslingden Flags, a major sandstone unit in the upper Namurian of the Craven Basin. The geology of the site is discussed by Collinson and Banks (1975) and Bristow (1988), and trace fossils from here are dealt with by Hardy (1970a, 1970b) and Eagar *et al.* (1985).

Description

The exposed sequence here is in the upper member of the Haslingden Flags Formation, and consists mainly of fine-grained sandstones. A distinctive feature of these strata, which is well displayed here, is the large sets of inclined-bedding, in excess of 25 m thick. The inclined beds are at a very low angle for sets of this size (dip 14° or less), and often show ripple laminations. The base of the sets is not well seen here, but in nearby quarries it has been shown that they could sometimes be non-erosional. Collinson and Banks (1975) compared them with the 'epsilon'-style cross-bedding of Allen (1963), and interpreted here as lateral accretion surfaces in deep channels. Subsequently however, Bristow (1988) argued that they are part of a synsedimentary growth faults.

The site is also particularly good for trace fossils (Hardy, 1970a, 1970b; Collinson and Banks, 1975; Eagar *et al.*, 1985). The most common are the escape shafts and resting burrows of the bivalve *Carbonicola*, and usually referred to as *Pelecypodichnus*. They are associated with sinuous trails known as *Cochlichnus*, thought to have been produced by annelid worms attracted to the decaying corpses of dead bivalves. Finally, there are traces produced by limulids such as *Belinurus* or *Euproops*; these include rows of resting places known as *Limulicubichnus rossendalensis* (Hardy), for which this is the type locality, and walking tracks with a clear groove produced by the telson (*Kouphichnium* aff. *variabilis* (Linck)). Eagar *et al.* (1985) argue that such an assemblage indicates shallow non-marine conditions, possibly with periodic intervals of emergence.

No body fossils have been reported from this site. However, in a nearby borehole, Collinson and Banks (1975) report the presence of the Cumbriense Marine Band immediately below these sandstones, which are thus upper Yeadonian.

Interpretation

This is the best available exposure of the Haslingden Flags, a unique development of deltaic strata in the Millstone Grit of the Central Province. There are other outcrops, such as Closebrow Quarry, but nowhere else can the distinctive sedimentological features of this unit be seen. These include the large-scale, low-angle cross-bedding, the relatively fine grain of the sandstones, and the internal ripple lamination. Collinson (1988) argued that they represent the mouth bars of an elongate birdfoot delta, similar to that seen in the present-day Mississippi. If correctly interpreted, the Haslingden Flags would be the only known example of this kind of delta to have been so far recognized in the Millstone Grit of the Central Province . Alternatively, Bristow (1988) has argued that the elongate form of the Haslingden Flags sandstone bodies merely reflects its deposition in a tectonically controlled half graben.

This is also one of the best localities for non-marine trace fossils in the British Millstone Grit. As pointed out by Eagar *et al.* (1985), *Pelecypodichnus*-type bivalve escape shafts do not necessarily indicate non-marine conditions. However, those found in the Haslingden Flags are of a similar order of size to those found in the non-marine Westphalian. The occurrence of a series of limulid resting marks in a line is thought to indicate the periodic emergence of the sediment from the water; Eagar *et al.* suggest that they were produced by the animal floundering, as it was lifted by the returning water, after it had been stranded on the sediment surface. The fact that it is associated with non-marine type *Pelecypodichnus* is thought to suggest that they were formed by the non-marine *Belinurus* or *Euproops*, rather than by the marine *Limulus*.

Conclusions

Heys Britannia Quarries are the best exposures of a suite of rocks, just over about 316 million years old, known as the Haslingden Flags. They represent deposits formed in an elongate, birdfoot-type delta, similar to those seen in the present-day Mississippi delta-complex.