British Upper Carboniferous Stratigraphy

C.J. Cleal and B.A. Thomas
Department of Botany
National Museum of Wales, Cardiff

GCR Editor: L.P. Thomas

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Chapter 4

South Wales

The Upper Carboniferous outcrops in South Wales in an elongate area about 75 km long and up to 16 km wide (Figure 4.1). The main part of the outcrop extends from Pontypool in the east to near Kidwelly in the west. Carmarthen Bay separates this from a smaller area of outcrop in Pembrokeshire. With the exception of the Iberian Peninsula (Lemos de Sousa and Oliviera; 1983, Martinez Diaz, 1983), South Wales provides by far the best exposed sequences of non-marine Upper Carboniferous in Europe. Good coastal exposures occur in Pembrokeshire, complemented by numerous inland exposures in the main area of outcrop. At one stage, South Wales was being considered as a potential stratotype for at least part of the Westphalian Series (George and Wagner, 1970, 1972). Rather strangely, the working group of the SCCS investigating this matter could not find any suitable exposures there and so opted for the much smaller outcrops in the Pennines (Calver *in* George and Wagner, 1972, p. 147). Nevertheless, in view of the extent of the outcrop, and the quality of the non-marine faunas and macrofloras, South Wales remains a key area for Upper Carboniferous stratigraphy.

As well as its scientific interest, the Upper Carboniferous of South Wales has been of considerable economic significance. Most important is the coal from the Westphalian part of the sequence. In 1857, South Wales had an annual production of 8.9 million tons, representing 13.5% of the UK's production, and over 9% of the entire world's (Hull, 1861). In 1933, this had gone up to more than 33 million tons, 16% of the UK's production (Bone and Himus, 1936), by the end of the 1980s this had declined to a mere 3.1 million tons per annum (British Coal Corporation Annual Report 1990/91).

During the 19th century, South Wales was also a major producer of iron ore (Joseph, 1880). However, it is a carbonate ore (siderite) unsuitable for modern smelting methods, and so its exploitation had ceased by the early 20th century (North, 1931).

History of research

Geological observations on the Upper Carboniferous of South Wales go back to the 16th century. However, serious geological work on the area started in the early 19th century, with the publication of William Smith's classic map in 1815, followed shortly by investigations undertaken by the newly-formed Geological Survey (De la Beche, 1846). This early phase in geological work in South

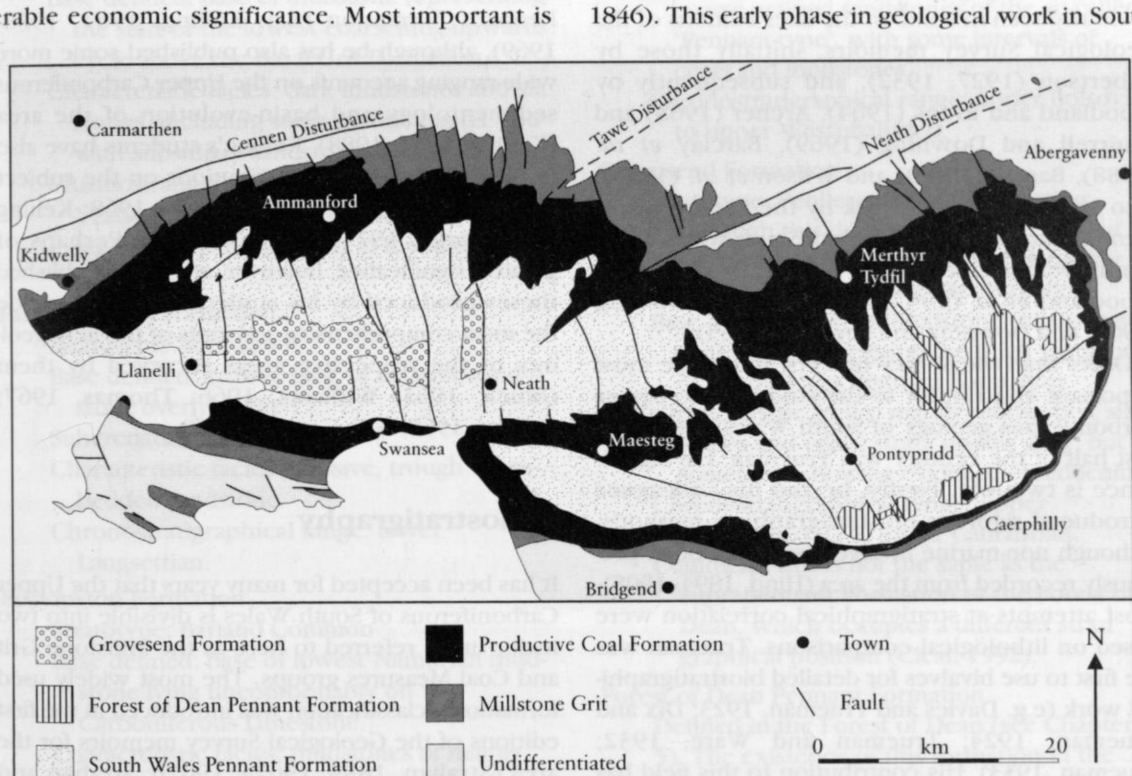

Figure 4.1 Map of the Upper Carboniferous of South Wales. Based on George (1970).

Wales is discussed by North (1928, 1933, 1934, 1936) and a full inventory of the early literature is provided by Bassett (1963).

The economic importance of the Upper Carboniferous of South Wales resulted in a number of studies during the 19th century. These concentrated on subjects of immediate practical significance, such as seam correlations, the nature of seatearths, and changes in rank of coal (e.g. Logan, 1840; Bevan, 1858; Brown, 1865, 1874; Joseph, 1870; Lewis and Reynolds, 1870; Barrow, 1873; Jordan, 1876; Hannah, 1892; Arnold, 1895 – again, see Bassett, 1961, 1963 for a full list of the relevant publications). This information was eventually brought together in a series of maps and monographs published by the Geological Survey (Strahan, 1899, 1907a, 1907b; Strahan and Gibson, 1900; Strahan and Cantrill, 1902, 1904; Strahan *et al.*, 1903, 1904, 1907, 1909, 1914; Cantrill *et al.*, 1916; Dixon, 1921).

During the early 20th century, most published data on the Upper Carboniferous of South Wales continued to be based on observations made in underground mines (e.g. Jordan, 1903, 1908, 1910, 1915). However, there gradually developed an awareness of the importance of natural surface outcrop for refining geological ideas. This is most obviously seen in some of the later editions of the Geological Survey memoirs, initially those by Robertson (1927, 1932), and subsequently by Woodland and Evans (1964), Archer (1968) and Squirrell and Downing (1969), Barclay *et al.* (1988), Barclay (1989) and Wilson *et al.* (1990). Also arising from this work by the Survey, documenting the exposed geology of South Wales, were a number of individual papers, such as by Woodland *et al.* (1957), Squirrell and Downing (1964) and Downing and Squirrell (1965).

Other than the Survey officers, the single most important contributor to the study of the Upper Carboniferous geology of South Wales during the first half of the century was Trueman. His significance is two-fold. Firstly, he and his colleagues introduced rigorous biostratigraphical methods. Although non-marine bivalve fossils had been previously recorded from the area (Hind, 1894–1905), most attempts at stratigraphical correlation were based on lithological comparisons. Trueman was the first to use bivalves for detailed biostratigraphical work (e.g. Davies and Trueman, 1923; Dix and Trueman, 1924; Trueman and Ware, 1932; Trueman, 1933). His contribution to this field has been usefully summarized by George (1974).

Trueman's other main contribution was to encourage students to investigate the area. Outstanding amongst these was Dix who, as well as studying the non-marine bivalves, made major advances in our understanding of the plant fossils of the area (Dix, 1933, 1934, 1937). Also, Moore made significant contributions to the detailed correlations of the strata, especially in the eastern part of the area (Moore, 1945, 1948; Moore and Cox, 1943; Moore and Blundell, 1952; Sullivan and Moore, 1956).

Most of the work mentioned so far deals with the Coal Measures. The Millstone Grit of South Wales was for many years not treated with the same interest, presumably because of its lesser economic importance. The group was mentioned in the various Survey memoirs, and there were also a few isolated publications describing the geology (e.g. Evans and Jones, 1929; Ware, 1939). However, significant progress was not made until the work of D.G. Jones, who established detailed correlations over large parts of the outcrop (e.g. Jones, 1958, 1969, 1974; Jones and Owen, 1957, 1967).

More recent work on the area is reviewed by Owen (1984). Some of the most important has been by Kelling and his students. Kelling himself has concentrated mainly on the sedimentology of the Rhondda Beds in the lower South Wales Pennant Formation (e.g. Kelling, 1964, 1968, 1969), although he has also published some more wide-ranging accounts on the Upper Carboniferous sedimentology and basin-evolution of the area (Kelling, 1974, 1988). Kelling's students have also published important contributions on the subject (Bluck and Kelling, 1963; Williams, 1968; Kelling and George, 1971; Thomas, 1974). Perhaps of greatest significance, however, are the unpublished theses produced by his students, which provide the most comprehensive accounts of the field geology of the respective areas surveyed by them (Bluck, 1961; Williams, 1966; Thomas, 1967; Oguike, 1969; G.T. George, 1970).

Lithostratigraphy

It has been accepted for many years that the Upper Carboniferous of South Wales is divisible into two major units, referred to here as the Millstone Grit and Coal Measures groups. The most widely used formational classification was introduced in the first editions of the Geological Survey memoirs for the area (Strahan, 1899, 1907a, 1907b; Strahan and Gibson, 1900; Strahan and Cantrill, 1902, 1904; Strahan *et al.*, 1903, 1904, 1907, 1909, 1914;

Cantrill *et al.*, 1916; Dixon, 1921). A revised classification for the Coal Measures was proposed by Stubblefield and Trotter (1957) and Woodland *et al.* (1957), but this was somewhat of a hybrid scheme, with greater emphasis being given to ensuring that the formational boundaries were isochronous, than to reflecting the lithological variations of the sequence. There is clearly no point in duplicating the internationally recognized Heerlen chronostratigraphy, and the revised scheme certainly fails to express the lithological variations. For this reason, this review has reverted largely to the earlier classifications, as follows.

Basal Grit Formation

Stratotype: Vale of Neath

Base defined: lowest coarse sandstone in the Millstone Grit.

Characteristic facies: medium to coarse sandstones often with low-angle trough cross-bedding, with subsidiary beds of dark, ammonoid-bearing mudstones.

Chronostratigraphical range: Arnsbergian to Marsdenian.

Middle Shales Formation

Stratotype: Marros Sands

Base defined: base of mudstone representing the start of the lowest coarsening-upwards cycle above the Basal Grit Formation.

Characteristic facies: dark mudstones and silt stones, including some marine bands, and with subsidiary sandstones.

Chronostratigraphical range: Marsdenian to Yeadonian in the west of the basin, extend ing up to the Langsettian in the middle and east.

Farewell Rock Formation

Stratotype: Nant Llech

Base defined: erosive base of massive sand stone overlying the Subcrenatum Marine Band.

Characteristic facies: massive, trough cross-bedded sandstone.

Chronostratigraphical range: lower Langsettian.

Bishopston Formation

Stratotype: Barland Common

Base defined: base of lowest Namurian mudstone lying unconformably on Carboniferous Limestone.

Characteristic facies: mudstones of mainly marine or littoral origin, and with only occasional thin ribs of sandstone.

Chronostratigraphical range: Chokierian to Marsdenian in the middle part of the south crop, extending up to the Yeadonian in the west.

Upper Sandstone Formation

Stratotype: Tenby–Saundersfoot Coast

Base defined: base of thick fluvial sandstone above the *Anthracoceratites* Marine Band.

Characteristic facies: massive, trough cross-bedded sandstones, with occasional, thin marine shales.

Chronostratigraphical range: Yeadonian.

Productive Coal Formation

Stratotype: Cwm Gwrelych–Nant Llyn Fach

Base defined: base of lowest mudstone above Farewell Rock Formation

Characteristic facies: coals, mudstones and siltstones, with subsidiary sandstones.

Chronostratigraphical range: Yeadonian (south crop) to Langsettian (north crop) at the base, ranging up to upper Bolsovian.

South Wales Pennant Formation

Stratotype: no specific site is designated, but the sequences exposed along the Rhondda Valley may be regarded as typical

Base defined: base of first thick sandstone bed above the Cambriense Marine Band.

Characteristic facies: mainly thick bedded, coarse-grained sandstones of the so-called 'Pennant-type', with some intervals of coals and mudstones.

Chronostratigraphical range: upper Bolsovian to upper Westphalian D.

Grovesend Formation

Stratotype: Penllergaer Railway Cutting; although this does not show the base of the formation, it is the best available sur face outcrop of part of the formation

Base defined: base of mudstone, siltstone and coal interval overlying the thick sandstones of South Wales Pennant Formation.

Characteristic facies: mainly mudstones, silt stones and coals; strata usually grey, but sometimes showing evidence of reddening.

Chronostratigraphical range: upper Westphalian D to lower Cantabrian.

Comment: this is not the same as the Suprapennant Formation of the Forest of Dean, which occupies a different strati graphical position (Cleal, 1992).

Forest of Dean Pennant Formation

Defined in the Forest of Dean (see Chapter 5). The existence of this formation in the eastern part of the coalfield, and which is distinct from the South Wales Pennant Formation found further west, is based on Cleal (1992).

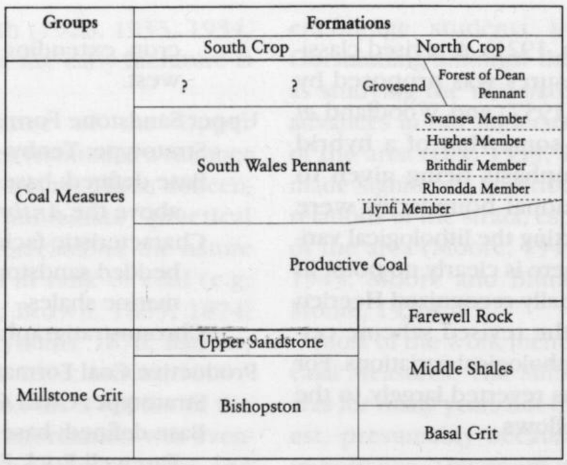

Figure 4.2 Formational classification of the Upper Carboniferous of South Wales.

The relative positions of these formations in South Wales is summarized in Figure 4.2. There are other formations recognizable, such as the Llanelen Sandstone in the Marsdenian of the Gower (Ramsbottom *et al.*, 1978), but they are not present in any of the sites covered in this review and so are not dealt with further here.

For convenience, the Productive Coal Formation is divided into lower, middle and upper members, with their junctions placed at the Vanderbeckei and Cambriense marine bands. This is based essentially on the proposals of Stubblefield and Trotter (1957). However, it should be noted that the Upper Productive Coal Member is only present in the eastern part of the coalfield. In the central part of the basin, strata above the Cambriense Marine Band belong to the South Wales Pennant Formation.

The subdivisions of the South Wales Pennant Formation proposed by Woodland *et al.* (1957) have also been retained in a modified form, as members. The Llynfi Member only occurs in the central part of the coalfield. In the eastern part, the base of the South Wales Pennant Formation is taken to be in the Rhondda Member, and the strata there that are coeval with the Llynfi Member assigned to the upper member of the Productive Coal Formation. The 'Grovesend Beds' of Woodland *et al.* have been raised in rank to formation, for the argillaceous beds above the South Wales Pennant Formation on the north crop.

Geological setting

The Upper Carboniferous of South Wales is the remains of an extensive fluvio-delatic system, occupying an area of downwarp on the southern margins of the Wales-Brabant Barrier. According to Kelling (1988), both this crustal downwarping and the associated uplift of neighbouring areas that provided the sediment-sources, were the result of nappe-loading as the Variscan Front migrated north.

The South Wales sequences represent progressively more proximal deposits, indicating the progradation of the delta (Figure 4.3). The dominant sediments are mudstones and siltstones, representing mainly pro-delta and littoral deposits in the Namurian (Middle Shales Formation), lower and then middle delta-plain deposits in most of the Westphalian (Productive Coal Formation), and upper delta-plain deposits in the uppermost Westphalian and Stephanian (Grovesend Formation). The delta was frequently flooded during the Namurian by eustatic rises in sea-level (Ramsbottom, 1978). Marine influence declined during the Westphalian and seems to have entirely disappeared by the upper Bolsovian. Kelling (1974) argued on sedimentological grounds that some of the lower South Wales Pennant Formation might be littoral or lagoonal deposits, but the highest strata to yield marine fossils, the Cambriense Marine Band, are mid-Bolsovian (Ramsbottom's (1984) suggestion that the estheriids found in the South Wales Pennant Formation were evidence of brackish conditions is not supported by the study by Vasey, 1985).

Imposed on this pattern of mainly mud/silt deposition were periodic inundations of alluvial sands. Sands form a natural part of any deltaic sedimentary system, in particular as distributary channel deposits. However, the main sandstone intervals of the South Wales basin seem to have

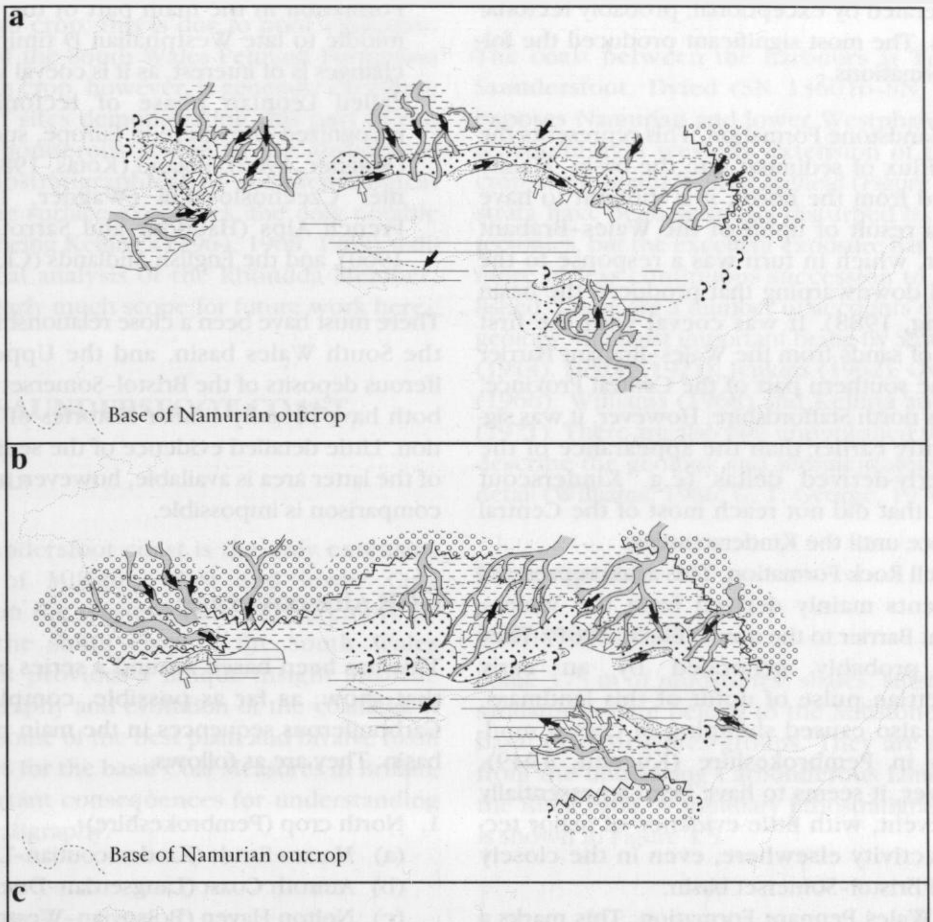

Figure 4.3 Palaeogeographical evolution of South Wales through the Late Carboniferous. (a) Kinderscoutian; (b) Yeadonian; (c) Duckmantian – note that whereas deltaic complexes A and B were most fully-developed in the early part of this time interval, delta-lobes C and D were more prominent in the period immediately preceeding the Cefn Coed marine transgression. Based on Kelling (1974, figs 45–7).

been generated by exceptional, probably tectonic processes. The most significant produced the following formations.

1. Basal Sandstone Formation. This represents the first influx of sediment into the basin. Mainly derived from the north, it is thought to have been a result of uplift of the Wales–Brabant Barrier, which in turn was a response to the crustal downwarping that produced the basin (Kelling, 1988). It was coeval with the first influx of sands from the Wales–Brabant Barrier into the southern part of the Central Province, such as north Staffordshire. However, it was significantly earlier than the appearance of the northerly-derived deltas (e.g. Kinderscout delta), that did not reach most of the Central Province until the Kinderscoutian.
2. Farewell Rock Formation. This again represents sediments mainly derived from the Wales–Brabant Barrier to the north (Bluck, 1961). They were probably generated by an early Langsettian pulse of uplift of this landmass, which also caused slumping of coeval mudstones in Pembrokeshire (Kuenen, 1949). However, it seems to have been an essentially local event, with little evidence of major tectonic activity elsewhere, even in the closely related Bristol–Somerset basin.
3. South Wales Pennant Formation. This marks a significant change in the depositional pattern in the basin, with the major sediment source changing from north to south. Also, particularly in the southern part of the basin, the sediment becomes significantly more proximal in nature (Kelling, 1974). The late Bolsovian uplift of land to the south that caused this change correlates with the basin inversion and tectonic deformation of the Culm Trough (present-day Devon and Cornwall), which in turn is thought to reflect a northwards migration of the Variscan Front (Kelling, 1988).
4. Forest of Dean Pennant Formation on the east crop. Mid-Westphalian D tectonic uplift of the Usk Axis has resulted in a non-sequence on the eastern margins of the basin. However, the newly uplifted area provided a fresh source of Pennant-like sediment, that extended over this eastern area in the late Westphalian D and probably early Cantabrian (Cleal, 1992). In contrast, the southern source seems to have ceased producing the coarse alluvial sands in the late Westphalian D, and so the South Wales Pennant Formation gives way to the Grovesend Formation in the main part of the basin. The middle to late Westphalian D timing of these changes is of interest, as it is coeval with the so-called Leonian phase of tectonic activity recognized elsewhere in Europe, such as Spain (Wagner, 1966), Poland (Kotas, 1985), the former Czechoslovakia (Wagner, 1977), the French Alps (Haudour and Sarrot-Reynauld, 1960), and the English Midlands (Cleal, 1987).

There must have been a close relationship between the South Wales basin, and the Upper Carboniferous deposits of the Bristol–Somerset area, since both have broadly similar histories of sedimentation. Little detailed evidence of the sedimentology of the latter area is available, however, and so a full comparison is impossible.

GCR site coverage

This has been based around a series of key sites that show, as far as possible, complete Upper Carboniferous sequences in the main parts of the basin. They are as follows.

1. North crop (Pembrokeshire)
   (a) Marros Sands (Kinderscoutian–Langsettian)
   (b) Amroth Coast (Langsettian–Duckmantian)
   (c) Nolton Haven (Bolsovian–Westphalian D)
2. North crop (central part of basin)
   (a) Vale of Neath (?Chokierian–Langsettian)
   (b) Nant Llech (Langsettian)
   (c) Cwm Gwrelych–Nant Llyn Fach (Langsettian– Bolsovian)
3. East crop
   (a) Llamarch Dingle (Marsdenian–Langsettian)
   (b) Brynmawr Road Cutting (Langsettian)
   (d) Wern Ddu (Langsettian–Bolsovian)
   (e) Coed-y-Darren (Bolsovian)
4. South crop (central part of basin)
   (a) Barland Common (Chokierian–Marsdenian)
5. South crop (Pembrokeshire)
   (a) Tenby–Saundersfoot Coast (Chokierian–Langsettian)

Arranged around this network of key sites, are a group of other localities demonstrating specific palaeontological (Lower House Stream Section, Cwm Twrch) or sedimentological (Earlswood Road Cutting, Blaenrhondda Road Cutting, Trehir Quarry, Penllergaer Railway Cutting) features.

There remain a number of major gaps in the coverage. In the case of the Productive Coal Formation on the south crop, and the Grovesend Formation on the north crop, this is due to poor exposure. Exposure of the South Wales Pennant Formation on the north crop, however, is generally excellent. The lack of sites demonstrating this part of the Upper Carboniferous is due to the absence of detailed biostratigraphical or sedimentological work on the surface exposures, the only notable exception being Kelling's (1964, 1968, 1969) sedimentological analysis of the Rhondda Member. There is clearly much scope for future work here.

TENBY–SAUNDERSFOOT COAST

Highlights

Tenby–Saundersfoot coast is the only extensive exposure of Millstone Grit and lower Coal Measures on the western extremity (Pembrokeshire) of the south crop of the South Wales Coalfield. It provides a unique insight into the palaeogeography and evolution of the coalfield. It also yields some of the best plant and bivalve fossil assemblages for the basal Coal Measures in Britain, with important consequences for understanding their biostratigraphy.

Introduction

The coast between the harbours at Tenby and Saundersfoot, Dyfed (SN 136016–SN 136046), exposes Namurian and lower Westphalian strata, representing a westerly extension of the south crop of the South Wales Coalfield (Figure 4.4). The strata have been seriously disturbed by Variscan tectonics, but the excellent exposure has allowed a more or less continuous succession to be established. There are a number of accounts of the field geology, the most important being by Strahan *et al.* (1914), Dixon (1921), Jenkins (1962), Owen *et al.* (1966), Williams (1968) and Kelling and George (1971). There are also two unpublished theses that describe the geology and sedimentology in great detail (Williams, 1966; G. T. George, 1970).

Description

Lithostratigraphy

Some 375 m of mudstones, shales, siltstones and sandstones here belong to the Millstone Grit and basal Coal Measures groups. They are separated from the underlying Carboniferous Limestone by the Ritec Fault. A summary lithostratigraphical log is shown in Figure 4.5.

Figure 4.4 Coast between Saundersfoot and Monkstone Point, Tenby–Saundersfoot Coast GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A333).

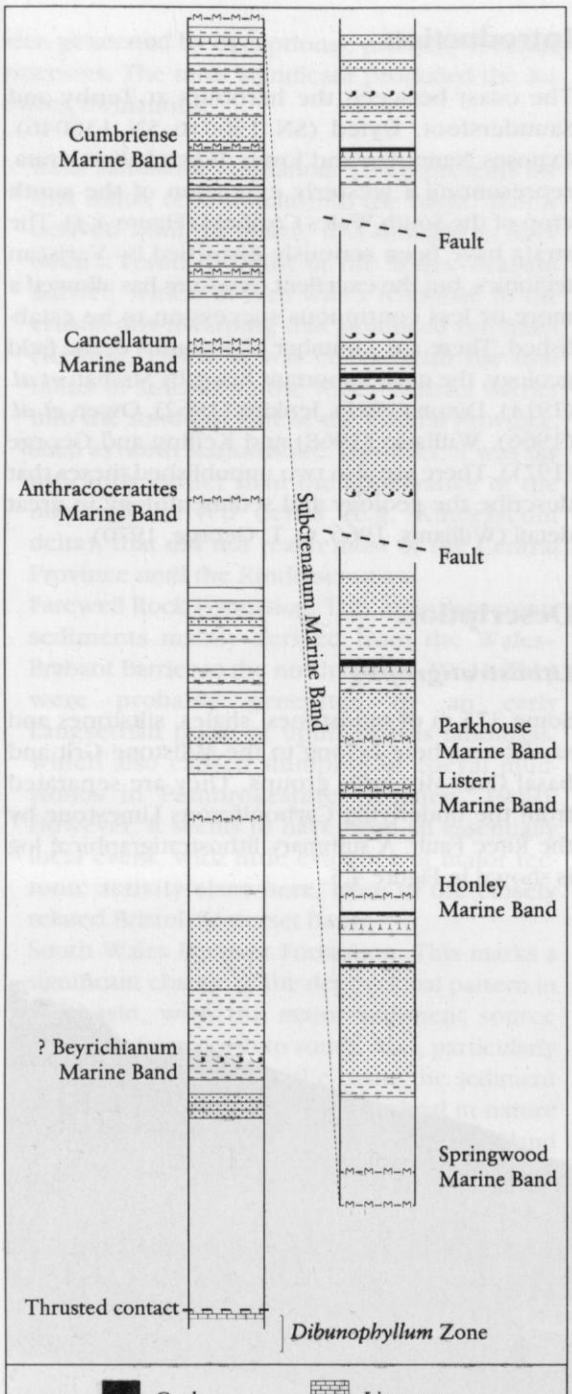

Figure 4.5 Upper Carboniferous stratigraphy exposed along the Tenby–Saundersfoot coast. Based on Jones (1974, fig. 25) and Jenkins (1962, pl. 5).

The lower 230 m consist of shales and siltstones, with subsidiary sandstones. They appear to be equivalent to the Bishopston Formation of the Gower (see Barland Common, below), which represents mid-basinal deposits. However, some of the sandstones in the Tenby sequence have been interpreted as beach deposits associated with a coastal barrier bar, whilst others may be fluvial in origin (G.T. George, 1970; Kelling and G.T. George, 1971). It is thus likely that the Tenby sequence was formed nearer the basin margin than the Gower succession (Kelling, 1974).

Overlying the Bishopston Formation is an interval dominated by sandstones, with only a few marine mudstones. Early authors took these sandstones to be a diachronous equivalent of the Farewell Rock Formation in the main part of the South Wales Coalfield. However, it is now evident that they represent a quite distinct body of sandstone, known as the Upper Sandstone Formation. This interval is taken to represent fluvial deposits associated with a delta lobe advancing from the north-west (Kelling, 1974).

Above the Upper Sandstone Formation is a sequence of five regressive cycles, which mark the base of the Coal Measures Group here. Each has a marine band at the base, overlain by beach and channel deposits, and terminated by a seat earth and coal representing emergent conditions (Williams, 1966, 1968). The lowest of these marine bands can be correlated with the Subcrenatum Marine Band, but the remainder have only limited, brackish water fossil assemblages (see below). Nevertheless, they probably equate to the four marine bands recorded as M_1–M_4 in the main part of the South Wales Coalfield by Leitch *et al.* (1958) (the M_5 Marine Band recognized by Leitch *et al.* does not occur at Tenby, but has been found in the Broadhaven section on the west coast of Pembrokeshire (Jenkins, 1962)).

This basal Coal Measures interval has a number of distinctive features. The Subcrenatum Marine Band is thicker here (15 m) than in any other parts of the South Wales Coalfield, and consists of a number of discrete layers. This would appear to agree with the model proposed by Bloxham and Thomas (1969), whereby this marine band was generated by a marine transgression originating from the west or south-west.

Between the Subcrenatum and M_1 marine bands is an interval of arenaceous deposits with spectacular slump structures (Kuenen, 1948; Williams, 1969). Williams argued that they were caused by the movement of partially consolidated sediment down a south-sloping palaeoslope, confirming palaeogeographical conclusions drawn elsewhere in the South Wales Coalfield (Bluck, 1961).

Above the M_3 Marine Band is a conglomerate with re-worked, silicified, coral fragments (Leach, 1933; Dix, 1942), known as the Monkstone Grit. Owen (*in* Nevill, 1961) compared it with the Clay-Gall Sandstone of the Leinster, Slieveardagh and Crataloe coalfields in Ireland, which contains similar coral fragments. Owen argued that both deposits were probably derived from a landmass to the south.

The top 200 m of the section consist predominantly of fluvial channel and floodbasin lake sediments. At the base is a thick, presumably channel sandstone unit with an erosive base, that forms the prominent Monkstone Point. Jenkins (1962) suggested that it is equivalent to the Farewell Rock further east, but this is unlikely in view of its stratigraphical position. Within this top part of the sequence are a number of thin coals and/or seat earths, including the Stammers Seams which was worked at one time at Saundersfoot.

Biostratigraphy

Marine bands

The lowest marine fossils are present in nodular limestones found near Barrel-post Rock (De la Beche 1846; Bisat, 1933). There has been disagreement concerning their biostratigraphical position, but it is now thought that they are of the *Homoceras beyrichianum* Zone, indicating the upper Chokierian.

Towards the top of the Bishopston Formation is a marine band which appears to correlate with the Anthracoceratites Marine Band on the north crop of the South Wales Coalfield. This level may thus be provisionally regarded as the Marsdenian–Yeadonian boundary in this sequence.

Within the Upper Sandstone Formation are three marine bands. From the lowest, Jones (1969) reported *Cancelloceras cancellatum* (Bisat) and *Agastrioceras carinatum* (Frech), clearly indicating the lower Yeadonian, whilst the upper one yielded *Cancelloceras cumbriense* (Bisat), indicating the upper Yeadonian. The middle band has so far only yielded the bivalves *Sanguinolites* and *Edmondia*.

Above the Upper Sandstone Formation is a sequence of five marine bands, but only the lowest has yielded a biostratigraphically diagnostic assemblage, indicating the Subcrenatum Marine Band. This thus marks the Yeadonian–Langsettian (Namurian–Westphalian) boundary. The remaining four have only yielded *Lingula*, *Orbiculoidea*, fish fragments and annelid tracks (Jenkins, 1962; Williams, 1966, 1968) and thus represent brackish, rather than fully marine, conditions. Nevertheless, it is generally agreed that they equate to the M_1–M_4 marine bands recognized by Leitch *et al.* (1958) in the main part of the South Wales Coalfield.

Non-marine bivalves

Eagar *in* Jones (1969) described a suite of bivalves from an interval within the Bishopston Formation known as the Gasker Rock Shell Bed. They appear to belong to the *Carbonicola ornata* Trueman–*Carbonicola deansi* Eagar group of species. Eagar noted that if correctly identified, this is the oldest known occurrence of this type of assemblage, which usually occurs in the topmost Marsdenian.

Nine horizons within the Coal Measures here have yielded non-marine bivalves. They are designated horizons 14–22 by Jenkins (1962) and although it is a little awkward (numerical order does not reflect stratigraphical order) this scheme is still used today. The lowest three beds occur in that part of the sequence also containing the marine bands. The lowest (Bed 20) yielded *Curvirimula* sp., which is more characteristic of brackish than fully non-marine conditions (Trueman and Weir, 1960). Beds 21 and 22 have yielded more typical non-marine assemblages, the former yielding *Carbonicola* cf. *extenuata* Eagar and *C.* aff. *fallax* Wright, and the latter rare examples of *C. lenisulcata* (Trueman). These appear to belong to the *C. fallax*–*C. protea* Subzone (lower *C. lenisulcata* Zone), and are the only evidence of this subzone reported so far from the South Wales Coalfield.

The bivalves from the next highest three beds (17–19) have been described by Jenkins (1960). The identifications made by Jenkins suggest that they belong to the *C. fallax*–*C. protea* Subzone. However, Eagar (1964) points out that the Bed 19 assemblage is typical of the *Carbonicola pontifex* Eagar group, which suggests a rather higher stratigraphical position, in the *Carbonicola proxima* Subzone. Furthermore, the drawings of shells from Bed 18 (Jenkins, 1960, text figs 3F–L) invite a comparison with *Carbonicola extima* Eagar (1964, textfigs 3A–K), which are small shells found frequently in the *C. proxima* Subzone. The Bed 17 assemblage (Jenkins, 1960, text fig. 2) is also similar to the *C. proxima* Subzone, such as described by

Eagar (1962, text fig. 9). The evidence from Tenby–Saundersfoot is therefore in general agreement with observations made in the Pennines (Calver, 1969a), that non-marine bivalves from just above the Listeri Marine Band usually belong to the *C. proxima* Subzone.

There are no published descriptions or illustrations of the fossils from the upper three beds (14–16). However, identifications given by Jenkins (1962) suggest that they include *Carbonicola extenuata* Eagar, which is consistent with them belonging to the *C. proxima* Subzone.

In similar stratigraphical intervals in the main part of the South Wales Coalfield, Leitch *et al.* (1958) recognized only two horizons yielding non-marine bivalves, which they designated C_1 and C_2. They are presumably equivalent to two of the horizons designated beds 14–19, but at present it is impossible to give a detailed correlation.

Plant macrofossils

Plant macrofossils are known from four horizons here, all in the Coal Measures (Goode, 1913; Kidston, 1923–1925; Dix, 1933, 1934). The best known are the two Monkstone Point Plant Beds, one of which underlies the M_1 Marine Band and the other overlies a thin coal between the M_3 and M_4 marine bands. They both yield essentially similar assemblages, including *Neuralethopteris jongmansii* Laveine, *Alethopteris urophylla* (Brongniart) Göppert, *Karinopteris acuta* (Brongniart) Boersma and *Sphenophyllum cuneifolium* Sternberg. The presence of *N. jongmansii* is of particular biostratigraphical significance, since it is normally restricted to the lower *Lyginopteris hoeninghausii* Zone (Laveine, 1967). Both in stratigraphical position and species composition, the lower of these two plant beds bears a striking similarity to the Plant Bed C at Nant Llech (see below).

A third bed yielding plants fossils occurs between Monkstone Point and Swallowtrees. Kidston (1923a, 1923b, 1925) recorded a number of species from here, but only one (*Adiantites* sp.) was described and illustrated.

The fourth and stratigraphically highest of the plant beds in this section outcrops 200 m south of Saundersfoot Harbour. Kidston (1923d) and Dix (1934) recorded from here *Lyginopteris hoeninghausii* (Brongniart) Gothan, *Karinopteris acuta* (Brongniart) Boersma, *Palmatopteris furcata* (Brongniart) Potonié and *Sphenophyllum cuneifolium* Sternberg. The assemblage is fully consistent with the *L. hoeninghausii* Zone, but as yet no species have been found which indicate the lower or upper parts of the zone.

Interpretation

This is the best available exposure of the Millstone Grit and lower Coal Measures at the western end of the south crop of the South Wales Coalfield. There are outcrops of a similar succession along the Cleddau (Jenkins, 1962), but exposure is on the whole very poor.

The Millstone Grit here is most similar to the south crop succession in the Gower, such as at Barland Common (see below). In neither section, is there a clearly defined Basal Grit Formation, as seen on the north crop, and most of the Millstone Grit is assigned to a single unit, the Bishopston Formation. The marine faunas are also very similar in both areas, belonging to the 'Goniatite-Pectinoid Biofacies' of Ramsbottom (1969b). There are nevertheless important differences between the Pembrokeshire and Gower successions. In particular, there is a higher proportion of sandstones in Pembrokeshire, resulting from coastal barrier bars and fluvial deltas, which indicates a position nearer the basin margin (Kelling, 1974).

The Coal Measures here can also be compared closely with the south crop near Swansea. The best documented succession in the latter area is in the Margam No. 1 Borehole (Woodland, Archer and Evans, 1957), which only differs from the Pembrokeshire succession by the greater development of marine strata. Compared with the north crop successions, such as seen at the Nant Llech and Cwm Gwrelych–Nant Llyn Fach (see below), the Saundersfoot sequence is significantly thicker and has more non-marine bivalve beds. Even compared with the north crop exposures only a few kilometres to the north, such as the Amroth Coast (see below), the Saundersfoot succession is significantly thicker. Both the thickness of the succession and the more numerous non-marine bivalve horizons suggest that the south crop occupies a more central position in the depositional basin (also see the isopachyte maps by Leitch *et al.*, 1957, figs 6–7).

There are certain similarities between the Coal Measures of Saundersfoot and that of the small coalfields in south-east Ireland (e.g. Leinster, Slieveardagh). For instance, the Clay Gall Sandstone, immediately below the Listeri Marine Band at Leinster, can be compared with the Monkstone Grit near Tenby (Owen *in* Nevill, 1961). However, the sequences between the Subcrenatum and Listeri marine bands in the Irish coalfields are much

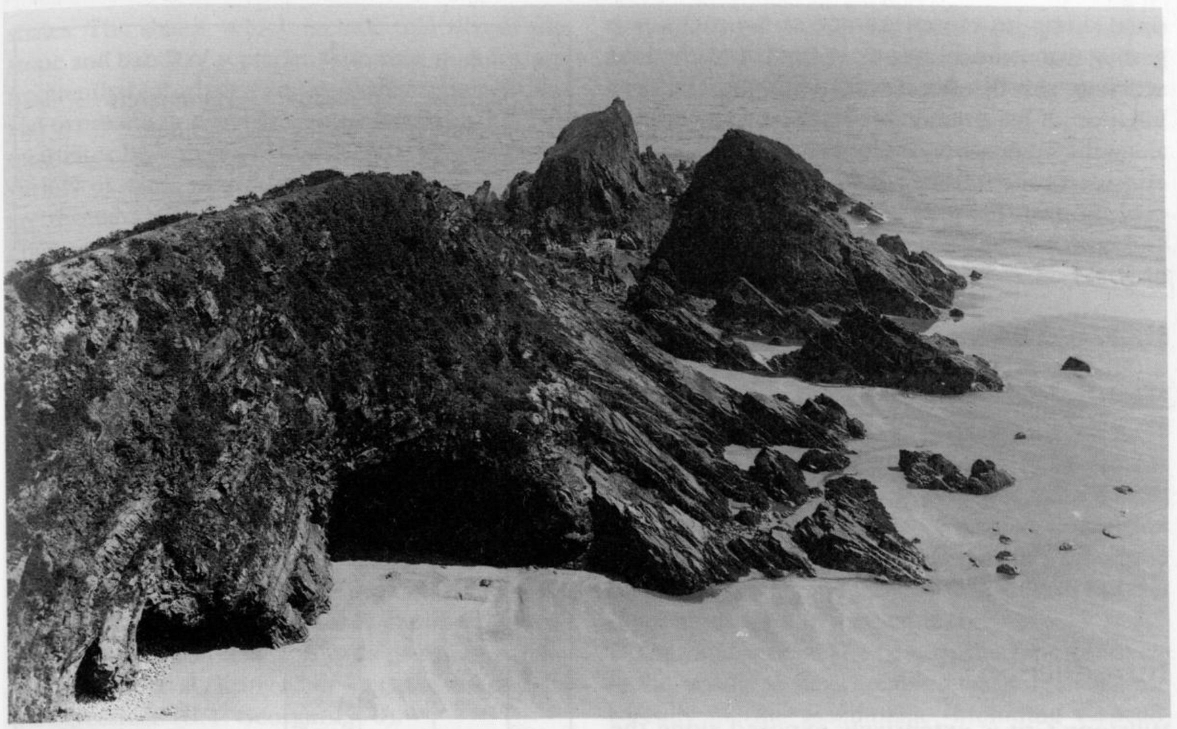

Figure 4.6 Monkstone Point, Tenby–Saundersfoot Coast GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A339).

reduced compared with the Tenby–Saundersfoot succession, and there is no evidence of the M_1, M_2 and M_4 marine bands.

The presence of slumped beds above the Subcrenatum Marine Band may have a tectonic significance. On the north crop, the Farewell Rock occurs at the same position in the sequence, and this extensive sandstone body presumably resulted from uplift of the hinterland allowing increased erosion. It is likely that earth movements associated with this uplift were responsible for the slumping of sediment near Saundersfoot.

The sequence offers one of the most complete records of lower Langsettian non-marine bivalve fossils outside of the Pennines coalfields. Based mainly on Eagar's (1956) work on the latter areas, Ramsbottom *et al.* (1978, pl. 1) subdivide the *C. lenisulcata* Zone into three subzones (or 'faunal belts'): in ascending order, *C. fallax–C. protea*, *C. extenuata* and *C. proxima*. The evidence from Saundersfoot does not support this view, however, as there is a complete overlap in the stratigraphical ranges of the *Carbonicola extenuata* and *C. proxima* assemblages. This is in general agreement with observations made in Belgium (Pastiels, 1960), and appears to support the original view of Calver (1956), that the *C. lenisulcata* Zone is divisible into just two subzones (or 'belts'): *C. protea–C. fallax* and *C. proxima*.

Conclusions

This is one of the best exposures of rocks known as Millstone Grit and basal Coal Measures in the western part of the South Wales Coalfield (Figure 4.6). There are abundant fossils, including the remains of marine animals such as ammonoids, non-marine bivalves, and plants, which allow detailed correlations to be made with other sequences of this age in Europe. The Coal Measures non-marine bivalve faunas are particularly rich here, and are only better developed in Europe in the Pennines Coalfield. The rocks here represent deposits laid down about 312–320 million years ago, in and adjacent to a river delta. Compared with many of the sequences of this age in South Wales, the Millstone Grit here has significantly less sandstone, suggesting that it was deposited further away from the main delta, which supplied the sands. The best comparison is with successions in the Gower, which also are relatively poor in sandstones, but which are mostly very poorly exposed. Also of interest here is the presence of well developed slump-structures in some of the rocks, suggesting that some seismic movement distrurbed the sediment shortly after it was laid down. The combination of features visible in the rocks exposed along the Tenby–Saundersfoot coast makes them of considerable significance for understanding the evolution of this part of Britain during the Late Carboniferous.

MARROS SANDS

Highlights

Marros Sands has the best available sequence through the Millstone Grit on the Pembrokeshire north crop. It shows characters of both the north crop on the main part of the coalfield and the south crop of Pembrokeshire.

Introduction

Millstone Grit is extensively exposed along the coast near Telpyn Point and Ragwen Point, east of Amroth, Dyfed (SN 183073–SN 198075 and SN 219071). Unlike most Upper Carboniferous sequences in Dyfed, the sequence here has suffered relatively little tectonic disturbance. The field geology has been described by Strahan *et al.* (1909, 1914), Reading (1971) and Kelling and George (1971). Stratigraphical and sedimentological details are also given in an unpublished thesis by G.T. George (1970).

Description

Lithostratigraphy

Exposed at Telpyn Point and Ragwen Point is an almost complete sequence through the Millstone Grit in this part of the coalfield, totalling 195 m (Figure 4.7). Between the promontories (a distance of about 2 km) there is little exposure but due to the low angle of dip, however, only a few metres of shale are missing from the visible succession.

As along most of the north crop, the Millstone Grit here is divided into three formations: the Basal Grit, Middle Shales and Upper Sandstone locally known as 'Farewell Rock'. The Basal Grit is *c.* 40 m thick and lies unconformably on Visean (?Brigantian) Carboniferous Limestone. It consists of five coarse quartzites, separated by dark, carbonaceous

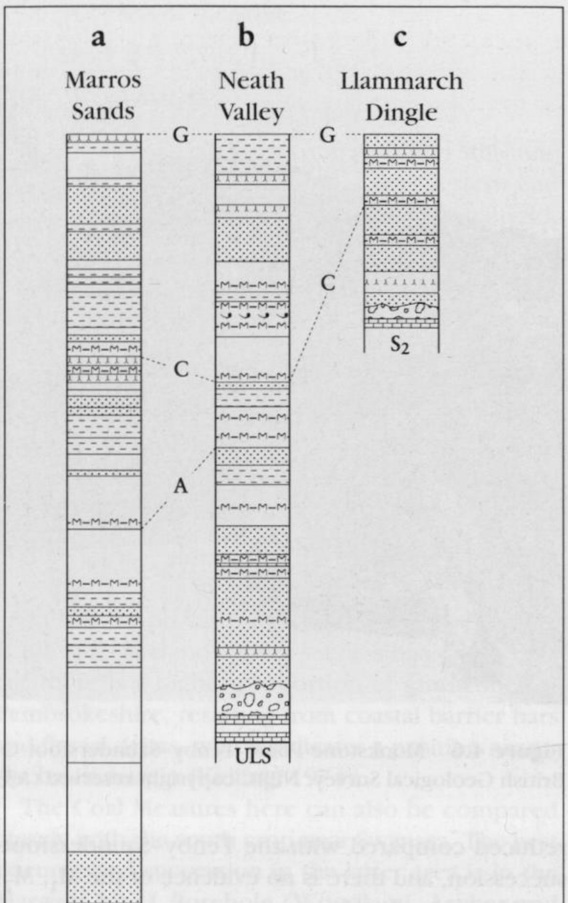

Figure 4.7 Millstone Grit successions of the north crop of the South Wales Coalfield. All after Jones (1974, fig. 24).

shales. The shales, which include thin ribs of siltstone and bands of septarian limestone nodules, are frequently bioturbated and probably represent fluvial overbank or distal crevasse-splay deposits. The quartzites have erosional bases and demonstrate a variety of cross-stratification morphologies. They are thought to represent distributary- or crevasse-channel deposits. G.T. George (1970) has interpreted the sequence as deposited in a regressive fluvial, flood-plain environment, transected by distributary channels, the latter probably being braided.

The Middle Shales Formation consists of six coarsening-upwards cycles, and attains a total exposed thickness of *c.* 105 m. The base of each cycle is marked by black mudstones, mostly representing lagoonal or brackish-marine deposits. These are overlain by increasingly coarse siltstones, which are progressively more proximal delta-front deposits, and are in some cases capped by sandstones formed as offshore shoals or beach barrier bars. The interval clearly represents a series of delta transgressions (G.T. George, 1970).

Overlying the Middle Shales is a prominent sandstone unit. Traditionally, it was referred to as the Farewell Rock. However, it is significantly lower, stratigraphically, than the 'classic' Farewell Rock in the main part of the South Wales Coalfield. In the Tenby–Saundersfoot Coast site discussed above, a sandstone body in a similar stratigraphical position is known as the Upper Sandstone Formation and it seems reasonable to use the same name for the sandstone here.

The Upper Sandstone Formation is *c.* 30 m thick, and is a major, fining-upwards cycle. At the base, which is erosive on the Middle Shales, there are shale and coal rafts, quartz clasts and ironstone pebbles. Most of the rest of the formation is thick, trough cross-stratified sandstones, but towards the top there are ripple and cross-stratified siltstones, eventually topped by a seat earth and coal. According to G.T. George (1970) they are delta-top deposits, mainly point- and channel-bar accretions, succeeded by floodbasin lake (?crevasse-splay) and eventually back-swamp deposits. The coal, which marks the top of the Upper Sandstone Formation, is immediately overlain by a marine mudstone – the Subcrenatum Marine Band.

Biostratigraphy

Few fossils have been reported from the Basal Grit at Ragwen Point. Comparing it with other sequences on the north crop, it would be expected to range from the Chokierian or possibly upper Arnsbergian, up to the Kinderscoutian (e.g. Vale of Neath – see below). From the thickness of the sequence, it probably does not range below the Kinderscoutian. Kelling and George (1971) report unnamed Pendleian conodonts from two levels within the lower half of the formation, but the evidence has not been documented. The biostratigraphical evidence from these strata is clearly in need of revision.

The black mudstones in the Middle Shales have yielded mostly restricted assemblages of *Anthracoceras* sp., *Lingula* sp., *Sanguinolites* sp. and *Carbonicola* sp. Jones (1974) correlated the mudstone at the base of the fourth cycle in this formation with the Anthracoceratites Marine Band recognized elsewhere (e.g. Tenby–Saundersfoot and Vale of Neath), but there is nothing in the assemblage which separates it from most of the other mudstones in this sequence.

The mudstone at the base of the topmost cycle of the Middle Shales contains a far more characteristically marine assemblage, including *Cancelloceras cancellatum* (Bisat), *Agastrioceras carinatum* (Frech), *Caneyella* sp. and mollusc spat (Archer, 1965; G.T. George, 1970). This clearly belongs to the *C. cancellatum* Zone, indicating the lower Yeadonian.

The mudstone at the top of the succession contains *Gastrioceras subcrenatum* (Frech) and thus is taken as the junction between the Namurian and Westphalian series.

Interpretation

This is by far the most complete section through the north crop Millstone Grit in Dyfed. There is also a good sequence exposed along the St Brides Bay coast (Archer, 1965), which includes the Sigma Marine Band not found at Marros (possibly represented in the gap between Ragwen and Telpyn points). However, the St Brides Bay sequence does not include the lower part of the Millstone Grit (Basal Grit Formation).

The sequence at Marros appears to demonstrate features of both the north crop of the main part of the coalfield, and the south crop of Dyfed. Like the north crop further east, there is an essentially tripartite formational division. However, the topmost arenaceous formation is not the Farewell Rock, such as in the Vale of Neath (see below) sequence, but the Upper Sandstone Formation of the Dyfed south crop at Tenby–Saundersfoot. This clearly reflects how the Millstone Grit of South Wales was being generated by a series of discrete fluvial systems, independently introducing sediment into the basin.

The Marros section also demonstrates clearly the contrasting sedimentary regimes that produced the Basal Grit and Upper Sandstone formations. The latter appears to represent a large, relatively simple delta-system with a heavily laden river probably flowing from the north-west. In contrast, the Basal Grit was generated by a complex set of small, coalescing deltas, possibly controlled by a number of structural axes.

Conclusions

Marros Sands is a nationally important site for understanding the evolution of Britain during the Namurian, approximately 310–320 million years ago. The exposed sequence shows Millstone Grit, including two thick units of sandstone, known as the Basal Grit and the Upper Sandstone. These are thought to be the deposits of river deltas that spread out from upland areas further north, in central Wales. Between the sandstones is an interval of shales, representing a time when the river delta had retreated, allowing more marine sediments to be deposited. Although there are other well-exposed sequences through this part of the Millstone Grit in South Wales, that at Marros Sands combines a unique set of characters allowing geologists to understand how the river deltas developed at this time.

AMROTH COAST

Highlights

Amroth shows the best sequence of middle Langsettian to middle Duckmantian strata in Pembrokeshire, and provides an important comparison with sections in the main part of the South Wales Coalfield. The sequence includes the distinctive Amroth Freshwater 'Limestone'.

Introduction

Coastal exposures between Wiseman's Bridge and Amroth, Dyfed (SN 148062–SN 168069) show middle Langsettian to middle Duckmantian strata on the north crop in Pembrokeshire. Although broken up into a series of blocks by Variscan faulting, it has

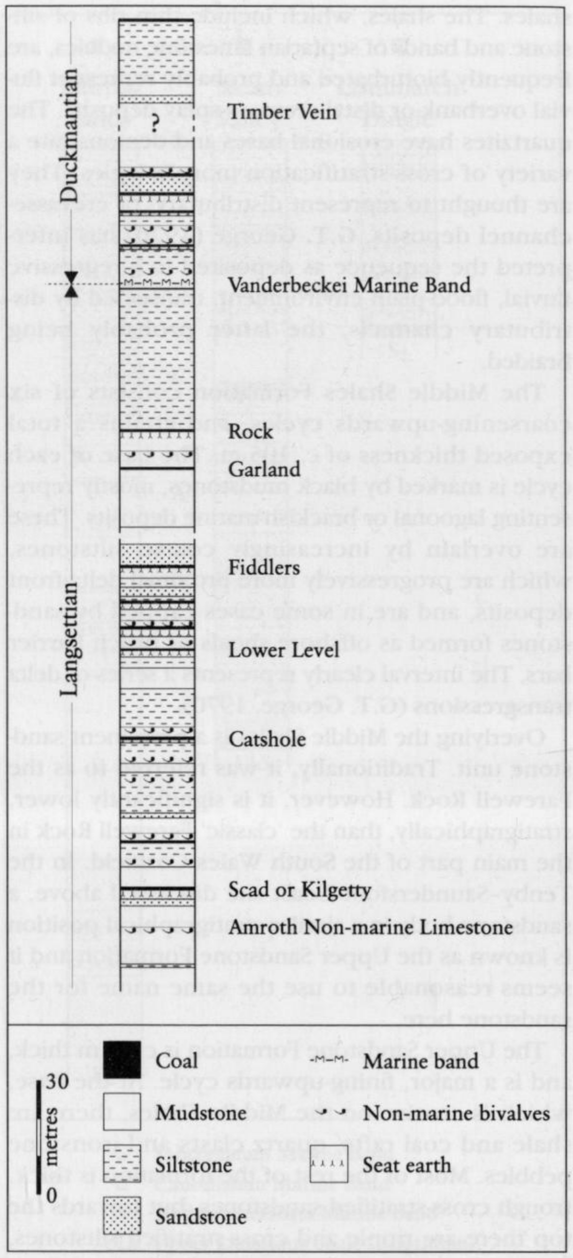

Figure 4.8 Coal Measures exposed along the Amroth Coast. After Jenkins (1962, pl. 5).

proved possible through a combination of litho- and biostratigraphy to establish a continuous succession. The geology was dealt with in a number of early studies, the most important by De la Beche (1846) and Strahan *et al.* (1914). Jenkins (1954, 1962) was able to establish the continuity of the sequence, enabling detailed sedimentological analyses to be made subsequently (Williams, 1966, 1968).

Figure 4.9 Coal Measures exposed along the Amroth Coast. (Photo: C.J. Cleal.)

Description

Lithostratigraphy

The combined sequence exposed here is some 250 m thick, with six named coal seams (Figures 4.8 and 4.9). The lower 100 m, up to just below the Fiddlers Seam, consist mainly of lacustrine and back-swamp deposits (Williams, 1968). A distinctive feature of this interval at Amroth is the so-called 'Amroth Freshwater Limestone', underlying the Kilgetty Coal. It is not a limestone in the strict sense, but a calcite or ankerite-cemented siltstone, with more than 20% detrital quartz, probably deposited in a lacustrine setting (Williams, 1968; Kelling and George, 1971; George and Kelling, 1982).

Above the Fiddlers Seam are *c.* 75 m of mainly mudstones and shales with a number of coals and/or seat earths. They appear to represent fluvio-deltaic sediments, probably deposited in floodbasin lakes in a middle delta-plain setting. In such a model, the mudstones and shales would represent mainly overbank deposits, while the coals/seat earths would reflect emergent conditions. Towards the top of this interval, high energy channel sandstones and siltstones occur (Figure 4.10). They reveal variable palaeocurrent directions and Williams (1966, 1968) attributes them to a highly sinuous river system running in a westerly or north-westerly direction.

Overlying this fluvial channel deposit is *c.* 0.3 m of dark shales, that are thought to represent the Vanderbeckei Marine Band. Thereafter, there are about 30 m of mudstones and siltstones, showing a gradual return to non-marine conditions (Williams, 1966, 1968). The lower 10 m are inter-tidal, with abundant ripple marks. These are succeeded by mudflat and sand-bar deposits, fluvial channel-fill deposits, and eventually a coal seam (the Timber Seam). The topmost 30 m of the Amroth succession, overlying the Timber Seam, see a return to predominantly marine deposits.

Biostratigraphy

Marine bands

Only one horizon in the Amroth section has been found to contain marine fossils: a shale, *c.* 175 m above the base. To date, it has only yielded a limited assemblage of *Lingula*, *Dunbarella*, *Conularia* and indeterminate bivalve fragments (Jenkins, 1962; Williams, 1966). On its own, such an assemblage is not sufficiently diagnostic for it to be identified with any of the marine bands in the main part of the South Wales Coalfield. However, it occurs in the middle of the *A. modiolaris* non-marine bivalve zone (see below) and is almost certainly a correlative of the Vanderbeckei Marine Band. It thus marks the boundary between the Langsettian and Duckmantian stages.

Non-marine bivalves

These have been found at 13 levels within the Amroth succession, numbered in ascending strati-

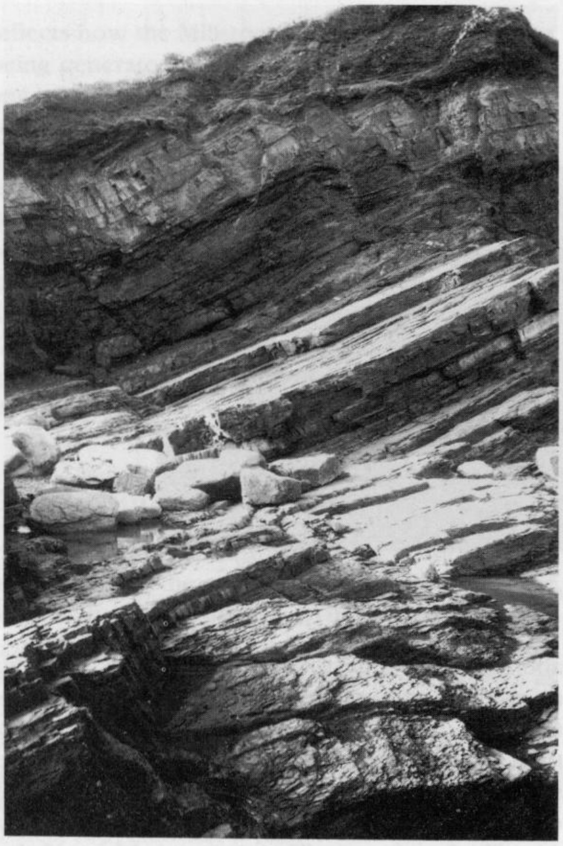

Figure 4.10 Amroth Coast GCR site, north of Wiseman's Bridge. Typical sequence of shales and crevasse splay sandstones of the Productive Coal Formation. (Photo: C.J. Cleal.)

graphical order 1–13 by Jenkins (1962). They fall into four groups: no. 1, the Amroth Freshwater Limestone; nos 2–8 in the lacustrine dominated sequence between the Amroth Freshwater Limestone and the Fiddlers Seam; no. 9 between the Garland and Rock seams; and nos 10–13 between the Vanderbeckei Marine Band and the Timber Seam.

The Amroth Freshwater Limestone contains abundant shells of the *Carbonicola* cf. *bipennis* (Brown) type, thus indicating the *C. bipennis* Subzone (lower to middle *Carbonicola communis* Zone). Other, larger shells were identified by Jenkins (1954) as *Carbonicola* cf. *aldamae* (Brown), a species known from the lower *C. communis* Zone of the main part of the South Wales Coalfield (Trueman and Weir, 1947). Later, Jenkins (1960, 1962) re-named these larger shells as cf.*Anthracosia regularis* (Trueman), but they do not have the umbonal structure typical of *Anthracosia* and are well below the normal stratigraphical range of that genus.

Jenkins' Bed 2, immediately above the Kilgetty Seam, yields an assemblage which, although indicative of the *C. communis* Zone, is not diagnostic of a particular subzone. However, the overlying six horizons (nos 3–8) yield assemblages dominated by large shells, typical of those normally found in the *Carbonicola pseudorobusta* Subzone. Interestingly, the lowest of these beds (no. 3) also contains shells similar in general shape to *C. bipennis* (Brown), which suggests that it represents a transitional phase between the typical *C. bipennis* and *C. pseudorobusta* subzones.

The bivalves from between the Garland and Rock seams (bed no. 9) were identified by Jenkins (1954, 1960) as *Carbonicola oslancis* Wright and *C.* cf. *rhomboidalis* Hind, clearly indicating the *Carbonicola cristagalli* Subzone. Consequently, the boundary between the *C. communis* and *A. modiolaris* zones probably lies somewhere between the Fiddlers and Garland seams.

The highest bivalves come from four horizons above the Vanderbeckei Marine Band. They all clearly belong to the *A. modiolaris* Zone (Jenkins, 1954, 1960), and the lowest (no. 10) has yielded an assemblage of the *Anthracosia ovum* Subzone. No evidence has been found of the *Anthracosia regularis* Subzone at Amroth.

It has often been stated that the succession at Amroth extends up into the 'similis-pulchra' zone (e.g. George and Kelling, 1982), but there is no biostratigraphical evidence to support this assertion. In Pembrokeshire, the only bivalve assemblages of this zone are from the coast at Broad Haven, and near Picton Point on the Cleddau (Jenkins, 1954, 1960, 1962).

Plant macrofossils

Plant fossils are not particularly abundant at Amroth. The best evidence is from two beds, above the Fiddlers and Garland seams (Goode, 1913). These have yielded assemblages including *Neuropteris obliqua* (Brongniart) Zeiller, *Alethopteris* cf. *urophylla* (Brongniart) Göppert and *Eusphenopteris* cf. *sauveurii* (Crépin) Novik, which indicate the upper *Lyginopteris hoeninghausii* Zone (Goode's records of *Macro-neuropteris scheuchzeri* (Hoffmann) Cleal *et al.* and *Annularia sphenophylloides* (Zenker) Gutbier are probably in error, this being well below the normal stratigraphical ranges of these species).

Goode (1913) described a sphenophyte assemblage of restricted diversity, just below the Fiddlers Seam. Such assemblages are often associated with

Figure 4.11 Nolton Haven GCR site, looking north from near Rickets Head. (Photo: C.J. Cleal.)

Upper Carboniferous lacustrine deposits (e.g. Scott, 1979).

In Jenkins' (1962, Pl. 5), a plant bed is shown immediately overlying the Kilgetty Seam, but no reference is made to the species found.

Interpretation

This is the best exposure of upper Langsettian and lower Duckmantian strata on the north crop of Pembrokeshire. Coeval strata are present near Broadhaven (Jenkins, 1962), but the succession there is not as complete, especially in the upper Langsettian. The Cleddau exposures of these strata also show a much less complete succession than at Amroth.

The general pattern of sedimentation seen at Amroth is consistent with that found on the north crop in the main part of the South Wales Coalfield, such as in the Gwendraeth Valley (Archer, 1968). In particular, predominantly lacustrine deposits occur in the upper *Carbonicola communis* Zone of both areas, although these conditions would seem to have lasted somewhat longer in Pembrokeshire. However, there is no evidence in the main part of the South Wales Coalfield of the complex of fluvial sandstones immediately below the Vanderbeckei Marine Band (e.g. Matthews, 1955).

The Amroth Freshwater 'Limestone' is only known from here. Jenkins (1962) found a similar 'limestone' near Broadhaven, but this lies above the Kilgetty Seam and contains non-marine bivalves of the *C. pseudorobusta* Subzone (Jenkins, 1960). No such 'limestones' are known from the main part of the South Wales Coalfield.

Detailed comparisons of thickness with the main part of the South Wales Coalfield are difficult, because Amroth shows neither the bottom of the *C. communis* nor the top of the *A. modiolaris* zones. The only interval for which a comparison is possible is between the base of the *A. modiolaris* Zone (between the Fiddlers and Garland seams) and the Vanderbeckei Marine Band, which is *c.* 85 m thick at Amroth. This is in general agreement with the succession in the Gwendraeth Valley, on the western part of the north crop (Archer, 1968).

Sequences in Ireland overlap only in part with that at Amroth. The top part of the Leinster Coalfield has yielded bivalves of the *C. bipennis* Subzone (Eagar, 1964), but there is no evidence of the upper *C. communis* Zone or *A. modiolaris* Zone. Nevill (1961) claims that the upper part of the Slieveardagh Coalfield also belongs to the lower to middle *C. communis* Zone, but there is little palaeontological evidence to confirm this view.

Conclusions

Amroth Coast is the most extensive natural exposure of Coal Measures rocks in southern Britain. It is possible to show how these rocks were formed in a river delta that flowed southwards from an upland area in present-day central Wales, some 312–314 million years ago. Recognizable deposits include mudstones and shales formed in flood-plain lakes, sandstones formed in the river channels, and coals representing the remains of swamp forests growing on the delta. Of especial interest is the occurrence of the so-called Amroth 'Freshwater Limestone' (in fact probably a calcite or ankerite-cemented mudstone) thought to have been deposited in a lake. Fossils are also abundant here, including marine shells, non-marine bivalve shells and plants. These make it possible to correlate the Amroth sequence with similar aged rocks elsewhere in South Wales, and to build up a picture of patterns of sedimentation in the region.

NOLTON HAVEN

Highlights

Nolton Haven is the only exposure of the South Wales Pennant Formation in Pembrokeshire, and provides an important comparison with coeval strata in the main part of the South Wales Coalfield.

Introduction

This is a coastal exposure of part of the Nolton–Newgale Coalfield, between Druidston and Newgale, Dyfed (SM 861173–SM 854208, Figure 4.11). It is a detached area of Coal Measures lying to the north of the main outcrop of Upper Carboniferous in Pembrokeshire. It was mentioned in a number of early geological studies on Pembrokeshire (e.g. Martin, 1806; De la Beche, 1846), and was described in detail by Cantrill *et al.* (1916). Jenkins (1962) was the first to establish the complete stratigraphical succession, which provided the background for sedimentological studies by Williams (1966, 1968).

Description

Lithostratigraphy

The Nolton Haven sequence is faulted into five discrete blocks. By correlating these five sequences, Jenkins (1962) established a complete stratigraphical succession of *c.* 600 m thick (a summary log is

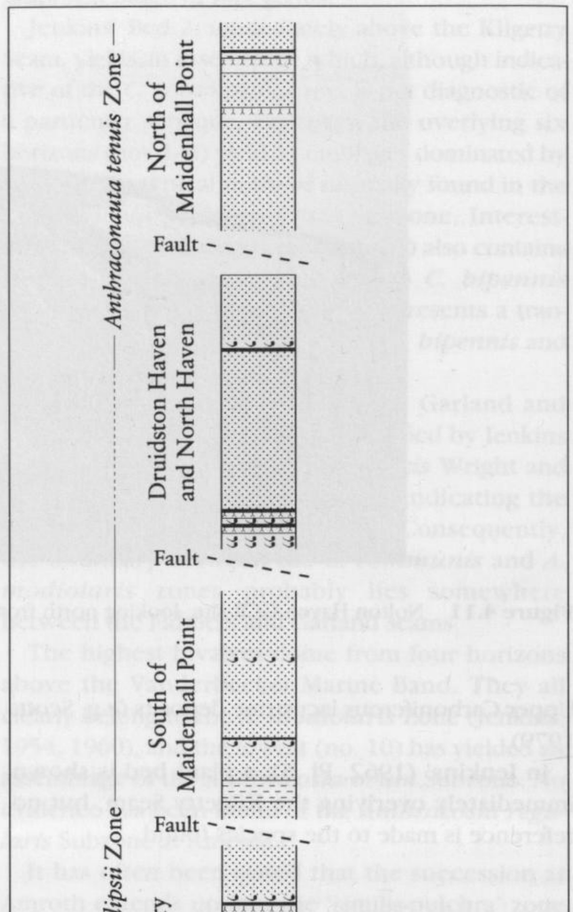

Figure 4.12 Sequence through the South Wales Pennant Formation exposed at Nolton Haven. Based on Jenkins (1962, fig. 7).

shown in Figure 4.12). Most of the strata are sandstones with subsidiary shales. Williams (1966) also noted nineteen coals, although only four are sufficiently prominent to have been named: the Cliff, Black Cliff, Rickets Head (Figure 4.13) and Madoc's coals.

Williams (1966) interpreted the sequence as being mainly fluvial point-bar accretions, and overbank and/or crevasse splay deposits. The energy regime was generally high, and probably reflects deposition in an alluvial setting. However, the presence of coal seams suggests that the distributary channels were subject to active confinement, allowing temporarily stable inter-distributary bay environments to develop. There is considerable variation in palaeocurrent vectors, but Williams demonstrated a statistically significant westward transport direction.

Biostratigraphy

Non-marine bivalves

Shells have been recorded from nine horizons in this sequence (Trueman, 1934; Jenkins, 1954, 1960, 1962). They yield assemblages mostly with *Anthraconauta phillipsi* (Williamson) and varying proportions of *A. tenuis* (Davies and Trueman). Jenkins (1962) placed the boundary between the *A. phillipsi* and *A. tenuis* zones somewhere between his beds III and IV at Druidston Haven, since the upper bed has yielded as many *A. tenuis* as *A. phillipsi*. As with other areas, however, the junction between the two zones is gradational here and it is difficult to fix a boundary accurately (Cleal, 1984a).

Plant macrofossils

Identifiable plant fossils occur at nine levels in this section, and are listed by Goode (1913), Cantrill *et al.* (1916) and Dix (1934). Most of these horizons yield assemblages including *Laveineopteris rarinervis* (Bunbury) Cleal *et al.*, *Macroneuropteris scheuchzeri* (Hoffmann) Cleal *et al.*, *Reticulopteris muensteri* (Eichwald) Gothan, *Mariopteris nervosa* (Brongniart) Zeiller, *Renaultia chaerophylloides* (Brongniart) Zeiller, *Annularia sphenophylloides* (Zenker) Gutbier and *Sphenophyllum emarginatum* Brongniart. Such assemblages belong to the *Paripteris linguaefolia* Zone, and thus indicate the Bolsovian Stage.

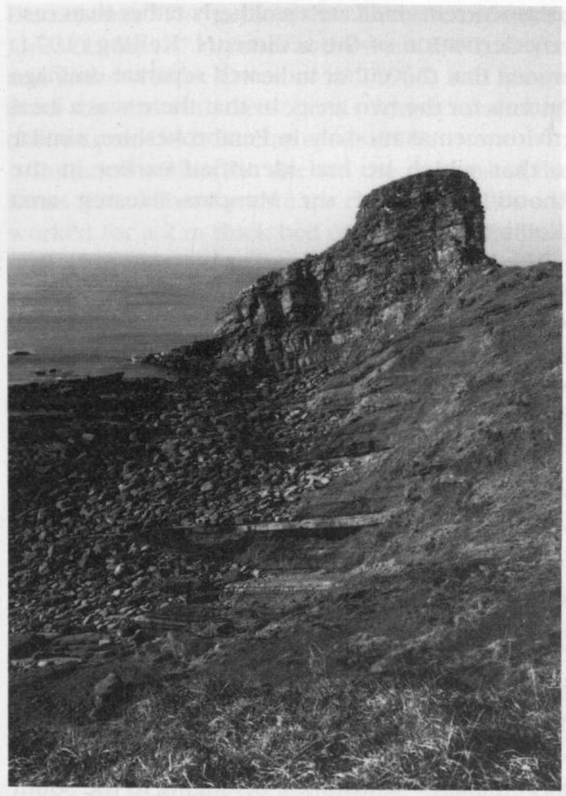

Figure 4.13 Nolton Haven GCR site. Rickets Head. (Photo: C.J. Cleal.)

The topmost horizon, found near Maidenhall Point, has yielded a slightly different assemblage. It includes *Neuropteris ovata* Hoffmann and *Lobatopteris* cf. *micromiltoni* (Bertrand) Wagner, and indicates the *Linopteris bunburii* Zone (Cleal and Thomas, 1992). On this evidence, it is possible to place the Bolsovian–Westphalian D boundary somewhere between 420 and 550 m above the base of the sequence.

Interpretation

This is the only extensive exposure in the Nolton–Newgale Coalfield. Jenkins (1962) mentions some inland exposures between Nolton and Newgale, but they are all much smaller than that available along the coast.

The lithology of the strata is clearly similar to that of the South Wales Pennant Formation (De la Beche, 1846; Cantrill *et al.*, 1916), and the biostratigraphical evidence suggests that they correlate with the Rhondda Beds. The Earlswood Road Cutting (see below) sequence is in many ways similar to that at Nolton Haven, except that the palaeocurrents indicate a southerly rather than easterly derivation of the sediments. Kelling (1974) argued that this either indicated separate drainage systems for the two areas, or that there was a local environmental anomaly in Pembrokeshire, similar to that which he had identified earlier in the Rhondda Beds of the Margam–Maesteg area (Kelling, 1968).

The lack of any good marker horizons at Nolton Haven makes it difficult to compare thicknesses with the main part of the South Wales Coalfield. However, the estimated 600 m thickness of the Nolton Haven sequence suggests that it is significantly thicker than coeval sections further east.

Conclusions

This is the best exposure in Britain of rocks of late Bolsovian to early Westphalian D age, just over 300 million years old. Not only is there extensive outcop of the rocks, but there are also several beds that have yielded fossils (mostly non-marine bivalve shells and plants), allowing detailed correlations with other successions to be made. The rocks are predominantly sandstones, belonging to the South Wales Pennant Formation, representing sediment deposits of meandering rivers.

BARLAND COMMON

Highlights

Barland Common is the stratotype for the Bishopston Formation, which is the mainly argillaceous facies of the Millstone Grit found on the south crop of the South Wales Coalfield. It provides the most complete sequence of Namurian marine bands in South Wales.

Introduction

This stream section near Bishopston, on the Gower Peninsula, Wales (SS 576897–SS 579902), exposes part of the Millstone Grit, as developed on the south crop of the South Wales Coalfield. It was described first by De la Beche (1846), who provided a lithostratigraphical log, and later by Dix (1931a), who described some of the animal fossils. The most detailed survey of the site was by J.V. Stephens, probably in the 1960s. This work has not been published in detail, although it is summarized by Owen (1971c) and Ramsbottom (1971b, 1978).

Description

Lithostratigraphy

This site exposes a sequence of *c.* 200 m of Upper Carboniferous (Chokierian–Marsdenian) strata, of the Bishopston Formation. It consists mainly of mudstones and shales, with only subsidiary sandstones. These so-called 'basinal' deposits have been interpreted by Kelling (1974) as pro-delta and floodbasin lake sediments, which were subject to periodic marine incursions.

Biostratigraphy

Palaeontological evidence here is restricted to marine animal fossils, which occur at 10 separate horizons (a further 3 marine bands have been recognized in the underlying Lower Carboniferous/Arnsbergian part of the sequence). They are in the 'goniatite–pectinoid facies' of Ramsbottom (1969b) and thus all yield biostratigraphically sensitive ammonoid assemblages. According to Stephens *in* Ramsbottom (1978), the following subzones can be recognized:

Stages	Subzones
Marsdenian	*B. bilinguis*
	B. superbilinguis
Kinderscoutian	*R. reticulatum*
	R. nodosum
	R. circumplicatile
	H. magistrorum
Alportian	*V. eostriolatus*
	H. undulatum
Chokierian	*H. beyrichianum*
	I. subglobosum

Interpretation

This is the stratotype and best exposure of the Bishopston Formation, which represents the 'basinal' facies of the Millstone Grit in South Wales, as developed along the central and western parts of the south crop. The formation consists mainly of argillaceous rocks, which explains why there are far fewer exposures than there are of the more resistant arenaceous Millstone Grit of the north crop (e.g. Vale of Neath – see below). The only other good exposure of the Bishopston Formation is along the Tenby–Saundersfoot coastal section in Pembrokeshire, but the sequence there is thinner, does not have as many marine bands, and is tectonically disturbed. The exposed sequence near Aberkenfig is also more condensed than that of the

Gower, and has a much greater proportion of arenaceous deposits due to the northwards progradation of a small fluvial delta (Woodland and Evans, 1964; Kelling, 1974).

According to Ramsbottom (1978), all of the Namurian mesothems identified in the Pennines region can also be recognized at Barland Common. The principal difference is that some of the mesothems (N5, N8 and N9) lack the basal marine band. Ramsbottom argued from this that 'a still more basinal sequence' might be present to the south of the Gower. However, no evidence of this has yet been forthcoming from the Bristol Channel (Cope and Bassett, 1987).

Conclusions

Barland Common is the most important site for a sequence of rocks known as the Bishopston Formation. They represent the deposits of mainly muds and silts, originally laid down some 315–320 million years ago (i.e. during the Namurian Epoch) in a marine basin, immediately in front of river deltas that lay to the north. They contrast with similar-aged deposits only a short distance to the north, which are far more sandy and represent the remains of those deltas. The Barland Common rocks contain numerous fossils of marine animals known as ammonoids, which allow detailed correlations with sequences elsewhere in Europe and North America.

VALE OF NEATH

Highlights

The Vale of Neath exposures provide the best available section through the Millstone Grit on the north crop of the South Wales Coalfield, showing a full range of sedimentary facies. Also present is the best known exposure of the Subcrenatum Marine Band in South Wales, which marks the boundary between the Namurian and Westphalian series.

Introduction

This site covers various exposures along the headwaters of the River Neath, near Pont-Nedd-Fechan, West Glamorgan and Powys (SN 890093 – SN 081077, and SN 915079). They provide an excellent sequence through the Basal Grit, Middle Shales and Farewell Rock formations on the north crop of the South Wales Coalfield, near the Neath Disturbance. The geology has been described by Jones (1958, 1971), Jones and Owen (1957), Owen and Jones (1961), Owen *et al.* (1966) and is covered by British Geological Survey memoirs (Robertson, 1932; Barclay *et al.* 1988).

Included within the site are the remains of the Dinas Silica Mine. Up until the early 1960s, this was worked for a 2 m thick bed of exceptionally pure quartzite, used for making foundry bricks which were extensively exported.

Description

Lithostratigraphy

The sequence exposed here is summarized in Figure 4.7(b). Exposures near the Silica Mine show quartzites of the Millstone Grit Group lying on Lower Carboniferous (Brigantian) limestones. Owen and Jones (1961) noted numerous pods and stringers of quartz pebbles in the limestones below the contact, which they used as evidence that it is conformable. However, the contact is sharp and sometimes undercut, suggesting that the sands flowed over a fissured limestone surface.

The Basal Grit Formation here is 40 m thick and consists mainly of sandstones, with occasional thin shales. The sandstones bodies are tabular or wedged, although X-ray photographs of thin slabs often reveal parallel laminations. Some are white or pale yellow, and consist of up to 99.5% silica (these are the quartzites that were worked commercially). Others, however, are grey due to a higher carbonaceous content, and often have rootlets. Accumulations of pebbles are often found towards the top of the sandstones. Kelling (1974) noted that similar inverse grading also occurs in Recent beach and barrier sands, and he used this (among other factors) to argue that the Basal Grit Formation represents littoral deposits. Palaeocurrents indicate a northerly source for the sediments.

Overlying these predominantly arenaceous strata are *c.* 90 m of Middle Shales Formation. They reflect a complex pattern of sedimentation, with alternating marine and non-marine facies (Oguike, 1969; Kelling, 1974). The marine deposits are mainly shales and mudstones, and form the marine bands used for stratigraphical correlation (see next section). The non-marine facies include lagoonal shales, littoral sandstones, fluvial sandstones, and floodbasin lake sediments (sometimes including non-marine bivalve assemblages). Two of the sandstones have proved persistent throughout much of the north crop of the coalfield and are thus useful

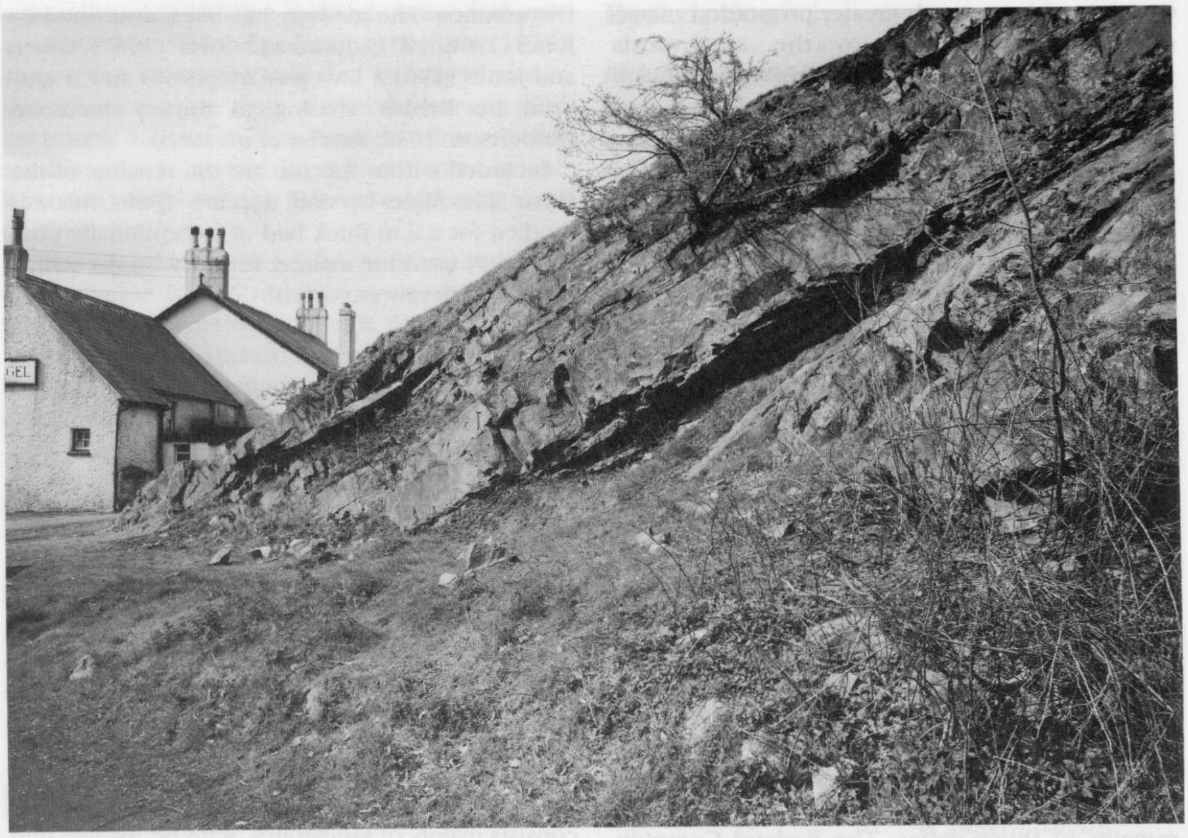

Figure 4.14 Farewell Rock exposed behind Angel Inn, Vale of Neath GCR site. Reproduced by permission of the Director, British Geological Survey: NERC copyright reserved (A11957).

marker horizons: the Twelve Foot Sandstone and the Cumbriense Quartzite, 9 m and 55 m, respectively, above the base of the Middle Shales Formation. The presence of *in situ* rootlets in some of the sandstones shows that they represent emergent conditions.

The highest marine shale in the Middle Shales Formation (the Subcrenatum Marine Band) was shown by Thomas and Bloxham (1971), Bloxham and Thomas (1969, 1970) and Bloxham (1974) to include a range of facies, from brackish to fully marine.

The top of the sequence here shows massive sandstones of the Farewell Rock Formation (Figure 4.14). As over most of the north crop of the coalfield, palaeocurrents indicate a sediment provenance from the north (Bluck, 1961). A number of sedimentological features were described by Kelling *in* Owen *et al.* (1966), and interpreted as the result of movement of the sands due to vertical loading.

Biostratigraphy

Marine bands

Several marine bands have been recognized in the sequence exposed here, as shown in Figure 4.7. Three occur in the Basal Grit Formation. The lowest contains *Homoceras* sp. and, although a fully diagnostic assemblage has yet to be reported, it probably indicates a position in the Chokierian or possibly Alportian. About 9–13 m above this level are two marine shales the lower of which yields a diagnostic assemblage of the Reticulatum Marine Band (Upper Kinderscoutian).

The base of the Middle Shales Formation here is placed at the Superbilinguis Marine Band, indicating the upper Marsdenian. Higher in the formation, marine shales with Yeadonian assemblages occur, including the Cancellatum and Cumbriense marine bands. At the very top of the formation is the Subcrenatum Marine Band (Figure 4.15), which marks the boundary between the Namurian and Westphalian series.

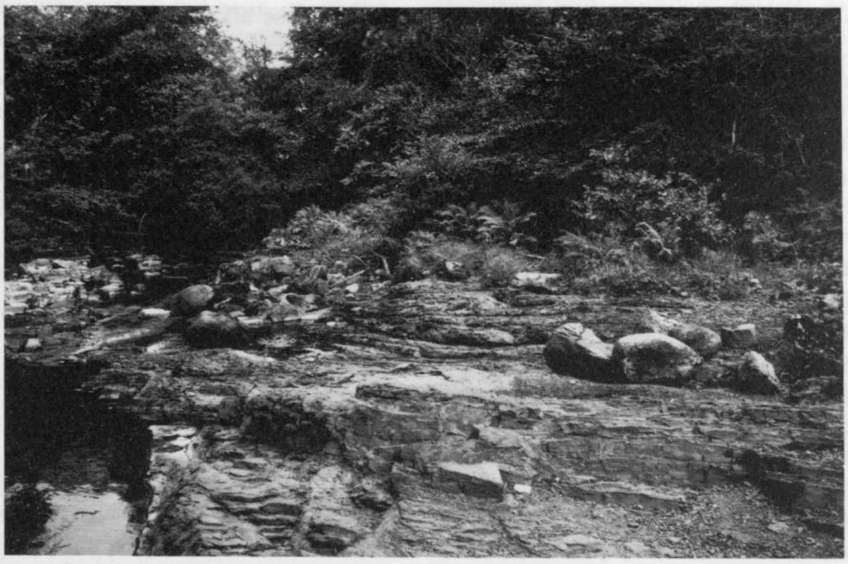

Figure 4.15 Vale of Neath GCR site. Subcrenatum Marine Band. (Photo: C.J. Cleal.)

Other marine bands have also been reported from here, in addition to those with biostratigraphically diagnostic ammonoids. The most significant is found between the Superbilinguis and Cancellatum marine bands, and is known as the Anthracoceratites Marine Band. It has been recognized at several other localities along the north crop of the coalfield, but it never develops beyond the '*Anthracoceras* and *Dimorphoceras* phase' of Archer (1968), and thus does not yield a biostratigraphically sensitive fossil assemblage.

Some 9 m above the Cancellatum Marine Band is another marine bed, this time containing a number of bryozoans, including *Fenestrellina* and *Rhombopora*. Such bryozoans are extremely rare in the Millstone Grit of Britain.

Non-marine bivalves

From mudstones between the Cancellatum and Cumbriense Marine Bands, Jones and Owen (1957) report *Carbonicola lenicurvata* Trueman and *C.* cf. *bellula* (Bolton). It compares with assemblages from the Yeadonian of the Pennines (e.g. Eagar, 1952b, 1954, 1964), although it cannot as yet be integrated into the wider model of pre-Westphalian non-marine bivalves distribution established by Eagar (1977).

Plant macrofossils

A mudstone near the base of the Basal Grit Formation has yielded fragments of the lagenostomalean frond *Lyginopteris porubensis* (Trapl) Gothan (Jones, 1958, 1971; Jones and Owen, 1957). Outside of Wales, this species is only known from the Arnsbergian of Upper Silesia (e.g. Purkyňová, 1977).

Plant macrofossils have also been reported from immediately above the Cumbriense Quartzite (Crookall *in* Robertson, 1932; Owen, 1971b). *Alethopteris* and *Neuropteris* are reported present, but the material has not been described in detail.

Interpretation

This is the best available section through the Millstone Grit Group on the north crop of the South Wales Coalfield. There are other complete successions, such as that exposed along the River Twrch, but they tend to be complicated by repetitive folding and are not as accessible. The sequence can be combined with that shown in the nearby Cwm Gwrelych–Nant Llyn Fach site, to provide an unrivalled section through the Arnsbergian to Duckmantian of Europe.

The Millstone Grit here is more condensed than further west on the north crop. There is only a very limited development of pre-Kinderscoutian deposits, due to the then limited geographical extent of the depositional basin (Jones, 1974). There are also probably non-sequences within the Kinderscoutian to Yeadonian succession, although they have not yet been recognized in the field. Nevertheless, most of the Kinderscoutian to Yeadonian marine bands, recognized elsewhere along the north crop, are present near Pont-Nedd-Fechan; the only significant exception is the Sigma Marine Band, such as is present at Llandebie (Jones, 1974). The attenuation of the Millstone Grit near Glyn Neath may be at least partly due to contemporaneous activity along the line of the Neath Disturbance (Kelling, 1974).

Further east, such as at Brynmawr, the Millstone Grit Group is even more condensed (Jones and Owen, 1967). The depositional basin did not extend this far east until the Marsdenian, probably due to uplift along the Usk Axis (Jones, 1974).

The north crop Millstone Grit differs significantly from that found on the south crop, such as at Barland Common. The latter occupied a position nearer the centre of the depositional basin, and consists predominantly of marine mudstones and shales.

Exposures at Pont-Nedd-Fechan played a central role in the palaeontological and geochemical analysis of the Subcrenatum Marine Band by Thomas and Bloxham (1971), Bloxham and Thomas (1969, 1970) and Bloxham (1974). Only here was it possible to recognize the full range of facies-types in the marine band, from brackish water to off-shore marine, and it thus provided a standard with which the other sites could be compared. The work of Thomas and Bloxham revealed a sequence of events in the development of the marine band, apparently correlated with water depth and post-depositional oxidation conditions. They were also able to show that organic material within the marine band was land-derived, probably mainly pollen and spores. This is the only published detailed work to have been carried out on an Upper Carboniferous marine band in South Wales.

Conclusions

The headwaters of the River Neath expose the best sequence through rocks known as the Millstone Grit in South Wales. They are the remains of a mixture of river delta deposits (mainly sands and siltstones) and marine deposits (mainly mudstones and shales), originally laid down about 315 million years ago (the Namurian Epoch). A wide variety of fossils occur, including those of plants, and non-marine and marine animals. These allow the sequence to be correlated in detail with the rocks of similar age elsewhere in Europe and North America, and especially with the standard succession of Namurian rocks in northern England (the Pennine Basin). It allows the evolution of this part of Britain during the Namurian to be charted in considerable detail, and for it to be placed in a wide national, and international, context.

SMARTS QUARRY

Highlights

Smarts Quarry is the only known locality in the Millstone Grit of South Wales to show stellate feeding traces made by bivalves.

Introduction

This old quarry or silica 'mine' lies about 1.5 km NE of Kidwelly, Dyfed, Wales (SN 434084). There is no published description of the site.

Description

Exposed in this quarry are quartzites from the Basal Grit Formation of the Millstone Grit. The principal point of interest is the presence, on one of the quartzite bedding planes, of stellate feeding traces thought to be produced by bivalves. It is the only known site to show such traces in the British Millstone Grit.

Interpretation

By analogy with modern examples, the presence of such stellate traces suggests that this part of the Basal Grit was deposited in an estuarine environment, rather than a simple shoreline as suggested by some earlier authors. It provides general support for the sedimentological model for the Millstone Grit of South Wales, described by Kelling (1974).

Conclusions

Smarts Quarry shows rocks belonging to the Millstone Grit, and probably represent estuarine deposits, some 320 million years old. The principal point of interest here is the presence of marks on some of the beds that are thought to represent marks left by bivalves as they fed near, or on the sediment surface. This is unique in Britain for rocks of this age.

LOWER HOUSE STREAM SECTION

Highlights

Lower House Stream Section is the best and most fossiliferous exposure of the Cancellatum Marine Band in South Wales, and marks the junction between the Marsdenian and Yeadonian stages in this basin.

Introduction

Along this stream, which lies just south of Lower House Reservoir, 3 km north of Rhymney, Mid-Glamorgan, Wales (SO 104102), is a small exposure in the Middle Shales Formation, as developed on the eastern end of the North Crop of the South Wales Coalfield. Other than a passing mention by Evans (1971), there is no published account of the geology. The following is based partly on an unpublished report submitted in 1978 to the Nature Conservancy Council by T.A. Mackay.

Description

Lithostratigraphy

The exposed sequence is just under 3 m thick. At the top is 75 cm of cross-bedded sandstone with an erosive base. This overlies 2 m of shales, the upper part of which is marine, with a thin limestone band.

Biostratigraphy

The Cancellatum Marine Band here yields a diverse assemblage, including uncrushed ammonoids *Cancelloceras cancellatum* (Bisat), productid brachiopods, bivalves and crinoid fragments, and marks the base of the Yeadonian Stage.

Interpretation

This is the best exposure of the Cancellatum Marine Band in South Wales. It is known from a number of other localities, such as Tenby-Saundersfoot Coast, Marros Sands, Vale of Neath and Llamarch Dingle (all discussed elsewhere in this chapter), but Lower House yields far better preserved and abundant fossils, especially the 'solid' ammonoids. The marine band is stratigraphically important, in that it marks the boundary between the Marsdenian and Yeadonian stages (see discussion on Orchard Farm in Chapter 2).

Conclusion

Lower House Stream Section is the best exposure in South Wales of marine beds known as the Cancellatum Marine Band. The band is just over 310 million years old, and marks the boundary between two geological ages known as the Marsdenian and Yeadonian.

CWM GWRELYCH–NANT LLYN FACH

Highlights

Cwm Gwrelych–Nant Llyn Fach provides the best exposed sequence of lower and middle Westphalian strata in Europe, with extensive evidence of non-marine bivalves, plant macrofossils and, to a lesser extent, marine bands.

Introduction

This stream section, extending south from Pont Walby, 1 km east of Glyn Neath, West Glamorgan, Wales (SN 891064–SN 906039), is one of the most remarkable Westphalian sites in Britain, providing a more or less complete sequence of Langsettian, Duckmantian and lower Bolsovian strata. Despite its importance, however, there is no comprehensive account of the site in the geological literature. The best published treatment is by Robertson (1932), who mentions parts of the succession in different sections of the memoir. Parts of the site are also mentioned by Barclay *et al.* (1988). Two unpublished theses also provide information on parts of the succession in greater detail than is available in the published literature (Matthews, 1955; Thomas, 1967).

Description

Lithostratigraphy

The full sequence exposed at Cwm Gwrelych–Nant Llyn Fach is *c.* 500 m thick (Figure 4.16). The base of the section is in the upper part of the Middle Shales Formation. At the top of the formation here are 1.1 m of dark grey shales with marine

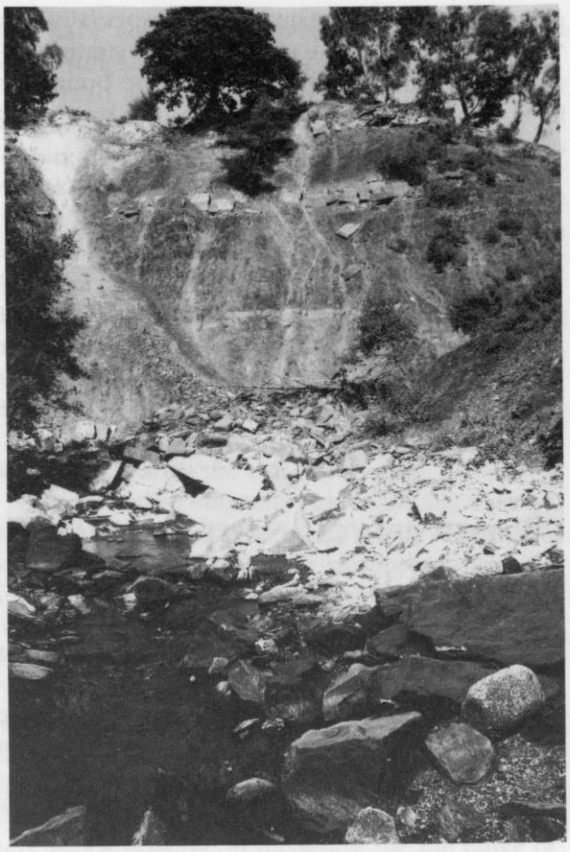

Figure 4.16 Cwm Gwrelych–Nant Llyn Fach GCR site. Succession above the Parkhouse Marine Band (lower Langsettian). (Photo: C.J. Cleal.)

Figure 4.17 Cwm Gwrelych–Nant Llyn Fach GCR site. Channel sandstones in upper Langsettian. (Photo: C.J. Cleal.)

fossils – the Subcrenatum Marine Band (see below). Compared with elsewhere in the coalfield (e.g. Vale of Neath), only the lower, transgressive phase of the marine band is developed, the upper, regressive phase being cut out by the erosive base of the Farewell Rock Formation.

The Farewell Rock Formation here consists of *c.* 45 m of mainly coarse grey sandstones (Figure 4.18). This outcrop was not dealt with in detail by Bluck (1961), in his sedimentological analysis of the formation, but evidence from neighbouring exposures suggests that the sediments were derived from the north.

Overlying the Farewell Rock is the base of the Productive Coal Formation. This is the lowest part of the Coal Measures Group in South Wales, and Cwm Gwrelych–Nant Llyn Fach may be taken as the stratotype (Figure 4.18(a)). The lower 60 m comprises mainly of shales, and include a series of marine bands, plant and non-marine bivalve beds. It compares well with the sequence at Nant Llech, which is the classic exposure for this part of the Langsettian in South Wales (discussed further below). The main difference is that there is no evidence at Cwm Gwrelych of the Astell Coal, or of its plant fossil bearing roof shales, which, at Nant Llech, immediately overlie the Farewell Rock. The distribution of the Astell Coal is generally patchy, however, being associated with relatively high-energy, fluvial deposits (Bluck, 1961).

This marine-influenced sequence is terminated by the Cnapiog Coal. This coal is no longer exposed here, being obscured by old workings, but its position is clearly marked by a thick seat earth (analysed by Wilson, 1965). It occurs widely in South Wales, sometimes under the alternative names Garw or Rhasfach coals.

The subsequent 35 m consists of dark grey, laminated shales with numerous bands and lenses of ironstone (known as 'mine' by earlier authors). This ironstone-bearing interval occurs over large areas of South Wales, and yielded much of the iron ore extracted from the coalfield during the 19th century and before (Joseph, 1880). Three significant ironstone bands can still be located here (the Cnapiog, Little Blue and Blue veins) and two others have been recorded, but are now obscured by old workings (the Garw and Spotted veins). The sequence is clearly lacustrine, except for an emergent interval represented by a seat earth *c.* 24 m above the Cnapiog Coal.

Overlying the interval of ironstones is a coal known as the Grey Coal, which includes a 2 m thick seat earth. The succeeding 27 m consists of a sequence of coarsening upwards cycles, each capped by a coal, including the Rhyd and Bluers coals. It represents a change from lacustrine to fluvial deposition, which can be recognized over large areas of the South Wales Coalfield. Detailed correlations of the coals between here and other parts of the coalfield have presented difficulties, as is shown by Robertson (1932, text fig. 2). Most probably, the Grey and Rhyd coals correlate with the Pumpquart and Trichwart coals, two of the most important seams in the western part of the main South Wales Coalfield. To the east, these coals are thought to coalesce to form the Lower Four Feet Coal, the lowest seam to be exploited commercially on the east crop (Howell, 1927).

Above the Bluers Coal are *c.* 40 m of mainly mudstones and thin coals with associated seat earths, representing emergent conditions. Most of the coals are little more than thin smuts, except for a 60 cm thick seam *c.* 30 m above the Bluers Coal. This 60 cm thick coal is a well known marker horizon in this area, known as the Queen or Enoch coal, but was never worked commercially here. The most detailed information on this part of the sequence is by Matthews (1955).

Overlying this interval of coals and seat earths are about 10 m of fluvial channel sandstones, which in turn are capped by a thin coal known as the Little Yard, and then by 18 cm of dark blue 'marine' shales, which is the Vanderbeckei Marine Band. Bloxham (1964) showed that it represents brackish to inshore conditions.

Above the Vanderbeckei Marine Band are some 250 m of 'typical' Coal Measures strata, representing a return to non-marine, mainly fluvial conditions (Figure 4.19). This interval consists mainly of a sequence of coarsening upwards cycles, many capped by a coal, and probably representing floodbasin lake sediments. It is the most important interval of coal-bearing strata in South Wales, the result of the maturation of the delta complex covering the area, and the tectonic quiescence of the surrounding hinterland. Seams identified in this interval include (in ascending

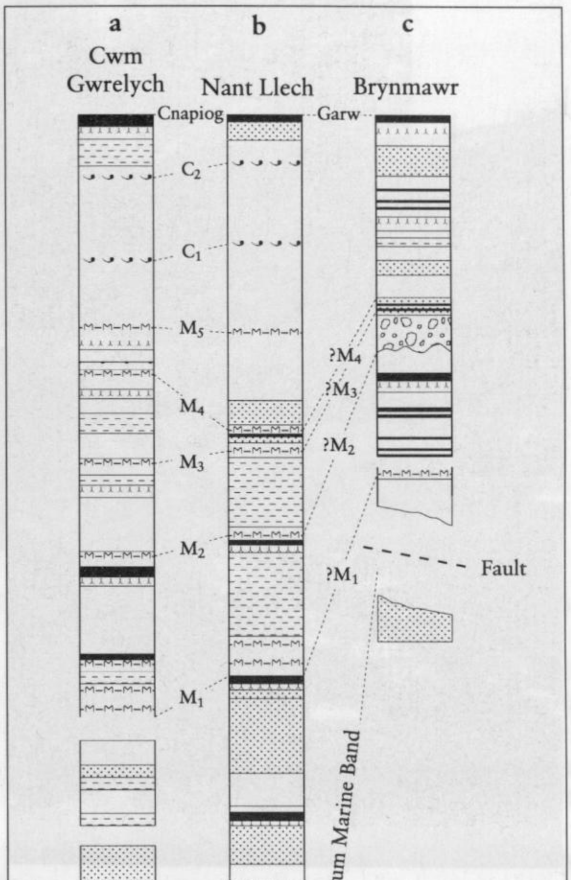

Figure 4.18 Lower Westphalian successions in South Wales. (a) Cwm Gwrelych; (b) Nant Llech; (c) Brynmawr. Based on Leitch *et al.* (1958).

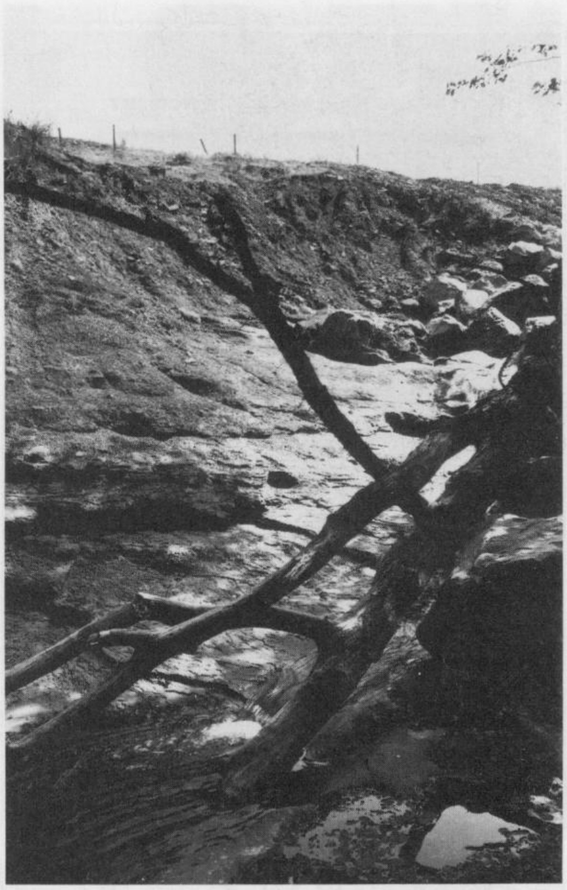

Figure 4.19 Cwm Gwrelych–Nant Llyn Fach GCR site. Productive Coal Formation above the Vanderbeckei Marine Band (lower Duckmantian). (Photo: C.J. Cleal.)

order) the Yard, Nine Feet, Upper Four Feet, Driver and Two Feet Nine coals. The most widely accepted scheme of correlation of these seams with the rest of the coalfield is that given by Robertson (1932) and Barclay *et al.* (1988), although there have been some disagreements as to detail (e.g. the position of the Nine Feet Coal here relative to that of the same name found near Swansea – Matthews, 1955). It is nevertheless clear that these coals are mostly of very wide geographical distribution within the coalfield.

Above this is what Robertson (1932) referred to as the 'Upper Marine Group'. It commences with a series of fluvial sandstones with erosive bases, each of which is succeeded by a fining upwards channel-fill sequence. The sandstones are easily recognizable in this exposure as they form clear waterfalls. Thomas (1967) has shown that the sudden change represented by the 'Upper Marine Group' is a widespread phenomenon, recognizable throughout South Wales, and that the sandstone bodies form discrete and easily identified marker-bands (e.g. the Cockshot Rock, Figure 4.20).

Elsewhere in the coalfield, this interval contains a number of marine bands. At Nant Llyn Fach, however, only two marine bands have been identified. The lowest occurs *c.* 1 m above the Cockshot Rock, and is probably the Aegiranum Marine Band, which is the most widespread of the group in South Wales (Ramsbottom, 1979a). At a slightly higher level, Robertson (1932) also recorded a thin shale band with fish fragments, which might be the Edmondia Marine Band.

Above the Aegiranum Marine Band, the strata represent tranquil, backswamp conditions, with gradually coarsening upwards cycles with coals. The latter include the Gorllwyn, Gorllwyn Rider and possibly the Pentre coals.

The top of the section here extends into the Llynfi Beds of the Pennant Formation. The contact with the underlying Productive Coal Formation is along a small fault, however, and so details of the junction are not preserved.

Biostratigraphy

Marine bands

The lowest marine band in this section, immediately below the Farewell Rock Formation, is only partially preserved here. However, in the upper preserved part are numerous specimens of *Gastrioceras subcrenatum* (Frech), clearly indicating that it is the Subcrenatum Marine Band. This therefore marks the junction between the Namurian and Westphalian series in this section.

A short distance above the Farewell Rock Formation are a further five shale bands with marine or brackish fossil assemblages (Leitch *et al.*, 1958; Bluck, 1961). None have yielded ammonoids, and the lower four contain little more than fish teeth and scales, but it is likely that they correlate with the bands M_1–M_5 identified at Nant Llech.

The 'marine' shale overlying the Little Yard Coal yielded only poorly preserved *Lingula* and rare fish fragments. This suggests brackish rather than fully marine conditions, a view supported by geochemical evidence (Bloxham, 1964). However, it is overlain by a shale containing a non-marine bivalve assemblage of the *Anthracosia ovum* Subzone, which is widely regarded as a guide to the position of the Vanderbeckei Marine Band.

The marine bands above the Cockshot Rock again yield assemblages dominated by inarticulate brachiopods and fish fragments, which are not biostratigraphically diagnostic. It is widely assumed

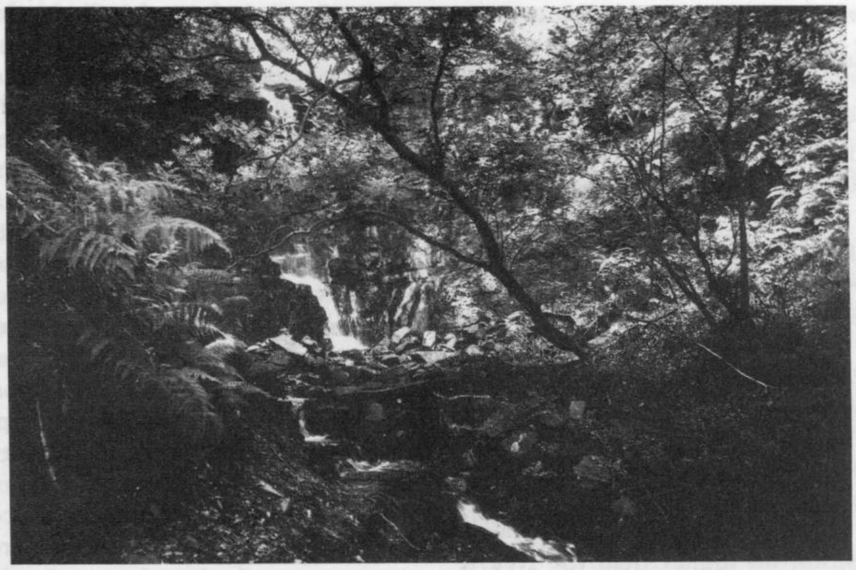

Figure 4.20 Cwm Gwrelych–Nant Llyn Fach GCR site. Cockshot Rock (upper Duckmantian). (Photo: C.J. Cleal.)

that they represent the Aegiranum and Edmondia marine bands, but this is based mainly on their lithostratigraphical position in the sequence.

Non-marine bivalves

These are widely distributed throughout the section. The lowest occur in two bands, known as C_1 and C_2 (Leitch *et al.*, 1958), between the M_5 Marine Band and the Cnapiog Coal. The C_1 assemblage includes *Carbonicola crispa* Eagar, *C. proxima* Eagar and *C. pontifex* Eagar (Eagar, 1962), which evidently belongs to the *C. proxima* Subzone (upper *C. lenisulcata* Zone). Interestingly, an almost identical assemblage occurs in the Pennines from above the Amaliae Marine Band, which is a correlative of the M_5 Marine Band.

The C_2 assemblage has not been studied in such detail, but is reported to yield *?Carbonicola bipennis* (Brown), and *C.* cf. *martini* Trueman and Weir. It is difficult to place this assemblage using these names in isolation, but there may be a comparison with the bivalves from the *Carbonicola torus* Band in the Pennines (Eagar, 1954, 1956). If correct, it belongs to the basal *C. communis* Zone.

Other *C. communis* Zone assemblages occur in the interval of ironstones, between the Cnapiog and Grey coals. Robertson (1932) mentions, among others, *Carbonicola pseudorobusta* Trueman suggesting the subzone of that name.

Matthews (1955) recorded from the Rhyd and Bluers roof-shales *Carbonicola cristagalli* Wright and *C. rhomboidalis* Hind. Calver (1956) and Ramsbottom *et al.* (1978) identify a *C. cristagalli* Subzone at the base of the *A. modiolaris* Zone, although Trueman and Weir (1947) note that these taxa can also occur in the upper *C. communis* Zone. In the absence of species of *Anthraconaia*, it is impossible to locate this biozonal boundary here.

The lowest unequivocal evidence of the *A. modiolaris* Zone is from near the Bluers and Queens coals, which have yielded forms similar to *Carbonicola venusta* Davies and Trueman (Matthews, 1955). According to Trueman and Weir (1947) this species characterizes the basal part of this zone.

From immediately over the Vanderbeckei Marine Band, Matthews (1955) reported a shale containing *Anthracosia ovum* Trueman and Weir, *A. planitumida* Trueman, *A. aquilinoides* (Tchernyshev) and *A.* cf. *concinna* (Wright). This clearly belongs to the *A. ovum* Subzone (upper *A. modiolaris* Zone), and compares closely with assemblages from just above the Vanderbeckei Marine Band elsewhere in South Wales (Jenkins, 1962; Woodland and Evans, 1964; Archer, 1968).

This is the highest level in the section from which non-marine bivalves have been reported. However, these higher strata have been described mainly from a sedimentological standpoint (Thomas, 1967), and further investigation may reveal evidence of the upper *A. modiolaris* and *A. similis–A. pulchra* zones.

Plant macrofossils

Plant remains are also extremely abundant through the sequence. The most complete records are by Matthews (1955). However, he did not figure the specimens and their present location is unknown, which makes it impossible to verify the identifications.

The lowest plant remains originate from a shale *c*.2 m above the Farewell Rock, and appears to correlate with the P_2 bed at Nant Llech. Leitch *et al.* (1958) record from here an assemblage typical of the *Lyginopteris hoeninghausii* Zone, including *L. hoeninghausii* (Brongniart) Gothan, *Paripteris gigantea* (Sternberg) Gothan, *Karinopteris acuta* (Brongniart) Boersma and *Neuralethopteris neuropteroides* (Šusta) Josten. The latter identification is of particular interest as, if it is correct, it tends to indicate a position no higher than the *Neuralethopteris jongmansii* Subzone (lower *L. hoeninghausii* Zone).

At Nant Llech, a second, lower horizon yields plant remains, and is known as P_1. However, this seems not to be exposed at Cwm Gwrelych.

Matthews (1955) mentions plant remains from several levels in the upper Langsettian part of the sequence here: from above the Rhyd Coal, below the Bluers Coal, between the Bluers and Queen coals, and from below the Vanderbeckei Marine Band. Some of the identifications (e.g. *Alethopteris serlii* (Brongniart) Göppert from below the Bluers Coal) are clearly in error. However, the presence of *Laveineopteris loshii* (Brongniart) Cleal *et al.* in many of the assemblages appears to support a position in the *L. loshii* Subzone (upper *L. hoeninghausii* Zone).

In the Duckmantian, Matthews (1955) records plant remains from the roof shales of the Yard and Nine Feet coals. The latter, in particular, is a well known source of plant fossils throughout South Wales. Both assemblages probably belong to the *Lonchopteris rugosa* Zone, but the material will need revising for this to be confirmed.

Interpretation

This is the only site in Europe to show a more or less continuous exposed succession through the Langsettian, Duckmantian and lower Bolsovian stages; only a short interval in the Duckmantian is not exposed, having been covered by a newly constructed road. When combined with the nearby Vale of Neath section, it provides a virtually complete sequence from the Chokierian(?) to mid-Bolsovian, thus spanning some 7 stages.

This section may be regarded as the type for the Productive Coal Formation in South Wales (and in effect in Britain as a whole). There are other sites in South Wales which either provide a more complete picture of parts of the section, such as Nant Llech for the basal Langsettian, and Cwm Twrch for the interval associated with the Vanderbeckei Marine Band. Cwm Gwrelych–Nant Llyn Fach is the only reasonably complete sequence, however, and provides the standard against which the others have to be compared.

The closest comparison is with exposures to the west, in Pembrokeshire, such as at Amroth and Tenby–Saundersfoot. None of these exposures to the west provide as full a sequence as at Cwm Gwrelych–Nant Llyn Fach, and are subject to greater tectonic disturbance. Furthermore, the Pembrokeshire sections reveal a number of differences in detail, such as in the distribution of fluvial channel sandstones, and in the development of lacustrine sediments in the lower Langsettian.

On the east crop of the coalfield, approximately coeval strata occur at Wernddu Claypit. In comparison, however, the sequence here is significantly condensed, as a result of its proximity to the Usk Axis.

Elsewhere in Britain south of the Wales–Brabant Barrier, Langsettian to Bolsovian strata are only known from the Bristol–Somerset Coalfield. Exposure here is very poor, however, the only good outcrop being at Cattybrook Brickworks (see Chapter 6), which is restricted to a short sequence just below the Vanderbeckei Marine Band. The most complete evidence from this coalfield came from the Ashton Park Borehole (Kellaway, 1967). This revealed a sequence generally similar to that at Cwm Gwrelych–Nant Llyn Fach, except that there are rather fewer coals and non-marine bivalve horizons, and the Langsettian part is more condensed.

Trueman (1933), among others, argued that South Wales should be regarded as the type-sequence for the 'Coal Measures' of Great Britain, and the excellent exposure could have justified having the stratotypes for the Westphalian stages here. However, the SCCS decided that relatively restricted assemblages usually found in the marine bands in South Wales was an obstacle to such a proposal, and has instead nominated sites in the Pennines coalfields (Langsett, Duckmanton Railway Cutting and River Doe Lea – see Chapter 2) as boundary stratotypes for the lower 3 stages (a stratotype for the base of the Westphalian D has yet to be nominated). If ever a decision was taken to have unit stratotype(s) for the Westphalian, then South Wales provides the only candidate sections, that would be compatible with the criteria outlined by the SCCS. In such circumstances, Cwm Gwrelych–Nant Llyn Fach would clearly play a most significant role.

Despite its importance, there is no coherent account of the site. The most complete information is provided in unpublished theses (e.g. Matthews, 1955; Thomas, 1967). Even these are incomplete, however, tending to concentrate either on the biostratigraphy or sedimentology of particular parts of the sequence. There is clearly much potential for future work on this internationally important site.

Conclusions

Cwm Gwrelych–Nant Llyn Fach is the only place in Europe to show a more or less complete and naturally-exposed sequence of lower to middle Westphalian coal-bearing strata (308–315 million years old). It contains abundant fossils, including the remains of non-marine bivalves, plants and marine shells, allowing detailed correlations to be established with other successions of this age.

NANT LLECH

Highlights

This is the best exposure of the lower Langsettian in South Wales, showing the complete set of seven marine bands, three plant beds and two non-marine bivalve horizons.

Introduction

The bed of Nant Llech, on the southern outskirts of Abercrave, Powys, Wales (SN 834127–SN 843120), is the classic exposure of the Namurian–Westphalian boundary in the South Wales Coalfield. It was noted in a number of early studies (De la Beche, 1846; Strahan *et al.*, 1904), and details of the plant fossils found here were given by Dix (1933, 1934). However, tectonic disruption associated with the Swansea Valley Disturbance (Owen, 1971a; Weaver, 1975) made it difficult to establish a continuous stratigraphical succession. This was not achieved until the publication of the now classic paper by Leitch *et al.* (1958). The sedimentology of the Farewell Rock here was described in Bluck's (1961) thesis but, other than a brief summary by Bluck and Kelling (1963), the data have not been published. Most recently, the site has been mentioned by Barclay *et al.* (1988).

Description

Lithostratigraphy

The exposed sequence here is summarized in Figure 4.18(b). The lowest strata seen are *c.* 3 m of dark grey mudstone belonging to the topmost Middle Shales Formation. They contain abundant marine fossils (see below) and are thought to represent the Subcrenatum Marine Band. It is not quite as thick as at other north crop exposures, such as Brynamman and the Vale of Neath (Bloxham and Thomas, 1969) and is dwarfed by the 16 m thick marine band reported on the south crop (Woodland *et al.*, 1957). However, it is significantly better developed than at sites such as Cwm Gwrelych, where it has been partially eroded away by fluvial activity associated with the overlying Farewell Rock (see discussion of previous site).

The Farewell Rock Formation here is some 30 m of massive sandstones and grits. Bluck (1961) reported extensive trough cross-bedding at this exposure, indicating a south-south-east palaeocurrent direction, which is consistent with observation made elsewhere in the middle part of the north crop. Bluck also noted the presence of a basal mélange with angular mud-clasts, rounded ironstone nodules and quartz pebbles, probably the result of reworking of channel deposits (see also Bluck and Kelling, 1963).

Overlying the Farewell Rock at Nant Llech is a 30 cm thick coal known as the Astell Seam, marking the base of the Productive Coal Formation. The coal is in turn overlain by *c.* 15 m of channel deposits, including a 3.5 m thick coarse, lenticular sandstone with an erosive base. At the top of this fluvial interval is a second emergent surface. Dix (1933) claims that there is a coal at this point in the sequence. It is no longer exposed, although its roof-shales containing abundant plant fossils (Plant Bed C) is still visible.

There then follows six cyclical intervals, each consisting in turn of marine mudstones, non-marine sandstones and coals. Leitch *et al.* recognized five marine bands which they designated M_1–M_5. Subsequently, W.A. Wimbledon (pers. comm.) has found a sixth marine band between M_4 and M_5. This interval probably represents lower delta-plain, possibly intertidal conditions; marine influence can never have been far away, although there is evidence of an emergent surface between M_1 and M_2.

The top part of the sequence sees a return to non-marine strata. Initially, this is in the form of dark-grey lacustrine shales, which include two discrete beds with non-marine bivalves (C_1 and C_2 of Leitch *et al.*, 1958). This is eventually capped by a coal, known locally as the Cnapiog Seam. It is the lowest of the South Wales coals to occur widely through the coalfield, and is sometimes known elsewhere as the Garw or Rhasfach coal. The position of this coal at Nant Llech was established by Leitch *et al.* (1958), but is no longer exposed.

Biostratigraphy

Marine bands

The only fully developed marine band in this sequence is in the top of the Middle Shales Formation (Robertson, 1932; Ware, 1939; Leitch *et al.*, 1958). It yields abundant ammonoids, mainly of *Gastrioceras subcrenatum* (Frech), but with some *Anthracoceratites*. There are also inarticulate brachiopods (*Lingula*, *Orbiculoidea*), bivalves (*Edmondia*, *Dunbarella*, *Schizodus*, *Nuculopsis*) and gastropods (*Euphemusites*). Although there is no published description of the assemblage, the listed taxa appear to indicate the Subcrenatum Marine Band, probably in the pectinoid facies of Calver (1968).

Most of the six 'marine' bands above the Farewell Rock here contain essentially brackish-water assemblages of inarticulate brachiopods and fish fragments. The only exceptions are M_1, which has yielded some indeterminable productid fragments, and M_2, which has yielded *Schizodus*, and indeterminable gastropods and productids (Leitch *et al.*, 1958).

Non-marine bivalves

Other than a band containing some crushed *Carbonicola* shells in the fluvial sequence above the Astell Coal (Leitch *et al.*, 1958), non-marine bivalves are restricted to two discrete bands towards the top of the sequence. They are known as C_1 and C_2. The bivalves from Nant Llech have not been described in the literature, although Eagar (1962) has described the fossils from what is probably a correlative of the lower bed at Cwm Gwrelych.

Plant fossils

Plant fossils occur at three horizons in the sequence, corresponding to the plant beds B–D of Dix (1933, 1934). Leitch *et al.* (1958) only recognized the lower two of these beds, which they termed P_1 and P_2.

Plant Bed B (or P_1) immediately overlies the Astell Coal. It has yielded a number of biostratigraphically sensitive taxa, including *Neuralethopteris rectinervis* (Kidston) Laveine, *Alethopteris decurrens* (Artis) Zeiller, *Karinopteris acuta* (Brongniart) Boersma, *Lyginopteris hoeninghausii* (Brongniart) Gothan, *L. baeumleri* (Andrä) Gothan and *Renaultia* cf. *crepinii* (Stur) Gothan. The assemblage clearly belongs to the *Neuralethopteris jongmansii* Subzone (lower *L. hoeninghausii* Zone), indicative of the lower Langsettian.

Plant Bed C (or P_2) is *c.*15 m higher, at the top of the fluvial interval between the Farewell Rock and the M_1 Marine Band. It differs from the Bed B assemblage, in not including *A. decurrens*, *L. hoeninghausii* or *R.* cf. *crepinii*. Also, *N. rectinervis* is rare, and is partially replaced by *Neuralethopteris jongmansii* Laveine. Nevertheless, the assemblage is also clearly from the *N. jongmansii* Subzone.

Plant Bed D occurs between the M_1 and M_2 marine bands. Again, the assemblage appears to belong to the lower *L. hoeninghausii* Zone, although there are no *Lyginopteris* species present. A number of distinctive lower Westphalian species occur here, but not in beds B and C, include *Pecopteris volkmannii* Sauveur and *Eusphenopteris hollandica* (Gothan and Jongmans) Novik. Dix (1934) also records *Neuropteris* cf. *heterophylla* Brongniart from Bed D, but this would be stratigraphically rather low for this species and it is more likely to refer to the very similar *Neuropteris obliqua* (Brongniart) Zeiller.

Interpretation

This is the most complete development of lower Langsettian strata in the South Wales Coalfield. There are exposures of similar strata, such as along the Tenby–Saundersfoot Coast in Pembrokeshire, and at Cwm Gwrelych on the north crop. However, nowhere other than at Nant Llech is there the full development of seven marine bands, three plant beds and two non-marine bivalve beds. It is also the best exposure on the north crop of the Farewell Rock Formation, and of the immediately overlying Astell Coal. For these reasons, Nant Llech has traditionally been regarded as the 'type' for the lower Langsettian of South Wales.

The most significant of the marker horizons are the marine bands, since they allow the sequence to be correlated in detail with coeval strata over much of northern Europe. The position of the Subcrenatum Marine Band, which marks the junction between the Namurian and Westphalian series, is readily identified at Nant Llech because of its diverse assemblage of marine fossils. The others are less easy to correlate, as they do not contain biostratigraphically sensitive fossils. Based on the assumption that they represent discrete eustatic events identifiable over wide geographical areas, Ramsbottom *et al.* (1978) and Ramsbottom (1979a) proposed a correlation between these bands and the standard sequence of marine bands established in the Pennines coalfields. This correlation now needs to be modified slightly, to take into account the discovery of the new marine band between M_4 and M_5, as follows:

Pennines	Nant Llech
Amaliae M.B.	M_5
Meadowfarm M.B.	Unnamed
Parkhouse M.B.	M_4
Listeri M.B.	M_3
Honley M.B.	M_2
Springwood M.B.	M_1
Holbrook M.B.	(Unknown)

Conclusions

This is the best exposure of rocks of early Langsettian age (315 million years old) in South Wales. No other locality in the coalfield has the complete set of fossil-bearing beds, which are important for establishing detailed correlations of these rocks.

CWM TWRCH

Highlights

Cwm Twrch is the best exposure of the Vanderbeckei Marine Band in the South Wales Coalfield.

Introduction

The banks of the River Twrch, 2 km north of Upper Cwm Twrch, on the border between Dyfed and Powys, Wales (SN 755125–SN 758130), expose part of the Productive Coal Formation, and include marine mudstones known locally as the Amman Marine Band. There is no published account of this site, but it is dealt with in an unpublished thesis by Matthews (1955).

Description

Lithostratigraphy

The strata exposed in the bed of the Twrch here are mainly mudstones and siltstones, representing non-marine, fluvial conditions. Within this essentially non-marine succession, however, there is about 0.20 m of dark blue marine shales – the Amman (or Vanderbeckei) Marine Band.

Biostratigraphy

There has been no systematic treatment of the fossils found in the Vanderbeckei Marine Band here. However, it is claimed to yield a diverse assemblage, including the index ammonoid *Anthracoceratites vanderbeckei* (Ludwig), as well as bivalves, gastropods and brachiopods.

Interpretation

The Vanderbeckei Marine Band is generally poorly developed in South Wales. It can be up to 3 m thick, such as at Wern Ddu on the east crop, and in the Ammanford area (Archer, 1968). However, it rarely yields more than bivalves and gastropods. Elsewhere in southern Britain (i.e. south of the Wales–Brabant Barrier) there are no known exposures of this band. Even in the Pennine Basin, where the band is normally much thicker, the band rarely yields a diverse fossil assemblage, at least in a surface outcrop (e.g. Duckmanton Railway Cutting – see Chapter 2). The exposure of the band at Cwm Twrch may be much thinner, but at least has the merit of yielding the index ammonoid.

The significance of Cwm Twrch lies in the context of the Cwm Gwrelych–Nant Llyn Fach succession. The latter is the best exposed sequence of lower and middle Westphalian strata in northern Europe, and has only one significant gap, at about the Vanderbeckei Marine Band. Cwm Twrch is the only site in South Wales that can reasonably convincingly fill this gap.

Conclusions

The River Twrch has the best exposure of rocks belonging to the Vanderbeckei Marine Band in South Wales, just under 310 million years old. It marks the boundary between two geological ages known as the Langsettian and Duckmantian, and is thus important for putting the succession in the South Wales Coalfield into a wider national and international setting.

EARLSWOOD ROAD CUTTING AND FERRYBOAT INN QUARRY

Highlights

Earlswood Road Cutting and Ferryboat Inn Quarry are the best exposures of a Rhondda Member channel-fill sequence on the south crop of the South Wales Coalfield, and provides important information on the sedimentary evolution of the coalfield.

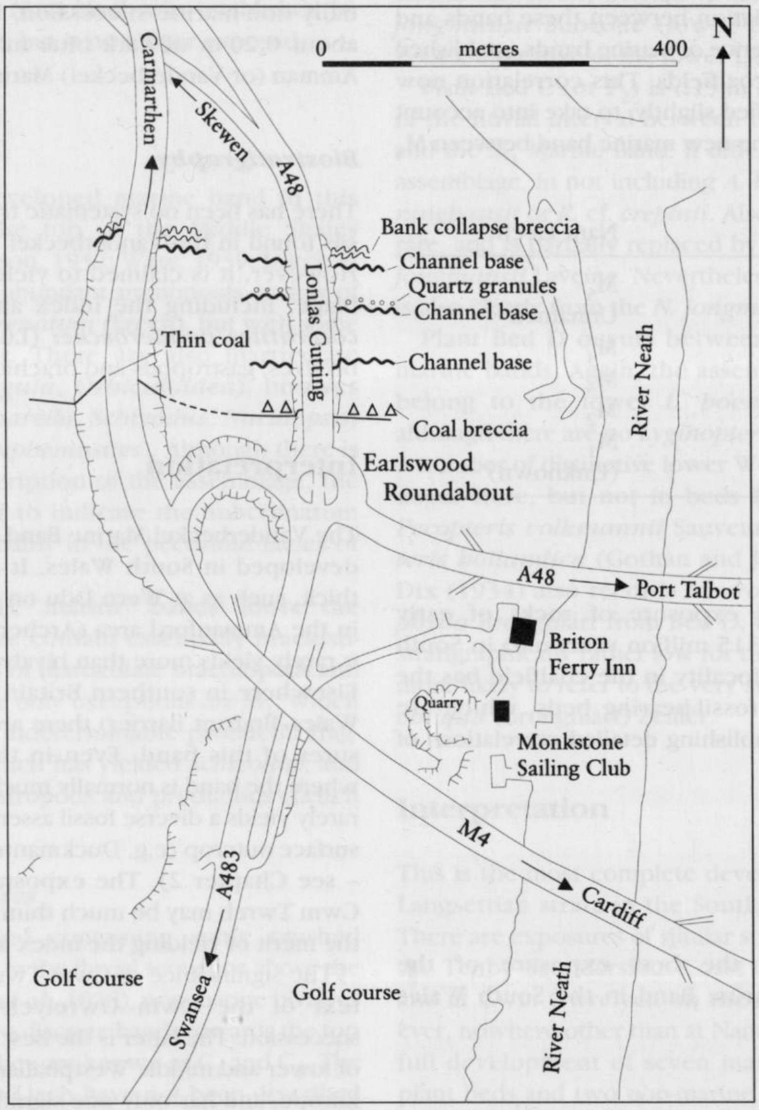

Figure 4.21 Exposure of Pennant Formation seen at Earlswood Road Cutting. Based on unpublished information provided by Professor G. Kelling.

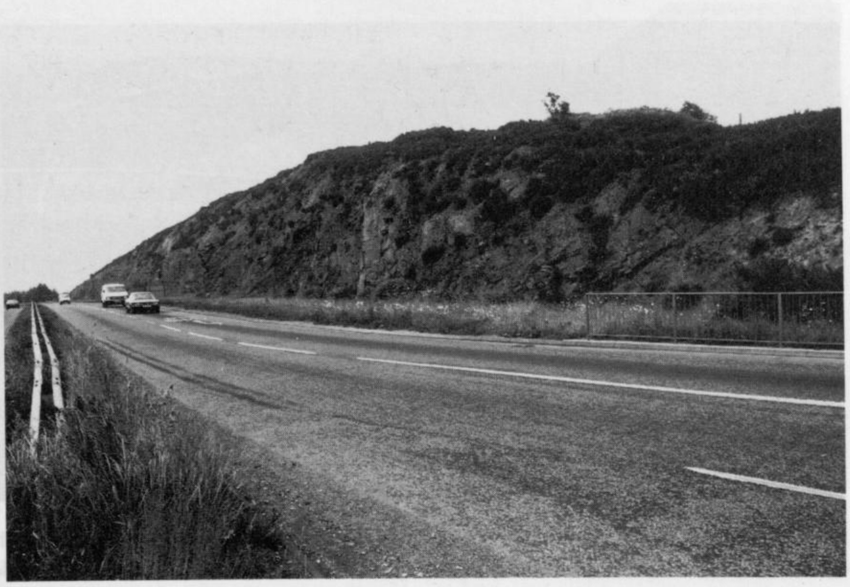

Figure 4.22 Rhondda Member of the Pennant Formation exposed at Earlswood Road Cutting (as seen in 1982). (Photo: C.J. Cleal.)

Introduction

The cutting at Earlswood roundabout on the A48 road, and a nearby disused quarry, near Briton Ferry, West Glamorgan, Wales (SS 729946 – SS 732939) provide excellent exposures of Upper Carboniferous cyclic, alluvial deposits. Details of the outcrop are provided by Owen *et al.* (1966), Kelling (1971) and Owen (1971d), and the results obtained here were incorporated into the wider, basinal analyses of the Rhondda Member in South Wales by Kelling (1968, 1969).

Description

About 170 m of the Rhondda Member (South Wales Pennant Formation) are exposed in the road cutting and consist of a series of fining-upwards cycles (Figures 4.21 and 4.22). At the base of each cycle is a breccia with an erosive base, and containing ironstone and coal pebbles, and 'logs' of fossil wood. This is overlain by medium-grained, cross-bedded sandstones, which in turn are replaced by ripple- and parallel-laminated fine-grained sandstones. The cycle is completed by siltstones, mudstones and eventually a seat earth and coal (this last part of the sequence has sometimes been eroded by the next cycle). The cycles are interpreted as the infills of a succession of fluvial channels. Current directions are remarkably uniform towards the north-west; except at one point, indicating a sediment derivation from the south-east. This is thought to indicate that the river channels were relatively straight, perhaps braided (Kelling, 1968, 1969, 1971).

In contrast to the road cutting, the north face of the disused quarry shows the channels in cross-section. The sloping erosional surfaces and basal breccias are particularly well seen here.

There is no direct biostratigraphical control on the sequence here. However, field relationships indicate that the strata must belong to the lower Rhondda Member, and are thus very late Bolsovian in age (Cleal, 1978).

Interpretation

This is the best and most accessible exposure of the Rhondda Member on the south crop, and provides important sedimentological information. In particular, it indicates that deposition was mainly in low-sinuosity, probably braided channels. This, together with the predominantly north-westerly palaeocurrent directions, suggests that the Earlswood sequence represents a more proximal position within the delta than the deposits found on the north crop, such as at Blaenrhondda. The change in sediment provenance between the Productive Coal and Pennant formations, as clearly

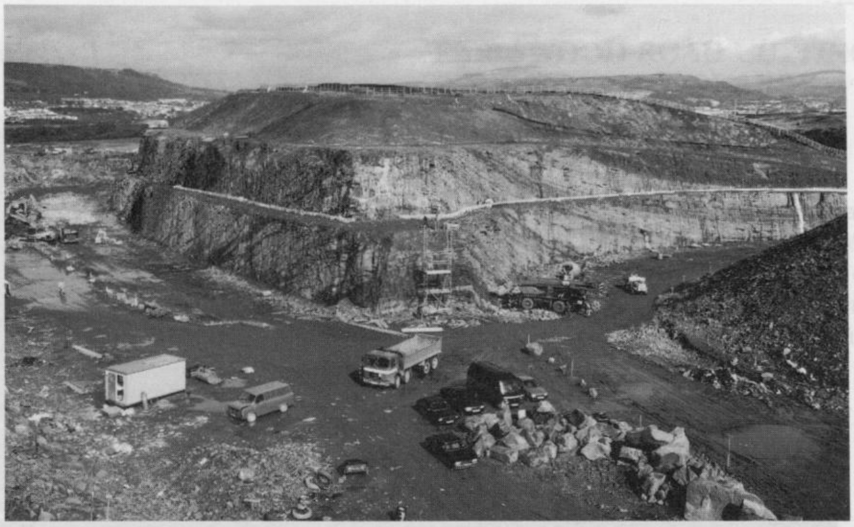

Figure 4.23 Earlswood Roundabout (March 1992): newly created cutting at the cusp between the slip road and main carriageway of the M4 extension between Briton Ferry and Lon Lâs. Excellent dip and strike sections through the Rhondda Member (Pennant Formation) enable detailed sedimentological studies to be conducted in this complex deltaic succession. (Photo: S. Campbell.)

demonstrated at Earlswood, is important for understanding the evolution of the South Wales Basin, and represents part of the evidence used by Kelling (1988) to develop the foreland-basin model.

Conclusions

The sandstones exposed at Earlswood Road Cutting and Ferryboat Inn Quarry belong to the Rhondda Member, and are 308 million years old. It can be demonstrated here that they are the remains of sediment deposited by a river flowing from an upland area in the present-day Bristol Channel. Although such fluvial sandstones are typical of this stratigraphical level within the South Wales Coalfield, this is the best avaliable exposure on the south crop of the coalfield for the study of how they were deposited.

BLAENRHONDDA ROAD CUTTING

Highlights

Blaenrhondda Road Cutting is the best available exposure of the Rhondda Member on the north crop of the South Wales Coalfield (Figure 4.24). The strata here show marked differences from coeval strata on the south crop, and provide an important insight into the sedimentary evolution of the coalfield.

Introduction

Roadside exposures on the east side of the Rhondda Valley road (A4061), 2 km north of Treherbert, Mid-Glamorgan, Wales (SN 927016–SN 933001) show a fining-upwards fluvial sequence in the Pennant Formation. Details of the site can be found in Kelling (1968, 1971).

Description

Exposed in this road cutting are 49 m of Rhondda Member (South Wales Pennant Formation), in the form of a fining-upwards cycle. At the base of the cycle are a series of trough cross-laminated, medium-grained sandstones, many of which have a basal lag of coal and ironstone pebbles. These grade up into a series of channels and scours of varying size, filled with siltstones and mudstones. Over this unit is an interval of parallel-laminated, mainly silty mudstones, which grade up into a seat earth and a thin coal (Bluck and Kelling, 1963).

The sandstones at the base show a wide variation in palaeocurrent directions. Kelling (1964) initially interpreted this as indicating that sediment was being derived from the Wales–Brabant Barrier to the north, as well as from 'Sabrina' to the south. Later, however, he re-interpreted them as point-bar deposits formed in a meandering fluvial system (Kelling, 1971, 1974). The remainder of the sequence probably consists of crevasse-splay and back-swamp deposits.

Figure 4.24 Rhondda Member of the Pennant Formation exposed at Blaenrhondda Road Cutting. (Photo: C.J. Cleal.)

No fossils have yet been reported from Blaenrhondda. However, Kelling (1971) suggests that the thin coal at the top of the sequence may be the Daren Rhestyn Seam in the lower Rhondda Member. Palaeobotanical evidence from similar strata in other parts of the coalfield indicates a position in the upper Bolsovian.

Interpretation

This is one of the most instructive exposures of the lower Rhondda Member on the north crop. It can be clearly seen that these strata were formed in a flood plain setting in a medial part of the delta, with representatives of point-bar, crevasse-splay and back-swamp deposits, This is in marked contrast to the south crop exposures, such as Earlswood Road Cutting (see previous site report), where the sediments were deposited in a series of stacked, straight channels, formed in a more proximal position within the delta. This helps confirm that the Pennant Formation in South Wales was formed by a northerly-spreading delta complex.

Conclusions

Blaenrhondda Road Cutting is the best available exposure of beds of the Rhondda Member (about 308 million years old) on the north crop of the South Wales Coalfield. They consist mainly of deposits formed in a flood plain of a large river-delta, and differ markedly from the much coarser, river-channel deposits found further south, such as at Earlswood Road Cutting near Swansea.

TREHIR QUARRY

Highlights

Trehir Quarry was one of the best exposures of the Pennant Formation in the eastern part of the South Wales Coalfield.

Introduction

This old building-stone quarry (ST 154897) lies on the eastern side of the Rhymney Valley, about 3 km north of Caerphilly. It was briefly mentioned by Squirrell and Downing (1969), but the only detailed account is in an unpublished thesis by Jones (1989a).

Description

When originally studied by Jones (1989a), this site showed a thick development of South Wales Pennant Formation. According to Squirrell and Downing (1969), these beds lie above the Daren-ddu Coal and thus belong to the middle Westphalian D Hughes Member. Of particular interest was the presence of stacked dunes of planar and trough cross-bedding, and numerous examples of channel lag deposits with erosive surfaces. At least some of this interest has been subsequently lost, due to infilling of the site, but some of the upper part of the face was still visible at the time of writing (summer, 1994).

Interpretation

This was the best site for showing some of the characteristic features of the sedimentology of the upper part of the South Wales Pennant Formation. The features suggest that these sandstones were deposited as bars by lower sinuosity rivers than were the sandstones in the lower part of the formation (most typically developed in the Rhondda Member, e.g. Earlswood Road Cutting). Jones (1989b) has argued that this change in pattern of bar accretion probably reflects one or more effects of tectonic movement in the hinterland, including increased sand production, faster river discharge, and increased depositional slope. It is thus evidence of the increasing seismic instability of northern Europe towards the end of the Westphalian and in the very early Stephanian, which culminated in the major Variscan basin inversion (probably in the late Cantabrian). This resulted in the cessation of sedimentation and coal formation in the main north European coalfields.

Conclusions

Trehir Quarry was one of the best exposures of the upper part of the South Wales Pennant Formation, which is about 307 million years old. It shows that these rocks were formed in rivers that were not as meandering as those that formed the lower part of this formation, which is important for understanding the geological evolution of this part of Britain towards the end of the Westphalian Epoch.

PENLLERGAER RAILWAY CUTTING

Highlights

This is the best available exposure of the Grovesend Formation in South Wales, representing a time of reduced sediment input in this part of the coalfield (Figure 4.25).

Introduction

The Grovesend Formation in South Wales consists mainly of argillaceous rocks and is consequently poorly exposed. One of the few available outcrops is in this railway cutting on the Port Talbot–Llanelli loop-line, about 1.5 km north-east of Penllergaer, near Swansea, West Glamorgan, Wales (SS 619999–SS 624997). It has been briefly described by Archer *in* Owen (1971d).

Description

Lithostratigraphy

Exposed here are 22 m of mainly grey mudstones and siltstones. Also present are two coals, the Little Loughor Seam (0.5 m thick) and Penyscallen Seam (0.4 m thick). A few centimetres above each coal is a thin lacustrine mudstone with abundant non-marine bivalves and estheriids. This is typical of the Grovesend Formation in central part of the coalfield, except for the absence of red beds.

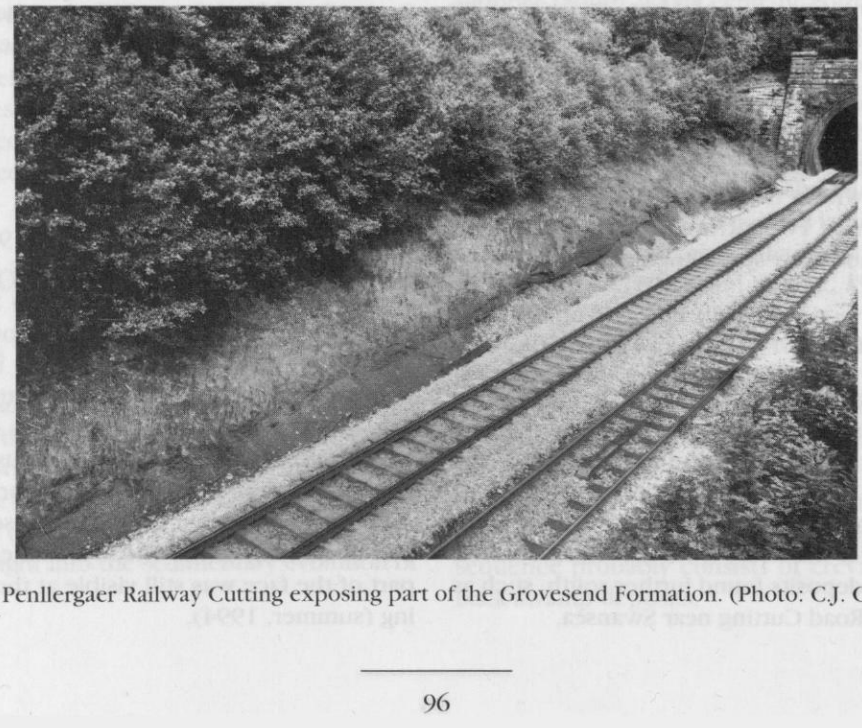

Figure 4.25 Penllergaer Railway Cutting exposing part of the Grovesend Formation. (Photo: C.J. Cleal.)

Biostratigraphy

This site yields very little biostratigraphical data. The non-marine bivalves appear to belong to the *Anthraconauta tenuis* Zone, but this only indicates a position anywhere between the upper Bolsovian and Cantabrian. However, shales above the Penyscallen Seam, exposed in a colliery at nearby Gorseinon, have yielded a diverse assemblage of plant fossils, which clearly belongs to the *Lobatopteris vestita* Zone (Cleal, 1978). This is an index for the upper Westphalian D in South Wales.

Interpretation

The Grovesend Formation, as exemplified by the Penllergaer sequence, is a set of flood-plain deposits, which contrast with the underlying Pennant Formation deposits that are mainly arenaceous, fluvial deposits (Kelling, 1974). These finer-grained deposits were formed at a time of reduced sediment-input from the southerly lying landmass (Sabrina *sensu* Kelling, 1974), allowing more stable flood-plain conditions to develop. The presence of estheriid bands suggests that there were periodic intervals when lacustrine conditions prevailed.

This contrasts with the situation in the south-eastern part of the coalfield, where arenaceous, fluvial deposits persist through to the top of the Westphalian D, in the form of the Forest of Dean Pennant Formation (Cleal, 1992). These sediments were derived from a different source, probably lying somewhere to the south-east, which seems to have remained active for some time after the Sabrina source.

Similar flood-plain deposits to the Grovesend Formation occur elsewhere in the upper part of the Coal Measures in southern Britain (i.e. south of the Wales–Brabant Barrier). In the Forest of Dean, they are known as the Suprapennant Formation (see Chapter 5), while in the Bristol– Somerset Coalfield they are known locally as the Farrington, Barren Red, Radstock and Publow formations (Kellaway, 1970). They also occur in the concealed Severn Coalfield (Cleal, 1986a). However, they almost certainly represent relatively localized deposits, and are not lateral equivalents in anything other than facies development. For this reason, they are given separate formational designations.

Conclusions

Penllergaer Railway Cutting is the best exposure of the upper beds in the South Wales Coalfield, known as the Grovesend Formation, about 300 million years old. They consist mainly of mudstones and shales, and are quite different from the beds lower in the sequence, which are mainly coarse sandstones of the South Wales Pennant Formation. It marks the end of the input of large quantities of sandy sediment into this part of the coalfield, probably reflecting reduced erosion in the hinterland areas to the south.

LLAMMARCH DINGLE

Highlights

Llammarch Dingle is the best exposure of Millstone Grit on the east crop of the coalfield, showing a condensed succession of mainly alluvial deposits.

Introduction

The entire Millstone Grit sequence of the east crop of the coalfield is exposed along this stream, on east side of Daran-felen to Blaenavon road, 3 km east of Brynmawr, Gwent, Wales (SO 218122). The geology here is mentioned by Robertson (1927), Jones (1971, 1974), and Barclay (1989), but the most complete account is by Jones and Owen (1967).

Description

Lithostratigraphy

The sequence here is summarized in Figure 4.7(c). It consists of about 25 m of mainly arenaceous strata of the Millstone Grit, lying unconformably on Carboniferous Limestone. The sandstones are mainly massive with an erosive base, and often show pronounced channelling. They were probably formed as part of an alluvial complex, dispersing sediment to the south-west, into the so-called 'Pontypridd–Margam Trough' (Kelling, 1974).

In between the sandstones are shales and mudstones. The lowest (*c.* 3.5 m above the unconformity) is a seat earth overlain by plant-bearing shales, representing emergent conditions (Jones and Owen, 1967). Jones and Owen also mention plant fossils from a shale some 5 m above the seat earth. The upper three of the mudstone bands have yielded marine fossil assemblages, and are regarded as being the Cancellatum, Cumbriense and Subcrenatum marine bands (see below).

Biostratigraphy

Marine bands

Jones and Owen (1967) give species lists for three marine bands exposed here. In the lower of the bands, juvenile specimens of *Cancelloceras cancellatum* (Bisat) are found, together with productid and chonetid brachiopods; the middle band has yielded *Cancelloceras cumbriense* (Bisat), *Nucula* sp. and *Productus* sp. and nuculoid shells; and the top band yields abundant *Gastrioceras subcrenatum* (Frech). It is clear that they represent the Cancellatum, Cumbriense and Subcrenatum marine bands, respectively.

Plant macrofossils

Plant fossils are not particularly abundant or well preserved in this exposure. The most diverse assemblage occurs in the shale 3.5 m above the base of the Millstone Grit, from which Jones and Owen (1967) record *Alethopteris* cf. *lonchitica* Sternberg, *Neuralethopteris* cf. *naechstebreckiana* (Leggewie and Schonenfeld) Josten and *Mariopteris* sp. The presence of foliage of the *A. lonchitica*-type tends to indicate a position no lower than the *Neuralethopteris larischii* Subzone (upper *Pecopteris aspera* Zone) indicating the middle Marsdenian or Yeadonian.

Jones and Owen (1967) record *Paripteris gigantea* (Sternberg) Gothan from the shale 9 m above the unconformity. This again suggests a position no lower than the *N. larischii* Subzone.

Interpretation

Llammarch Dingle clearly demonstrates both the thickness and the style of sedimentation of the Millstone Grit on the east crop of the coalfield. The sequence is evidently very incomplete, with only the upper Marsdenian and Yeadonian being present. Furthermore, what is present is condensed compared with sequences further west. For instance, the Yeadonian here is only 10 m thick, compared with 51 m in the Vale of Neath, 45 m at Marros Sands and 73 m at Tenby–Saundersfoot. Only about 5 km further east, at Blorenge Mountain, the Namurian is totally missing, with Westphalian strata lying directly on Carboniferous Limestone (Jones, 1971).

The reduced development of Millstone Grit in this part of the coalfield is assumed to be a result of uplift of the Usk Axis, which lay just to the east (George, 1956). The proximity of this positive area also affected the nature of the sedimentation, with alluvial deposits predominating, in contrast to the fluvio-delatic and marginal marine deposits found further west.

Conclusions

Llammarch Dingle is the best site for showing the Millstone Grit on the eastern margins of the South Wales Basin. This sequence of rocks, which is about 316 million years old, is much thinner than the same-aged successions in the main part of the basin, such as near Swansea and Neath. It is also thought to represent the deposits formed higher up in the river delta, nearer to the source of the sediment.

BRYNMAWR ROAD CUTTING

Highlights

Brynmawr Road Cutting is the best exposure of the lower Langsettian on the east crop of the South Wales Coalfield, and provides important data for determining the basin-shape and controls on sedimentation in South Wales.

Introduction

This site refers to exposures on the south side of the 'Heads of the Valleys' road (A465 (T)), 1 km east of Brynmawr, Gwent, Wales (SO 197121–SO 206122, Figure 4.26). It is one of the classic exposures of lower Langsettian in South Wales, clearly showing the nature of the sequence on the east crop. The geology here was described by Robertson (1927) and Leitch *et al.* (1958). However, the exposures were enhanced considerably by the construction of the Heads of the Valleys road in the early 1960s, and the geology as now seen is briefly outlined by Jones *in* Owen *et al.* (1966) and Barclay (1989).

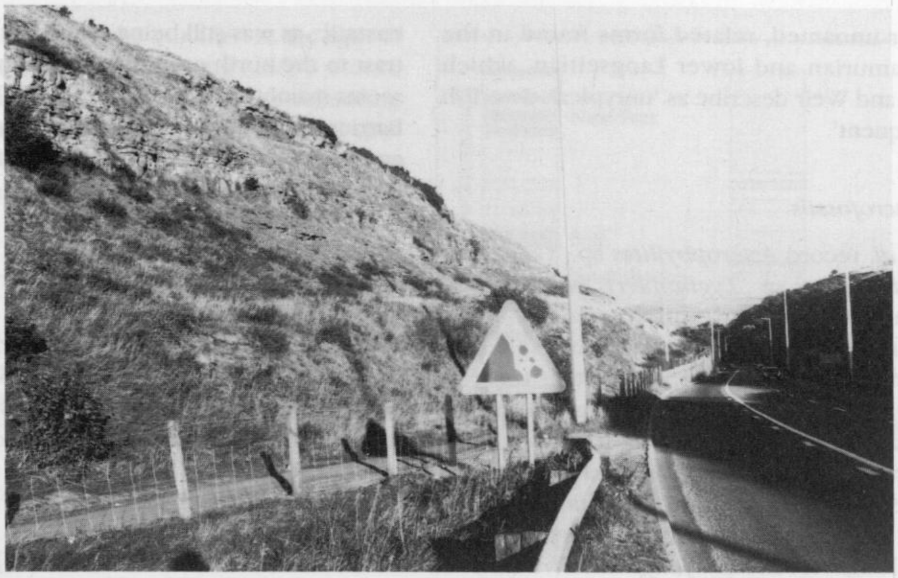

Figure 4.26 Exposures of lower Coal Measures seen at Brynmawr Road Cutting. (Photo: C.J. Cleal.)

Description

Lithostratigraphy

The sequence as described by Leitch *et al.* (1958) is 38 m thick, and its base is marked by a fault (see Figure 4.18(c)). The lower 10 m consists predominantly of mudstones, and belongs to the Middle Shales Formation. A 28 cm thick coal seam in this part of the sequence was identified by Leitch *et al.* as the Engine Seam (probably the same as the Sun Seam further south on the east crop).

The overlying 19 m are more arenaceous, and include both fluvial channel deposits and ganister palaeosols. Traditionally, this has been referred to as the Farewell Rock. It occupies a significantly higher position than the type Farewell Rock on the north crop, such as seen at Nant Llech and Cwm Gwrelych (see earlier in this chapter), indicating that it is a diachronous unit (Leitch *et al.* 1958, fig. 5). As is typical for the Farewell Rock in other parts of the coalfield, the base is marked by a basal mélange, probably the result of reworking of previously deposited sediments by fluvial processes (Kelling, 1974). Palaeocurrent vectors are to the west or north-west (Bluck, 1961; Bluck and Kelling, 1963), suggesting the uplifting Usk Axis is the major source of sediment here.

The Farewell Rock here is overlain by a 75 cm thick coal known here as the Garw Seam, which occurs widely throughout the South Wales Coalfield (sometimes given the alternative names Cnapiog or Rhasfach coal). On the east crop, this coal marks the base of the Productive Coal Formation, to which the rest of the Brynmawr sequence belongs.

This is easily the best site for showing the lower Langsettian of the east crop of the South Wales Coalfield. Waun Llwyd Quarry near Caerphilly used to show part of the succession, from the Upper Cwm Gorse Marine Band ...

Biostratigraphy

Marine bands

Leitch *et al.* (1958) identified three mudstones at Brynmawr as marine bands, although they contain little more than *Lingula* and fish scales. The lowest occurs at the very base of the section, in the Middle Shales Formation, and was taken by Leitch *et al.* to be the M_1 band recognized elsewhere in the coalfield. If correct, then the Subcrenatum Marine Band, which marks the base of the Westphalian Series, is absent here. The M_2 band is thought to have been removed by a scour at the base of the Farewell Rock, but M_3 and M_4 have been identified as thin mudstone intercalations within the otherwise mainly arenaceous Farewell Rock.

Above the Garw Coal occurs a fifth mudstone containing fish scales, teeth and spines, and *Planolites*. However, this cannot be the M_5 band recognized elsewhere in the coalfield, which lies some distance below this coal.

Non-marine bivalves

Leitch *et al.* record *Naiadites flexuosus* Dix and Trueman from a 'papery' (?lacustrine) shale at the top of the section. From comments made by Trueman and Weir (1956, p. 256), however, this is unlikely to be the true *N. flexuosus*, which is an index for part of the upper Langsettian, but one of the so far unnamed, related forms found in the upper Namurian and lower Langsettian, which Trueman and Weir describe as 'untypical, dwarfish and infrequent'.

Plant macrofossils

Leitch *et al.* record *Asterophyllites* sp., *Calamites* sp., *Lepidophloios* sp., *Lyginopteris hoeninghausii* (Brongniart) Gothan and *Neuralethopteris schlehanii* (Stur) Laveine from the roof-shales of the Engine Seam. However, the last of these is probably a misidentification, as this level is below the normal range of *N. schlehanii*. It is more likely to be *Neuralethopteris jongmansii* Laveine, which is the species normally found in strata of this age (Laveine, 1967). If this is the case, then the assemblage belongs to the *N. jongmansii* Subzone (lower *L. hoeninghausii* Zone).

Interpretation

This is easily the best site for showing the lower Langsettian of the east crop of the South Wales Coalfield. Waun Fawr Quarry near Caerphilly used to show part of the succession, from just above M_1 to the lower Farewell Rock (George and Squirrell *in* Owen, 1971d), but the site has recently been filled-in. Otherwise, these strata can only be seen in small, isolated outcrops showing small parts of the succession (Robertson, 1927; Squirrell and Downing, 1969).

Leitch *et al.* (1958) in identifying the marine bands, provided a useful means of making detailed comparisons with sequences elsewhere in the coalfield. Perhaps surprisingly, there is little significant attenuation of this part of the east crop succession compared with sites in the middle part of the north crop; at Nant Llech the M_1–M_4 thickness is 15 m compared with 23 m at Brynmawr. Further west, in the Ammanford area, however, the same interval is 46 m thick (Archer, 1968), while in the Pontypridd area it is 90 m thick (Woodland and Evans, 1964). These comparisons are important for determining the configuration of the South Wales Basin during the lower Westphalian.

The Brynmawr section can be used in conjunction with the exposures on the north crop to demonstrate the complex and diachronous form of the sandstone interval known as the Farewell Rock Formation. As pointed out by Kelling (1974), this demonstrates that the major control on sedimentation was tectonic and possibly climatic, rather than eustatic, as was still being argued by some. In contrast to the north crop, where sediment derivation seems mainly to have been from the Wales–Brabant Barrier to the north, the Farewell Rock sands of the east crop originated from the east, presumably from the uplifting Usk Axis.

Conclusions

Brynmawr Road Cutting is the best exposure of the of early Langsettian age (about 315 million years old) on the east crop of the South Wales Coalfield. By comparing this sequence with rocks of similar age elsewhere in South Wales, it is possible to determine details of the shape and sedimentation within the South Wales Basin.

WERN DDU

Highlights

Wern Ddu shows the only continuous sequence from the lower Langsettian to upper Bolsovian in the eastern part of the South Wales Coalfield. It is also the only extant site in the coalfield from which palynomorphs have been obtained, and which thus allows an approximate identification of palynological zones.

Introduction

This is a disused claypit 1.5 km south-east of Caerphilly, Mid-Glamorgan, Wales (ST 168857). The site has provided an extensive exposure of Productive Coal Formation on the east crop of the coalfield (Figure 4.28). The claypit has not been worked for many years and exposure is now poor, but there is considerable potential for re-excavation. Details of the field geology, as originally exposed, are given by Moore (1945) and Squirrell and Downing (1969), while Sullivan (1962) has described the palynology of some of the coals.

Description

Lithostratigraphy

The sequence exposed here in the 1940s and described by Moore (1945) was 185 m thick. Although Moore provided a detailed stratigraphical log (summarized in Figure 4.27), his interpretation of the sequence needs to be modified in the light of the work by Squirrell and Downing (1969). Moore used local names for the coals and the following table shows their equivalents in the standard classification of Squirrel and Downing (the latter names will be used through the rest of this report).

Moore	Squirrell and Downing
Big Rock Vein	No. 2 Rhondda Coal
Bodwr Fach Coal	No. 3 Rhondda Coal
Bodwr Fawr Coal	Hafod Coal
Limog Fach Coal	Abergorky Coal
Limog Fawr Coal	Pentre Rider Coal
	Pentre Coal
Yard Coal	Lower Pentre Coal
	Eighteen Inch Coal
Big Vein Group	Big Coal
Black Vein	Nine Feet Coal
Fork Vein	Bute Coal
Brass Vein	Seven Feet Coal
Hard Vein	Five Feet–Gellideg Coal

At the base of the sequence are flaggy sandstones which seem to represent the upper part of the Farewell Rock Formation. This is overlain by a 7 cm thick coal, which is probably the Garw Coal (Squirrell and Downing, 1969). The roof of this coal consists of shales containing fish fragments, and is thus similar to the roof of the Garw Coal as seen at Brynmawr Road Cutting.

The succeeding 6 m are shales, mudstones and clayband ironstones. Similar deposits, albeit rather thicker, occur in most of the South Wales Coalfield at this level (for instance, the interval between the Cnapiog and Grey coals at Cwm Gwrelych–Nant Llyn Fach), and seem to represent an interval of lacustrine conditions that prefaced the onset of more typically fluvio-deltaic conditions represented by the Productive Coal Formation.

More typical Productive Coal Formation deposits start with the Five Feet–Gellideg Coal. In more central parts of the basin, the Five Feet and Gellideg coals can be individually recognized, and in some places the Five Feet further splits to form a group of closely spaced seams (e.g. near Pontypridd – Woodland and Evans, 1964). At Wern Ddu, however, they have coalesced to form a 75 cm thick coal with thin dirt bands.

About 3 m above this is another compound coal with thin dirt partings called the Seven Feet Coal. The local name, Brass Vein, reflects the high pyrite content of both the coal and the partings. A little way to the west, the partings become thicker, and three discrete seams become recognizable, known as the Seven Feet, Yard and Amman Rider coals (or the Seven Feet Group).

This in turn is overlain by 3 m of shales containing marine fossils, which is thought to be the Vanderbeckei Marine Band (see below). There then

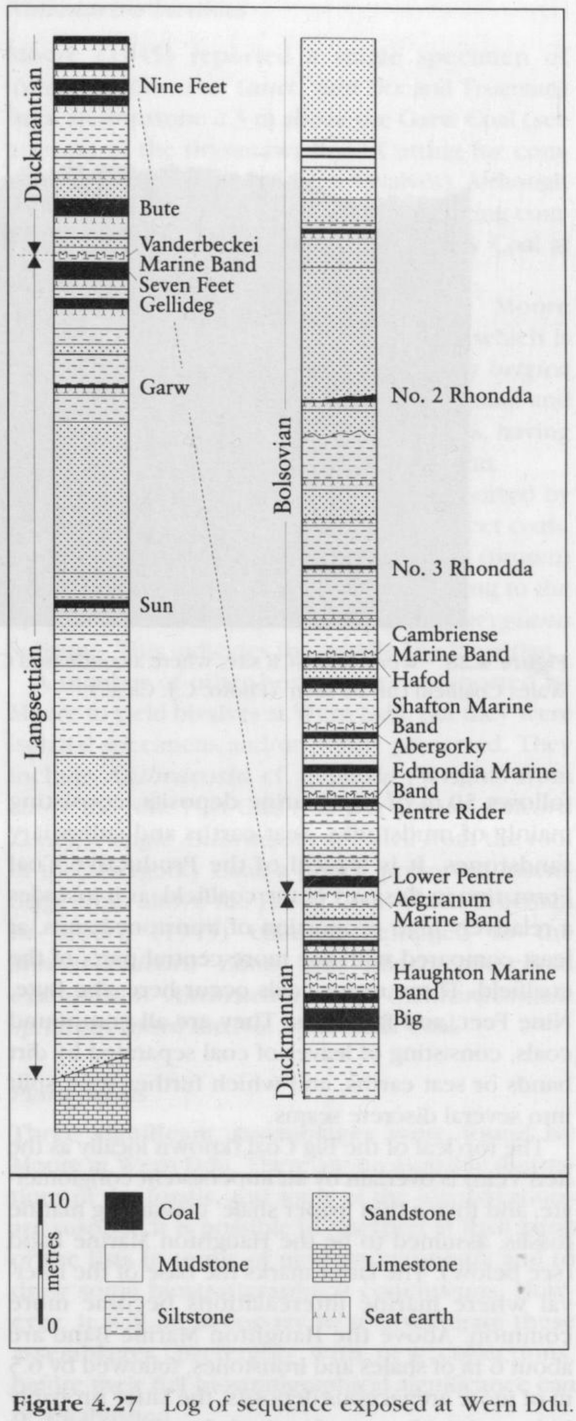

Figure 4.27 Log of sequence exposed at Wern Ddu. Based on Moore (1945).

Figure 4.28 Wern Ddu GCR site, where a condensed Coal Measures sequence on the eastern margins of the South Wales Coalfield can be seen. (Photo: C.J. Cleal.)

follows 50 m of non-marine deposits, consisting mainly of mudstones, seat earths and subsidiary sandstones. It is typical of the Productive Coal Formation in this part of the coalfield, as it includes a relatively high proportion of ironstone-bands, at least compared with the more central parts of the coalfield. Three major coals occur here: the Bute, Nine Feet, and Big coals. They are all compound coals, consisting of leaves of coal separated by dirt bands or seat earths, and which further west split into several discrete seams.

The top leaf of the Big Coal (known locally as the Red Vein) is overlain by an impersistent conglomerate, and then a thin 'paper shale' containing marine fossils, assumed to be the Haughton Marine Band (see below). The latter marks the base of the interval where marine intercalations become more common. Above the Haughton Marine Band are about 6 m of shales and ironstones, followed by 6.5 m of more arenaceous deposits, the latter probably being equivalent to the Cockshot Rock. This is overlain by 15 cm of black shales which, from its position relative to the Cockshot Rock, is probably the Aegiranum Marine Band.

There follows 6 m of unfossiliferous, non-marine shales with ironstones, overlying which are about 3 m of sandy shales and seat earths. Moore (1945) interpreted this emergent interval as the probable position of the 'Yard Seam' (a local name for the Eighteen Inch Coal), but Squirrell and Downing (1969) argued that it could be equated with all the seams between the Eighteen Inch and Pentre Rider coals, inclusive. However, Moore located the position of another coal about 12 m above what he called the Yard Coal, and in its roof shales found *Lingula*. If, as is argued by Squirrell and Downing, the roof shales are the Edmondia Marine Band, then this second coal is likely to be the Pentre Rider Coal. It seems more likely, therefore, that Moore's Yard Coal is a combination of only the Eighteen Inch, Lower Pentre and Pentre coals.

Overlying the Pentre Rider are 9 m of sandstones and some shales and seat earths. One 30 cm thick shale in this interval has a bright red colour, perhaps reflecting a slight lowering of the water-table, and offering a foretaste of the reddening of the strata seen in the Pennant Formation of the east crop (Downing and Squirrell, 1965). The next coal is generally referred to as the Abergorky Coal and, as elsewhere in the coalfield, is overlain by black, 'papery' shales of the Shafton (or Lower Cwm Gorse) Marine Band.

Above the Shafton Marine Band, sandstones become less common than in the Pentre-Abergorky interval; the succeeding 7 m includes only just over 1 m of sandstone. This interval is relatively characterless, other than for the presence of a thin coal, which Squirrell and Downing (1969) claim is known nowhere else in this part of the coalfield. It is overlain by another, but this time more widely occurring coal – the Hafod Coal. The roof of this coal is mudstones containing marine fossils, and represents the highest marine band in the coalfield – the Cambriense (or Upper Cwm Gorse) Marine Band.

In the central part of the coalfield, the Cambriense Marine Band is almost immediately overlain by coarse sandstones of the Pennant Formation. On the east crop, however, the Productive Coal Formation extends well above the Cambriense Marine Band. This is particularly well demonstrated at Wern Ddu where there are some 23 m of mudstones, ironstones, seat earths and coals, with only a few thin sandstones. Coals recognizable in this part of the sequence include the Blackband Coal (represented here by what Moore calls 'Coaly "rashings" and dark shale'), the 30 cm thick No. 3 Rhondda Coal, a 5 cm thick smut which is probably the Taldwyn Coal, and the 40 cm thick Gilfach Coal.

The roof of the Gilfach Coal is a 12–15 m thick sandstone, which in this part of the coalfield marks the base of the Pennant Formation. A total of 25 m of Pennant Formation was reported here by Moore (1945), consisting mainly of coarse sandstones and conglomerates, although there was also a 40 cm thick coal and its seat earth – the No. 2 Rhondda Coal. Squirrell and Downing (1969) identify the conglomerate and sandstone which overlie the No. 2 Rhondda Coal and which marks the top of the sequence exposed at Wern Ddu, as the Saron Sandstone.

Biostratigraphy

Marine bands

As already stated, six mudstone or shale bands in the Wern Ddu sequence have been identified as marine bands. They yield assemblages of only very limited diversity, restricted mainly to inarticulate brachiopods, *Dunbarella* and *'Productus'*. However, they are thought to be the Vanderbeckei, Haughton, Aegiranum, Edmondia, Shafton and Cambriense marine bands, based on their position relative to widespread coals and sandstones in the section.

A seventh mudstone, immediately overlying the Garw Coal near the base of the sequence, was reported by Moore (1945) to yield fish fragments. It is uncertain whether it is a marine band, but it is interesting to note the presence of an identical bed above the Garw Coal at Brynmawr Road Cutting, some distance to the north.

Non-marine bivalves

Moore (1945) reported a single specimen of *'Naiadites flexuosa' (auct., non* Dix and Trueman) from an ironstone 2.3 m above the Garw Coal (see account of the Brynmawr Road Cutting for comments on the affinities of these bivalves). Although an isolated example, it provides an interesting comparison with shells found above the Garw Coal at Brynmawr.

From the Five Feet-Gellideg Coal, Moore reported *Anthraconauta minima auct.*, which is now normally referred to as *Curvirimula belgica* (Hind) following proposals made by Trueman and Weir (1960). This is a long ranging species, having been reported from the Viséan to Bolsovian.

More diagnostic assemblages were reported by Moore from between the Bute and Nine Feet coals. They included *Anthraconaia williamsoni* (Brown) and *A. robertsoni* (Brown), and thus belong to the *A. modiolaris* Zone, probably the *A. phrygiana* Subzone. This indicates the middle Duckmantian.

A number of other horizons were reported by Moore to yield bivalves at Wern Ddu, but they were isolated specimens and/or poorly preserved. They include *Anthracosia* cf. *acutella* (Wright) from above the Nine Feet Coal (? Lower *Similis–Pulchra* Zone), a single *Anthracosia* sp. shell from the roof of the Abergorky Coal, a poorly preserved assemblage from above the Hafod Coal which Trueman *in* Moore (1945) claimed belonged to the *Similis–Pulchra* Zone, and poorly preserved examples of *'Anthracomya'* sp. (?*Anthraconaia* sp.) from above the No. 3 Rhondda Coal.

Plant fossils

Three significant assemblages were found by Moore at Wern Ddu. There are no available illustrations of the fossils, and some of the identifications are suspect. It is possible to interpret at least parts of the lists in terms of modern taxonomy and to draw some biostratigraphical conclusions. However, it will be necessary to re-investigate these assemblages, preferably with new collections, before their full biostratigraphical significance can be established.

The lowest includes *'Neuropteris grangeri'* (probably *N. heterophylla* Brongniart), *N. obliqua* (Brongniart) Zeiller, *Renaultia gracilis* (Brongniart) Zeiller, *Sphenophyllum cuneifolium* Sternberg, *Annularia radiata* (Brongniart) Sternberg and *Asterophyllites charaeformis* (Sternberg) Unger. Although containing a range of taxa, the assemblage is not particularly diagnostic, indicating only a position somewhere between the upper *Lepidophloios hoeninghausii* Zone to upper *L. rugosa* Zone (upper Langsettian to upper Duckmantian).

The second assemblage was found in shales 5 m below the Nine Feet Coal. It includes *'Neuropteris gigantea'* (probably *Paripteris pseudogigantea* (Potonié) Gothan), *'N. heterophylla'* (probably *Laveineopteris loshii* (Brongniart) Cleal *et al.*) *N.* cf. *obliqua*, *Alethopteris decurrens* (Artis) Zeiller, *Lonchopteris rugosa* Brongniart, *Mariopteris muricata* (Brongniart) Zeiller, *Bertrandia avoldensis* (Stur) Danzé, *Sphenophyllum cuneifolium* and *Annularia radiata*. Such an assemblage probably belongs to the *L. rugosa* (or possibly lowest *P. linguaefolia*) Zone, indicating the Duckmantian Stage. Determining the true identity of Moore's *N.* cf. *obliqua* would provide a more accurate biostratigraphical control on the assemblage, particularly if it could be fitted into the phylogenetic model outlined by Josten (1962).

About 8 m above the Abergorky Coal, Moore found *Laveineopteris tenuifolia* (Sternberg) Cleal *et al.*, *Paripteris pseudogigantea*, *Macroneuropteris scheuchzeri* (Hoffmann) Cleal *et al.*, *Eusphenopteris obtusiloba* (Brongniart) Novik, *Renaultia chaerophylloides* (Brongniart) Zeiller, *R. rotundifolia* (Andrä) Zeiller and *Sphenophyllum majus* (Bronn) Bronn. This almost certainly belongs to the *P. linguaefolia* Zone, indicating the Bolsovian or uppermost Duckmantian.

Palynology

The palynology of this site was described by Sullivan (1962). Other than an unpublished thesis by Williams (1956), the results of which were summarized by Butterworth and Millott (1960), this is the only account of Upper Carboniferous palynomorphs from the South Wales Coalfield. Sullivan's work was also important in that he demonstrated that the non-marine shales yielded assemblages of similar composition to the coals; previous studies on Upper Carboniferous palynology had been based only on the coals, and there had been some debate as to whether the shales would yield similar palynomorphs. This is not the place to provide a detailed biostratigraphical analysis of Sullivan's study; there appear to be differences in the taxonomy used in his paper compared with later biostratigraphical reviews, such as by Smith and Butterworth (1967) and Owens (1984). The following is thus a brief resumé of his conclusions.

That part of the section below the Seven Feet Coal was included in the *Cirratriradites aligerens* Zone of Butterworth and Millott (1960) (the *Radiizonates aligerens* Zone of Smith and Butterworth, 1967). This is a well defined zone in the upper Langsettian of much of western Europe (Owens, 1984).

Smith and Butterworth (1967) assigned the very topmost Langsettian of South Wales to the *Schulzospora rara* Zone, but Sullivan found no evidence of it at Wern Ddu. His next highest assemblages, other than those from the Vanderbeckei Marine Band, originated from the Bute Coal. The samples from here up to the Aegiranum Marine Band were assigned to the *Dictyotriletes bireticulatus* Zone. This seems to correspond to the *M. nobilis – F. junior* Zone of Owens (1984), which is known in the Duckmantian and topmost Langsettian in western Europe.

Assemblages from just above the Aegiranum Marine Band up to just below the Hafod Coal were assigned by Sullivan to the *Novisporites magnus* Zone of Butterworth and Millott (1960). It marks a significant change in the palynomorph assemblages, with the incoming of taxa such as *Vestispora magna* (Butterworth and Williams) Smith and Butterworth, *Microreticulatisporites nobilis* (Wicher) Knox and *Triquitrites sculptilis* Balme. However, the change appears to be a relatively local affair, and is not recognized in the classification outlined by Owens (1984).

The Hafod Coal was reported to yield the first rare occurrences of *Torispora securis* Balme, and was taken by Sullivan to mark the base of the zone of that name. This is a major palynological event, which can be identified throughout much of Europe (Owens, 1984). However, the exact level can vary between basins: in South Wales it occurs at about the middle Bolsovian, whereas in the Lorraine (France) and Donetz (Ukraine) it is near the base of the Bolsovian. This in part explains the discrepancies between the zonation of Smith and Butterworth (1967), in which the base of the *T. securis* Zone is placed at the Cambriense Marine Band, and that of Owens (1984), in which it is placed in the lower Bolsovian.

Interpretation

This is the only site in the eastern part of the South Wales basin to show a continuous sequence from the lower Langsettian to the upper Bolsovian. Moore (1945) and Squirrell and Downing (1969) describe similar strata from a number of other places in this part of the coalfield, but they either show only small parts of the sequence, or were underground workings. Although exposure at Wern Ddu is now poor, there is still the potential to open up a continuous sequence through the Productive Coal Formation here. When combined with Brynmawr Road-Cutting and Coed-y-Darren, it will be possible to examine most of the Coal Measures in the eastern part of the basin.

The Productive Coal Formation is significantly condensed compared with sequences to the west. For instance, at Wern Ddu the Duckmantian is only 75 m thick, whereas near Pontypridd it is 180 m (Woodland and Evans, 1964) and near Ammanford it is 235 m (Archer, 1968). Also, significantly more of the sequence consists of seat earths, and the coals are compound seams which further west split into a number of separate seams. This all combines to indicate significantly lower rates of subsidence in this part of the coalfield, which is symptomatic of its position near the margins of the depositional basin.

Another feature of the Wern Ddu sequence is that the Pennant Formation facies occurs significantly higher than in the central part of the coalfield. The junction between this and the underlying Productive Coal Formation is gradational here, with some sandstones occurring just above the Pentre Coal. However, the lowest really massive and conglomeratic sandstones typical of the Pennant appear between the No. 3 and No. 2 Rhondda coals. In contrast, in the middle part of the north crop, such as at Cwm Gwrelych–Nant Llyn Fach, the Pennant Formation appears immediately above the Cambriense Marine Band. According to Kelling (1988), the Pennant Formation reflects the generation of new nappes near the Variscan Front to the south, which increased both basin subsidence and sediment supply into the South Wales basin. The delay in the introduction of Pennant-type lithologies into this marginal part of the basin may reflect the stabilizing effect of the Usk Axis to the east, which may have been able to resist the nappe-loading, at least for a time.

Biostratigraphically, Wern Ddu is important because it is one of the few places in South Wales to have yielded palynological evidence. South Wales provides good biostratigraphical evidence for the other groups, such as plant macrofossils, non-marine bivalves and marine fossils. However, the rank of the coals is normally too high for the preservation of palynomorphs (Smith and Butterworth, 1967); only in the eastern part of the coalfield, such as at Wern Ddu, is the rank sufficiently low for them to be preserved. There is a problem in relating the evidence from these marginal areas to the main part of the coalfield, as the sequence is condensed and detailed comparisons of the coals are difficult. Sullivan's (1962) discovery that the non-marine mudstones here yielded essentially similar palynomorphs to the coals offers a potential solution to this problem; palynomorphs in shales are less vulnerable to the destructive effects of coalification, and thus might still be preserved in the more central parts of the coalfield. However, although 30 years have now lapsed since Sullivan's discovery, there have been no reported attempts to investigate the palynomorphs from shales in the main part of the coalfield, and thus to provide a more detailed palyno-stratigraphical analysis of the South Wales sequence.

Conclusions

Wern Ddu shows the only continuous sequence of rocks ranging in age from the early Langsettian to late Bolsovian (300–315 million years old) in the eastern part of the South Wales Coalfield. It is also the only site in the coalfield from where the fossilized remains of plant pollen and spores can still be obtained, which is important for establishing correlations of the strata with sequences in other parts of Europe. This is also helped by a range of other types of fossils, including the remains of various marine and non-marine animals.

COED-Y-DARREN

Highlights

Coed-y-Darren is the best exposure of the junction between the Productive Coal and Pennant formations on the east crop, and provides important information on the geological evolution of this part of the South Wales Coalfield.

Introduction

A landslip scar on the side of Twmbarlwm, 2 km north of Risca, Gwent, Wales (ST 240921) shows the junction between the Pennant and Productive Coal formations, as developed on the east crop of the coalfield. Descriptions of the outcrop are provided by Moore (1948), Squirrell and Downing (1964, 1969). George and Squirrell *in* Owen (1971d) and Squirrell (1971).

Description

Lithostratigraphy

The main part of the exposed sequence here is just under 30 m thick (Figure 4.29). The lower 15 m consists of a series of mudstones and sandstones of the Productive Coal Formation. Only one thin coal (0.15 m thick) is exposed, but there are also a number of seat earths, particularly in the lower part of this interval. Squirrell (1971) assigned the upper part of this predominantly argillaceous interval (i.e. between the Cambriense Marine Band and the base of the Rhondda Member) to the Pennant 'Measures', based on the pseudo-chronostratigraphical classification of Woodland *et al.* (1957). However, they are quite clearly of the same facies as the Productive Coal Formation.

The upper 15 m of the sequence belong to the Pennant Formation, which lies unconformably on the Productive Coal Formation. Immediately above the unconformity are 7.6 m of massive quartz-conglomerate (a brief petrological description is provided by Hawkes *in* Squirrell and Downing, 1969). This is in turn overlain by about the same thickness of massive sandstones, typical of the Rhondda Beds. These sandstones, which are often referred to as orthoquartzites (although Kelling, 1974 has queried the use of this term for these deposits), are quite different from the lithic arenites present in the central part of the coalfield, such as at Earlswood Road Cutting and Blaenrhondda (see earlier reports in this chapter). Kelling (1964, 1968) interpreted them as alluvial deposits derived from a nearby source to the east, probably the Usk Axis, but later (1974) modified this, and regarded them as probably littoral or lagoonal deposits, but it is difficult to reconcile this with the absence of any palaeontological evidence of marine conditions in the Pennant Formation.

Biostratigraphy

A thin mudstone 5.5 m above the base of the section has yielded trace fossils known as *Planolites ophthalmoides* Jessen. This is generally taken to represent the Cambriense Marine Band (e.g. George and Squirrell *in* Owen, 1971d; Squirrell and Downing, 1969).

About 4 m below this is a seat earth. Squirrell and Downing (1969) regard it as marking the position of the coal that underlies the Shafton Marine Band elsewhere in this part of the coalfield. However, the marine band itself has not been found here.

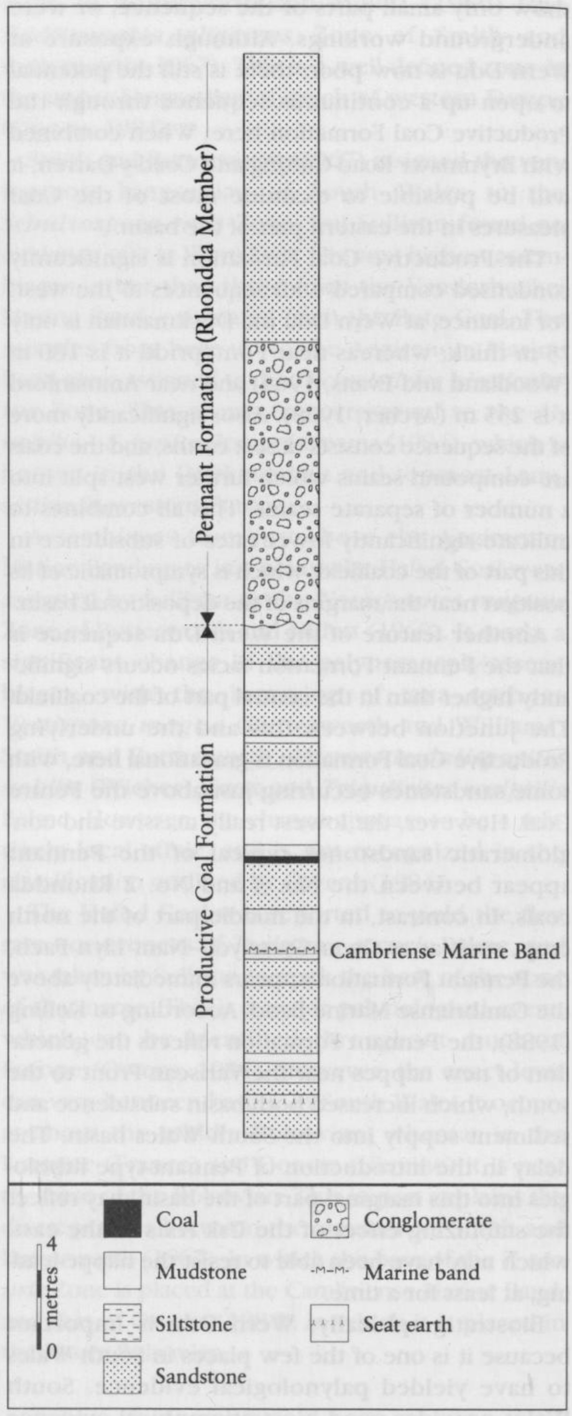

Figure 4.29 Exposed sequence at Coed-y-Darren. Based on Squirrell (1971, pp. 51–2).

Interpretation

This section demonstrates the significantly condensed nature of the succession developed on the east crop of the coalfield. This is partly as a result of unconformity, with part of the Productive Coal Formation and probably the lower part of the Rhondda Beds having been removed by erosion. However, it is also probably a result of reduced rates of sedimentation. Assuming that the marine band correlations mentioned above are correct, the 4 m distance between the Shafton and Cambriense marine bands contrasts with about 45 m for a similar interval in the main part of the coalfield (e.g. Archer, 1968).

The lower part of the section here overlaps with that seen at Wern Ddu Claypit (see above). However, it shows higher strata than is present at the latter site, as well as demonstrating the unconformity below the Rhondda Member.

The site is also important for understanding the lithostratigraphy of the coalfield. Following the classification proposed by Woodland *et al.* (1957), all strata between the Cambriense Marine Band and the No. 2 Rhondda Seam should be assigned to the Llynfi 'Beds', the basal member of the Pennant Measures. While in the central part of the coalfield, this interval consists largely of Pennant-like strata, on the east crop (such as at Coed-y-Darren) they are clearly of the same facies as the Productive Coal Formation. It thus seems reasonable to assign these strata on the east crop to the Productive Coal Formation, and to place the base of the South Wales Pennant Formation at the unconformable base of the Rhondda Beds.

Conclusions

Coed-y-Darren is the best exposure of the junction between rocks known as the Productive Coal and South Wales Pennant formations on the east crop of the South Wales Coalfield. The junction marks a significant change in the environment in the coalfield, due to the development of major river systems flowing from the south. The information visible at this site has proved important for understanding the geological evolution of this part of the South Wales Coalfield at about 308 million years ago.