British Lower Carboniferous Stratigraphy

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Chapter 9

South Wales–Mendip Shelf

A.E. Adams, V.P. Wright and P.J. Cossey

INTRODUCTION

The South Wales–Mendip Shelf area embraces Dinantian outcrops in an area some 200 km in greatest extent, from the shores of Milford Haven in the west, through South Wales to the Forest of Dean, and across the River Severn to Bristol and the Mendips, with the most south-easterly exposures found near Frome in Somerset (Figure 9.1). In South Wales, strata are folded into a giant syncline, which becomes more complex westwards into Gower and Pembrokeshire. This allows the distinction between the broadly southerly dipping north crop, running from Haverfordwest to Abergavenny, and a broadly northerly dipping south crop, running from the Pembroke Peninsula to north of Cardiff. The syncline closes at its eastern end, allowing delineation of an east crop which is much attenuated in thickness as a result of erosion prior to deposition of the Namurian Series (Figure 9.1).

In the Forest of Dean, Lower Carboniferous strata surround the synclinal coalfield, except in the south-east where they are overstepped by the Upper Carboniferous sequence, and there is an extension of the outcrop south-westwards to Chepstow and Magor. An isolated outcrop occurs 60 km to the north of the Forest of Dean at Titterstone Clee. East of the Severn, Lower Carboniferous rocks rim the north side of the Bristol Coalfield, cropping out in an arc from Alveston to Chipping Sodbury. Around the Bristol area, Lower Carboniferous rocks occur in a number of inliers, and to the south, form the spine of the Mendips running for more than 50 km from the Bristol Channel coast to Frome. Isolated outcrops occur on Flat Holm and Steep Holm, islands in the Bristol Channel, and to the south at Cannington, west of Bridgwater (Figure 9.1).

Exposures vary from the superb shoreline sections of Gower and Pembrokeshire (although access to these can be limited by the steepness of the cliffs), to weathered inland exposures such as those of Burrington Combe and Cheddar Gorge in which details of fauna and lithology can be difficult to distinguish. The Carboniferous Limestone has been extensively quarried and most of the best inland exposures are in disused or working quarries. These range from small quarries which produced stone for local use, to the vast quarry complexes of ARC and Foster Yeoman in the Mendips, which supply aggregate to much of southern England, and to the largely disused quarries of the north crop between Abergavenny and Merthyr Tydfil used formerly to supply flux to the now-defunct local iron and steel industry and more recently in the supply of aggregate to the South Wales area.

History of research

The original geological survey of this area leading to the production of maps at a one-inch-to-a-mile scale was undertaken in the mid-19th century. The main results of the survey were summarized by De la Beche (1846). During the late 19th century and early 20th century, mapping at a six-inches-to-a-mile scale was undertaken, and the first editions of sheet memoirs were published, much of it under the guidance of Mr (later Sir) Aubrey Strahan. These included the 13 parts of *The Geology of the South Wales Coalfield*, which began with the Newport area (Strahan, 1899). Other early memoirs in this series that have descriptions of Lower Carboniferous rocks include Abergavenny (Strahan and Gibson, 1900), Cardiff (Strahan and Cantrill, 1902), Merthyr (Strahan *et al.*, 1904), Bridgend (Strahan and Cantrill, 1904), Ammanford (Strahan *et al.*, 1907) and Swansea (Strahan, 1907a).

East of the Severn, after the initial survey the most important contribution in the 19th century was the publication of the explanatory memoir on the Bristol and East Somerset coalfields (Woodward, 1876). Other 19th century work included Morgan (1889) and Winwood (1889) on sections in the Tytherington area. The publication of Arthur Vaughan's seminal account on the faunal zonation of the Carboniferous Limestone, based on his work in the Avon Gorge (Vaughan, 1905, 1906), marked a turning point in stratigraphical studies and a stimulus to many other researchers who applied his scheme to rock successions throughout the area. This included the remaining memoirs in the series *The Geology of the South Wales Coalfield*, namely those for West Gower (Strahan, 1907b), Carmarthen (Strahan 1909), Haverfordwest (Strahan *et al.*, 1914), Milford (Cantrill *et al.*, 1916) and Pembroke and Tenby (Dixon, 1921). At the same time, second editions of the Newport and Cardiff memoirs, incorporating an application of Vaughan's zones, were published (Strahan, 1909; Strahan and Cantrill, 1912). Other important works on the Carboniferous

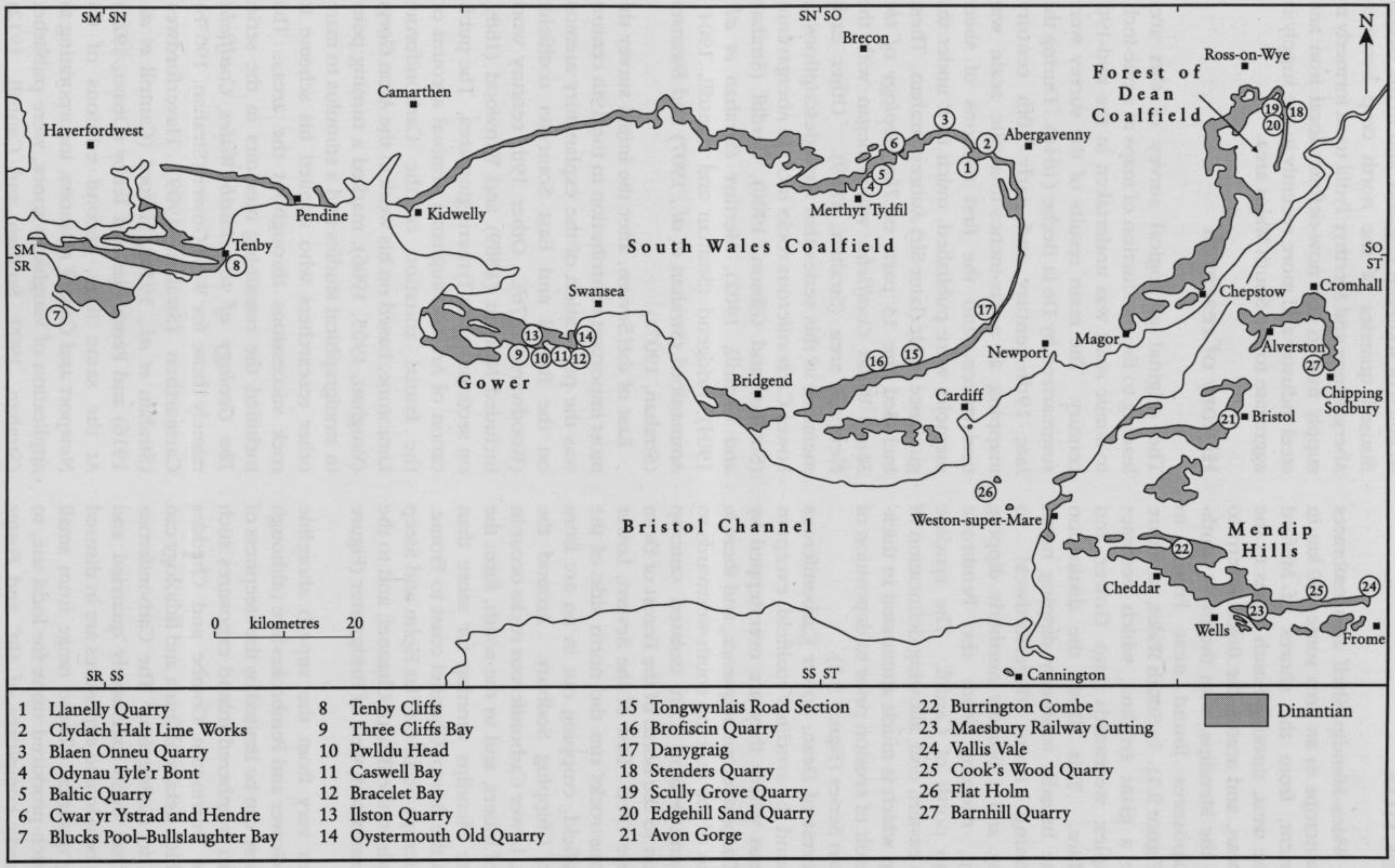


Figure 9.1 Outcrop map showing the distribution of Dinantian strata in South Wales, Gloucestershire, Avon and north Somerset, and the locations of GCR sites described in the text. Compiled from various sources and including information from [British] Geological Survey maps of the area (principally Insitute of Geological Sciences, 1979b).

Limestone of South Wales, which built upon Vaughan's contribution at this time, were by Dixon and Vaughan (1911) on Gower, Dixey and Sibly (1918) on the south-eastern part of the area, and Sibly (1920) on the Cardiff area.

In the Bristol, Weston-super-Mare and Mendips area, many publications built on the work of Vaughan, notably those of Sibly (1905a,b, 1906), Reynolds and Vaughan (1911), Bamber (1924), Bush (1925, 1929) and Welch (1929, 1933) on the Mendips; Reynolds and Innes (1914) and Wallis (1924a) on the area to the north of Bristol; and Reynolds (1918, 1920, 1921, 1926, 1936) mainly on the area around Bristol and south-west to Clevedon. The limestones of the inlier at Cannington Park were described by Wallis (1924b). In the Forest of Dean, the early work of Wethered (1883, 1886, 1888) was followed by the contributions of Sibly (1912, 1918, 1919) and Sibly and Reynolds (1937). The succession at Titterstone Clee was described by Dixon (1917).

One of the most significant contributors to our understanding of the structure, stratigraphy and depositional history of the Carboniferous Limestone in South Wales was T. Neville George, whose publications on the area span more than 50 years. Important works include George (1927, 1954) and Robertson and George (1929) on the north crop, George (1933) on the western part of the Vale of Glamorgan, George (1956a) on the east crop, George (1956b) on the Usk Anticline and Titterstone Clee, and George (1940, 1978b) on Gower. George (1958), on the Lower Carboniferous palaeogeography of the British Isles, contains substantial information on the whole of the area covered by this chapter. A review of the Dinantian geology of South Wales was also published (George, 1974).

Second editions of the memoirs for Abergavenny and Merthyr were produced (Robertson, 1927, 1933) and subsequent memoirs include those for the Forest of Dean and surrounding areas (Trotter, 1942; Welch and Trotter, 1961), Wells and Cheddar (Green and Welch, 1965); and the third edition for Newport (Squirrel and Downing, 1969). In recent years, new memoirs or editions of memoirs for a number of areas have been published, such as Taunton, which includes the outcrop at Cannington (Edmonds and Williams, 1985), Weston-super-Mare (Whittaker and Green, 1983), Cardiff (Waters and Lawrence, 1987), Merthyr (Barclay *et al.*, 1988), Abergavenny (Barclay, 1989), Bridgend (Wilson *et al.*, 1990) and Bristol (Kellaway and Welch, 1993).

Other contributions to our knowledge of the structure and stratigraphy of the Dinantian strata of the area include Kellaway and Welch (1955) who reviewed stratigraphical nomenclature in the eastern part of the area; Evans and Cox (1956) and Gayer *et al.* (1973) on the basal Carboniferous Limestone to the north of Cardiff; Owen and Jones (1961) on the Neath disturbance; R. Sullivan (1964, 1965, 1966) on aspects of the Dinantian succession in Pembrokeshire; Rhodes *et al.* (1969) and Butler (1972, 1973) on conodont faunas around Bristol and the Mendips; Dolby (1970), Dolby and Neves (1970), Utting and Neves (1970) and Higgs and Clayton (1984) on Tournaisian miospore assemblages from the Bristol and Mendips area; and H.J. Sullivan (1964a,b) and Spinner (1984) on miospore and megaspore assemblages from the Forest of Dean. Other faunal studies include those of Batten (1966) on gastropod faunas from the Hotwells Limestone, Mitchell (1971, 1972, 1981, 1993) mostly on the Bristol and Mendips area, Mitchell *et al.* (1986) on Tournaisian–Viséan boundary rocks in Gower, Strank (1981) on the foraminiferal faunas of various sections across the region, and Austin (1987) and Simpson and Kalvoda (1987) on the Arundian type section in southern Pembrokeshire. Contributions on the palaeobotany of the Lower Carboniferous succession in the Forest of Dean area are by Cleal (1986), Rowe (1988) and Cleal and Thomas (1995). The Carboniferous Limestone north of Bristol was described by Murray and Wright (1971), and aspects of the Courceyan and Chadian stages of the eastern part of the Vale of Glamorgan by Waters (1984). The Knap Farm Borehole at Cannington, which proved Lower Carboniferous strata to a depth of more than 1100 m, was described by Whittaker and Scrivener (1978, 1982), Lees and Hennebert (1982) and Mitchell *et al.* (1982).

Namurian strata of the area are described in the memoirs mentioned above. The lower part of this succession is, at least in some places, demonstrably of Pendleian and Arnsbergian age, and hence falls within the remit of this volume. Papers that include a discussion of the stratigraphy of the lower part of the Millstone Grit and the contact with the Carboniferous Limestone include Owen (1954), Jones and Owen (1957), Archer (1965) and Ramsbottom

(1971). The Namurian succession of South Wales was reviewed by Jones (1974) and Kelling (1974) and the large-scale cyclicity interpreted by Ramsbottom (1978b). Upper Carboniferous GCR sites in the area are described by Cleal and Thomas (1996).

Our understanding of depositional environments and diagenesis of Lower Carboniferous strata in the area has been dramatically improved by the expansion in geological research during the last 30 years. This has been particularly true in South Wales, but the Forest of Dean and the Bristol and Mendips areas have not received the same degree of attention. Many research theses (MPhil, MSc and PhD) have involved studies of the sedimentology of Lower Carboniferous rocks in the area. These include George (1970) on the Namurian rocks of Pembrokeshire, Kirkham (1976) on the Clifton Down Limestone, Burchette (1977) and Lovell (1978) on the Lower Limestone Shale, Thorne (1978) on the Oxwich Head Limestone, Jeffreys (1979) on the volcaniclastic and carbonate rocks at Weston-super-Mare, Wright (1981a) on the Llanelly Formation, Spalton (1982) on terrestrial deposits, Atta-ntim (1984) on the Drybrook Sandstone, Raven (1983) on the diagenesis of the Oolite Group, Simpson (1985a) on the Arundian Stage, Searl (1986) on the diagenesis of oolites, Hird (1986) on dolomitization, Weedon (1987) on the Clifton Down Mudstone, Scott (1988) on the Holkerian Stage, Faulkner (1989a) on the Black Rock Limestone Group, and Vanstone (1993) on palaeosols. Publications resulting from this postgraduate research include Kelling and George (1971), Burchette and Riding (1977), George and Kelling (1982), Simpson (1985b, 1987), Burchette (1987), Hird *et al.* (1987), Faulkner (1988, 1989b), Hird and Tucker (1988), Searl (1988a,b,c, 1989a,b), Faulkner *et al.* (1990) and Vanstone (1991, 1996).

Two authors stand out as having made a particularly significant contribution to our understanding of Dinantian environments in South Wales. Ramsay (1987, 1989, 1991) reports the results of a long-term field study of the Carboniferous Limestone with a detailed analysis of environments and controls on deposition. Wright, in a long series of papers, has made a special contribution to the understanding of subaerial exposure within marine limestone successions with many examples drawn from the Welsh Dinantian succession, as well as authoring more general papers on Lower Carboniferous environments in the area (Wright, 1980, 1981b,c, 1982a,b,c,d, 1983, 1984, 1986a,b, 1987a,b, 1988, 1990b; Riding and Wright, 1981; Wright and Wright, 1981, 1985; Wright *et al.*, 1991; Wright and Vanstone, 2001).

Other contributions to the sedimentology and palaeoecology of the Lower Carboniferous succession of the South Wales–Mendip Shelf include Kelling and Williams (1966) on sedimentary structures in the Lower Limestone Shale of Pembrokeshire, Whitcombe (1970) on the diagenesis of the Lower Limestone Shale, Bhatt (1975, 1976) on evidence for evaporites in the Dinantian sequence and regional petrology and geochemistry, Wu (1982) on storm deposits and trace fossils, and Beus (1984) on faunas in the High Tor Limestone.

Stratigraphy

In early surveys of the area, the major units recognized included the Lower Limestone Shale, the Main Limestone or, particularly in the Mendips, the Mountain Limestone, and the Millstone Grit. Towards the end of the 19th century and into the 20th century these units began to be subdivided, often using a mixture of lithostratigraphical terms, such as 'Gully Oolite', introduced by Morgan (1889), units named after characteristic fossils such as '*Lithostrotion* Beds', and numbered beds or groups of beds as used in Pembrokeshire by Dixon (1921). Vaughan's (1905) zonal scheme for the Carboniferous Limestone and its later revisions gave a biostratigraphical framework with which local successions could be correlated, and much effort was expended in fitting sequences from all areas into the Avonian scheme. Many anomalies remained, and facies terms such as '*Modiola* Phase', used for lagoonal limestones with an impoverished fauna, tended to be used as stratigraphical units.

Gradually, names for lithostratigraphical units across the area of the South Wales–Mendip Shelf were adopted, many as a result of the work of the [British] Geological Survey in revising maps and memoirs and also as a result of the report on Dinantian stratigraphy by George *et al.* (1976). In this report, a series of regional stages for the Dinantian rocks of Britain was proposed, with the type section of one of them, the Arundian Stage (at Hobbyhorse Bay, Pembrokeshire; **see Blucks Pool–Bullslaughter**

Bay GCR site report, this chapter), within the area covered by this chapter.

Since this chapter covers an area of 200 km from west to east, and great changes in facies and thickness occur from north to south, a large number of names of varying geographical application have been proposed. Those in most common use are tabulated in Figure 9.2. Some features of this table call for comment. The Caswell Bay Mudstone was originally regarded as being of Chadian age (e.g. George *et al.*, 1976; Whittaker and Green, 1983), but was placed in the Arundian Stage on sedimentological grounds (Riding and Wright, 1981; Wright, 1986b). Since then, there has been some variation in usage, with Ramsay (1987), for example, still regarding it as Chadian in age. Some units are demonstrably diachronous, such as the Drybrook Sandstone of the Forest of Dean (Welch and Trotter, 1961) and the Gully Oolite (Searl, 1988b). No doubt many other lithostratigraphical units are also diachronous, but it may not be possible to demonstrate it unequivocally. There are areas where there is still no uniform usage of lithostratigraphical names. On Gower, for example, the older name from the Bristol area, 'Gully Oolite' has been used by some workers (e.g. Searl, 1988a,b) to replace the local name 'Caswell Bay Oolite', which is used on the published geological map (Institute of Geological Sciences, 1973). Similarly the term 'Black Rock Limestone', taken from the Bristol area, has been applied by Mitchell *et al.* (1986) to the Gower succession, where others have used the name 'Penmaen Burrows Limestone'. Note that in this account the term 'Castell Coch Limestone' is used both as a formation name in the description of sites in the Clydach and Cardiff areas, and as the name given to a subdivision of the 'Castell Coch Formation' in the description of sites in the Forest of Dean area, in keeping with current usage (see Figure 9.2).

Geological setting

The whole area under consideration in this chapter formed an area of carbonate-dominated sediment deposition in relatively shallow water lying between the Wales–Brabant Massif (St George's Land of earlier workers) to the north and the deep waters of the Culm Trough to the south. No single name to embrace the whole area is in general use, but for convenience we have adopted the term 'South Wales–Mendip Shelf' in this work. The succession thickens markedly from the north crop of the South Wales Coalfield to the south crop, Gower and southern Pembrokeshire (Figure 9.3a) and from the Forest of Dean to Bristol and the eastern Mendips (Figure 9.3b). The thickest known Dinantian succession in this area is on the south side of the Pembroke Peninsula where upwards of 1500 m of Dinantian strata are exposed (George, 1974).

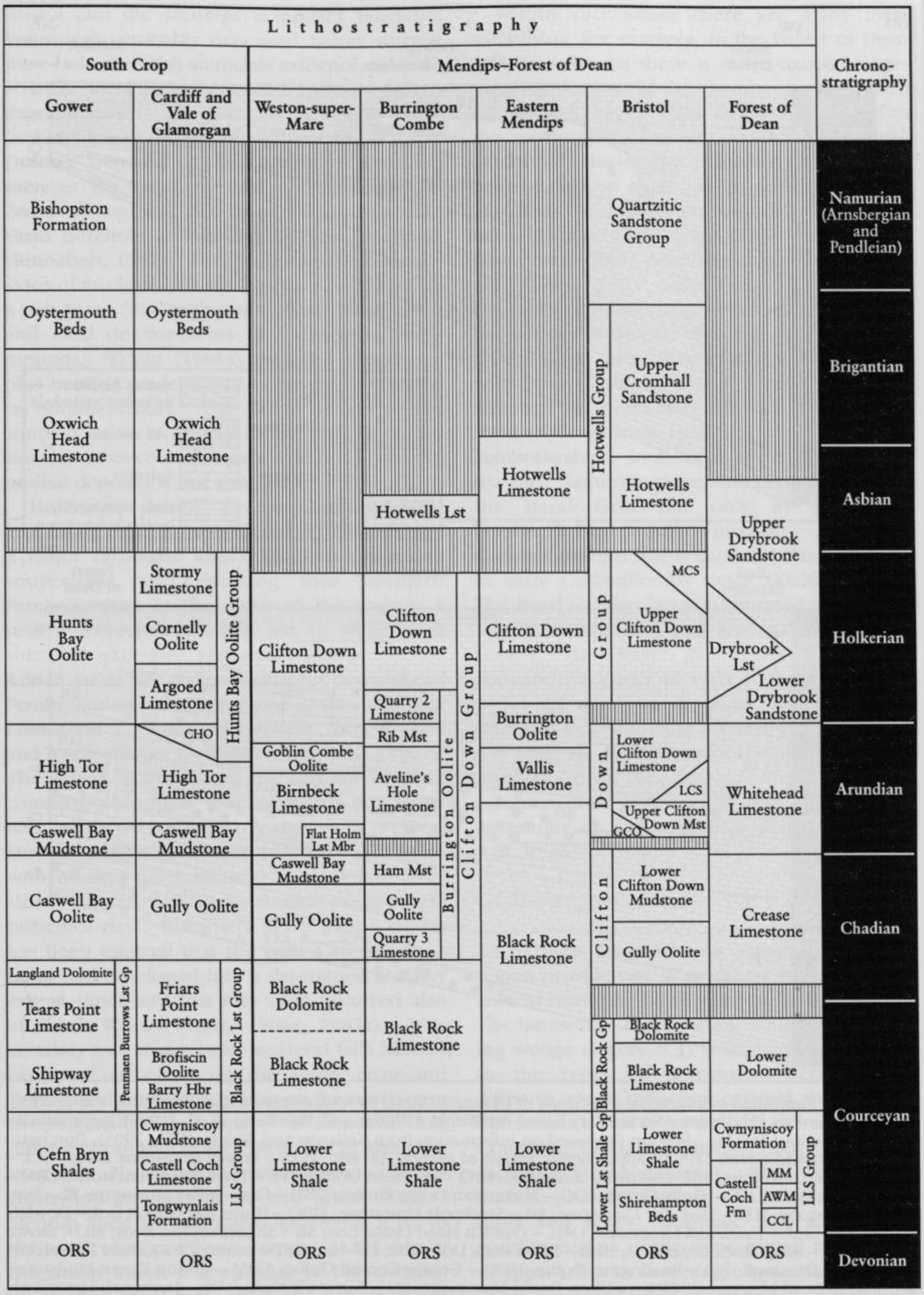
At the base of the Carboniferous succession there is a gradual transition from Old Red Sandstone facies to marine limestones and shales but it is often difficult to establish the exact position of the Devonian–Carboniferous boundary. North of Cardiff, the facies change appears to be more-or-less coincident with the system boundary, but in Pembrokeshire (Skrinkle Sandstone) and around Bristol (Shirehampton Beds) Old Red Sandstone facies have been dated as extending into the Courceyan Stage (Bassett and Jenkins, 1977).

For the Courceyan to Arundian interval, Wright (1986a) interpreted the area as a southerly dipping carbonate ramp. The inner ramp is represented on the north crop of the South Wales Coalfield, and consists of a thin succession of oolitic carbonate sand-bodies and peritidal limestones, with evidence of repeated episodes of subaerial exposure and non-sequence. Occasional uplift resulted in fluvial incision. The mid-ramp facies found over much of the south crop of the coalfield and around

Figure 9.2 (see overleaf) Simplified stratigraphical chart illustrating the most widely used lithostratigraphical terms for the Lower Carboniferous sequences in South Wales, the Forest of Dean, Bristol and the Mendips. (SD – Sychnant Dolomite; PCO – Pwll y Cwm Oolite; PB – Pantydarren Beds; BOO – Blaen Onnen Oolite; CFF – Coed Ffyddlwn Formation; CHM – Clydach Halt Member; CLM – Cheltenham Limestone Member; POM – Penllwyn Oolite Member; GCM – Gilwern Clay Member; LLS – Lower Limestone Shale; CHO – Cefnyrhendy Oolite; CCL – Castell Coch Limestone; AWM – Astridge Wood Member; MM – Mitcheldean Member; GCO – Goblin Combe Oolite; LCS – Lower Cromhall Sandstone; MCS – Middle Cromhall Sandstone.) Areas of vertical ruling indicate non-sequences. Not to scale. Based on information from and after Welch and Trotter (1961), Green and Welch (1965), Institute of Geological Sciences (1973, 1977c), George *et al.* (1976), Wright (1982b), Whittaker and Green (1983), Burchette (1987), Waters and Lawrence (1987), Barclay *et al.* (1988), Scott (1988), Barclay (1989), Wilson *et al.* (1990) and Kellaway and Welch (1993).

South Wales–Mendip Shelf

Chronostratigraphy	Lithostratigraphy: North Crop – Pendine	North Crop – Kidwelly	North Crop – Black Mountains	North Crop – Merthyr Tydfil	North Crop – Clydach	North Crop – Risca	South Crop – South Pembrokeshire
Namurian (Arnsbergian and Pendleian)	Basal Grit	Basal Grit					
Brigantian	Upper Limestone Shales	Upper Limestone Shales Mynydd-y-Gareg Limestone	Upper Limestone Shales Llandyfan Limestone	Upper Limestone Shales Penwyllt Limestone			Upper Limestone Shales Bullslaughter Limestone
Asbian		Penderyn Oolite Honeycombed Sst Greenhall Lst		Penderyn Oolite			Crickmail Limestone
Holkerian	Dowlais Limestone	Dowlais Limestone	Cil-yr-ychen Limestone	Dowlais Limestone	Dowlais Limestone		Stackpole Limestone
Arundian				Llanelly Formation	Garn Caws Sandstone Llanelly Formation (GCM, POM, CLM, CHM)		Pen-y-Holt Limestone Hobbyhorse Bay Lst Linney Head Beds
Chadian	Pendine Conglomerate			Abercriban Oolite	Abercriban Oolite Group (W): Gilwern Oolite	Clydach Valley Group (E): Rudry Formation	Berry Slade Formation
Courceyan	Pendine Oolite Lower Limestone Shale	Lower Limestone Shale	Lower Limestone Shale	Lower Limestone Shale	Abercriban Oolite Group (W): CFF, BOO, PB, PCO, SD Lower Lst Shale Group: Cwmyniscoy Mudstone, Castell Coch Limestone	Lower Limestone Shale	Blucks Pool Limestone Lower Limestone Shale
Devonian	ORS	ORS	ORS	ORS	ORS	ORS	Skrinkle Sandstone


Lithostratigraphy
South Crop
Mendips–Forest of Dean
Chrono-stratigraphy
Gower
Cardiff and Vale of Glamorgan
Weston-super-Mare
Burrington Combe
Eastern Mendips
Bristol
Forest of Dean
Bishopston Formation
Oystermouth Beds
Oxwich Head Limestone
Hunts Bay Oolite
High Tor Limestone
Caswell Bay Mudstone
Caswell Bay Oolite
Langland Dolomite
Tears Point Limestone
Shipway Limestone
Penmaen Burrows Lst Gp
Cefn Bryn Shales
ORS
Oystermouth Beds
Oxwich Head Limestone
Stormy Limestone
Cornelly Oolite
Argoed Limestone
CHO
High Tor Limestone
Caswell Bay Mudstone
Gully Oolite
Hunts Bay Oolite Group
Friars Point Limestone
Brofiscin Oolite
Barry Hbr Limestone
Black Rock Lst Group
Cwmyniscoy Mudstone
Castell Coch Limestone
Tongwynlais Formation
LLS Group
ORS
Clifton Down Limestone
Goblin Combe Oolite
Birnbeck Limestone
Flat Holm Lst Mbr
Caswell Bay Mudstone
Gully Oolite
Black Rock Dolomite
Black Rock Limestone
Lower Limestone Shale
ORS
Hotwells Lst
Clifton Down Limestone
Quarry 2 Limestone
Rib Mst
Aveline's Hole Limestone
Ham Mst
Gully Oolite
Quarry 3 Limestone
Burrington Oolite
Clifton Down Group
Black Rock Limestone
Lower Limestone Shale
ORS
Hotwells Limestone
Clifton Down Limestone
Burrington Oolite
Vallis Limestone
Black Rock Limestone
Lower Limestone Shale
ORS
Quartzitic Sandstone Group
Upper Cromhall Sandstone
Hotwells Limestone
Hotwells Group
MCS
Upper Clifton Down Limestone
Lower Clifton Down Limestone
LCS
Upper Clifton Down Mst
GCO
Lower Clifton Down Mudstone
Gully Oolite
Clifton Down Group
Black Rock Dolomite
Black Rock Limestone
Black Rock Gp
Lower Limestone Shale
Shirehampton Beds
Lower Lst Shale Gp
ORS
Upper Drybrook Sandstone
Drybrook Lst
Lower Drybrook Sandstone
Whitehead Limestone
Crease Limestone
Lower Dolomite
Cwmyniscoy Formation
Castell Coch Fm
MM
AWM
CCL
LLS Group
ORS
Namurian (Arnsbergian and Pendleian)
Brigantian
Asbian
Holkerian
Arundian
Chadian
Courceyan
Devonian

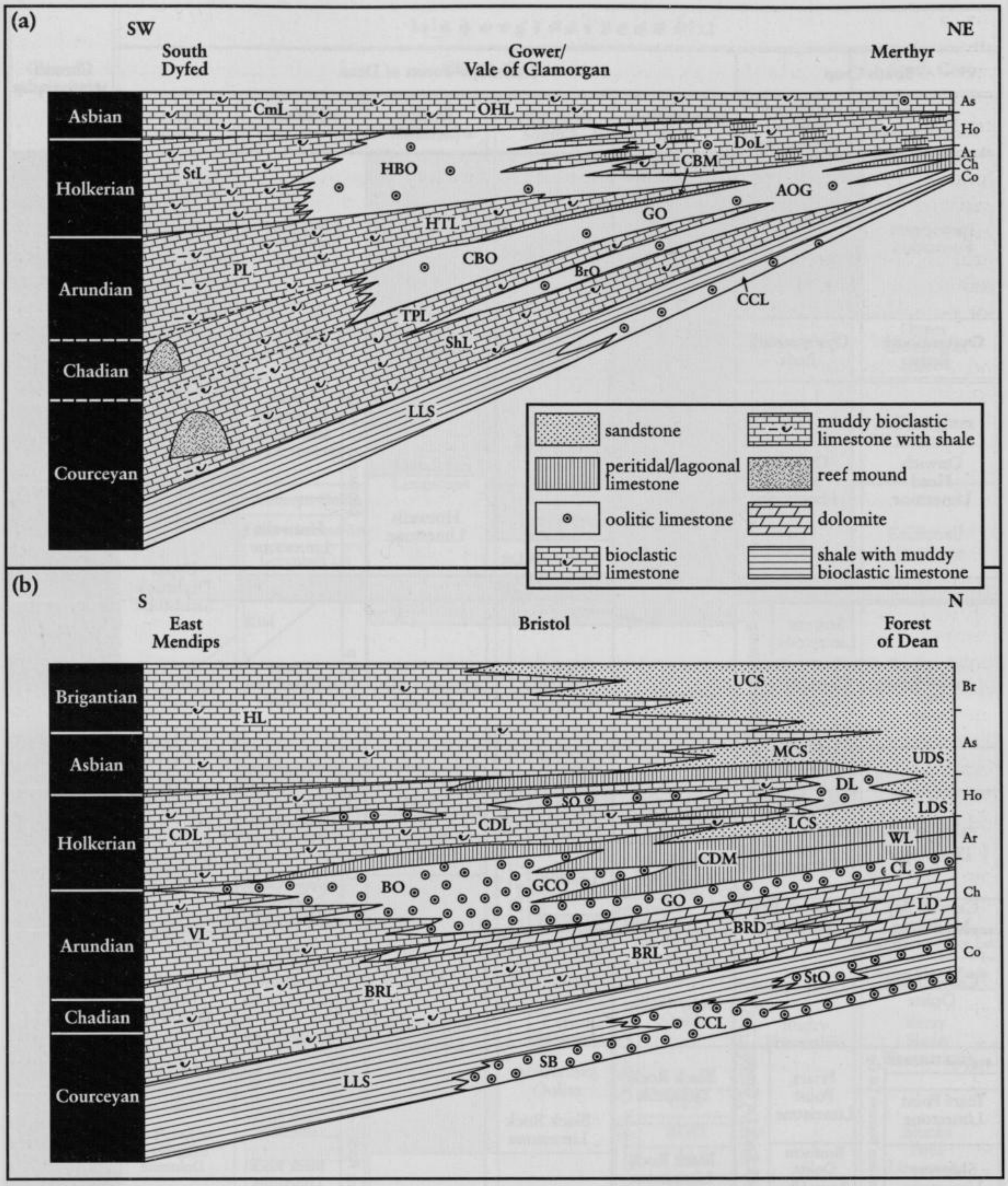


Figure 9.3 Simplified stratigraphical sections of Dinantian strata in south-west Britain illustrating the distribution of Dinantian lithofacies. Section (a) based on Wright (1986a) and Burchette *et al.* (1990); approximate length of section, 100 km. Section (b) based on information from Kellaway and Welch (1955, 1993), Burchette *et al.* (1990) and Green (1992); approximate length of section, 80 km. (LLS – Lower Limestone Shale; CCL – Castell Coch Limestone; ShL – Shipway Limestone; BrO – Brofiscin Oolite; TPL – Tears Point Limestone; CBO – Caswell Bay Oolite; GO – Gully Oolite; AOG – Abercriban Oolite Group; CBM – Caswell Bay Mudstone; PL – Pen-y-Holt Limestone; HTL – High Tor Limestone; StL – Stackpole Limestone; HBO – Hunts Bay Oolite; DoL – Dowlais Limestone; CmL – Crickmail Limestone; OHL – Oxwich Head Limestone; SB – Shirehampton Beds; StO – Stowe Oolite; BRL – Black Rock Limestone; BRD – Black Rock Dolomite; LD – Lower Dolomite; CL – Crease Limestone; VL – Vallis Limestone; BO – Burrington Oolite; GCO – Goblin Combe Oolite; CDM – Clifton Down Mudstone; WL – Whitehead Limestone; CDL – Clifton Down Limestone; SO – Seminula Oolite; DL – Drybrook Limestone; LDS – Lower Drybook Sandstone; UDS – Upper Drybook Sandstone; LCS – Lower Cromhall Sandstone; MCS – Middle Cromhall Sandstone; UCS – Upper Cromhall Sandstone; HL – Hotwells Limestone.)

Bristol and the Mendips comprises bioclastic limestones, probably deposited below normal wave-base, but with abundant evidence of storm activity. Occasional regressive episodes led to the southwards progradation of oolitic sand-bodies such as the Gully Oolite or Caswell Bay Oolite. Deposits of the outer-ramp zone are seen in the southern part of the Pembroke Peninsula and are also known from the Knap Farm Borehole at Cannington Park (Lees and Hennebert, 1982). They comprise thick successions of muddy bioclastic limestones, often with a rich fauna (the 'zaphrentid-phase' limestones) and local developments of Waulsortian mud-mounds. Wright (1986a) regarded subsidence plus eustatic sea-level rise as the major controls on sedimentation. The Culm Trough to the south consists of basinal facies, but the transition zone between the carbonate ramp and the basinal deposits is not exposed.

Holkerian strata overstep older beds suggesting renewed subsidence or sea-level rise. A major carbonate sand-body then prograded southwards, just reaching into southern Pembrokeshire at the close of the stage. A relative sea-level fall then led to widespread subaerial exposure and non-sequence. Early Asbian strata are unknown except in southern Pembrokeshire where the base of the Crickmail Limestone contains *Daviesiella llangollensis* and early Asbian foraminifera (Strank, 1981). The Asbian and much of the Brigantian stages comprise a relatively thin succession compared with many other areas (George *et al*., 1976). However, facies are similar to other shelf areas, with massive bioclastic and some oolitic limestones separated by palaeokarstic surfaces and palaeosol clays. Elsewhere in the British Isles it has been inferred that the early Carboniferous ramp had developed into a flat-topped shelf by Asbian times and this may have occurred also in South Wales (Wright, 1986a, 1987a). It is certainly true that relative sea-level falls have as profound an effect on the south crop and Pembrokeshire successions as on the north crop successions at this time – a situation very different from that in the Courceyan to Arundian interval. However, the whereabouts of any contemporary margin to the South Wales–Mendip Shelf are unknown; apparently it lay to the south of all present outcrops. At the end of Brigantian times, a deepening of the environment affected all areas, with the deposition of the Upper Limestone Shales.

Within successions there are many local variations. For example, in the Forest of Dean and Bristol areas there is more coarse terrigenous clastic material than in other areas, as local rejuvenation of the Wales–Brabant Massif led to the southwards progradation of quartz sands, particularly during the Holkerian to Brigantian interval (Wilson *et al*., 1988). In the western Mendips, around Weston-super-Mare, there are basaltic lavas and pyroclastic deposits of Courceyan and Arundian ages (Whittaker and Green, 1983: Stephenson *et al*, 2003). Examples of palaeogeographies at various times for part of the area are shown in Figure 9.4.

Across the area, Namurian successions rest with non-sequence on Dinantian strata, although the break may be slight in the more southerly exposures such as Gower and south Pembrokeshire. In most places in South Wales, the early Namurian succession is represented by the Basal Grit, but only in south-west Pembrokeshire and possibly in west Carmarthenshire is this confirmed as beginning in early Carboniferous times (Kelling, 1974). The Basal Grit has been interpreted as a deltaic sand-body (Kelling and George, 1971). In Gower, the basal Namurian Bishopston Formation is partly of early Carboniferous age and is of open marine shale facies. Marine fossils of Pendleian age are also reported from the base of the Quartzitic Sandstone Group north of Bristol (Kellaway and Welch, 1993). A reconstruction of the early Namurian palaeogeography of South Wales is shown in Figure 9.5.

GCR site coverage

The Lower Carboniferous limestones of this region provide one of the finest examples of an ancient carbonate ramp succession in the world. The limestones form a thick, southerly thickening wedge (Figure 9.3) with marked variations in the types of limestones deposited in different areas, reflecting original water depth differences. This is particularly the case for the Courceyan–Holkerian interval, but less so for the latest Viséan sequence. Sites were chosen both to provide coverage of key stratigraphical units and facies variations, and to illustrate specific aspects of the depositional regime and of approaches in detecting climate fluctuations, in order to provide models for research at national and international level. The later

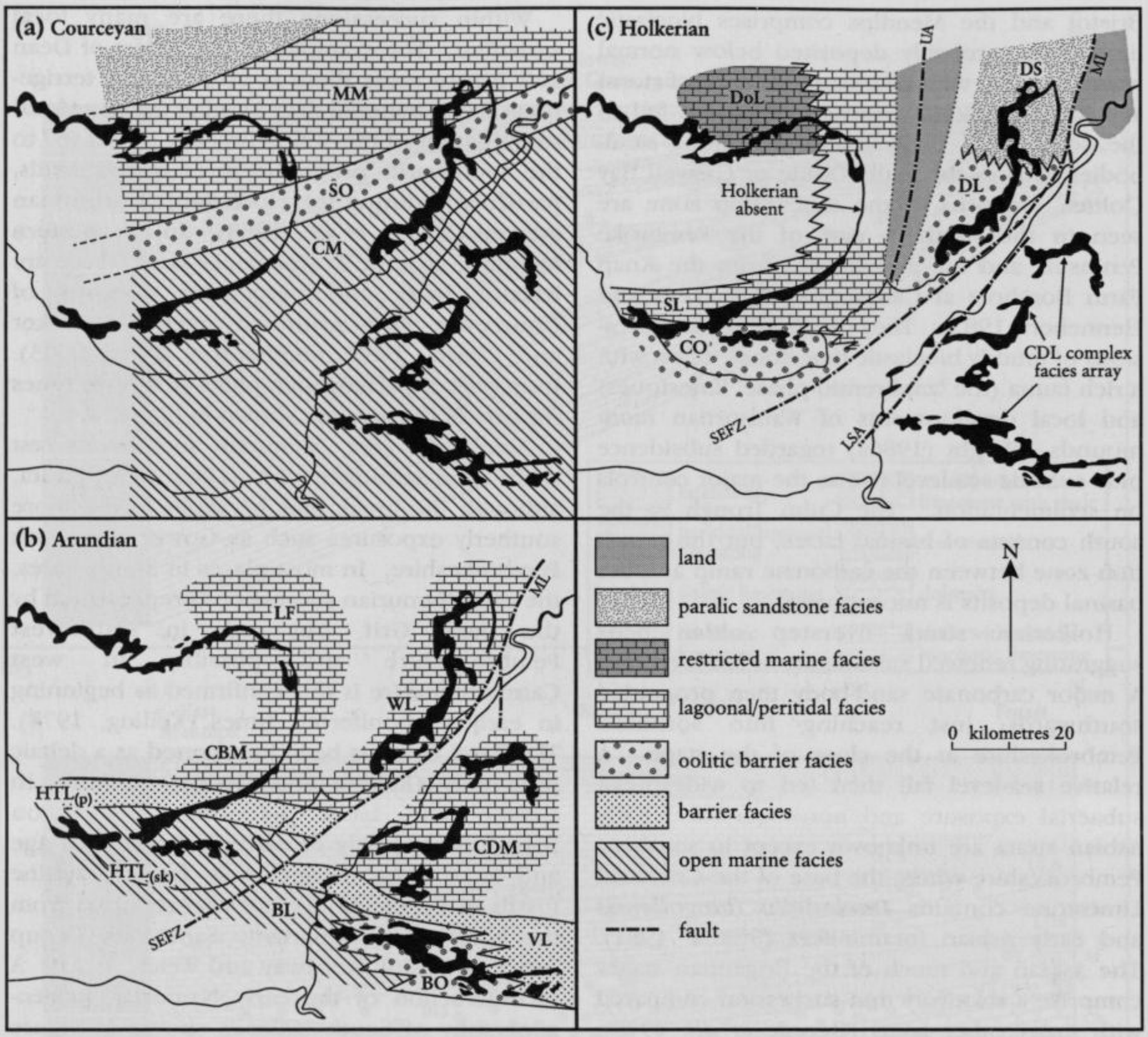


Figure 9.4 The Lower Carboniferous palaeogeography of south-east Wales and part of southern England illustrating the distribution of facies for the (a) Courceyan, (b) Arundian, and (c) and Holkerian stages. (MM – Mitcheldean Member; SO – Stowe Oolite; CM – Cwmyniscoy Mudstone; LF – Llanelly Formation; CBM – Caswell Bay Mudstone; HTL – High Tor Limestone (p – peloidal; sk – skeletal); BL – Birnbeck Limestone; BO – Burrington Oolite; VL – Vallis Limestone; CDM – Clifton Down Mudstone; WL – Whitehead Limestone; DL – Drybrook Limestone; DoL – Dowlais Limestone; SL – Stormy Limestone; DS – Drybrook Sandstone; CO – Cornelly Oolite; CDL – Clifton Down Limestone; UA – Usk Axis; ML – Malvern Line; SEFZ – Severn Estuary Fault Zone; LSA – Lower Severn Axis.) Based on Burchette (1987) and Wilson *et al.* (1988).

Viséan succession is somewhat different and provides examples of the effects of global climate changes and the onset of the late Palaeozoic ice age.

Sites were rarely chosen for a single reason and most have both stratigraphical and sedimentological significance. Some sites were chosen at least partly because they provided the type sections for stratigraphical units, such as **Caswell Bay**, **Brofiscin Quarry** and **Llanelly Quarry**. Some, such as the **Avon Gorge**, **Tenby Cliffs**, **Three Cliffs Bay** and **Blucks Pool–Bullslaughter Bay** were chosen because they provided very extensive stratigraphical sections, and also in some cases provided type sections. For example, **Three Cliffs Bay** is of international significance for the definition of stratigraphical models in limestone successions, and **Blucks Pool–Bullslaughter Bay** includes the nationally important stratotype section for the Arundian Stage. Another group of sites were selected as they offered the best examples of certain strati-

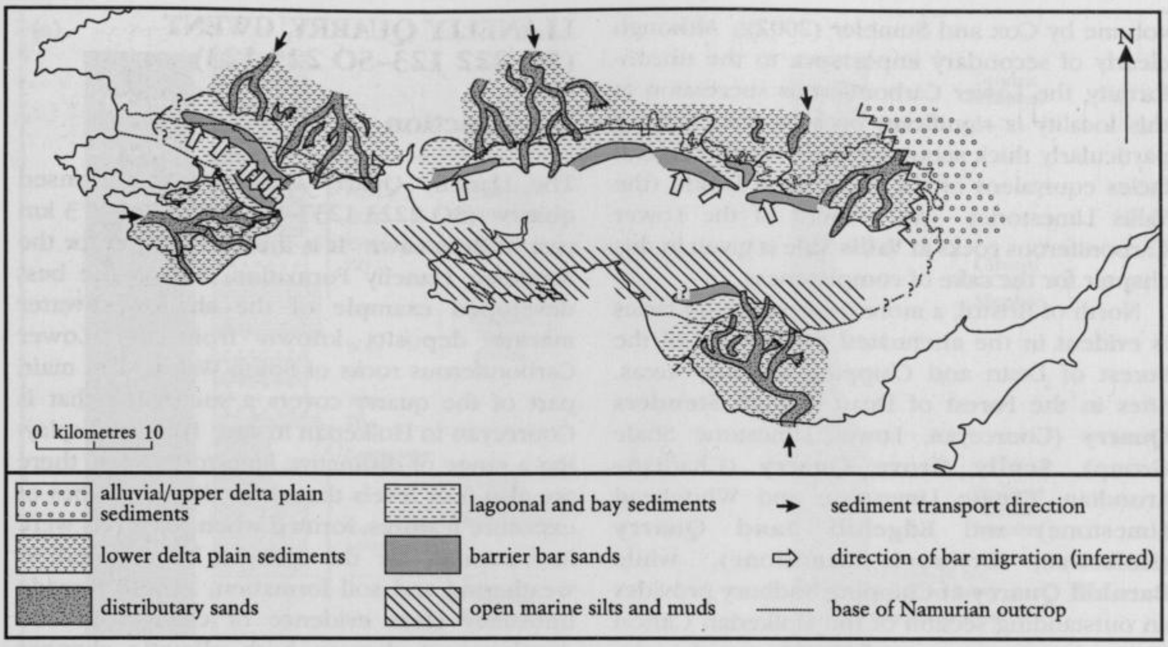


Figure 9.5 Early Namurian palaeogeography of South Wales. After Kelling (1974).

graphical units, such as **Ilston Quarry** (Oxwich Head Limestone – and also illustrating the depositional style of glacio-eustatically controlled cyclicity), **Tongwynlais Road Section** (Lower Limestone Shale Group), **Barnhill Quarry** (Clifton Down Limestone), **Oystermouth Old Quarry** (Oystermouth Beds) and **Burrington Coombe** (Black Rock Limestone Group). Others were selected because they illustrate significant facies variations that allow depositional models to be developed (e.g. **Danygraig** and **Flat Holm**) or because they contain features of specific palaeontological and/or sedimentological interest (**Bracelet Bay** and **Pwlldu Head**).

A group of sites in South Wales was chosen to illustrate the range of features that develop when limestone-producing environments are subaerially exposed following sea-level falls. These are **Llanelly Quarry**, **Clydach Halt Lime Works**, **Cwar yr Ystrad and Hendre**, **Baltic Quarry**, **Odynau Tyle'r Bont** and **Blaen Onneu Quarry**. These sites exhibit palaeokarsts, palaeosols and related terrestrial deposits, with marked variations in the successions at each site resulting from the complex phases of landscape development and climate change that took place in those areas during the Chadian–Holkerian time interval.

Central to those sites selected in southern England is the classic **Avon Gorge** section at Bristol where Vaughan (1905) established the first widely used biostratigraphical (coral–brachiopod) zonal scheme for the Lower Carboniferous sequence. Elsewhere, the choice of sites reflects regional variations in sedimentary facies developed across the shelf area during Early Carboniferous times.

To the south, in the Mendips area, they include sites of historical, stratigraphical and sedimentological significance from the more distal parts of the carbonate ramp where successions are known to be thicker and more complete than in the Bristol district. These sites include **Burrington Combe** (Courceyan–Asbian, Lower Limestone Shale Group to Hotwells Limestone), **Maesbury Railway Cutting** (Courceyan, Lower Limestone Shale Group and lower Black Rock Limestone), **Cook's Wood Quarry** (Holkerian–Asbian, Clifton Down Limestone to Hotwells Limestone) and **Vallis Vale** (Courceyan–Arundian, upper part of the Black Rock Limestone to Vallis Limestone). The feature of particular interest at **Vallis Vale** is the spectacular and historically important angular unconformity between the Carboniferous Limestone and a much younger Jurassic section of the Middle Jurassic Inferior Oolite of Bajocian age. The unconformity and the Bajocian strata with which it is associated are described in detail in the *British Middle Jurassic Stratigraphy* GCR volume by Cox and Sumbler (2002). Although clearly of secondary importance to the unconformity, the Lower Carboniferous succession at this locality is significant because it includes a particularly thick sequence and a unique lateral facies equivalent of the Burrington Oolite (the Vallis Limestone). An account of the Lower Carboniferous rocks at **Vallis Vale** is given in this chapter for the sake of completeness.

North of Bristol, a more proximal ramp facies is evident in the attenuated successions of the Forest of Dean and Chipping Sodbury areas. Sites in the Forest of Dean include **Stenders Quarry** (Courceyan, Lower Limestone Shale Group), **Scully Grove Quarry** (Chadian–Arundian, Crease Limestone and Whitehead Limestone) and **Edgehill Sand Quarry** (Holkerian, Drybrook Sandstone), while **Barnhill Quarry** at Chipping Sodbury provides an outstanding section of the Holkerian Clifton Down Limestone unconformably overlain by Rhaetian deposits. The latter are described as a part of an Upper Triassic GCR site at Barnhill Quarry in a companion GCR volume *Permian and Triassic Red Beds and the Penarth Group of Great Britain*, by Benton *et al.* (2002).

Other GCR sites of Lower Carboniferous age near Weston-super-Mare at Middle Hope (Courceyan–Chadian Black Rock Limestone–Gully Oolite) and at Spring Cove (Arundian, Birnbeck Limestone) are of interest primarily because of the spectacular volcanic rocks they contain. These are described in the GCR volume, *Carboniferous and Permian Igneous Rocks of Great Britain North of the Variscan Front* (Stephenson *et al.*, 2003).

The lack of GCR sites containing lower Namurian rocks in this chapter is partly a function of limited outcrop and exposure, and partly because substantial Pendleian–Arnsbergian sections have yet to be recognized in many areas. However, other GCR sites that may include strata of a Pendleian and/or Arnsbergian age (e.g. Marros Sands and Barland Common) are described by Cleal and Thomas (1996) in the *British Upper Carboniferous Stratigraphy* GCR volume. Further gaps in the site coverage to be considered in the future include the representation of the Holkerian–Brigantian interval in parts of South Wales (North Crop especially), and of isolated Lower Carboniferous inliers and outliers in other parts of central and southern England.

LLANELLY QUARRY, GWENT (SO 222 123–SO 225 123)

Introduction

The Llanelly Quarry GCR site is a disused quarry (SO 2223 1237–SO 2250 1233), 3 km east of Brynmawr. It is the type section for the Arundian Llanelly Formation, and is the best developed example of the shallowest-water marine deposits known from the Lower Carboniferous rocks of South Wales. The main part of the quarry covers a succession that is Courceyan to Holkerian in age. Besides displaying a range of distinctive limestone types, there are also four levels that show different types of exposure features, formed when sea levels were low enough for the area to be exposed to weathering and soil formation. These provide unusually clear evidence of changes in soil development due to both climatic changes and sea-level rise. The site also includes the transition from the non-marine Old Red Sandstone into the shallow marine Lower Carboniferous succession. George (1954) provided the earliest detailed description of the succession in the area. Detailed descriptions of the sedimentology of the Llanelly Formation were given by Wright (1981a), and the stratigraphy of the whole Lower Carboniferous succession was revised by Barclay (1989).

Description

The site was probably worked intermittently from 1863 until 1963, and displays a range of early industrial features (van Laun, 1979, 2001). It includes a steep stream section, Nant Sychnant, which exposes a near-continuous succession from the Old Red Sandstone through the Castell Coch Limestone and Cwmyniscoy Mudstone (Lower Limestone Shale Group) and into the lower part of the Clydach Valley Group (Burchette, 1981; Barclay, 1989) (Figure 9.6a). A complex range of lithologies is present in the stream section below the quarry road (Castell Coch Limestone), representing the transition from continental deposition with fluvial sandstones and floodplain palaeosols, to lagoonal and shoreline deposits (Lovell, 1978; Burchette, 1981). In exposures immediately upstream of the road crossing there are dark shales (Cwmyniscoy Mudstone) with graded sandstone storm beds. Immediately adjacent to the quarry

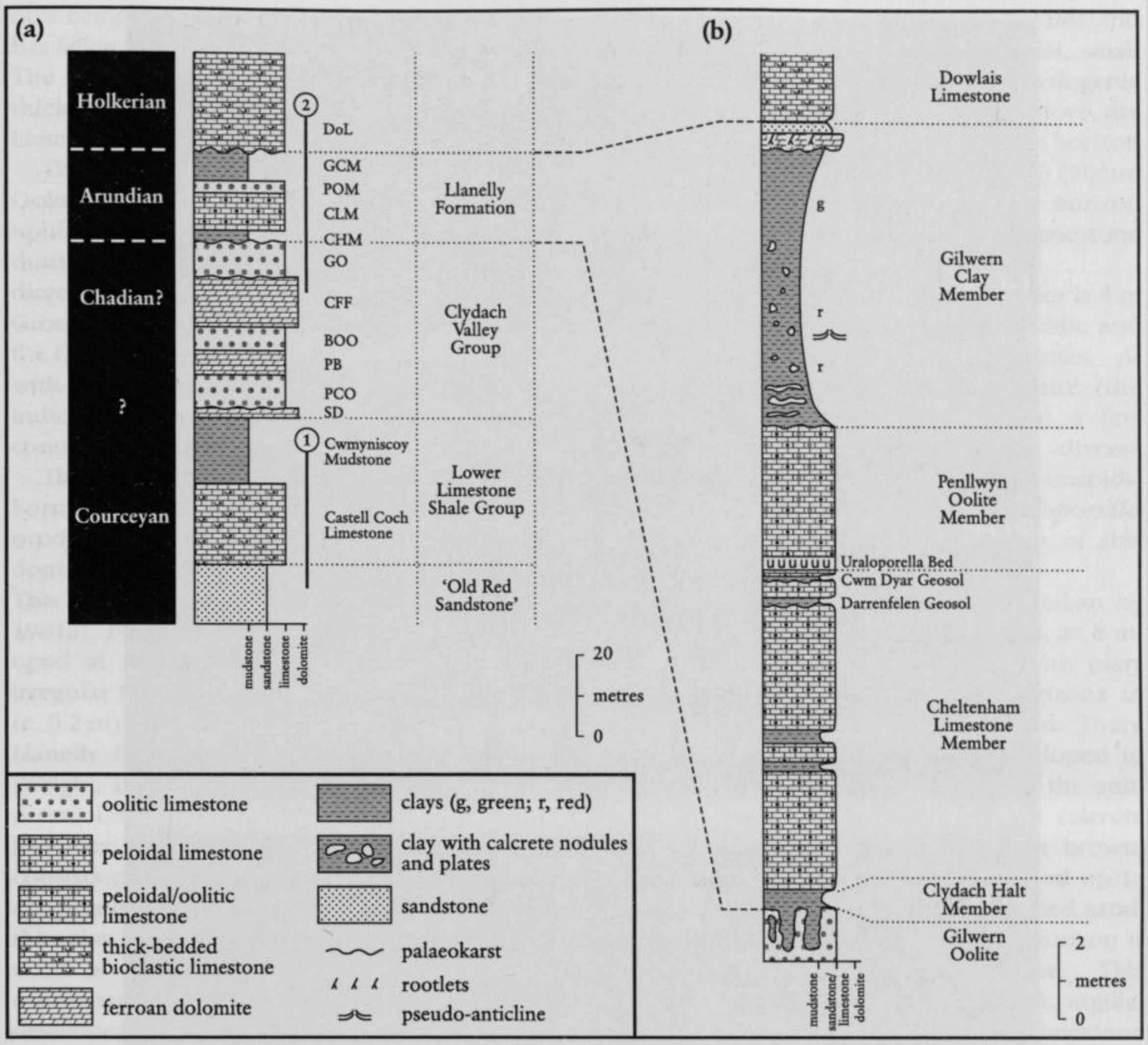


Figure 9.6 (a) The Lower Carboniferous succession of the Clydach area illustrating the positions of the main sections exposed at the Llanelly Quarry GCR site (1 – Nant Sychnant section; 2 – Llanelly Quarry section. SD – Sychnant Dolomite; PCO – Pwyll-y-Cwm Oolite; PB – Pantydarren Beds; BOO – Blaen Onnen Oolite; CFF – Coed Ffyddlwn Formation). After Barclay (1989). (b) Details of the Llanelly Formation succession at Llanelly Quarry. The formation extends from the base of the Clydach Halt Member to the base of the Dowlais Limestone. The units of special interest here are the Darrenfelen Geosol and the Gilwern Clay Member. After Wright (1981a). Note, the key relates specifically to Figure (b) only.

entrance are dolomitized, bedded limestones in which faint microbial lamination can be seen. These limestones, and small exposures in the disused railway cutting in front of the quarry, represent the Coed Ffyddlwn Formation (Barclay, 1989) (Figure 9.6a).

The main quarry faces (Figure 9.7) are unstable because thickly bedded Dowlais Limestone overlies soft, recessive clays in the Llanelly Formation. Great care should be exercised when examining the main exposure. These faces expose the upper part (at least 5 m) of the massive Gilwern Oolite, overlain by the Llanelly Formation. The junction of these two units is seen by the change from massive, brilliant white (when fresh), very well-sorted oolitic grainstones, to medium-bedded, fine-grained limestones of the Cheltenham Limestone Member of the Llanelly Formation (see below). The junction is irregular and is marked by varying degrees of dissolution features, including small solution pits, caverns up to 1 m wide and 0.3 m high at the western end of the quarry, to pipes at the eastern end (illustrated in Wright, 1982a, but

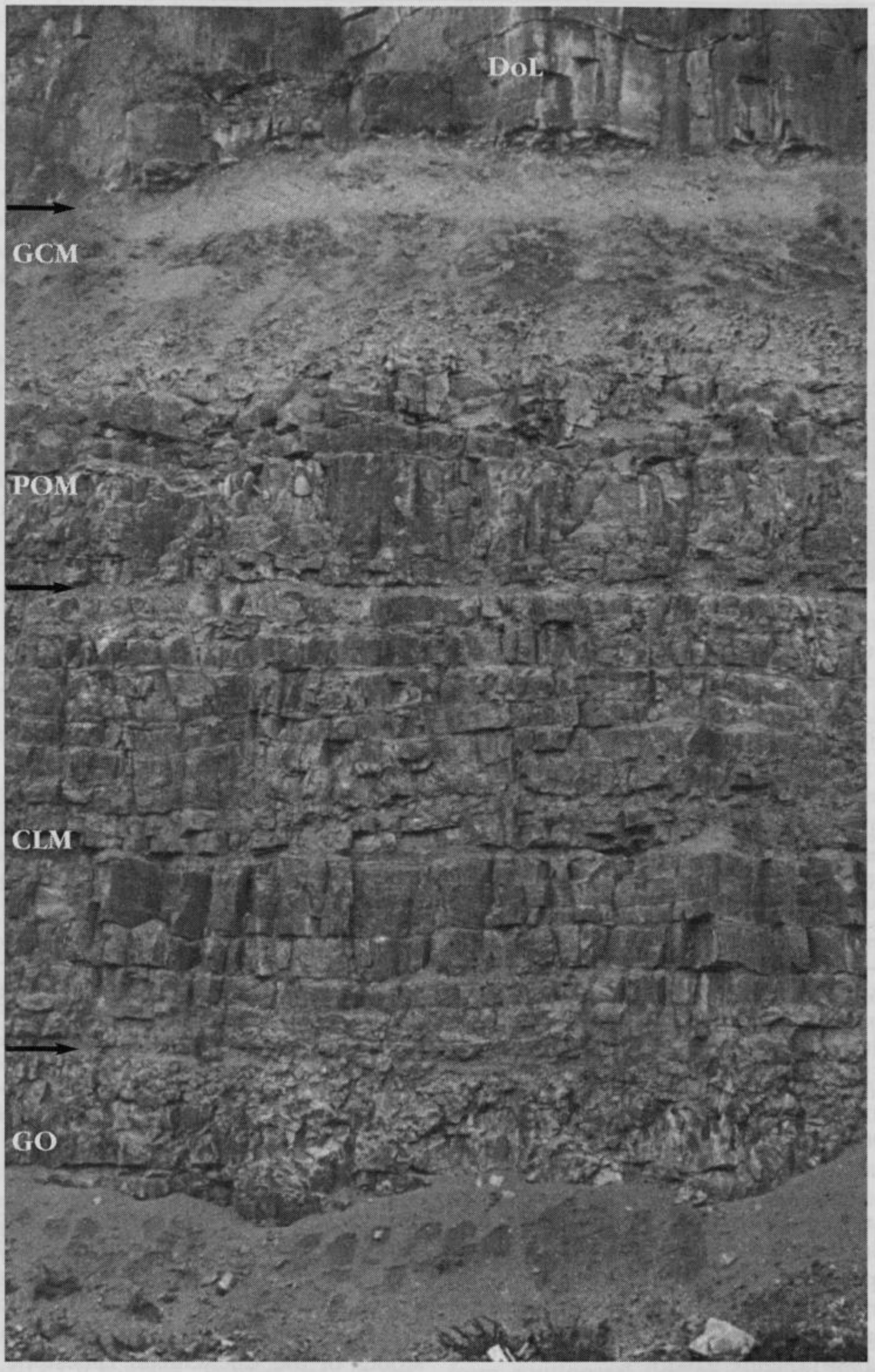


Figure 9.7 The main face at the Llanelly Quarry GCR site. The illustrated section extends from the top of the Gilwern Oolite (GO) through the overlying Llanelly Formation (CLM – Cheltenham Limestone Member; POM – Penllwyn Oolite Member; GCM – Gilwern Clay Member) and into the Dowlais Limestone (DoL). The lower arrow marks the position of an erosion surface/palaeokarst at the top of the Gilwern Oolite and the base of the Llanelly Formation, while the upper arrow marks the base of the Dowlais Limestone and the top of the Llanelly Formation. The middle arrow indicates the position of the Cwm Dyar Geosol at the top of the Cheltenham Limestone Member. (Photo: V.P Wright.)

now completely buried by clay and rubble which has fallen from the upper part of the formation). The upper half of the quarry is composed of thickly bedded limestones of the Dowlais Limestone.

The Llanelly Formation rests on the Gilwern Oolite, but as a result of intra-Carboniferous uplift, erosion and overstep, the Gilwern Oolite thins westwards until the Llanelly Formation lies directly on lower units in the Clydach Valley Group (George, 1954; Barclay, 1989). The age of the Gilwern Oolite is problematic (Barclay, 1989), with macrofossils from the Coral Bed at its base indicating an Arundian age, but foraminifera and conodonts suggesting a Chadian age.

The quarry is the type section for the Llanelly Formation (George *et al.*, 1976) and has produced foraminifera (Barclay, 1989) and conodonts (Stone, 1991) indicating an Arundian age. This formation contains four members (Wright, 1981a), but only three of these are well developed at the quarry. Immediately above the irregular top of the Gilwern Oolite is a thin unit (*c.* 0.2 m) representing the basal member of the Llanelly Formation, the Clydach Halt Member (Wright, 1981a). Whereas this member contains prominent palaeosol horizons at many other localities in the area (Wright, 1982b), here it consists of less than one metre of interbedded conglomerates, with thin sandstone lenses, and thin clay interbeds, the latter containing lithoclasts of cemented oolitic grainstones, calcrete microspar and micrite. This unit is only patchily developed in depressions along the irregular surface of the Gilwern Oolite.

The bulk of the formation is composed of the second member, the Cheltenham Limestone Member (Figure 9.6b). This well-bedded unit (*c.* 9 m thick) consists of a variety of shallow-water limestones with a restricted biota. Lithologies include centimetre-thick bioclastic and intraclastic grainstones with open marine biotas, peloidal grainstones, packstones and wackestones with ostracodes and vermiform gastropod (?microconchid – see Weedon, 1990, 1991) debris, small (< 20 cm thick) porostromate–vermiform gastropod bioherms, fenestral laminated micritic limestones, centimetre-thick green clays and calcrete horizons. Two of the latter can be traced to other outcrops in the area and are worthy of note. At 8 m above the base of the formation is a prominent calcrete crust horizon that is up to 20 cm thick, named the 'Darrenfelen Geosol' by Wright (1983) (Figure 9.6b). It contains abundant small peloids and millimetre-sized burrows, faecal material, small rhizocretions and a range of other pedogenic microfabrics. Approximately 8.6 m above the base is a thin (15 cm) truncated calcrete horizon (the Cwm Dyar Geosol of Wright, 1982b) (Figure 9.6b) which is locally absent. This horizon marks the top of the Cheltenham Limestone Member in this section.

The overlying Penllwyn Oolite Member is 4 m thick (Figure 9.6b) and consists of oolitic and peloidal grainstones with grain aggregates. At the base is a coarse bioclastic unit (the 'Uraloporella Bed' of Wright, 1981a) a few centimetres thick which contains a diverse skeletal assemblage including rare large oncoids, and the problematic fossil *Uraloporella variabilis* (Wright, 1982c). The top of this member is a highly irregular surface.

The Penllwyn Oolite Member is overlain by the Gilwern Clay Member (Figure 9.6b), an 8 m-thick unit composed of soft clays with platy calcrete near the base and with horizons in which calcrete nodules are concentrated. There are pseudo-anticlinal slip planes developed in the clays, especially in the lower half of the unit. The upper part of the member lacks calcrete nodules and the top is marked by a brown-weathering ferroan dolomite rootlet bed up to 0.6 m thick, capped by a medium-grained sandstone up to 20 cm thick. A thin coal horizon is present locally beneath the sandstone. This sandstone is overlain by the very thick, argillaceous limestones of the Dowlais Limestone (Figure 9.7). The Dowlais Limestone is of Holkerian age (Barclay, 1989).

Interpretation

This is an important site for several reasons. Firstly the stream section provides a unique opportunity to examine the complexities of the transition from the continental Old Red Sandstone into the shallow marine Lower Carboniferous strata. Burchette (1981) has provided a detailed log of the changing environments as a mixed carbonate–clastic shoreline system developed over the area. The dark shales and graded beds above the road crossing probably represent offshore, deeper ramp deposits with storm beds. These shales may represent the deepest water conditions experienced by the area during Late Palaeozoic times. The Coed Ffyddlwn Formation is a series of limestones, heavily dolomitized, representing peritidal deposits, similar to the Llanelly Formation.

However, it is the Gilwern Oolite and Llanelly Formation that represent the main interest at this site. The top of the Gilwern Oolite is a major subaerial exposure surface representing a palaeokarst. The distinctive piping found at the eastern end of the section (now buried and requiring excavation) probably formed under a humid climate, and yet is overlain, at other localities, by up to six well-developed calcrete profiles, indicating formation under a semi-arid climate. Thus a climate change took place at this level (Wright, 1982a) prior to the return to marine conditions represented by the two middle units of the formation.

The regional importance of the Llanelly Formation rests on it being the best single outcrop illustrating the range of lithologies associated with the most proximal, inner-ramp settings of the Lower Carboniferous sequence in South Wales (Wright, 1986a). It contains a mixture of subaerial, alluvial and peritidal deposits indicating the complex interplay of sea-level and climate changes that characterize deposition in marginal marine settings. The Clydach Halt Member, by comparison, represents a thin alluvial, lowstand unit, produced by the interplay of the Chadian–Arundian sea-level lowstand and local tectonic effects.

The Cheltenham Limestone Member is a peritidal unit composed mainly of very shallow, restricted lagoonal deposits. Thin intercalations of fully marine limestones occur but are minor in volume (Wright, 1981a). Laminated, fenestral limestones represent deposition in intertidal settings. The green clays are problematic. Throughout the outcrop area of the member, the calcretes are found with green clays, but not all the green-clay horizons show evidence of palaeosol development. Thus their exact significance is unresolved. These lithologies are only weakly cyclic and are not comparable to classical peritidal deposits.

The Darrenfelen Geosol is remarkable for the preservation of abundant faecal pellets (peloids) of soil animals. Even well-preserved burrows are present, attributable to soil animals, probably mites (Wright, 1983, 1987b). The Cwm Dyar Geosol, although truncated at this locality, is a prominent unit in the area and represents a well-developed calcrete. This palaeosol probably represents a longer period of subaerial exposure than the Darrenfelen Geosol, and the relationship of the two has been interpreted as indicating decreasing rates of accommodation space creation through the member, indicating deposition in a highstand system tract (Wright, 1996).

The Penllwyn Oolite Member is a back shoal deposit with a bioclastic basal unit containing the rare problematic ?alga *Uraloporella variabilis*, the first reported occurrence of this species in Britain (Wright, 1982c). The member represents a minor transgressive phase.

The Gilwern Clay Member represents three different palaeosol associations that provide evidence of lowstand deposition and of climate change during late Arundian times. The lower part, with abundant calcrete nodules and pseudo-anticlines, marks a slowly aggrading floodplain under a strongly seasonal, semi-arid climate. This is overlain by a green, calcrete-free unit with evidence of seasonal but wetter conditions. This shift in climate has also been recorded in the Bristol area, and is the first indication of shifts in seasonal moisture budgets in late Palaeozoic times, which is a motif that characterizes the later Carboniferous Period. The top of the unit, with a horizon of ferroan dolomite, represents marine flooding and the development of a brackish marsh environment. This is the best outcrop example of this feature, which is typical of transgressive sequences throughout the earliest part of the Lower Carboniferous succession in South Wales. The palaeosols in the member have been discussed in detail by Wright and Robinson (1988) and Wright *et al.* (1991).

Conclusions

Llanelly Quarry provides a unique opportunity to examine the nature of deposition along the margins of the early Carboniferous basin in southern Britain. The stream section exposes the details of the transition from non-marine to marine environments during earliest Carboniferous times, whereas the rest of the section, besides being the type section for the Llanelly Formation, reveals the characteristic facies assemblages of inner-ramp deposits. In addition, the site contains exposures of palaeokarst and palaeosols that provide clear evidence of the climate changes that took place during early Carboniferous times. The Darrenfelen Geosol gives a unique glimpse of the soil biota during this time.

CLYDACH HALT LIME WORKS, GWENT (SO 234 126)

Introduction

The Clydach Halt Lime Works GCR site, at the disused Clydach Halt Lime Works (SO 2342 1261), 4 km east of Brynmawr, is the type section for the Arundian Clydach Halt Member of the Llanelly Formation, and contained within it are excellent exposures of fossil soils (palaeosols). The unit represents an extended period of soil development during a major, regional retreat of the sea, exposing newly formed limestones to weathering and soil formation under different climatic conditions. The member is underlain by the Gilwern Oolite, which formed in very shallow water but became exposed to rainwater following a sea-level fall leading to extensive dissolution. The member provides an example of the sorts of complex histories associated with marginal marine terrestrial land-surfaces. This section is also the type locality for the Cwm Dyar Geosol, a prominent fossil soil. George (1954) provided early descriptions of the section. Detailed accounts of the sedimentology and palaeosols have been given by Wright (1981a, 1982b) and Barclay (1989).

Description

This site was used for lime production, from at least the mid-19th century until about 1959 (van Laun, 1979). It covers both the accessible southern, smaller quarry and the larger, largely inaccessible main face to the north. The oldest exposed beds comprise shelly crinoidal dolomite representing the Blaen Onnen Oolite (3 m) and these are overlain by the Coed Ffyddlwn Formation. Barclay (1989) provides a log of this section marked as the 'Cwm Quarries'. The Coed Ffyddlwn Formation (12 m) consists of medium-bedded, largely dolomitized peloidal limestones with minor thin shale and clay bands. The main part of the south quarry provides a near-continuous section in the Llanelly Formation (18 m), together with the top few metres of the underlying Gilwern Oolite. The top of this oolite is rubbly with numerous small pipes filled with light-green clay (Wright, 1982a). Overlying it is the Clydach Halt Member (averaging 1.4 m in thickness) of the Llanelly Formation (Figure 9.8), with nodular to columnar to prismatic, finely crystalline pedogenic calcretes (Wright, 1982b). Within it, two main horizons can be identified, with the lower one preserved apparently in a depression in the top of the Gilwern Oolite (Figure 9.8). Each calcrete would correspond to developmental stages 3–4 in the classification of Machette (1985). Separating the two calcrete units is a discontinuous conglomerate composed of reworked calcrete and oolite clasts, set in a calcrete matrix (Figure 9.8). Within the upper calcrete unit are irregular lenses and nodules of brown-weathering ferroan dolomite (Figure 9.8). The first bed of the overlying Cheltenham Limestone Member is a 15 cm-thick ostracode-bearing limestone. The rest of this member (total thickness of 7.6 m) consists of peloidal limestones with a restricted biota of vermiform gastropods (?microconchids) and ostracodes with oncoids and microbial laminites. Detailed sedimentological descriptions of this unit are to be found in Wright (1981a). Thin green clay horizons also occur in the member, and one of these, 6.1 m above the base, is associated with a calcrete crust horizon a few centimetres thick, the Darrenfelen Geosol (Wright, 1981a). At 6.8 m above the base of the member is a prominent clay-rich horizon, 0.5 m thick, with highly contorted centimetre-thick plates of finely crystalline calcrete (pseudo-anticlines), the Cwm Dyar Geosol, marking the top of the member (Figure 9.9). It is overlain by the bioclastic grainstone, the Uraloporella Bed, which forms the base of the Penllwyn Oolite Member (total thickness of 4.1 m) of the Llanelly Formation. The unit consists of oolitic and peloidal limestones with grapestone-like aggregates. The uppermost member of this formation, the Gilwern Clay Member (3.5 m), is partially exposed but is difficult to access near the top of the northern quarry, where the unit is broadly similar in nature to that found in nearby Llanelly Quarry and consists of red and green clays with calcrete nodules. A few metres of the overlying Dowlais Limestone are also exposed at the top of the northern quarry.

The Blaen Onnen Oolite, the Coed Ffyddlwn Formation and the Gilwern Oolite comprise the upper part of the Clydach Valley Group of Barclay (1989). The age of the unit is problematic (Barclay, 1989), with macrofossils from the base of the Gilwern Oolite (the Coral Bed) indicating an Arundian age, but foraminifera and conodonts suggesting a Chadian

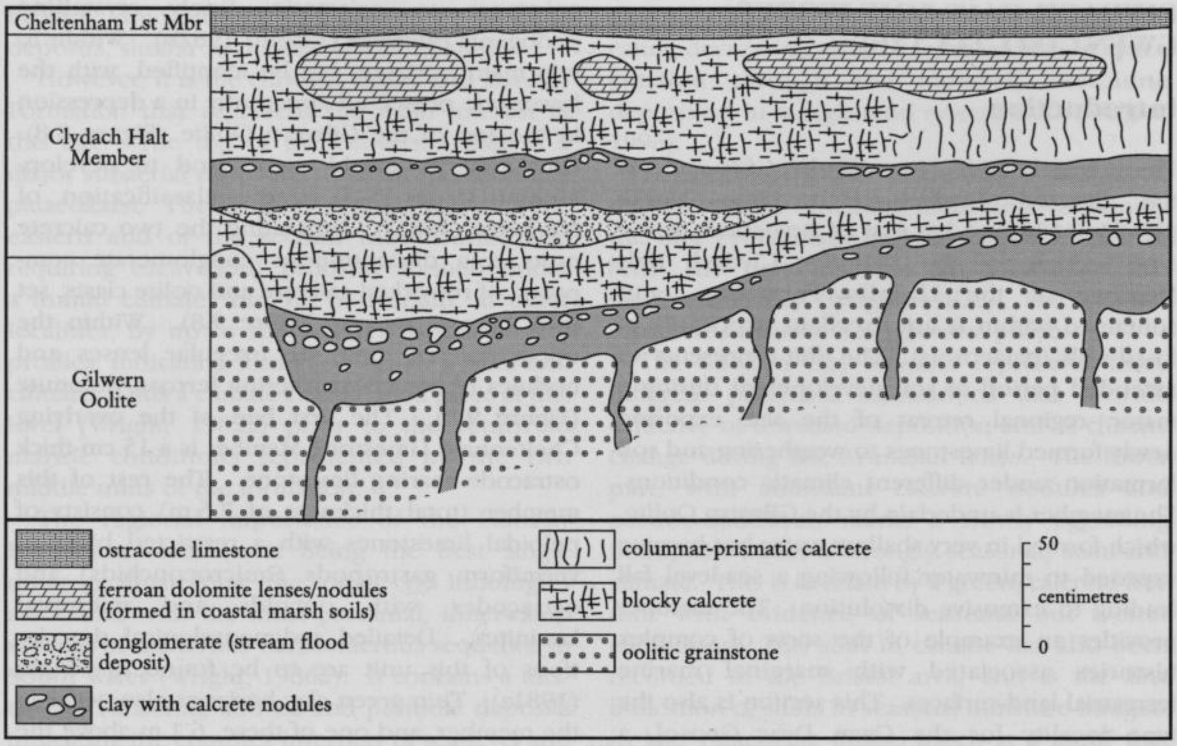


Figure 9.8 Schematic representation of the complex relationships found in the Clydach Halt Member at Clydach Halt Lime Works. The Gilwern Oolite was deposited in very shallow marine conditions and exposed by a fall in sea level. It underwent dissolution by rainwater to produce a distinctive type of rubbly palaeokarst horizon, in a humid climate. This is overlain by two calcrete palaeosols separated by a thin conglomerate composed of calcrete and oolite clasts. This thin conglomerate was also calcretized. The lower calcrete is preserved in a small depression in the top of the Gilwern Oolite but in other sections at the site only the upper calcrete is visible. See text for further details. After Wright (1982b).

age (Figure 9.2). The Llanelly Formation has produced foraminifera (Barclay, 1989) and conodonts (Stone, 1991) indicating an Arundian age. The Dowlais Limestone is of Holkerian age (Barclay, 1989).

Interpretation

The key features of this site are the exposures of the Clydach Halt Member and the Cwm Dyar Geosol. The juxtaposition of the highly solution-weathered top of the Gilwern Oolite and the calcrete-bearing palaeosols of the Clydach Halt Member could only be explained by invoking a climate change between the two units. The top of the Gilwern Oolite is a major subaerial exposure surface in the region, and although better exposed in other sections, its relationship with the Clydach Halt Member makes this small site an important one. The nature of the palaeokarst at the top of the Gilwern Oolite has been discussed by Wright (1982a), and probably represents a relatively short-lived humid phase. The Clydach Halt Member, with its calcretes (Figure 9.8), is best explained as the deposits of a semi-arid landscape, with stable terrace surfaces on which calcrete-bearing soils developed, cut through by stream-flood and sheet-flood deposits. The calcretes correspond to highly developed forms indicating that the land surfaces on which they formed existed for long periods of time, perhaps as much as several hundred thousand years in each case for the two calcretes. The conglomerate separating the two calcretes probably represents a minor stream-flood deposit, which was itself calcretized. The process of calcretization has taken place largely within clays, but locally the oolitic grainstones of the Gilwern Oolite have also been replaced by calcrete. The ferroan dolomite lenses and nodules are identical to other forms found widely in the pre-Holkerian successions in the region, and were analysed by Wright *et al.* (1997), and interpreted as having formed as

Figure 9.9 Deformed calcretes (pseudo-anticlines) of the Cwm Dyar Geosol in the Cheltenham Limestone Member of the Llanelly Formation at Clydach Halt Lime Works. (Photo: V.P. Wright.)

primary precipitates and not as a replacement of calcrete, in a brackish marsh. It seems likely that this brackish event occurred immediately before the deposition of the first ostracode-bearing limestone of the restricted marine Cheltenham Limestone Member. However, because of the ambiguous relationships between the ferroan dolomite and the host calcrete it is not possible to categorically identify which was the earlier, and it is possible that the brackish event occurred before formation of the upper calcrete.

Restricted marine conditions prevailed during the deposition of the Cheltenham Limestone Member, with subaerial exposure surfaces represented by the thin palaeosol, the Darrenfelen Geosol (Wright, 1983), and the prominent Cwm Dyar Geosol capping the member. This latter palaeosol is a stage 3-type calcrete representing a prolonged period of soil formation and suggests that the Cheltenham Limestone Member represents a late highstand to lowstand system tract (Wright, 1996).

The Penllwyn Oolite Member represents very shallow water, protected, back-shoal deposition, with the Uraloporella Bed forming the transgressive base to this unit. The overlying Gilwern Clay Member is a floodplain deposit which at nearby **Llanelly Quarry** (see GCR site report, this chapter) reveals a complex history of climate change and marine flooding. The Dowlais Limestone is a low-energy, marine deposit, which was probably deposited in a very broad non-restricted lagoon.

Conclusions

The site contains a well-exposed section through the middle part of the Lower Carboniferous succession; however, its main importance is that it provides a unique glimpse into the nature of the early Carboniferous landscape and its climates. The calcrete palaeosols and associated deposits reveal that there was a major period of exposure prior to the Arundian, with a short humid phase followed by a prolonged semi-arid phase. The humid phase created an extensive rubbly palaeokarstic horizon at the top of the Gilwern Oolite. Calcrete soils developed over long periods on stable land surfaces, with minor erosion phases, during the semi-arid phase. During early transgressive phases, ferroan dolomites developed in brackish marshes.

BLAEN ONNEU QUARRY, POWYS (SO 155 169–SO 158 169)

Potential GCR site

Introduction

The Blaen Onneu Quarry site is a disused limestone quarry (SO 1550 1690–SO 1575 1685), 5 km north of Beaufort. It provides a world-class section for understanding the sedimentary processes that operated at the margin of an ancient tropical sea and how to recognize the great variety of features that develop in newly formed carbonate sediments as they become subaerially exposed during periods of sea-level fall. The locality is a priceless teaching resource of national and international significance. The section extends from the top of the Pwll y Cwm Oolite, through the Pantydarren Beds, Blaen Onnen Oolite, with locally preserved Coed Ffwddlwn Formation and the Llanelly Formation. Included within it are ancient nearshore carbonate sand shoals, peritidal microbial developments (oncoids and stromatolites), a variety of exposure features (palaeosols and palaeokarsts) relating to episodes of subaerial weathering and indicating climate changes as well as ancient river channel and floodplain deposits.

The site is of particular stratigraphical importance because the Arundian Llanelly Formation here overlies a Courceyan succession consisting of the partially preserved Coed Ffyddlwn Formation and the Blaen Onnen Oolite, with the Chadian Gilwern Oolite having been removed by erosion before the Llanelly Formation was deposited. This local unconformity is probably related to uplift caused by faulting in the area (George, 1954). Informative site details are provided by Wright (1981a) and Dickson and Wright (1993).

Description

The main quarry face is in the Clydach Valley Group (Barclay, 1989). At the base are up to 5 m of the Pwll y Cwm Oolite overlain by some 4 m of the Pantydarren Beds (Barclay, 1989) (Figure 9.10). Barclay identifies the latter unit in oolitic

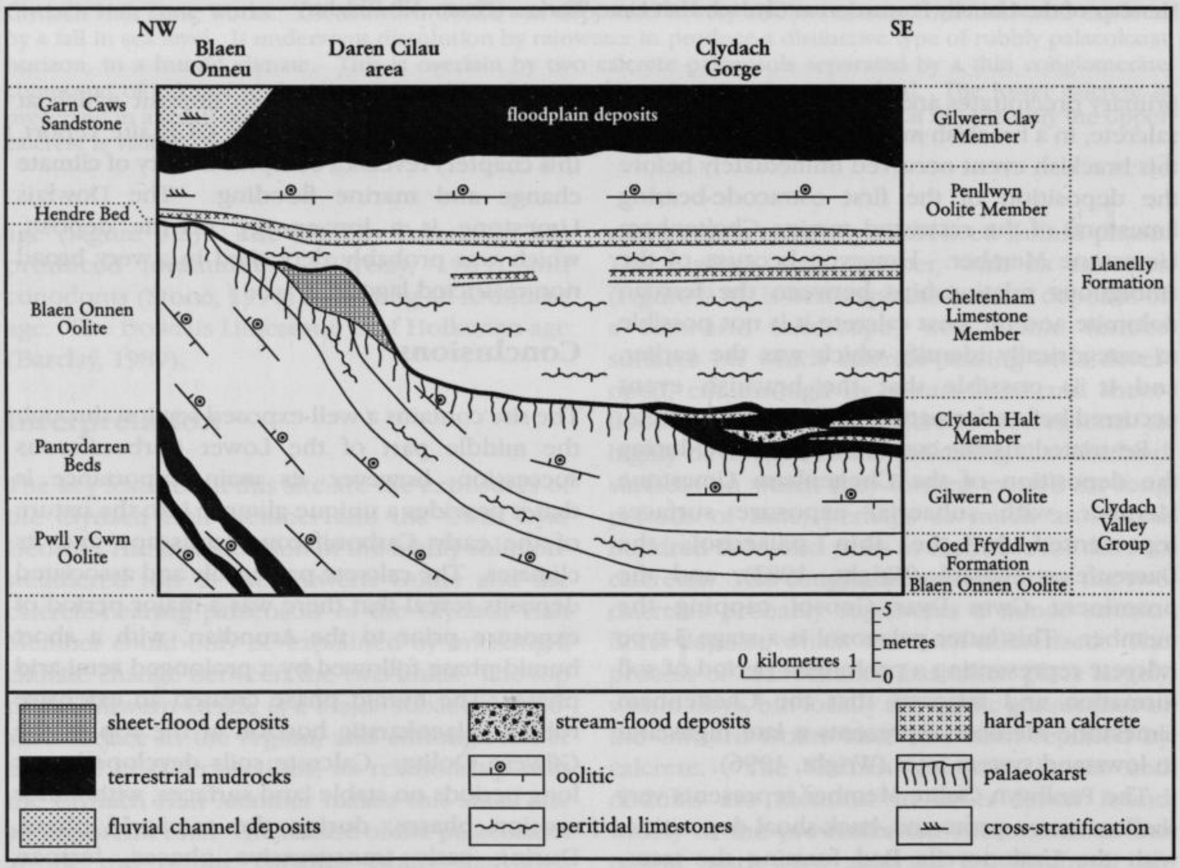


Figure 9.10 Stratigraphical relationships of the section at Blaen Onneu Quarry and the sections to the east towards the Clydach Gorge, showing westerly overstep by the Llanelly Formation.

grainstones but over most of its outcrop it consists of dolomites. However, at the top is a distinctive metre-thick development of lensoid ferroan dolomites and large calcite spherulites, set in a green to black shale.

This is overlain by 14 m of the Blaen Onnen Oolite, the top 3–5 m of which is rubbly (Figure 9.11) and riddled with green clay-filled fissures and solution pipes. This horizon is well exposed in the lower part of the first bench where large blocks of limestone lacking fissures and pipes can be seen within the highly altered zone. Small thicknesses of the Coed Ffyddlwn Formation were recorded here before recent quarrying (see Barclay, 1989). At present, the accessible outcrops lack this unit and the rubbly top of the Blaen Onnen Oolite is erosively overlain by a coarse, sandy bioclastic grainstone at the base of the Llanelly Formation, a few centimetres thick with oolite lithoclasts. This limestone is capped by a thin clay band, some 0.2 m thick, containing horizontally elongate centimetre-sized nodules of micrite and microspar resembling calcrete (Figure 9.12). This nodule-bearing clay is sharply overlain by a metre-thick bioclastic grainstone with oncoids composed of *Garwoodia*. This horizon was regarded as the equivalent of the Hendre Bed of the Cheltenham Limestone Member of the Llanelly Formation by Wright (1981a) (Figure 9.12) and is penetrated by numerous millimetre- to centimetre-wide, sub-vertical micritic 'stringers' which increase in density upwards into the grey, buff-weathering Cwm Dyar Geosol (Figure 9.12). This bed has a brecciated fabric, locally with millimetre-sized spherulites of replaced gypsum (Wright, 1982b). This is overlain by a coarse, sandy bioclastic grainstone containing centimetre-sized clasts of the Cwm Dyar Geosol and is the local equivalent of the Uraloporella Bed, at the base of the Penllwyn Oolite Member (Figure 9.12). It is

Figure 9.11 Section of strata at Blaen Onneu Quarry showing massively bedded bioclastic and oolitic grainstones of the Blaen Onnen Oolite (BOO) with a 3–5 m thick rubbly palaeokarst zone (r) at its top (just above centre) penetrated by irregular clay-filled pipes and fissures, capped by well-bedded, bioclastic, oncoidal and oolitic limestones of the Llanelly Formation (LF). (Photo: P.J. Cossey.)

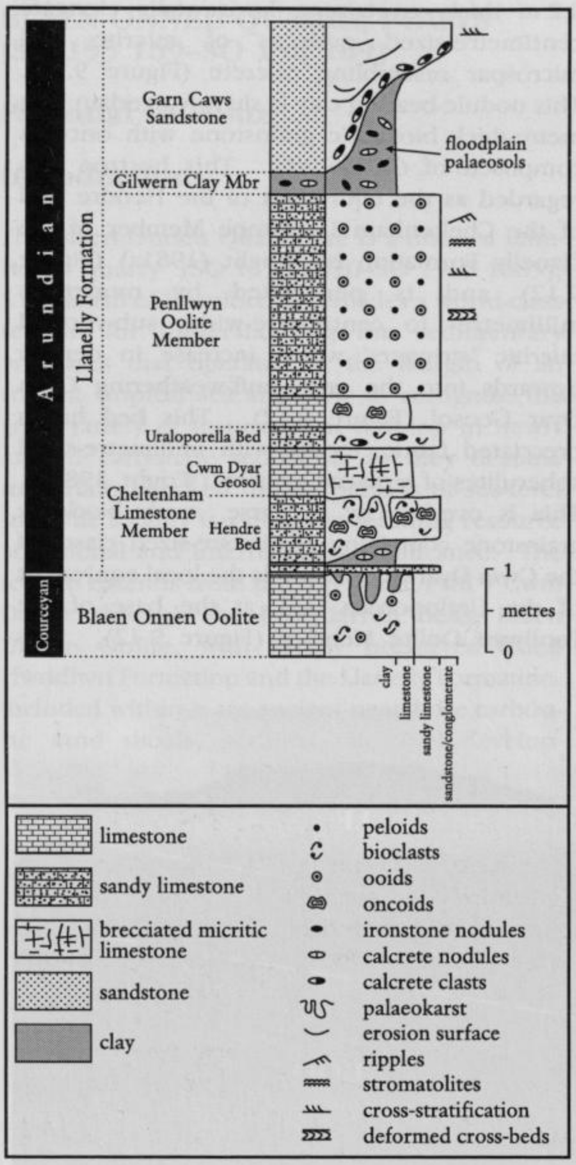


Figure 9.12 Sedimentary log of the Llanelly Formation succession at Blaen Onneu Quarry.

capped by a thin horizon of loosely cemented oncoids in a buff clay, passing up into an oncoidal limestone up to 0.6 m thick. The oncoids are commonly up to 8 cm in diameter and consist of laminae of micrite with porostromate microbial growths, and irregular layers of fascicular optic calcite (Wright, 1981a,c). Many of the oncoids have nucleii that were originally partly open cavities, now filled with calcite cement. The overlying peloidal and sandy oolitic limestones display very clear low-angle cross-stratification, some of which is overturned. Near its top is a 15 cm-thick band of stromatolites which nucleated off ripple marks (Wright and Wright, 1985).

The upper bench exposes the Gilwern Clay Member of the Llanelly Formation, which is exposed to a height of 6 m, and is replaced laterally by the cross-stratified conglomerates and coarse sandstones of the Garn Caws Sandstone, up to 10 m thick (Barclay, 1989). The detail visible in the Gilwern Clay Member is dependent on the degree of slumping, but Wright *et al.* (1991) were able to provide a detailed description following trenching. The unit has a prominent calcrete nodule horizon at the base, overlain by clays with haematite and goethite nodules. Sandstone-filled desiccation cracks up to 2 m in depth occur at the top of the member, some of which are connected to thin sandstones which are probably extensions of the main Garn Caws Sandstone section (see Wright and Robinson, 1988).

The Blaen Onnen Oolite is Courceyan in age (Barclay, 1989), with the base of the *Pseudopolygnathus multistriatus* Zone within the unit. The Llanelly Formation has produced foraminifera (Barclay, 1989) and conodonts (Stone, 1991) indicating an Arundian age.

Interpretation

The oolitic limestones of the Pwll y Cwm Oolite and Blaen Onnen Oolite represent shallow-water shoal deposits. The dolomites of the Pantydarren Beds were interpreted by Searl (1988c) as probable marsh precipitates, whereas the spherulitic calcites represent an unusual form of calcrete (Searl, 1989b). Thus the shallow-water phase of deposition represented by the Clydach Valley Group was interrupted by at least one period of subaerial exposure.

The absence of the Gilwern Oolite and patchy presence of the Coed Ffyddlwn Formation has been interpreted as the result of erosion followed by overstep by the Llanelly Formation (George, 1954). The piping and dissolution seen at the top of the Blaen Onnen Oolite has been interpreted as a palaeokarst by Wright (1982a).

The thin oncoidal unit capping the palaeokarst may represent the Hendre Bed equivalent. The thin nodular horizon at the base of the Llanelly Formation resembles calcretes recognized elsewhere at this level (Wright, 1982b). The overlying bioclastic horizon represents a short-lived marine incursion and the unit is capped by calcrete stringers and the more massive calcrete of the Cwm Dyar Geosol (Wright, 1982b). The transgressive base of the Penllwyn Oolite Member is marked by the Uraloporella Bed and the overlying oncoids had a complex growth history with phases of microbial calcification and marine cement encrustation (fascicular optic calcite) (Wright, 1981a,c).

The low-angle cross-stratification in the overlying limestones is similar to beach lamination and probably represents the top of a sand bar. The stromatolites here are of particular interest in that they preserve very fine details of diurnal lamination (Wright and Wright, 1985).

The Gilwern Clay Member is a floodplain deposit with palaeo-Vertisols (see Wright and Robinson, 1988), which reveal evidence of having developed under two different climatic regimes (Wright *et al.*, 1991). The Garn Caws Sandstone is a river channel deposit, possibly of a large, high-sinuosity river. Both these units provide further evidence of yet another prolonged period of lowered sea level in Arundian times.

Conclusions

Blaen Onneu is a very special site that is unrivalled in showing a wide range of features indicating fluctuating sea levels during Courceyan and Arundian times. A remarkable range of exposure-related features are present, including pedogenic dolomites, calcretes, palaeosols and palaeokarsts. Microbial limestones, with oncoids and stromatolites, are also well exposed. The section also allows the full effects of the pre-Arundian unconformity to be assessed.

ODYNAU TYLE'R BONT, POWYS (SO 063 113)

Introduction

The Odynau Tyle'r Bont GCR site is a disused quarry (SO 0635 1125), 5 km north of Merthyr Tydfil. It exposes the top of the Courceyan–Chadian Abercriban Oolite Group and the lower part of the Arundian Llanelly Formation. The lowermost unit of this formation, the Clydach Halt Member, contains a unique exposure of a set of well-developed fossil soils (palaeosols) which formed on a land surface during a period of major sea-level fall in early Carboniferous times. Six palaeosols are recognized here and these can be compared to present-day calcrete soils found in semi-arid regions. Not only does the site provide evidence of the prevailing climate at this time, but the developed nature of the palaeosols tells us that the area was a land surface for a very long period of time, with each palaeosol possibly having required several hundred thousand years in which to form. Underlying the palaeosols is the rubbly top of the Abercriban Oolite. The rubbly effect is due to a period of rain-water dissolution following exposure of the shallow-water oolite by a fall in sea level. The juxtaposition of dissolution features and semi-arid palaeosols is evidence of climatic change during the Carboniferous Period. The Cheltenham Limestone Member of the Llanelly Formation overlies the palaeosols and exhibits typical features found in very shallow-water limestones. George (1954) provided descriptions of the section. Further details are to be found in Wright (1981a) and Barclay *et al.* (1988).

Description

The key feature of this site is the development of a set of calcrete profiles in the Clydach Halt Member of the Llanelly Formation. The top of the underlying Abercriban Oolite displays minor rubbling, a characteristic of the top of this unit and its equivalent to the east, the Clydach Valley Group (Barclay *et al.*, 1988; Barclay, 1989). This rubbly horizon in the Clydach Valley Group at sites such as **Llanelly Quarry** (see GCR site report, this chapter) and **Clydach Halt Lime Works** (see GCR site report, this chapter) is hosted in the Gilwern Oolite, which is probably of Chadian age (Barclay, 1989). However, due to the progressive erosion and overstep of the Abercriban Oolite Group–Clydach Valley Group by the Llanelly Formation (George, 1954; Barclay *et al.*, 1988), the rubbly horizon is here at a lower level in the stratigraphy and may equate to the top of the Clydach Beds of George *et al.* (1976). The Clydach Halt Member, 6.2 m thick, is distinguished from other exposures at this level by the strong development of the palaeosols, named the Tyle'r Bont Pedocomplex by Wright (1981a, 1982b). A pedocomplex is a sequence of soil profiles in close vertical succession. The palaeosols occur as nodular and massive fine-grained carbonates hosted in green and purple-red clays (Figures 9.13a and 9.14). In the middle of the unit is a 2 m-thick

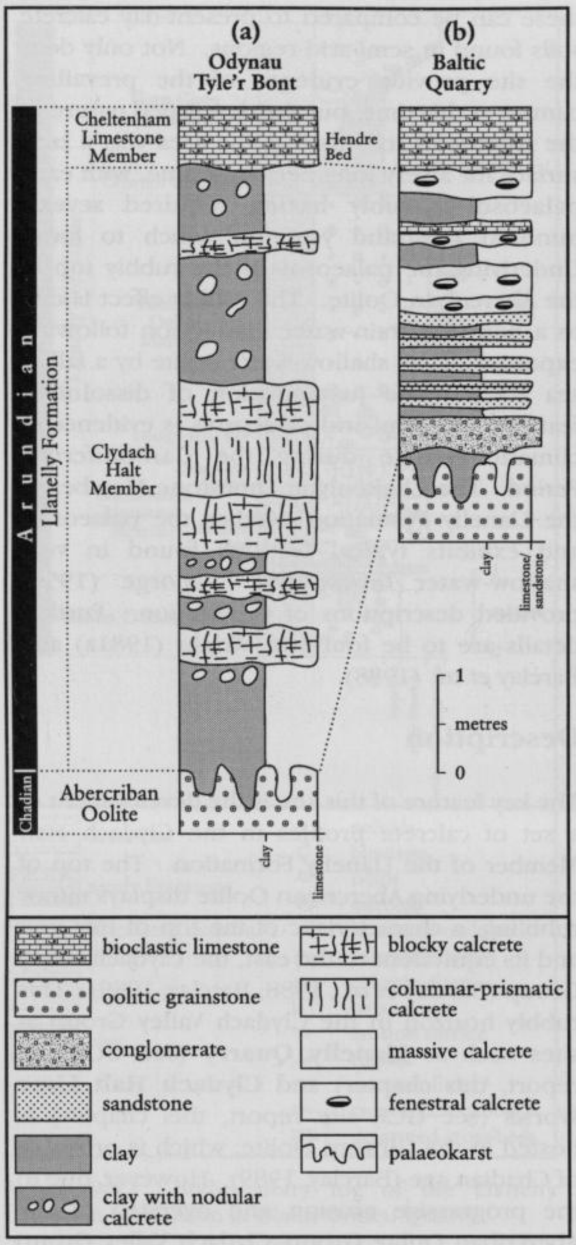


Figure 9.13 Comparative log sections of the Clydach Halt Member (Llanelly Formation) at (a) Odynau Tyle'r Bont and (b) **Baltic Quarry**, illustrating the development of multiple calcrete palaeosols of the Tyle'r Bont Pedocomplex. Such calcretes are found today forming in semi-arid regions and require extended periods of time in which to develop. The presence of stacked calcrete horizons of this type indicate that the land surfaces aggraded in stages, but it is likely that between each phase the land surface remained stable for possibly hundreds of thousands of years. Note the development of fluvial siliciclastic deposits (conglomerates and sandstones) associated with fenestral calcretes in the Clydach Halt Member at Baltic Quarry. See text for further details. After Wright (1982b).

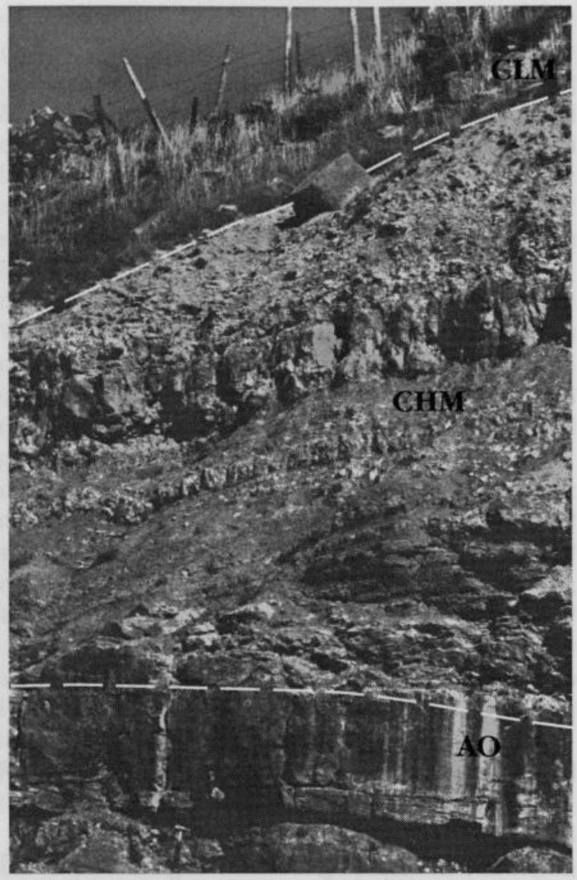


Figure 9.14 Calcrete deposits in the Clydach Halt Member (CHM) of the Llanelly Formation at the Odynau Tyle'r Bont GCR site sandwiched between the top of the Abercriban Oolite (AO) (base of section), and the base of the Cheltenham Limestone Member (CLM) (top of section). The calcretes represent a prolonged phase of soil formation under semi-arid conditions and probably developed on a highly dissected landscape, the modern equivalents of which can be found in New Mexico and Texas. (Photo: P.J. Cossey.)

carbonate which is probably three amalgamated calcretes, the middle part having a strong prismatic structure. Such continuous horizons of calcrete would be classified as stage 3–4 in the sense of Machette (1985). The base of the overlying Cheltenham Limestone Member is marked by a 20 cm-thick bioclastic grainstone with foraminifera, dasycladacean algae (*Koninckopora*) and oncoids, corresponding to the Hendre Bed of Wright (1981a). A bench obscures the complete succession in the Llanelly Formation, which consists of some 4 m of peloidal limestones with prominent clay seams and other related pressure-solution features.

The carbonate nodules and beds of the palaeosols consist of microsparitic calcite and exhibit a range of typical calcrete microfabrics such as floating grains, circum-granular crystallaria and micro-nodules (Wright, 1982b). Although calcretes can be found at this level in other localities, the unique aspect of this site is that so many calcrete horizons occur, providing information of the likely length of subaerial exposure represented by this regional disconformity.

Although Courceyan brachiopod and conodont faunas have been recorded from the Abercriban Oolite, this unit is believed to span the Courceyan–Chadian boundary (Barclay *et al.*, 1988), the younger Chadian Gilwern Oolite having been removed by intra-Carboniferous erosion. The Llanelly Formation has produced foraminifera (Barclay, 1989) and conodonts (Stone, 1991) indicating an Arundian age.

Interpretation

The rubbly horizon at the top of the Abercriban Oolite has been interpreted as a palaeokarstic effect caused by the subaerial exposure of the shallow-water oolites under a humid climate (Wright, 1982a). The overlying palaeosols of the Clydach Halt Member can be compared in terms of macro-structure, microfabric and geochemistry to modern calcrete soils found today in semi-arid to sub-humid regions (Wright, 1982b; Wright *et al.*, 1997). Thus a climate change took place between these two phases. Such soils develop from an initial stage with dispersed concentrations of carbonate, precipitated from downward-moving soil waters, through to the growth of nodules, which become so numerous and large that they coalesce to form continuous beds of soil-formed carbonate. These horizons would most likely have formed between 0.5 m and 1.5 m below the actual land surface at the time of formation. The fact that several horizons occur suggests that the land surface aggraded in stages. Although the rates at which calcretes form vary, soils with the horizons of stage 3–4 calcrete comparable to those seen in the middle part of the member, are generally only found associated with land surfaces that are many tens to several hundreds of thousands of years old. The presence of so many calcrete horizons in the member is a clear indication that the area remained as a land surface for probably half a million years or more. The fact that the horizons are so well developed also indicates that the sedimentation rate was virtually zero for very long periods, followed by periods of aggradation, after which soil formation was renewed at a slightly higher position. Such settings are found in landscapes that are isolated from deposition or erosion on terraced surfaces. The post-Chadian land surface was a complex of stable terraces, with areas between having been eroded by ephemeral rivers that deposited stream and sheet-flood deposits (such as at the nearby site of **Baltic Quarry**, see GCR site report, this chapter). By integrating this site with other exposures of the Clydach Halt Member it is possible to begin to understand the complexity of a long-lived landscape preserved within the Lower Carboniferous rocks of the region.

Above the Clydach Halt Member, the Cheltenham Limestone Member represents deposition in restricted shallow lagoons and intertidal flats, with occasional influxes of more fully marine waters (Wright, 1986a).

Conclusions

This site, with the best exposure of Lower Carboniferous fossil soils in the region, provides evidence that the sub-Arundian unconformity in the area represents a profoundly long period of time, during which multiple palaeosols developed. Together with other sites containing sections at this level, such as **Clydach Halt Lime Works** (see GCR site report, this chapter), it is possible to reconstruct a complex and dissected early Carboniferous landscape which developed during what was mainly a period of shallow marine limestone deposition.

BALTIC QUARRY, POWYS (SO 066 118)

Introduction

The Baltic Quarry GCR site is a disused quarry (SO 0659 1184), 5.5 km north of Merthyr Tydfil. It exposes a succession from the Courceyan–Chadian Abercriban Oolite Group to the upper part of the Arundian Llanelly Formation. It is important because it provides the best, safely accessible section of ancient river or lake deposits in the Clydach Halt Member at the base of the Llanelly Formation, and above these, fossil soils are preserved. The site complements that of nearby **Odynau Tyle'r Bont** in illustrating the complex features and variable preservation of early Carboniferous terrestrial deposits in what is predominantly a shallow marine limestone sequence. It also provides a thick section of the Abercriban Oolite Group and of the lagoonal and intertidal limestones of the Cheltenham Limestone Member (Llanelly Formation). The section has been documented by George (1954), and Dickson and Wright (1993) provide a simple log of the section, based on Searl (1988c).

Description

The base of the disused quarry exposes part of the Abercriban Oolite Group with, at the base, nearly 5 m of the Pwll y Cwm Oolite, a bioclastic, oolitic grainstone which exhibits calcite- and dolomite-filled vugs. Stratiform dolomites occur at the top of this unit and are overlain by a metre or so of the Pantydarren Beds. The remainder of the lower part of the quarry face is composed of the Blaen Onnen Oolite (approximately 23 m), possibly with the uppermost 6 m corresponding to the Coed Ffyddlwn Formation (Dickson and Wright, 1993). There are stratiform and irregular masses of dolomite within the Blaen Onnen Oolite, as well as some thin clay bands. The uppermost few metres of the Abercriban Oolite (Figure 9.15) have a rubbly appearance typical of the unit immediately below the Llanelly Formation throughout its area of outcrop. Due to intra-Carboniferous erosion and overstep, the upper units of the Abercriban Oolite Group–Clydach Valley Group are missing (Barclay *et al.*, 1988). The overlying Llanelly Formation has a conglomerate at its base (Figure 9.13b) which merges into the rubbly top of the Abercriban Oolite. This conglomerate is 0.5 m thick and contains mainly clasts of oolitic and bioclastic limestones derived from the underlying Abercriban Oolite. It is overlain by 1.25 m of interbedded thin green clays and finely laminated sandstones (Figure 9.15). The latter have laminae ranging from 0.5 mm to 6 mm thick, of quartz arenite and sub-litharenite, with very coarse-sand grade grains of oolitic grainstone. Many of the thinner laminae are graded and some have distinctive clay seams between them, resembling varves. The thicker and coarser laminae have scoured bases. These are overlain by 1.7 m of fenestral microsparitic limestones

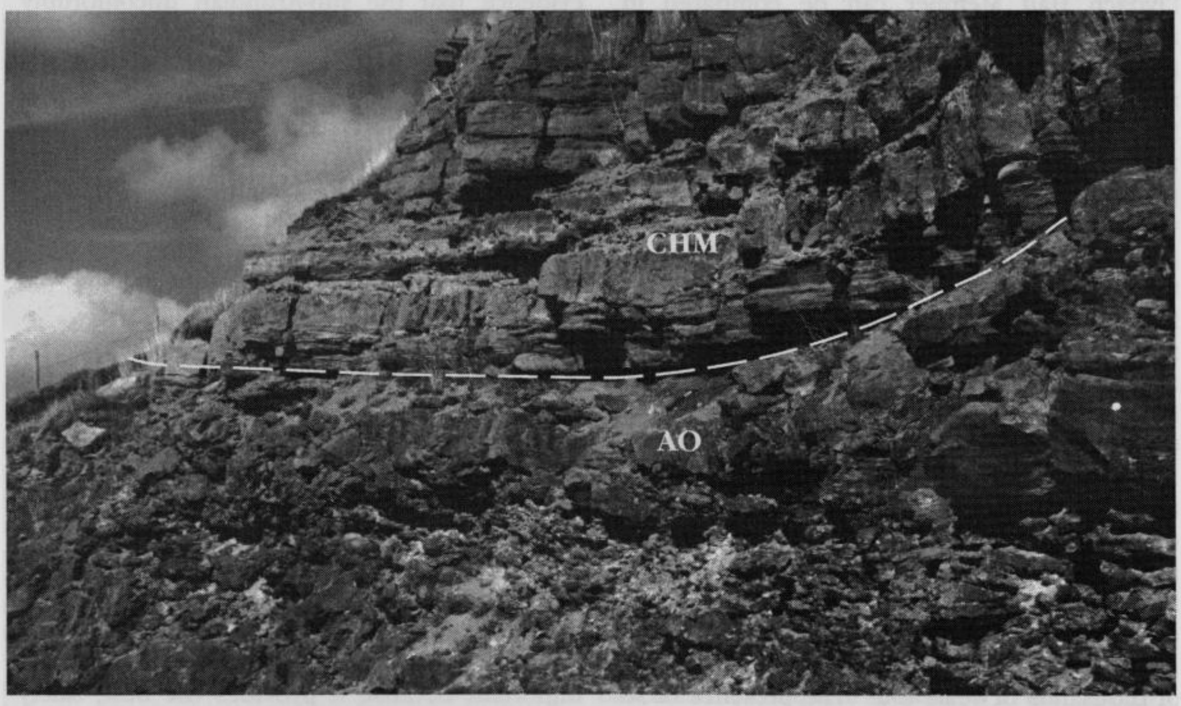


Figure 9.15 Alluvial deposits in the Clydach Halt Member (CHM) of the Llanelly Formation at Baltic Quarry. The rubbly top to the Abercriban Oolite (AO) is seen towards the middle of the figure. Note the hammer for scale (centre). (Photo: P.J. Cossey.)

resembling calcrete palaeosols. Above these, the Cheltenham Limestone Member (Llanelly Formation) comprises 5 m of peloidal limestones containing superficial ooids and a restricted biota of ostracodes and vermiform gastropods (possible microconchids – see Weedon, 1990, 1991), although a thin bioclastic limestone at the base contains foraminifera, dasycladacean algae (*Koninckopora*) and oncoids (the Hendre Bed of Wright, 1981a).

Brachiopod and conodont evidence suggests that most of the Abercriban Oolite Group is of middle or upper Courceyan age, but the group is thought to straddle the Courceyan–Chadian stage boundary (Barclay *et al.*, 1988). Microfaunas including foraminifera (Barclay, 1989) and conodonts (Stone, 1991) suggest that the Llanelly Formation is of Arundian age.

Interpretation

Besides providing a clear succession in the Abercriban Oolite, the site is important because of the presence of siliciclastic facies in the Clydach Halt Member. There are thicker examples of this facies in the Daren Cilau area to the north-east but these exposures are on steep slopes beneath unstable cliffs. This site is a substitute for these other outcrops. The rubbly top of the Abercriban Oolite has been interpreted as a palaeokarstic horizon, caused by a period of rain-water dissolution following a sea-level fall. The erosion of the top of the Abercriban Oolite Group–Clydach Valley Group limestones took place prior to this dissolution phase. The style of dissolution suggests that a humid climate prevailed at that time (Wright, 1982a). The overlying conglomerates of the Clydach Halt Member have been interpreted as either ephemeral stream-flood deposits or possibly colluvium. The partly gradational nature of the contact between the rubbly oolite and this unit suggests that local colluvial material was being reworked by short-lived streams. The overlying sandstones probably formed in part from suspension, and partly from traction currents. These sandstones and clays probably represent overbank (floodplain) or distal alluvial-fan sheet-flood deposits, associated with ponded waters in which graded and clay laminae settled from suspension. Although only a few metres thick, these provide further insights into the types of terrestrial environments that developed on the land surfaces during Courceyan and Arundian times. The overlying calcrete horizons are somewhat unusual in being distinctly fenestral, but represent prolonged periods of soil development in a semi-arid climate. A climate change took place after the dissolution of the Abercriban Oolite to drier conditions. A rise in relative sea level led to the flooding of the area with the development of restricted, very shallow marine conditions of the Cheltenham Limestone Member.

Conclusions

The site provides the only safely accessible site in the Clydach Halt Member (Llanelly Formation) that exposes colluvial, stream and sheet-flood deposits, as well as fossil soils. This thin terrestrial unit contains evidence of complex changes in landscape development during a period of time in which shallow-water marine conditions generally predominated. The section complements those seen at **Odynau Tyle'r Bont** and **Clydach Halt Lime Works** (see GCR site reports, this chapter).

CWAR YR YSTRAD AND HENDRE, POWYS (SO 082 141 and SO 099 149)

Introduction

These two disused quarries at Cwar yr Ystrad (SO 0815 1410) and Cwar yr Hendre (SO 0995 1492), 6 km north-east of Tredegar, provide the best outcrops of both the lower part of the Courceyan–Chadian Abercriban Oolite Group–Clydach Valley Group and the Arundian Llanelly Formation; the Gilwern Oolite having been removed by erosion in this area before the Llanelly Formation was deposited. The succession was formed in very shallow marine waters no more than a few metres deep, and numerous falls in sea level led to prolonged periods of subaerial exposure which produced dissolution effects best seen at Cwar yr Ystrad at the top of the Abercriban Oolite Group–Clydach Valley Group, and spherulitic, nodular and dolomitic horizons representing fossil soils. The spherulitic calcretes are highly unusual but similar horizons occur in Belgium and southern Germany. Together, these two sites provide an outstanding set of exposures in which it is possible to examine a range of features that formed during sea-level fluctuations.

George (1954) described the overall succession in these outcrops and Barclay (1989) revised the stratigraphy. Wright (1981a) described the sedimentology of the Llanelly Formation and Searl (1988c) provided detailed information on the sedimentology and diagenesis of the Abercriban Oolite Group–Clydach Valley Group. Faulkner *et al.* (1990) briefly described some of the exposure features at Cwar yr Ystrad.

Description

The two sites are at the boundaries of a large quarrying complex that has been used intermittently for many years. Up to 25 m of the Abercriban Oolite Group is exposed, capped by a few metres of the Llanelly Formation (Figure 9.16). The floor of the disused quarries consists of fine-grained dolomite that may correspond to the Sychnant Dolomite, the lowest unit in the

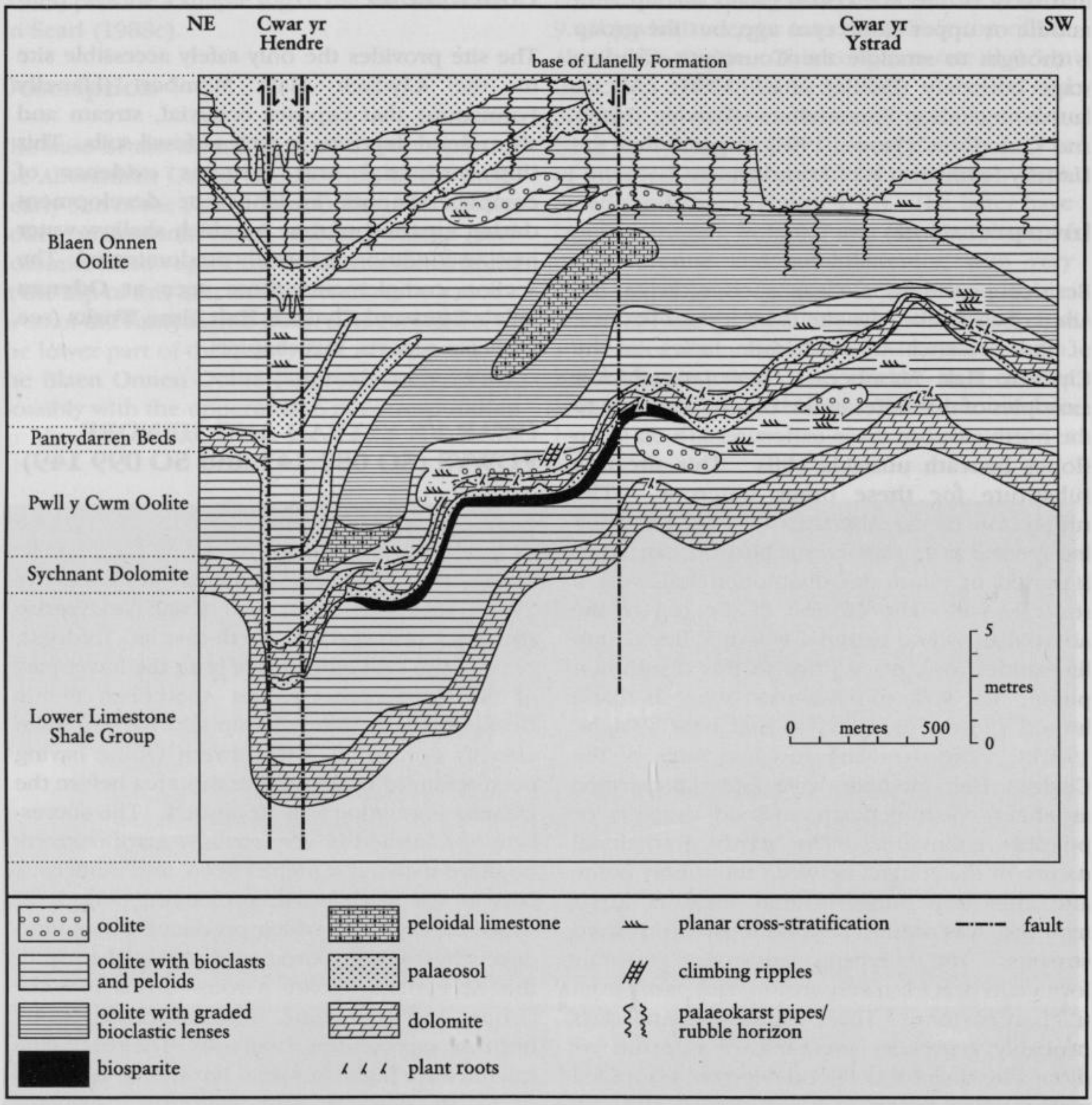


Figure 9.16 Sedimentary facies within the Clydach Valley Group–Abercriban Oolite Group in the Cwar yr Hendre and Cwar yr Ystrad area. The Pantydarren Beds contain a range of exposure-related features, including coastal marsh dolomites. After Searl (1988c).

Abercriban Oolite Group–Clydach Valley Group (Barclay, 1989). This is overlain by a few metres of oolitic grainstone with an irregular top (the Pwll y Cwm Oolite) capped by a metre of dolomite, spherulitic and columnar calcite and green shale, probably corresponding to the Pantydarren Beds. Barclay (1989) provided a basic log of the section. Searl (1988c) carried out detailed studies of the sections below the Llanelly Formation.

Of particular note are the nodular to lensoid to stratiform ferroan dolomites within the sections (Searl, 1988c), associated with rootlet horizons, organic-rich shales and thin coals. These are also associated with spherulitic and columnar calcites (Searl, 1989b; Faulkner *et al.*, 1990). These are best developed in the Pantydarren Beds (the 'Daren Ddu Beds' of some authors), and at Cwar yr Ystrad there are two levels with spherulitic and columnar calcites, separated by a bioclastic, peloidal and oolitic limestone up to 3 m thick. Fish remains are common in this limestone.

This is overlain by approximately 14 m of Blaen Onnen Oolite, capped by a rubbly horizon up to 5 m thick. Possible palaeosol horizons occur within this unit, which consists of bioclastic and oolitic grainstones.

The section at Cwar yr Hendre is a cliff face near the entrance to the main quarry. It has a talus apron allowing easy access to a 4 m section of the Llanelly Formation, and this long section also exposes two normal faults forming a small graben-like structure. Several metres of the Blaen Onnen Oolite are exposed, with horizons of sparitic calcite nodules which probably represent palaeosols. The Llanelly Formation is condensed here (Figure 9.17), with the lower two members being only 3.5 m thick. A single calcrete palaeosol, less than 1 m thick, overlies the Blaen Onnen Oolite and constitutes the

Figure 9.17 Section of strata at Cwar yr Hendre illustrating the unconformity between the marine Courceyan Blaen Onnen Oolite (BOO) and the overlying Arundian–Holkerian sequence comprising peritidal and terrestrial deposits of the Llanelly Formation (LF) and marine beds of the Dowlais Limestone (DoL). Evidence of this unconformity is seen in the development of a palaeokarst and pedogenic fabrics in the rubbly top of the Blaen Onnen Oolite. Note the development of the soft-weathering Gilwern Clay Member towards the top of the Llanelly Formation, and the prominent steeply dipping fault towards the right side of the figure. The height of the quarry face is approximately 20 m. (Photo: P.J. Cossey.)

Clydach Halt Member. This is overlain by a 40 cm-thick coarse bioclastic horizon, the Hendre Bed, with oncoids, dasycladacean algae (*Koninckopora*) and foraminifera (Wright, 1981a), marking the base of the Cheltenham Limestone Member. This is overlain by another palaeosol, and in the remaining metre or so of this member, two other palaeosols can be recognized, corresponding to the Darrenfelen and Cwm Dyar geosols of Wright (1981a). Only 1 m of the overlying Penllwyn Oolite Member is easily accessible, but just above its base is a prominent bed with abundant oncoids, several centimetres in diameter. These are commonly found at the base of the cliff in large slabs. The bed occurs within a unit containing the problematic *Uraloporella* in abundance, and constitutes the equivalent of the Uraloporella Bed at the base of the Penllwyn Oolite Member. The oncoids contain laminae with spongiostromate and porostromate microfabrics, as well as dark laminae of fascicular optic calcite (Wright, 1981a,c). Similar oncoids occur widely at this horizon in the region but are most abundant at this site and at Cwar yr Ystrad. The Gilwern Clay Member of the Llanelly Formation is exposed, but is not accessible, within the small graben area of the section, and this is composed of medium-bedded sandstones and mudstones.

About 8 m of the Llanelly Formation are recorded from Cwar yr Ystrad although parts of the section, including the Cwm Dyar Geosol (4 m above its base), are now obscured by recent quarrying operations. The original section exposed a thick calcrete palaeosol (the Cwm Dyar Geosol) with abundant fractures, in some of which large calcite spherulites (12–15 cm diameter) had grown (Dixon and Wright, 1983). This site showed that such problematic spherulitic horizons were related to calcrete palaeosol development. This palaeosol unit can be accessed with care along this main section, where spherulitic horizons are associated with ferroan dolomites. Oncoids with fascicular optic calcite are abundant in the Uraloporella Bed overlying the Cwm Dyar Geosol.

The Blaen Onnen Oolite is of Courceyan age (Barclay, 1989), with the base of the *Pseudopolygnathus multistriatus* Zone occurring within the unit. The Llanelly Formation has produced foraminifera (Barclay, 1989) and conodonts (Stone, 1991) indicating an Arundian age.

Interpretation

The key aspect of these sites relates to the range of exposure features that are displayed, including spherulitic calcites and nodular ferroan dolomites, green clays, calcretes and rubbly horizons. These constitute a distinct assemblage of features important for identifying sea-level changes. The rubbly horizon at the top of the Blaen Onnen Oolite has been interpreted as a palaeokarstic horizon, produced by dissolution by rainwater following a retreat of the sea, under a humid climate (Wright, 1982a). The overlying palaeosols in the Llanelly Formation indicate a semi-arid climate (Wright, 1982b). At Cwar yr Hendre, the close vertical juxtaposition of many exposure features at the top of the Blaen Onnen Oolite and in the Llanelly Formation is a classic example of the sorts of successions that develop on the edges of carbonate ramp deposystems. The spherulitic and columnar calcites in the Llanelly Formation and in the Pantydarren Beds are highly unusual and have no exact modern soil analogue, yet are associated only in the region with exposure features, and have been interpreted as pedogenic in origin by Searl (1989b). They are not replaced evaporites. They pass laterally into nodular horizons resembling calcretes in the Pantydarren Beds, and are associated with less ambiguous calcretes in the Cwm Dyar Geosol in the Llanelly Formation at Cwar yr Ystrad. The lensoid to nodular ferroan dolomites have been interpreted by Searl (1988c) and Wright *et al.* (1997) as the products of coastal marshes, and may have formed after calcrete development, but immediately ahead of the marine transgression leading to the deposition of the Blaen Onnen Oolite. This distinctive association of spherulites, calcretes and ferroan dolomites represents a subaerial diagenetic facies association which has also been recorded from the late Tournaisian–early Viséan sequences of Belgium and Germany (Faulkner *et al.*, 1990).

Many of the oncoids in the Uraloporella Bed in the Llanelly Formation show evidence of having had hollow nucleii, which is a characteristic of oncoids that have initially grown on plant stems before becoming detached when the plant died. The fascicular calcite laminae probably represent microbially mediated primary calcitic cements. Such oncoids are very rare in the geological record.

Conclusions

Besides providing exposures through the middle part of the Lower Carboniferous succession, the sites reveal a unique association of exposure features allowing their complex relationships to be determined. The Llanelly Formation, particularly at Cwar yr Hendre, illustrates the complex association of exposure surfaces and shallow-water limestones that characterize the depositional edge of carbonate platforms. The association of calcretes, pedogenic spherulitic and columnar calcites, and ferroan coastal marsh dolomite palaeosols found in the Pantydarren Beds and the Llanelly Formation provides the best example of the types of exposure features associated with lowstand surfaces of early Carboniferous times. Grainstones associated with the Pantydarren Beds at Cwar yr Ystrad contain common fish remains and warrant more detailed study.

BLUCKS POOL–BULLSLAUGHTER BAY, DYFED (SR 890 976–SR 941 941)

Introduction

The Blucks Pool–Bullslaughter Bay GCR site encompasses more than 10 km of the south Pembrokeshire coastline from Blucks Pool (SR 890 976) southwards around Linney Head and then eastwards to Bullslaughter Bay (SR 941 941). An almost complete Dinantian succession is exposed here; the thickest development of its kind in South Wales. Exposures are spectacular and abundantly fossiliferous. The site consists of precipitous cliffs and is entirely within the Castlemartin Artillery Range, both of which restrict access to the exposures, and the succession is therefore one of the least well known in the British Isles. The only description of the whole site is found in the [British] Geological Survey memoir (Dixon, 1921). More recent work has focused on particular parts of the succession, especially the stratotype for the Arundian Stage, which is at Hobbyhorse Bay, and on which correlations within the UK are based (e.g. George *et al.*, 1976; Ramsbottom, 1981; Simpson, 1985a).

Description

Dinantian strata are exposed on either limb of the Bullslaughter Bay Syncline, the axis of which runs east–west, intersecting the coast near Hanging Tar, north of Linney Head. The section is also considerably faulted. The total thickness of Dinantian rock in the area is approaching 1500 m (see, for example, George, 1974), the thickest succession in South Wales. The base and top of the Dinantian sequence are not exposed within the boundaries of the site, although the base can be found to the north at Freshwater West.

A large part of the succession in south Pembrokeshire is made up of interbedded bioclastic wackestones and calcareous mudstones. Within the site this includes the Courceyan Blucks Pool Limestone, the Chadian Berry Slade Formation and the Arundian Pen-y-Holt Limestone. The term 'zaphrentid-phase' was used for this distinctive rhythmically bedded facies of southern Britain by Vaughan (1910) and Dixon (1921), because it is particularly rich in solitary corals. This facies in Pembrokeshire was further described by Sullivan (1966) who noted that chert and dolomitized limestones are sometimes present. Dixon (1921) provides full faunal lists, but the principal characteristics of the fauna are summarized by Sullivan (1966). He noted an abundant and diverse fauna of corals, brachiopods, crinoids and bryozoans, with trilobites, bivalves, gastropods and foraminifera more local in occurrence. The most obvious fossils are the solitary corals, which include *Rotiphyllum*, *Allotropiophyllum*, *Cryptophyllum*, *Cyathaxonia* and *Zaphrentites*. Brachiopods are also abundant and include spinose productoids, chonetoids, orthotetoids, frilled athyrids, rhipidomellids and schizophoriids.

There are two features of special interest within the 'zaphrentid-phase' at this site. The first is the occurrence of 'reefs' in the west-facing cliffs between Berry Slade and Linney Head. Dixon (1921) and Sullivan (1966) recorded reefs at two levels within the Chadian Berry Slade Formation (George *et al.*, 1976), but the lower, thicker development is entirely dolomitized. According to Sullivan (1966), the lower, main reef at Linney Head is approximately 75 m thick. Fine to medium crystalline dolomite has obscured the original reef textures and constituents, with the exception of some crinoid debris. Petrography and geochemistry of the reef dolomites were studied by Faulkner (1989a). The contact of the reef with the surrounding bedded limestones is sharp and steep, with evidence of local erosion surfaces and reef debris at the contact.

Sullivan (1966) described smaller lens-shaped reefs which he considered to occur above the reef dolomites. These are composed of pale-coloured, peloidal carbonate muds with the remains of crinoids, brachiopods, bryozoans, ostracodes, calcispheres and foraminifera. These small reefs pass laterally into crinoidal limestones which then grade laterally into the normal dark-coloured 'zaphrentid-phase' limestones. The top contacts of these structures are sharp, with evidence of local erosion (Sullivan, 1966). Lees and Miller (1985), in their review of Waulsortian buildups in Europe and America, recognized their phases C and D in these small structures.

However, in their field guide notes, Ramsbottom and Jones (1977) disputed the presence of reefs at two stratigraphical levels and regarded it as a single occurrence repeated by faulting. Ramsbottom and Jones (1977) also list conodont faunas from the reef and from the beds that occur immediately above and below it.

The second feature of interest within this part of the succession is the stratotype for the Arundian Stage, which was defined by George *et al.* (1976) at the base of the Pen-y-Holt Limestone where it is seen in contact with dolomitic beds at the top of the crinoidal Hobbyhorse Bay Limestone in Hobbyhorse Bay (SR 888 956) (Figure 9.18). This corresponds with the base of the 'Group 4' beds of Dixon (1921). George *et al.* (1976) took the boundary at the first change in lithology below the entry of typical Archaediscidae, especially *Permodiscus* (now *Uralodiscus*) (see also Ramsbottom, 1981). Characteristic macrofossils of the Arundian Stage at Hobbyhorse Bay include *Delepinea carinata*, *D. destinezi*, *Pustula pyxidiformis*, *Siphonodendron martini*, *Siphonophyllia garwoodi*, *Michelinia megastoma* and early koninckophylloids (George *et al.*, 1976). Conodonts from the stratotype have been described by Austin (1987), who noted the appearance of the Arundian guide *Gnathodus symmutatus* just above the base of the Pen-y-Holt Limestone. The foraminiferal biostratigraphy of the stratotype was studied by Simpson and Kalvoda (1987). They noted a diverse Chadian assemblage in the Hobbyhorse Bay Limestone, but, according to them, Arundian archaediscids do not appear until 16 m above the stratotype boundary. Simpson and Kalvoda (1987) also recognized a transitional facies change from packstones to wackestones within the limestones of the lower part of the Pen-y-Holt Limestone.

Simpson (1985a, 1987) has described the whole 300 m succession of the Pen-y-Holt Limestone in South Wales, including the accessible parts of the section between Hobbyhorse Bay and The Wash in this site. He described an alternation of wackestones and carbonate mudstones, the former being dominated by sharp-based unlaminated beds averaging 40 cm in thickness with some thin laminated units less than 5 cm in thickness. The trace fossils *Zoophycus*, *Teichichnus*, *Thalassinoides* and simple vertical tubular burrows are common near the tops of the unlaminated wackestones. Body fossils are fragmented within the units, but include organisms *in situ* at the tops of beds, including *Syringopora*, *Michelinia*, *Schizophoria resupinata*, *Cleiothyridina roysii*, *Schellwienella crenistria* and spiriferoids. The carbonate mudstones contain similar trace fossils to the wackestones together with a few *Chondrites* and a body fossil fauna that includes solitary corals, lengths of crinoid stem with articulated calices, echinoid tests, fenestellid bryozoans and complete trilobite skeletons.

The Arundian–Holkerian boundary was taken by George *et al.* (1976) at the base of the more massive limestones of the Stackpole Limestone Formation. However, on the basis of a record of the Holkerian foraminifer *Draffnia biloba* within the upper part of the 'zaphrentid-phase' limestones, Scott (1988) placed the boundary lower, at the junction between the 'Group 8' and 'Group 9' beds of Dixon (1921) and within the Pen-y-Holt Limestone. The Green Bridge of Wales (SR 925 943) shows the transition between the 'zaphrentid-phase' facies and the more massive bioclastic limestones typical of the Holkerian Stage at this site. Medium-bedded crinoidal limestones make up most of the Stackpole Limestone Formation; in the lower part of the succession they tend to be wackestones with little disarticulation of crinoidal material, but higher up there is less matrix and signs of winnowing are more apparent (Scott, 1988). The topmost part of the Stackpole Limestone Formation consists of oolitic and peloidal limestones.

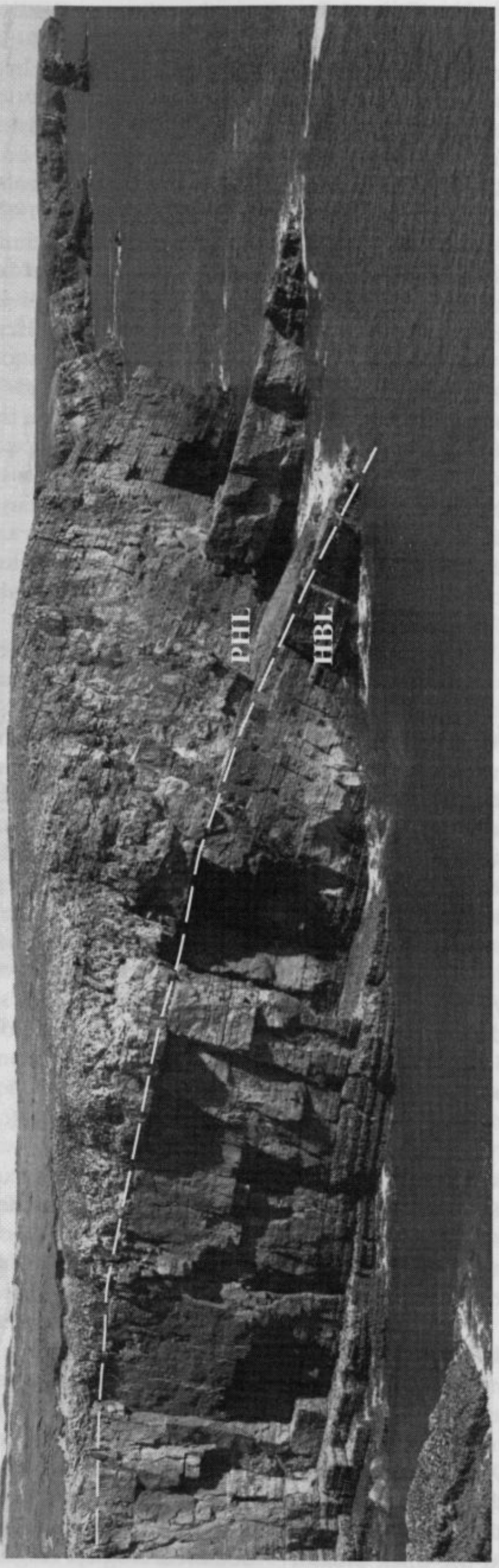


Figure 9.18 The Arundian Stage stratotype at Hobbyhorse Bay. The base of the stage is defined at the boundary between the top of the Hobbyhorse Bay Limestone (HBL) and the base of the overlying Pen-y-Holt Limestone (PHL). (Photo: S. Howells.)

The Asbian and Brigantian succession at this site has received little attention since the work of Dixon (1921). The Asbian Crickmail Limestone is seen mostly in cliff sections of difficult access; Dixon (1921) records it as consisting of thick limestones and thin clays. The contact between the Crickmail Limestone and the Bullslaughter Limestone can be seen on the east side of Bullslaughter Bay (SR 939 943). Dixon (1921) recorded the Crickmail Limestone as being pale grey and relatively pure, with fewer fossils than in the overlying beds, but containing frequent *Davidsonina septosa* near the top. The overlying Bullslaughter Limestone consists of thinly bedded dark limestones with abundant chert and silicified fossils. Dixon (1921) recorded the presence of some paler crinoidal and oolitic limestones and noted that, amongst the fossils, zaphrentids were particularly common. Overall, the Asbian and Brigantian strata at this site appear to be of similar facies and thickness to the Oxwich Head Limestone (George *et al.*, 1976) (Figure 9.2).

Interpretation

Wright (1986a) has proposed that, at least for the Courceyan to Arundian interval, South Wales was occupied by a southerly dipping carbonate ramp (Figure 9.3a). Reconstructions for Pembrokeshire (e.g. Sullivan, 1966) suggest that southern Pembrokeshire, including this site, lay on the most distal exposed part of the ramp and hence received the thickest and most continuous deposition. The succession thus represents deeper-water deposits, typified by the 'zaphrentid-phase' limestones, compared to the equivalent successions elsewhere in South Wales. For example, shallow-water deposits of the Chadian Stage, such as the Caswell Bay Oolite–Gully Oolite and Caswell Bay Mudstone, present in most of South Wales, are not seen at this site. Clearly, however, depths were sufficiently shallow to allow an abundant and diverse fauna to flourish.

Mid-Dinantian buildups commonly occupy the deeper part of ramps, and Lees and Miller (1985) interpreted phases C and D of Waulsortian facies, as present at Hanging Tar, as having formed at water depths of 100–250 m. Dolomites from the reef facies were interpreted as the product of burial diagenesis with fluids sourced from basin de-watering by Faulkner (1989a). Simpson (1987) interpreted the depth of the ramp in south Pembrokeshire during Arundian times as being about 100 m. He interpreted the thick unlaminated wackestones as being storm deposits, with their top surfaces colonized by various burrowing organisms and by the organisms whose skeletons are found *in situ* on the surfaces. He interpreted the mudstones to be background pelagic deposits with an autochthonous fauna.

The status of the Arundian stratotype has been discussed by Riley (1993) who highlighted the fact that the lowest 16 m of the stratotype lacked a diagnostic Arundian fauna and was thus indistinguishable from the late Chadian succession. Riley (1993) also discussed the possiblity of moving the stratotype to the level at which primitive archaediscids made their first entry without moving the stratotype from Hobbyhorse Bay.

The Holkerian sequence in South Wales oversteps older deposits, indicating regional unconformity at the base of the Holkerian Stage (as in the Lake District, North Wales and the Craven Basin; see **Barker Scar** GCR site report, Chapter 4, and **Dowshaw Delf Quarry** GCR site report, Chapter 6), followed by overall subsidence and transgression (George, 1974). This unconformity also occurs in the former Soviet Union and the USA (N. Riley, pers. comm., 2002). However, in south Pembrokeshire, the Holkerian succession overall records shallowing from the zaphrentid-phase limestone, through crinoidal limestones showing increasing signs of current activity upwards, to oolitic and peloidal deposits interpreted as part of a barrier complex by Scott (1988). The Asbian and Brigantian stages of the area are not well known, but they appear to represent similar environments to those on Gower, with shallow marine bioclastic limestones punctuated by episodes of emergence and the development of clay palaeosols.

Conclusions

This site shows spectacular exposures of much of the Dinantian succession in south Pembrokeshire. The facies are different to those elsewhere in South Wales, with a thick development of deeper-water 'zaphrentid-phase' limestones containing an abundant and diverse fauna. In addition, the associated reef structures are unique in the Lower Carboniferous sequences of South Wales. The locality also contains the stratotype of the Arundian Stage, which is the standard for the correlation of successions of this age throughout the British Isles. The site offers much potential for future palaeontological, stratigraphical and sedimentological research.

TENBY CLIFFS, DYFED (SN 132 001–SN 138 004)

Introduction

The Tenby Cliffs GCR site includes the cliffs of the South Sands from Castle Sands (SN 138 004) south-west to the cliffs below the Esplanade (SN 132 001). The locality is important for exposing the only complete section of Chadian, Arundian and Holkerian strata in eastern Pembrokeshire. The Holkerian foraminiferal assemblages here are particularly diverse and abundant. Although there is no detailed recent description of the whole site, the fullest account of the geology is to be found in the [British] Geological Survey memoir (Dixon, 1921). The Holkerian part of the succession has been described by Scott (1988).

Description

The site runs across the axis of the eastwards-plunging Tenby Anticline, the northern limb of which is cut out by a fault through Castle Sands (SN 138 004). A section from Chadian dolomites almost to the top of the Holkerian Stage, dipping southwards at 65°–70°, is present on the southern limb of the fold. In the core of the anticline, the lowest beds seen are dolomites, which have been compared to the Laminosa Dolomite of Gower by Dixon (1921). They consist of well-bedded dark-grey fine-grained dolomites with pockets of white coarsely crystalline calcite and dolomite (Dixon, 1921). The only easily visible primary constituents are crinoid fragments, although in the report of a field excursion, Leach (1909) recorded *Syringopora* cf. *reticulata* and *Fasciculophyllum omaliusi* from the dolomites.

The overlying Caswell Bay Oolite is quite thin (*c.* 25 m) compared to the section at its type locality, but recognizable by its very pale colour and fine oolitic texture. As at many localities farther east in South Wales, the top of the Caswell Bay Oolite is a palaeokarst with a soil developed above, and calcrete features, such as rhizocretions, within the top of the limestone (Spalton, 1982). The Caswell Bay Mudstone ('*Modiola*' or 'lagoon-phase' of Dixon, 1921) consists of alternating fine-grained limestones and dolomites, with some brecciated beds (Figure 9.19). According to Spalton (1982), the Caswell Bay Mudstone at this site is 19 m thick and shows its thickest development in South Wales. It is softer than the surrounding limestones and has been eroded to form a cave with its north wall the top of the Caswell Bay Oolite (Dixon, 1921) (Figure 9.19).

The Arundian High Tor Limestone is in the order of 100 m thick and consists of medium-bedded dark-grey limestones with a fauna including crinoids, corals, brachiopods and *Bellerophon*. Detailed faunal lists are supplied by Dixon (1921); the corals include *Caninia cornucopiae*, *Siphonophyllia cylindrica*, *Syringopora* and *Michelinia megastoma*. The Holkerian Hunts Bay Oolite is at least 150 m thick and comprises bioclastic limestones at the base succeeded by light-grey, thickly bedded oolites. The upper part consists of bioclastic and peloidal limestones interbedded with carbonate mudstones (Scott, 1988). The fauna is described by Dixon (1921) and includes *Composita ficoidea*. In their report of a field excursion to the site, Owen *et al*. (1971) noted a particularly large colony of *Siphonodendron martini* in the Hunts Bay Oolite.

Strank (1981) studied the foraminiferal faunas of the Holkerian part of the succession at Tenby (called the 'Stackpole Limestone' by her, using the nomenclature of south-west Pembrokeshire), initially to confirm its age. She discovered the richest and best preserved Holkerian foraminiferal assemblages from anywhere in the British Isles, which contain all the forms commonly found in areas such as the Askrigg Block, Derbyshire and north Cumbria, together with many other species. Among the distinctive foraminifera she recorded here are *Eostaffella irenae*, *Archaeodiscus longus*, *Brunsia irregularis*, *Florennella*, *Spinobrunsiina landeliesi*, *Dainella holkeriana*, *Endothyranopsis utahensis*, *Nevillella tetraloculi*, *N. dytica* and a new species assigned to 'cf. *Koskinobigenerina*', a genus which in other regions is not generally recognized below the latest Asbian sequence.

Interpretation

The lithological succession at Tenby is broadly similar to that on the Gower Peninsula described and interpreted by Ramsay (1987), although with the exception of the Caswell Bay Mudstone, units are thinner at Tenby. This has been taken to indicate that the locality lies farther

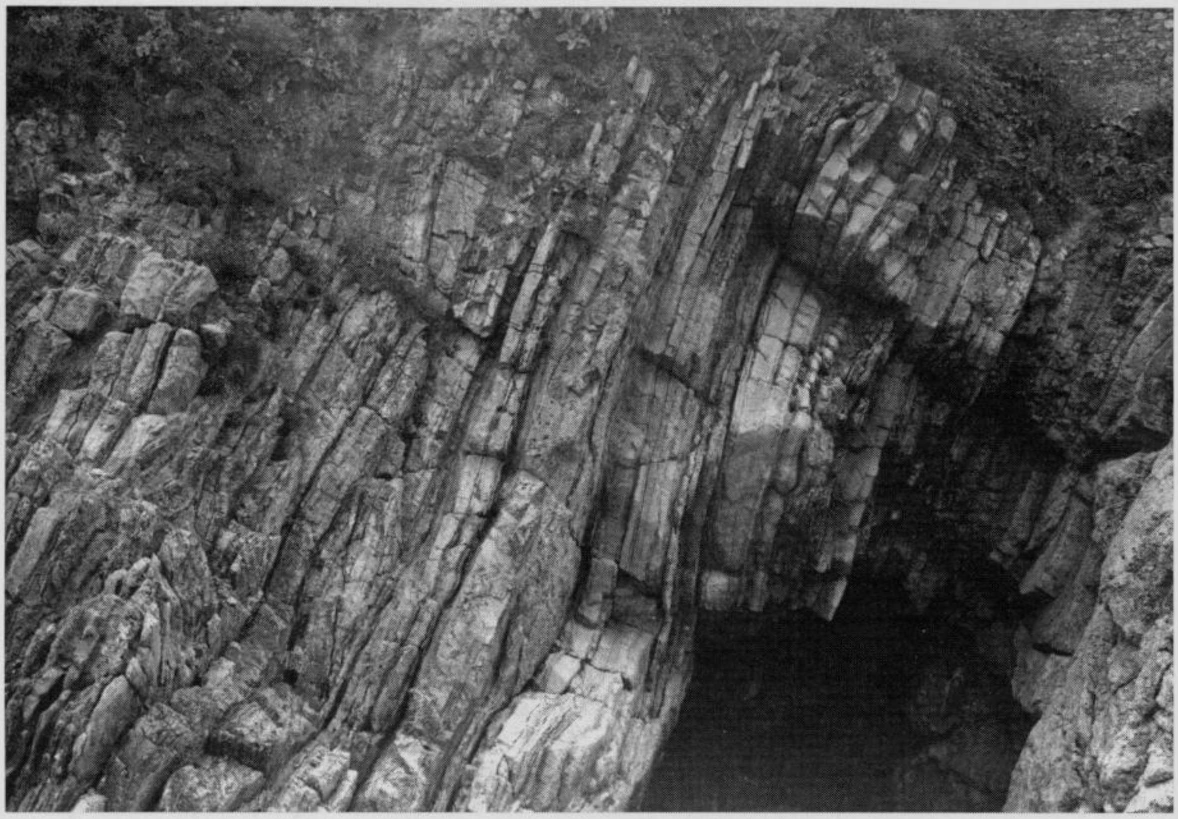


Figure 9.19 Steeply dipping section of the thinly bedded Caswell Bay Mudstone overlying the top of the Caswell Bay Oolite (bottom right) at the Tenby Cliffs GCR site. (Photo: British Geological Survey, No. A327, reproduced with the permission of the Director, British Geological Survey, © NERC, all rights reserved (IPR/19-39C).)

shoreward on a carbonate ramp compared to Gower (e.g. Wright, 1986a). The Chadian succession records shallowing, from dolomitized bioclastic limestones to oolite shoals (Caswell Bay Oolite), followed by emergence and soil development. The overlying Caswell Bay Mudstone records the establishment of tidal-flat environments. This unit is regarded as being either Chadian or Arundian in age in South Wales. The thick development of the Caswell Bay Mudstone indicates that peritidal conditions persisted longer in the Tenby area than in Gower, although this thickening appears to be very local (Simpson, 1985a). An Arundian transgression led to the deposition of further bioclastic limestones represented by the High Tor Limestone.

The lower part of the Holkerian Hunts Bay Oolite records the establishment of an oolitic barrier and this is succeeded by finer-grained back-barrier deposits (Scott, 1988). Strank (1981) suggested that the exceptionally rich Holkerian foraminiferal faunas might indicate slightly deeper, less restricted waters compared to the Holkerian shelf carbonates of the Pennines.

Conclusions

The Tenby Cliffs site provides the best Dinantian exposure in the Tenby area and shows a succession intermediate in thickness between the thick successions of Gower and South Pembrokeshire and the attenuated successions of the north crop. Although most units are thinner than on Gower, the locality is notable for its thick development of the Caswell Bay Mudstone. It is also important for its exceptionally rich Holkerian foraminiferal faunas. There has been little modern work in the area and the site offers considerable potential for future research.

THREE CLIFFS BAY, GOWER, WEST GLAMORGAN (SS 529 877–SS 536 880)

Introduction

The Three Cliffs Bay GCR site is a large coastal site (SS 529 877–SS 536 880), situated south of the hamlet of Penmaen on the Gower Peninsula. It offers an outstanding and almost unbroken Courceyan–Holkerian section extending from the base of the Shipway Limestone (Penmaen Burrows Limestone Group) to the Hunts Bay Oolite. It provides one of the finest sites in Britain, not only for examining this stratigraphical interval, but also for the study of limestones in general. The detail visible in many of the outcrops, particularly those in the lower part of the succession, is unsurpassed in Britain, giving many important insights into the controlling factors of limestone deposition. As a result, many papers have been written on this section and the quality of exposure will allow this section to be a focus for future research. This gives the section international significance as a model for the interpretation of early Carboniferous limestones and for ramp deposits of other ages. Of particular significance are the exposures of storm bedding preserved in the Shipway Limestone, the fossil soil and related exposure features at the top of the Caswell Bay (Gully) Oolite, and the Caswell Bay Mudstone–High Tor Limestone transgressive barrier shoreline succession. Detailed descriptions of parts of the succession are to be found in Dixon and Vaughan (1911), George (1978b), Wu (1982), Simpson (1985b), Ramsay (1987) and Faulkner (1988). The stratigraphical divisions were revised by the [British] Geological Survey (Institute of Geological Sciences, 1973) and George *et al.* (1976).

Description

This extensive section (see Figure 9.20) begins in cliffs to the west of the sand dunes behind the main beach area. The lowest exposed units belong to the Penmaen Burrows Limestone Group (Institute of Geological Sciences, 1973; George *et al.*, 1976), for which this is the type section. This is a major unit which correlates with the Black Rock Limestone Group of the Bridgend, Cardiff (Figure 9.2) and Bristol areas. The underlying Cefn Bryn Shales are not exposed. The first limestone outcrops are the Shipway Limestone (Institute of Geological Sciences, 1973; George *et al.*, 1976), which contains a variety of matrix-rich bioclastic limestones with trace fossils, and which were described in considerable detail by Wu (1982), Faulkner (1988), with additional information given by Wright (1986a) and Ramsay (1987). The main fauna consists of brachiopods, crinoids and bryozoans. Faulkner (1988) identified five lithofacies types within this unit, including graded beds and hummocky cross-stratification. Trace fossils include *Zoophycos*, *Planolites*, *Chondrites*, rare *Rhizocorallium* and common escape burrows. Truncated vertical burrows filled with coarse shell material also occur. The Shipway Limestone is here some 47 m thick (Faulkner, 1988), and is the equivalent of the Barry Harbour Limestone in the Cardiff area, which is dated as Courceyan in age (*Siphonodella-Pseudopolygnathus multistriatus* Interzone; Waters and Lawrence, 1987).

Overlying these bioclastic limestones is a partially dolomitized, reddened oolitic–bioclastic unit (*c.* 4 m), which has been regarded as the Brofiscin Oolite (Faulkner, 1988), a widespread unit in the Vale of Glamorgan (Waters and Lawrence, 1987; Wilson *et al.*, 1990). It has been discussed by Burchette *et al.* (1990), and exhibits trough cross-bedding, with vadose cements preserved in its uppermost part. This unit is repeated by a thrust some distance along the cliff to the south-west. The contact with the bioclastic limestones of the Shipway Limestone is in a recess in the cliff face but the oolite appears to be sharp based. No clasts of the underlying limestones have been found in the Brofiscin Oolite. This unit is sharply overlain by the Tears Point Limestone, a package (*c.* 60 m) of muddy, highly crinoidal limestones, described by Ramsay (1987) and Faulkner (1989a). The upper part of the Penmaen Burrows Limestone Group, arguably part of the Tears Point Limestone, was named the 'Langland Dolomite' by the [British] Geological Survey (Institute of Geological Sciences, 1973). This is a fine-grained replacive dolomite. The age of the upper part of this group has been determined at nearby Tears Point (Mitchell *et al.*, 1986) as being late Tournaisian–early Viséan in age.

Above this, the Chadian Caswell Bay (Gully) Oolite (Ramsay, 1987; Searl, 1989a) is a cross-bedded oolitic grainstone unit (*c.* 45 m). A minor palaeokarst associated with rhizocretions

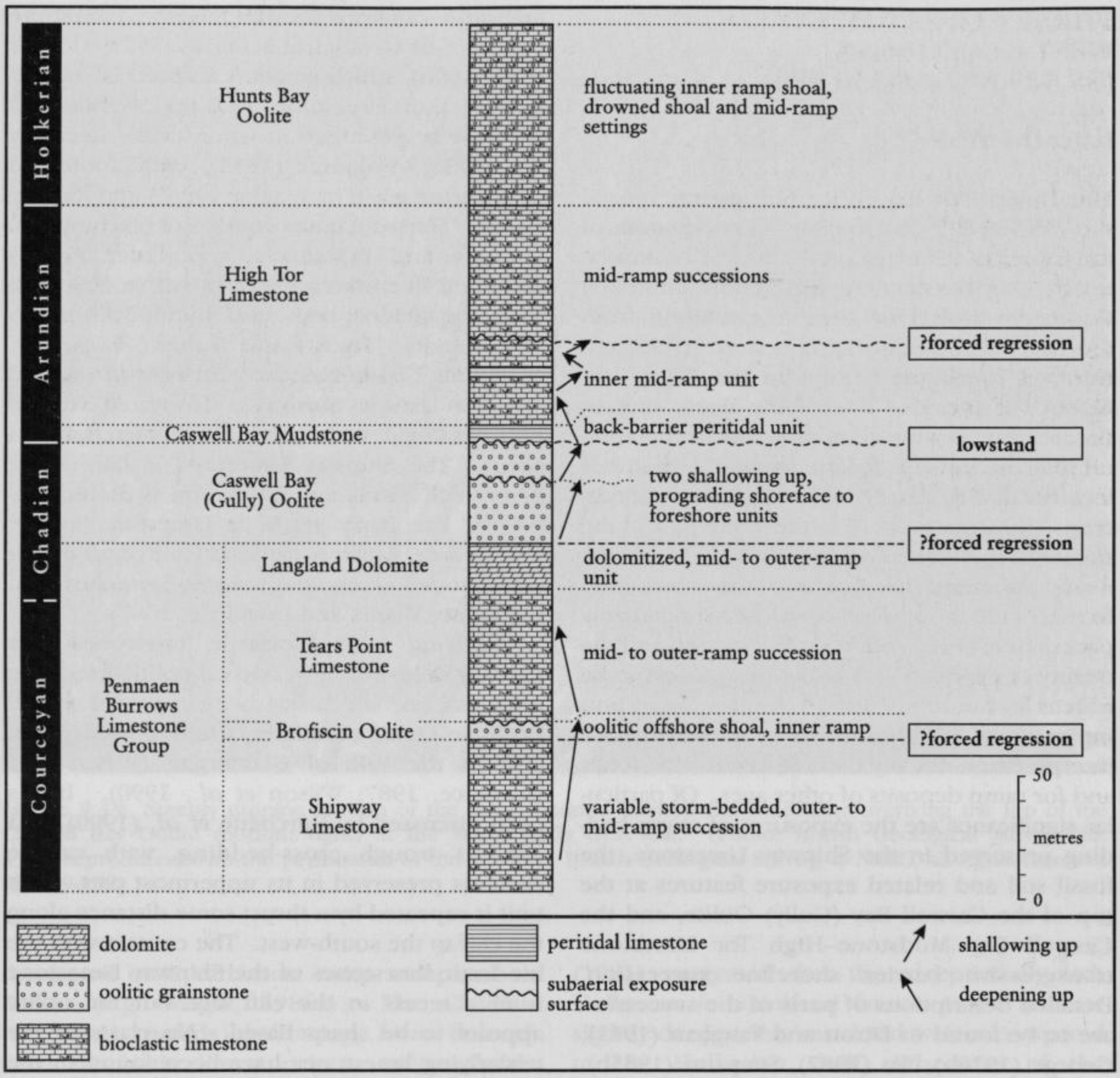


Figure 9.20 The interpretation of depositional environments represented by the Lower Carboniferous succession at the Three Cliffs Bay GCR site, Gower.

occurs approximately 10 m from its top. The unit is capped by a more prominent, undulating palaeokarstic surface with a thin calcrete crust (Wright, 1982a). This second surface exhibits smooth pits and intervening highs, with relief of up to a metre. The calcrete crust is more of a discontinuous veneer, and contains abundant rhizocretions with an alveolar-septal structure composed of well-preserved micron-sized needle fibre calcite, a form of calcite regarded as the product of soil fungal activity (Wright, 1986b). Overlying this is 7 m of the Caswell Bay Mudstone, which consists of argillaceous and peloidal limestones and dolostones, described in detail by Ramsay (1987). This unit has a restricted biota mainly of ostracodes and calcispheres.

The top of this unit is erosional and is overlain by the Arundian High Tor Limestone (*c.* 100 m), with richly fossiliferous bioclastic grainstones passing up into a more matrix-rich lithofacies. Detailed descriptions of the facies have been provided by Ramsay (1987), and aspects of the biota have been documented by Beus (1984) for nearby localities. Simpson (1985b) provides a simple interpretive log for the unit. There is a finer-grained unit capping the lower third of the section, and also a palaeosol (Ramsay, 1987).

The overlying Holkerian Hunts Bay Oolite, which reaches a thickness of 275 m thick in the area (Figure 9.21), is dominated by cross-stratified and structureless oolitic grainstones, laminated fine bioclastic packstones and grainstones, and extensive developments of peloidal, grapestone grainstones (Ramsay, 1987).

Interpretation

This site has been used in a number of detailed sedimentological and palaeontological studies, making it one of the best documented limestone sections in Britain. The overall setting for the succession has been interpreted as a southward-dipping carbonate ramp (Wright, 1986a), and sea-level changes during Courceyan to Holkerian times created a set of distinctive facies, ranging from outer ramp to terrestrial (Figure 9.20).

The Shipway Limestone was mainly deposited in a storm-dominated mid- to inner-ramp setting (Wu, 1982; Faulkner, 1988). Anderson and Goodwin (1990) offered an unusual interpretation for this unit, suggesting it represents a cyclic peritidal deposit, but this view has not found support (for example, Wright and Faulkner, 1991). The Brofiscin Oolite has been interpreted as a progradational shoreline-detached sand-body with a strong longshore transport component (Burchette *et al.*, 1990). The sharp base to this unit might suggest that it represents a forced regressive sand, which became subaerially exposed to generate vadose cements. The overlying Tears Point Limestone represents a return to deeper, mid- or even outer-ramp conditions (Ramsay, 1987; Faulkner, 1989a). The exact environmental significance of the Langland Dolomite is unclear but there is evidence, at least locally, of subaerial exposure at the top of the Friars Point Limestone, beneath the Caswell Bay (Gully) Oolite to the east in the Bridgend and Cardiff areas (Waters and Lawrence, 1987; Wilson *et al.*, 1990), and a prominent exposure surface occurs at this level south of Bristol, developed on offshore limestones (Faulkner *et al.*, 1990). This implies that a rapid (forced) regression may have taken place at the end of Penmaen Burrows Limestone Group times, and within early Viséan times.

The overlying Caswell Bay (Gully) Oolite represents two prograding shoreface–foreshore packages, each capped by a palaeokarst and palaeosol (Searl, 1989a; Burchette *et al.*, 1990). The Caswell Bay Mudstone and lower part of the High Tor Limestone are transgressive deposits formed in back-barrier and shoreface settings

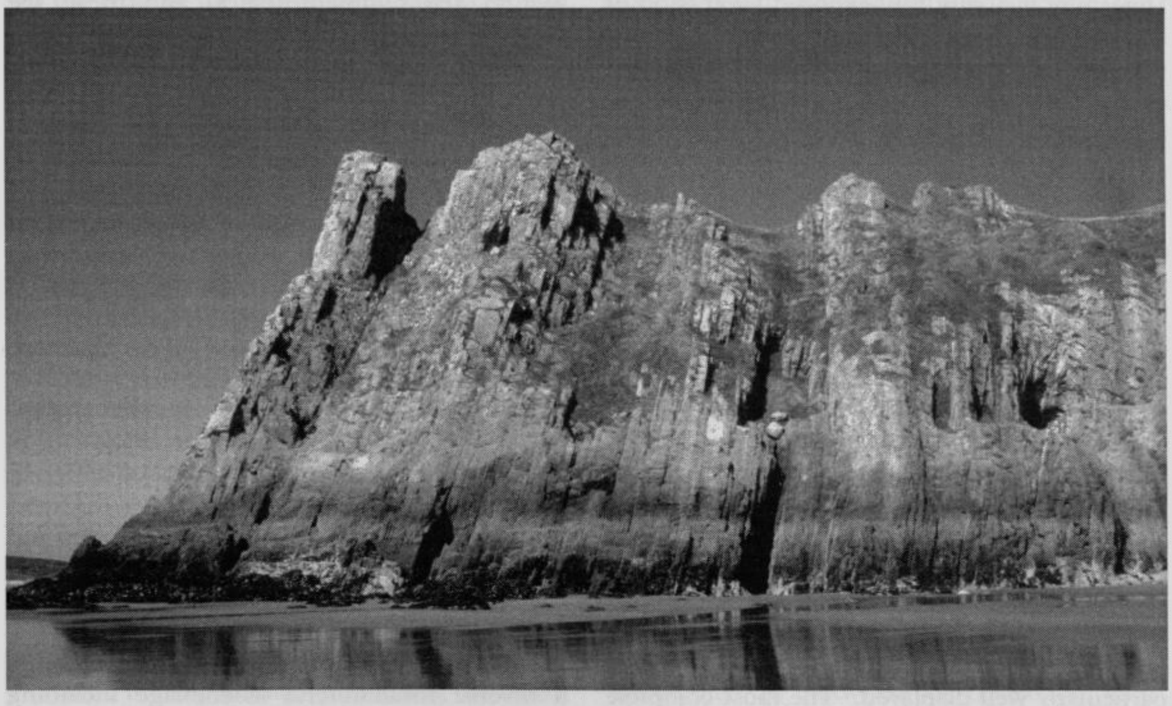


Figure 9.21 General view of the cliff section in the Hunts Bay Oolite (Holkerian) at Three Cliffs Bay. (Photo: P.J. Cossey.)

(Riding and Wright, 1981; Burchette *et al.*, 1990). The contact between the two units represents a shoreface erosion surface or ravinement. The bulk of the High Tor Limestone is a storm-dominated inner- to mid-ramp succession with shoaling events, evidenced by a peritidal unit, and also a thin palaeosol (Simpson, 1985b; Ramsay, 1987).

The Hunts Bay Oolite was deposited as a complex of oolite shoals covered in small sand waves, together with protected settings intermittently agitated where grapestones were produced. Deepening phases resulted in the deposition of finer-grained bioclastic packstones and grainstones (Ramsay, 1987).

Conclusions

The variety of related carbonate facies in the full succession makes this site one of national importance not only for studying early Carboniferous carbonates, but also for illustrating ancient limestone deposystems. A ramp model provides the best explanation for the succession, over which sea-level changes and progradational events created fluctuating water depths. The Shipway Limestone provides an especially good outcrop for examining a range of storm deposits. The top Caswell Bay (Gully) Oolite to basal High Tor Limestone is a very well-exposed succession of shallowing-upwards oolitic shoreface deposits, capped by a prominent subaerial exposure surface, and overlain by transgressive back-barrier and lower shoreface facies.

PWLLDU HEAD, GOWER, WEST GLAMORGAN (SS 568 863–SS 574 870)

Introduction

The Pwlldu Head GCR site includes the cliffs and foreshore from the west side of Pwlldu Head on the south Gower coast (SS 568 863) eastwards and northwards to Pwlldu Bay (SS 574 870). Strata exposed include the top of the Hunts Bay Oolite (Holkerian) and the lower part of the Oxwich Head Limestone (Asbian). Highlights of the site are its sedimentological features, with a beachrock, karstic surfaces and 'pseudobreccias' particularly well displayed. The most complete description of the Asbian succession at Pwlldu is the account of Thorne (1978).

Description

The upper part of the Hunts Bay Oolite and the contact with the Oxwich Head Limestone are exposed on Pwlldu Head (SS 568 864). The Hunts Bay Oolite is well bedded and jointed, contrasting with the more massive Oxwich Head Limestone. The contact is a palaeokarstic surface. The upper part of the Hunts Bay Oolite consists of oncoidal, bioclastic and peloidal packstones and grainstones with some thin interbedded mudstones (Scott, 1988) and a rich coral–brachiopod fauna which includes *Palaeosmilia murchisoni*, *Siphonodendron* and *Syringopora*. A diverse foraminiferal assemblage dominated by *Pojarkovella 'Nibelia' nibelis*, *Eostaffella parastruvei* and *Archaediscus stilus* is also recorded from this formation (Strank, 1981).

The Oxwich Head Limestone consists of massive packstones and grainstones punctuated by palaeokarstic surfaces and palaeosol clays, although the latter have often been washed away by marine erosion. One palaeokarstic surface has been exhumed and its potholed structure is excellently exposed on the foreshore. The upper part of the succession is faulted and difficult to place stratigraphically, but around 70 m of the formation can be reliably logged (Ramsay, 1989). The principal features of interest in the section are sedimentological and these are described in detail by Thorne (1978).

Near the base of the Oxwich Head Limestone is a thick cross-bedded grainstone unit. The top of this bed, which lies about 10 m above the base of the formation, is a ridged and grooved erosion surface (Thorne, 1978). Petrographical studies have shown that the upper part of the grainstone contains abundant early diagenetic radial fibrous cement and that both grains and cement are cut through at the erosion surface (Thorne, 1978). This erosion surface is exposed on the foreshore where it can been seen to display up to 70 cm of relief (Thorne, 1978). Above the grainstone, massive, structureless limestones dominate the succession, but there are a number of rubbly weathering horizons containing paler and darker coloured areas much affected by pressure solution and dolomitization. These are the 'pseudobreccias' (Figure 9.22) first described in detail from Gower by Dixon and Vaughan (1911) and further discussed by Thorne (1978). Strank (1981) recorded a diverse foraminiferal assemblage including abundant double-walled palaeotextulariids from the Oxwich Head Limestone at Pwlldu.

Figure 9.22 Pseudobreccias in the Oxwich Head Limestone (Asbian) at the Pwlldu Head GCR site. (Photo: P.J. Cossey.)

Interpretation

On the basis of the foraminiferal faunas, Strank (1981) interpreted the Hunts Bay Oolite at Pwlldu to be of Holkerian age and the Oxwich Head Limestone to be of late Asbian age, with the early Asbian interval apparently not represented. This agrees with the ages of these formations on Gower determined from the macrofaunas (e.g. George *et al*., 1976).

The top part of the Holkerian sequence at Pwlldu was interpreted as back-barrier deposits by Ramsay (1987) and Scott (1988), with the succession terminated by a prominent erosion surface and capped by a well-developed soil profile. Asbian sedimentation was similar to that in many other shelf areas of the UK, deposition of shallow marine packstones and grainstones being punctuated by episodes of emergence, soil formation and karstification. The cements at the top of the grainstone near the base of the Oxwich Head Limestone have been interpreted as marine precipitates and the eroded surface as a beachrock horizon (Thorne, 1978).

Pwlldu is a key locality for studying the origin of the rubbly weathering beds that characterize many Asbian shelf limestones, the 'pseudobreccias' of Dixon and Vaughan (1911). In many Asbian successions, such as the Urswick Limestone of south Cumbria and the Eglwyseg Limestone Formation of Llangollen (see **Eglwyseg Mountain** GCR site report, Chapter 8), these pseudobreccias consist of darker 'clasts' in a paler 'matrix' and have been interpreted in terms of early patchy cementation, the 'clasts' being the areas of early lithification (Horbury, 1987; Solomon, 1989). In some cases, early cementation has enhanced a structure caused by bioturbation. On Gower, these mottled units have, in many cases, been subjected to a greater degree of subsequent diagenesis and are associated with pressure-solution seams and partial dolomitization (Thorne, 1978).

Firstly, pressure solution has led to the development of sutured seams concentrated along the boundaries between 'clasts' and 'matrix', and secondly, coarse, late diagenetic dolomite has formed preferentially along the sutured seams, spreading out to replace the adjacent limestone. This eventually leads to a texture consisting of 'islands' of limestone surrounded by networks of coarse dolomite. These effects are variably developed such that all stages in the process are well seen at Pwlldu, particularly in the upper part of the exposed succession (Thorne, 1978). The overall effect of these processes is to enhance the brecciated appearance of the deposits.

Conclusions

The particular value of this site lies in the spectacular coastal section with sedimentological features clearly seen. Whereas the features indicative of emergence are seen at other localities, they are rarely as well displayed in bedding plane exposures. The diagenetic features that can be studied in the field, including the beachrock and development of pseudobreccias, are better seen here than at any other locality. The site is also valuable stratigraphically, showing the contact between the Holkerian Hunts Bay Oolite and the late Asbian Oxwich Head Limestone, with the early Asbian interval apparently unrepresented.

CASWELL BAY, GOWER, WEST GLAMORGAN (SS 594 877–SS 598 869)

Introduction

The Caswell Bay GCR site lies on the south coast of the Gower Peninsula, 8 km south-west of Swansea. The site includes the cliffs along the east side of Caswell Bay from high water mark at the head of the bay (SS 594 877) south-eastwards to Whiteshell Point (SS 598 869). The site thus includes cliff and raised beach exposures along a shoreline nearly 1 km in length. The section is exposed across a faulted anticline (Figure 9.23) and comprises one of the finest and most accessible sections of Courceyan to Holkerian age in South Wales. The site is particularly valuable for the superb exposures of a variety of sedimentary features relating to deposition and diagenesis, as well as for studying characteristic faunas.

Aspects of the geology of Caswell Bay have been described by many workers. General accounts include those of Strahan (1907a) and Dixon and Vaughan (1911). The sedimentology of the whole exposed succession has been examined as part of a larger study of the Carboniferous Limestone in Gower by Ramsay (1987). George (1978b) provided a detailed account of the Chadian part of the succession and the effects of early subaerial exposure were described by Spalton (1979, 1982). The Arundian succession has been described by Simpson (1985a) and the Holkerian succession by Scott (1988).

Description

Structural complexities (folding and thrusting) relating to the Variscan Orogeny have resulted in the repetition of several sections of the Penmaen Burrows Limestone Group, Caswell Bay Oolite and Caswell Bay Mudstone, thus providing a unique opportunity for the examination of lateral facies changes in these units, a circumstance that is precluded in the complementary section at **Three Cliffs Bay** (see GCR site report, this chapter) where significant repetitions are not apparent.

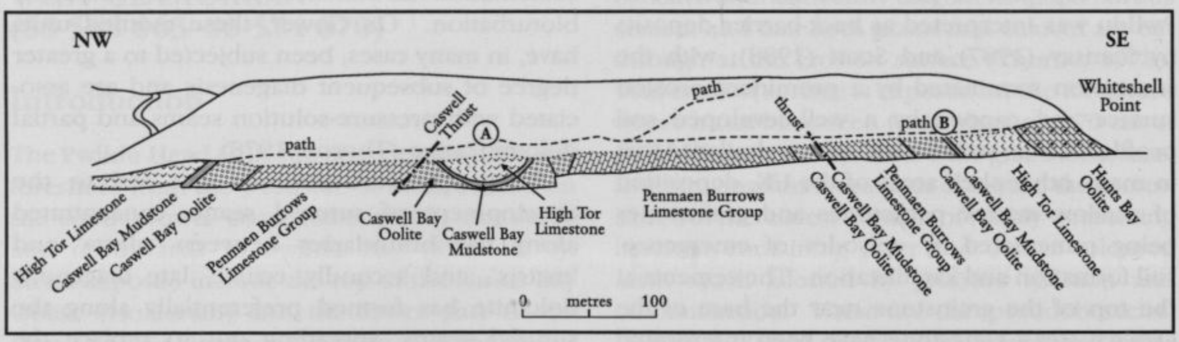


Figure 9.23 Diagrammatic section illustrating the structure and stratigraphy of the Penmaen Burrows Limestone Group–Hunts Bay Oolite succession (Courceyan–Holkerian) along the eastern side of Caswell Bay. The section length is approximately 750 m. (A) and (B) refer to the location of the sections illustrated in Figure 9.25. After Owen and Rhodes (1969).

The stratigraphical thickness of the beds is about 250 m, but individual units are repeated along the exposure (Figure 9.23). The oldest unit exposed is the Penmaen Burrows Limestone Group (also known as the 'Black Rock Limestone') which occurs in the core of the Langland Anticline and is repeated by faulting on both limbs (Figure 9.23). It is strongly dolomitized, particularly at its top where it is referred to as the Laminosa or Langland Dolomite. Mitchell *et al.* (1986) established that the Courceyan–Chadian boundary lies within the Penmaen Burrows Limestone Group (their Black Rock Limestone) farther west on Gower, but it has not been recognized at Caswell Bay. However, Ramsay (1987) attempted to extrapolate the position of the boundary on lithological grounds and placed it about 20 m below the contact with the Caswell Bay Oolite, with approximately another 20 m of Penmaen Burrows Limestone Group seen below the boundary in the exposure nearest the head of the bay. Despite dolomitization, Ramsay (1987) was able to recognize bioturbated bioclastic packstones in the Penmaen Burrows Limestone Group.

The Caswell Bay Oolite, which is the lateral equivalent of the Gully Oolite of the Bristol area (and is so-called on Gower by some workers), is a massive pale-grey limestone about 40 m thick, composed mainly of cross-stratified oolitic grainstone (Figure 9.24). It is of Chadian age (George *et al.*, 1976). The field characteristics have been described in detail by Spalton (1979, 1982) and Ramsay (1987), the petrography and chemistry by George (1978b), and the diagenesis by Searl (1988a,b, 1989a). The Caswell Bay Oolite shows considerable lateral variation, which is evident in the various sections exposed at this site logged by Ramsay (1987). In particular, an erosion surface that is present midway through the unit in sections near the head of the bay is represented by thick channel deposits in the seaward sections. The surface at the top of the Caswell Bay Oolite is a distinctive erosive feature, consisting of a pot-holed surface with associated calcrete (Spalton, 1979, 1982). Fossils are not abundant in the Caswell Bay Oolite and are concentrated at certain horizons. Most characteristic are bellerophontid gastropods, schuchertellid brachiopods and the corals

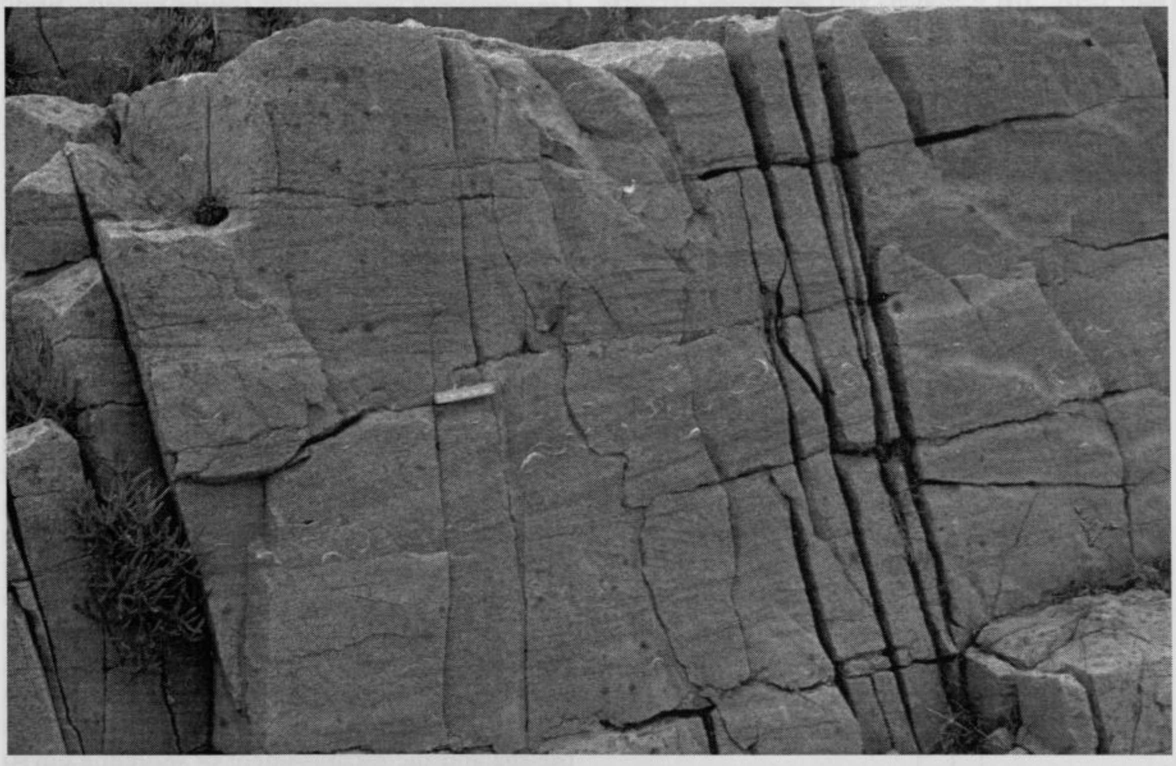


Figure 9.24 Cross-stratification and disarticulated brachiopod valves in oolitic grainstones of the Caswell Bay Oolite at Caswell Bay. (Photo: A.E. Adams.)

Syringopora cf. *reticulata*, *Michelinia megastoma* and *Koninckophyllum praecursor* (George, 1978b).

The Caswell Bay Mudstone is particularly well seen at this site and consists of a thin succession (4–6 m) of well-bedded, impure fine-grained limestones and dolomites that show significant lateral variation within the site (Figure 9.25). It has been called the '*Modiola* phase' or 'lagoon phase' by Dixon and Vaughan (1911). A detailed description of the lithologies is provided by George (1978b), Spalton (1979) and Ramsay (1987). Laminated dolomitic mudstones are the most common rock types, but disrupted, brecciated and slumped beds also occur. Fossils are limited, but calcispheres, ostracodes, foraminifera and crinoid fragments are characteristic.

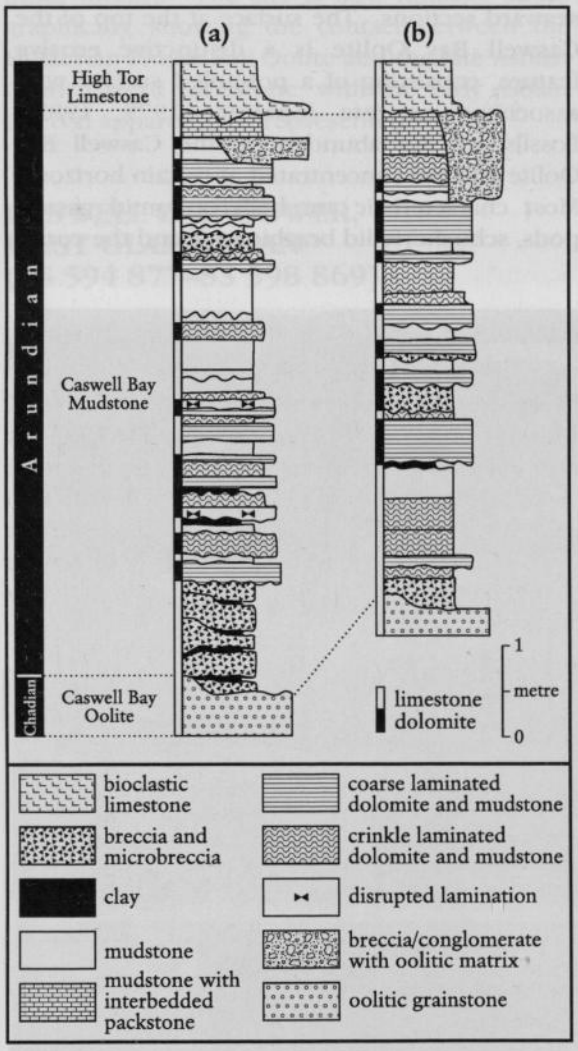


Figure 9.25 Comparative sections of the Caswell Bay Mudstone at Caswell Bay illustrating some of the lateral variations in lithofacies. The location of the sections is shown in Figure 9.23. After Ramsay (1987).

The High Tor Limestone is Arundian in age (George *et al.*, 1976) and consists of roughly 100 m of bioturbated bioclastic and peloidal carbonate sands, resting with sharp, erosive contact on the Caswell Bay Mudstone. About one-third of the way up the succession, trough cross-bedded and planar laminated carbonate sands are overlain by a mudstone with pedogenic features (Spalton, 1979; Ramsay, 1987). Above this are a few metres of dolomitic mudstones and wackestones, before a return to the more characteristic bioclastic and peloidal packstones. As well as large amounts of crinoid debris, the High Tor Limestone contains abundant gastropods, *Syringopora* cf. *geniculata*, *Michelinia grandis*, *Siphonophyllia cylindrica* and *Palaeosmilia* (Owen and Rhodes, 1969).

The lower part of the Hunts Bay Oolite is seen at Whiteshell Point at the south-eastern extremity of the site. There is a gradational contact with the High Tor Limestone. Bioturbated packstones at the base give way to cross-bedded oolitic and mixed grain packstones and grainstones with horizons rich in the brachiopods *Linoprotonia corrugato-hemispherica* and *Composita ficoidea* (Owen and Rhodes, 1969). *Koninckopora* is a particularly common element of the microflora (Spalton, 1979).

Interpretation

The exposed Dinantian succession at Caswell Bay consists entirely of shallow marine limestones deposited on a southerly dipping carbonate ramp (Wright, 1986a) (Figure 9.3). The succession dates probably from latest Courceyan (Ramsay, 1987) to early Holkerian age. A variety of shallow marine and marginal environments are represented, and detailed interpretations of these are provided by Ramsay (1987). The following are brief summaries based mostly on his work.

The Penmaen Burrows Limestone Group records storm-influenced offshore environments perhaps deeper than the rest of the succession. Bioturbation and dolomitization have destroyed many of the primary sedimentary structures. The Caswell Bay Oolite marks a shallowing of the sea and the establishment of shoreline environments in the area. Ramsay (1987) interpreted the Caswell Bay Oolite as the deposits of ebb-tidal deltas and beaches of a barrier-island coastline cut by storm-generated channels. He noted that the deep channel seen in the seaward exposures at this site records a catastrophic event that resulted in the erosion of at least 4000 m^3 of sediment. The top of the Caswell Bay Oolite is marked by subaerial exposure and soil formation.

The Caswell Bay Mudstone is a heterolithic assemblage representing a carbonate tidal-flat environment. George (1978b) used the presence of desiccation features and evaporite pseudomorphs as indicators of arid sabkha-type deposits, but Ramsay (1987) noted the paucity of evaporite-related features and interpreted the climate as humid rather than arid or semi-arid. Although George (1978b) and Ramsay (1987) regarded the Caswell Bay Mudstone to be of Chadian age, Riding and Wright (1981) considered the formation to be Arundian in age on sedimentological grounds. The erosive contact of the High Tor Limestone with the Caswell Bay Mudstone is attributed to marine transgression and migration of barrier, shoreface and tidal-channel environments across the tidal-flat complex (Ramsay, 1987). The High Tor Limestone beds record the existence of a barrier–lagoon–inlet complex that was prone to occasional periods of subaerial exposure and soil development.

Initial deposits of the Hunts Bay Oolite record a gradual deepening of the sea, with facies resembling those of the Penmaen Burrows Limestone Group. An oolitic sand-belt was then established in the area, suggesting a return to shallower water environments.

Conclusions

Caswell Bay provides spectacular exposures of a major part of the Dinantian limestone succession in Gower and is the type locality for both the Caswell Bay Oolite and the Caswell Bay Mudstone. A range of environments are represented, from tidal flats and beaches, through shallow marine sand-bodies, to offshore fair-weather and storm deposits. It is thus an extremely valuable teaching and research resource. Repetition of units through folding and faulting allows some lateral variation in these units to be studied. The site is also excellent for studying the effects of subaerial exposure during deposition of a limestone succession, and for studying the effects of later diagenesis. Caswell Bay also displays many faunal elements regarded as typical of the Chadian, Arundian and Holkerian stages in Gower.

BRACELET BAY, GOWER, WEST GLAMORGAN (SS 629 872)

Introduction

The Bracelet Bay GCR site (SS 629 872) lies 500 m west of Mumbles Head on the south Gower coast. The site is important for its well-exposed section of the Holkerian Hunts Bay Oolite which includes a sponge bioherm. The site (also known as 'Broadslade') is mentioned by Dixon and Vaughan (1911) and briefly described by Owen (1971). Although the Holkerian succession on the Gower Peninsula has been studied generally by Ramsay (1987) and Scott (1988) there is no published detailed description and interpretation of this site.

Description

Bracelet Bay lies on the hinge of the eastwards-plunging Langland Anticline (George, 1940) and exposes the higher part of the Holkerian Hunts Bay Oolite (Owen, 1971). On the southern limb of the fold, about 80 m of strata can be seen on the foreshore and in the low cliffs along the western side of the bay (Figure 9.26). Near the base of the succession a biostrome up to 0.5 m thick occurs. The biostrome is dominated by the demosponge *Chaetetes*, together with disarticulated productoids, solitary rugose corals, *Syringopora* and crinoid stems. The chaetetid sponges formed columnar- and domal-shaped colonies, some of which were clearly inverted before final deposition. In many of the colonies the early stages of development show a meandrine growth form whereas later stages show the more typical cerioid form.

About a third of the way up the succession, oncoidal packstones and wackestones with bands containing *Composita ambigua* are prominent (Figure 9.27). Some specimens of *Composita* have been weathered to show their internal structure. In the uppermost part of the succession chaetetids re-appear, together with beds of disarticulated but unbroken productoids, alternating with cross-stratified and planar-laminated grainstones up to a metre thick.

Interpretation

The Holkerian sequence records the establishment and southwards migration of a linear oolitic sand-belt orientated parallel with the

Figure 9.26 General view of the Hunts Bay Oolite (Holkerian) at Bracelet Bay, Gower. (Photo: P.J. Cossey.)

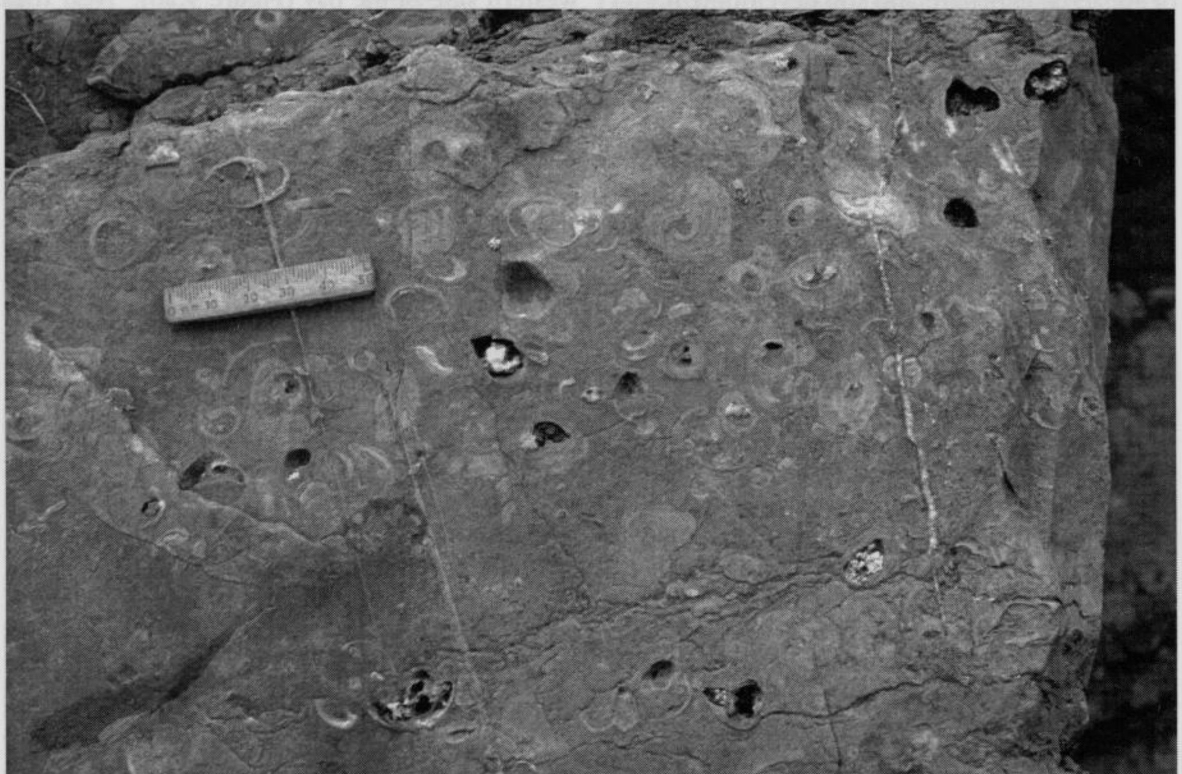


Figure 9.27 Oncoids associated with *Composita ficoidea* in the Hunts Bay Oolite (Holkerian) at the Bracelet Bay GCR site. (Photo: A.E. Adams.)

contemporary shoreline, with sand-flat and lagoonal deposits occurring on the northern, landward, protected flanks of this sand-body (Ramsay, 1987). The oncoidal and bioclastic wackestones and packstones which dominate the upper part of the Hunts Bay Oolite, including those seen at Bracelet Bay, are interpreted as part of the barrier platform interior, bordering the lagoon, by Ramsay (1987).

The biostrome at Bracelet Bay contains chaetetid sponges that have been toppled over or inverted, but the rich faunal association of large sponges together with disarticulated but unfragmented brachiopods suggests that the assemblage has not been transported any great distance. Other bioherms are known from the Hunts Bay Oolite, including examples dominated by lithostrotionid corals, such as that exposed on Spaniard Rocks in the north-west of the peninsula (Ramsay, 1987), but biostromes dominated by *Chaetetes* are not known elsewhere on Gower.

Conclusions

Bracelet Bay offers one of the best and most accessible sections of the Hunts Bay Oolite in eastern Gower and is important for its well-exposed faunas, including a small biostrome characterized by *Chaetetes*. It also shows the muddier, lower energy facies of oncoidal and bioclastic limestones in the Hunts Bay Oolite, interpreted as back-barrier deposits.

ILSTON QUARRY, GOWER, WEST GLAMORGAN (SS 555 906)

Introduction

The Ilston Quarry GCR site is a disused quarry (SS 555 906) immediately adjacent to the hamlet of Ilston. It is the most accessible section on Gower for illustrating the cyclic nature of the Asbian and Brigantian limestones. This cyclicity reflects frequent sea-level oscillations caused by the build-up and melting of ice sheets over the southern continental mass, called Gondwana. There are at least eight cyclothemic rock units in the quarry, each separated by a clay horizon interpreted as a fossil soil, overlying an irregular dissolution (palaeokarstic) surface. This style of sedimentation, with cyclothems capped by subaerial exposure surfaces, is the pattern found in all post-Holkerian to late Permian limestones globally. It stands in marked contrast to that represented by older Carboniferous successions in the region that were not affected by frequent sea-level oscillations. The Ilston fossil soil horizons differ somewhat from those found in Derbyshire and North Wales (see chapters 7 and 8) in lacking evidence of arid climate intervals.

The currently accessible section falls entirely within the Oxwich Head Limestone. Above this, approximately 10 m of the Oystermouth Beds (= Black Lias of the D_3 Zone) was formerly exposed. This stratigraphical terminology follows the subdivisions recognized by the [British] Geological Survey (Institute of Geological Sciences, 1973) and George *et al.* (1976). Ramsay (1991) provided a detailed log of the section. He also defined the position of the Asbian–Brigantian stage boundary within the Oxwich Head Limestone (following George *et al.*, 1976) immediately above a couplet of clay bands and below a massively bedded unit at the northern end of the site. A general reference to the succession is made by Dixon and Vaughan (1911).

Description

The main face of this disused quarry exposes some 100 m of limestones dipping 50° NNE, although Ramsay (1991) recorded a section totalling 160 m in thickness. The bulk of the section consists of crudely cyclic, thickly bedded to massive bioclastic, peloidal and oolitic limestones, many of which show pseudobrecciated features typical of limestones of this age. Ramsay (1991) has discussed the lithofacies types for this stratigraphical interval in South Wales but the account presented here includes information from unpublished data by N.A.H. Pickard (Figure 9.28). Bioclastic ooid grainstones are the main lithology present, commonly medium- to coarse-sand grade, and these tend to be the lithology beneath the exposure surfaces. The major bioclasts are corals, crinoids, brachiopods, foraminifera and algae (e.g. *Koninckopora*); clay intraclasts also occur. Bioclastic peloidal grainstones and packstones are also common, typically more bioclast-rich and with grainstone textures in the lower parts of cyclothems, and more matrix-rich in the mid parts. Less common are fine skeletal wackestones–packstones and carbonate mudstones, the latter with ostracodes. These two

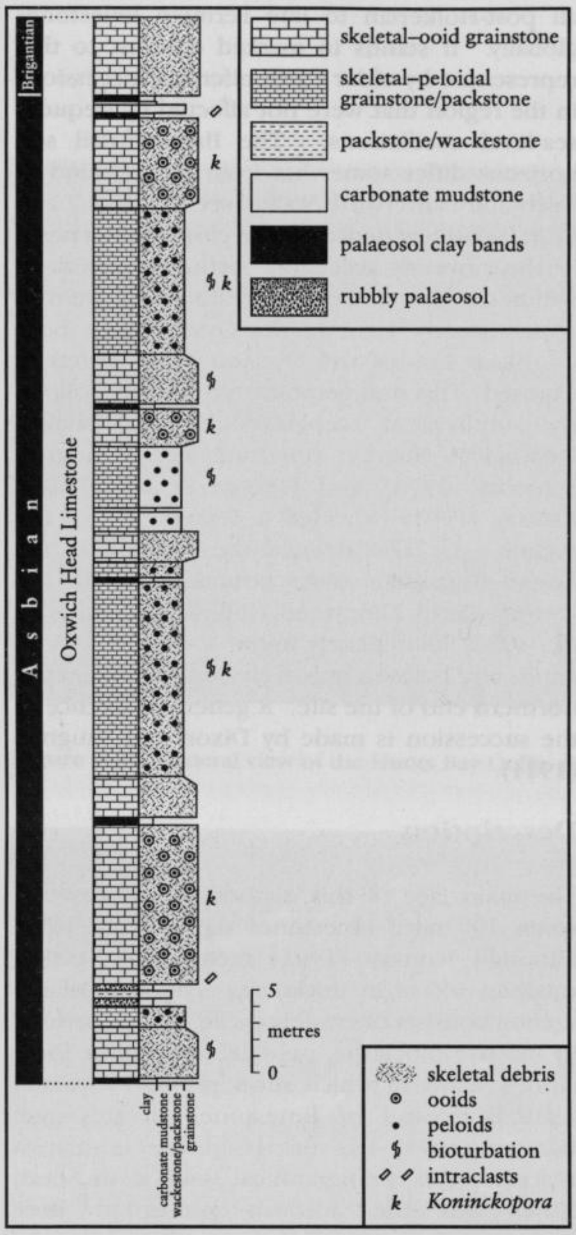


Figure 9.28 Sedimentary log of the main quarry face in the Oxwich Head Limestone (Asbian) at Ilston Quarry showing the location of six clay palaeosols and two rubble horizons. After information supplied courtesy of N.A.H. Pickard.

lithologies are confined to thin cyclothems or to the boundaries between cyclothems. Many of the limestones display irregular centimetre-sized pale-grey mottling patterns referred to as 'pseudobreccias', which is an early diagenetic product common to limestones of this age.

The most distinctive feature of the section is the presence of six distinctly recessed clay horizons, each of which is up to 0.75 m in thickness (Figure 9.28) and which contain minor thin rubble horizons. These have a high illite–smectite content. They range from green to grey in colour when fresh, and weather to red and brown, largely as a result of pyrite oxidation. Associated with this decomposition of pyrite is the production of sulphur and gypsum. The pyrite occurs as crusts on the underlying limestone, as nodules within the clays, and associated with thin organic-rich horizons at the tops of the clays. Thin coals, some with rootlets, are also present, capping many of the clays in the quarry. The underlying tops of the limestones are irregular and locally display smooth circular pits up to a metre deep and filled with clay (Figure 9.29). Unlike many other Asbian sections showing these features, calcrete crusts are not well developed.

Interpretation

The association of limestones and clay beds with subaerial exposure features is characteristic of late Viséan sequences in Britain and elsewhere, with some 40 different stratigraphical levels showing these effects in the Asbian Stage and nine in the Brigantian Stage (Vanstone, 1996). The limestones are all of shallow-water character, with skeletal-rich grainstones representing initial transgressive phases. The more matrix- and peloidal-rich lithologies probably represent somewhat deeper and lower-energy deposits marking the deeper-water phases. The oolitic grainstones represent shallowing, highstand units. The clays are typical of Asbian and Brigantian deposits throughout Britain and have been termed 'K-bentonites', produced by the degradation of basaltic volcanic ashes. The general characteristics of these late Viséan exposure features have been reviewed by Vanstone (1996, 1998). The underlying limestone surfaces represent palaeokarsts on which small pits developed, probably initially around individual trees (Vanstone, 1998), and because of the increased drainage around these trees caused by the funneling of rainwater along branches and down the tree trunks (stem-flow effect). These surfaces elsewhere in Britian are veneered with calcrete crusts and rhizocretions, representing semi-arid intervals, as well as palaeokarstic surfaces representing more humid phases. Thus at each exposure surface a history of humid to semi-arid conditions can be

Figure 9.29 General view of the Oxwich Head Limestone (Asbian) at Ilston Quarry. Beds dip from top left to bottom right (to the north-east). Note the presence of two prominent clay-filled solution pits (each approximately 2 m deep) on a palaeokarstic surface seen towards the centre of the illustration. (Photo: V.P. Wright.)

identified (Vanstone, 1996). The absence of calcrete crusts and rhizocretions from the Gower surfaces has been interpreted by Vanstone (1996) as possibly reflecting deposition of these limestones in deeper water than comparable sections elsewhere in Britain. As a result, the Gower area did not become exposed until the climate had become more humid (since calcrete crusts developed under more arid conditions), the area being re-flooded before the later phase of calcrete formation could take place (Figure 9.30). The clays underwent soil development in a climate humid enough to allow the movement of iron, resulting in concentrations of iron which later became pyritized. The occurrence of this pyrite has been interpreted as due to marine hydromorphism causing sulphate reduction as the carbonate platforms were flooded by sea water. As the sea level rose, the local freshwater lenses will also have risen, which probably created freshwater ponds in which the peats formed that were later transformed into thin coals (Wright *et al.*, 1997). Vanstone (1996) has suggested that the paucity of clay soils from the bulk of the Brigantian section in the Gower was due to deepening conditions.

These late Viséan cyclothems have been widely regarded as the products of glacio-eustatic sea-level oscillations (Wright and Vanstone, 2001), taking place on a 100 000 to 125 000 year frequency (Horbury, 1989). These were most likely triggered by Milankovitch eccentricity cycles, causing cooling in higher latitudes that resulted in the build-up and subsequent melt-out of continental ice-sheets over southern Gondwana. Thus, if no cycles are missing, the main part of the section at Ilston represents about 800 000 to 1 million years. Sea-level oscillations were probably in the range of 10–30 m (Horbury, 1989).

Conclusions

The Ilston section provides a exceptional Asbian–Brigantian section of the Oxwich Head Limestone, revealing evidence of the oscillations in global sea-level that characterized the late Viséan to late Permian world. The result of these sea-level oscillations was to create cyclic limestones with prominent subaerial exposure surfaces marked by palaeokarsts and palaeosols. These oscillations were the result of the growth and melting of continental ice sheets over the southern continental mass of Gondwana. Slightly deeper water conditions in the Gower compared to areas such as North Wales and Derbyshire resulted in the platforms only being exposed for shorter intervals, with the result that the limestones were exposed only during humid climate phases.

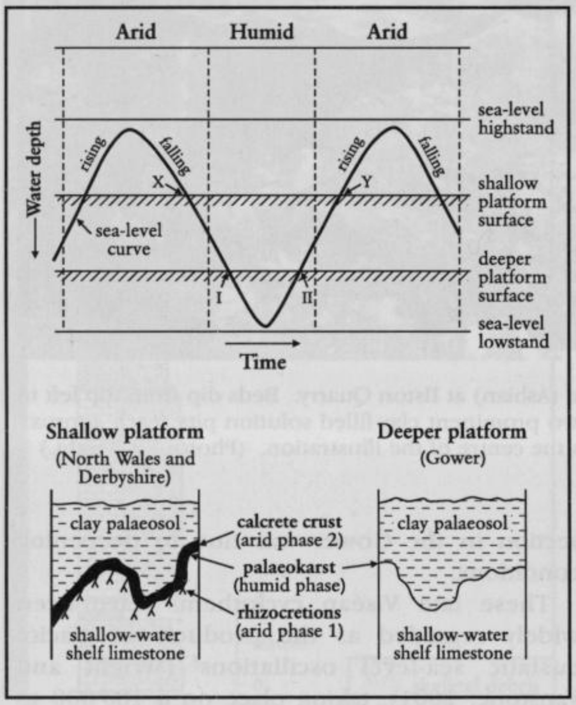


Figure 9.30 Model to show why the exposure surfaces at Ilston Quarry differ from those in other parts of the UK. Differences arise because of the contrasting depths of the platforms. Shallow platforms were exposed early during periods of sea-level fall, when the prevailing climate was more arid (X). As a result, the exposed carbonate sediments acted as substrates for roots that became lightly calcified in the semi-arid conditions forming rhizocretions. These shallow platforms were not flooded until late on in the rise part of each sea-level cycle, when the climate was again more arid (Y) after a humid phase. In the case of platforms that were slightly deeper (perhaps by only a few metres, as the sea-level oscillations were only in the order of 10–30 m), subaerial exposure did not take place until the climate had become more humid (I), and the exposure surface was flooded while the prevailing climate was still humid (II). The sea-level oscillation curve is here drawn as symmetric in form, but an asymmetric form is more likely, with the rise part of each cycle being rapid. After Vanstone (1996).

OYSTERMOUTH OLD QUARRY, GOWER, WEST GLAMORGAN (SS 615 883)

Introduction

The Oystermouth Old Quarry GCR site, also known as 'Clements Quarry', lies 6 km south-west of Swansea, on the seaward side of Oystermouth Castle (SS 615 883). The floor of the quarry is now a car park. Despite having become rather overgrown, the site offers the best exposure of the late Brigantian Oystermouth Beds; the topmost unit of the Carboniferous Limestone on the Gower Peninsula. The sedimentary facies recorded in this unit are transitional between the pure shelf limestones of the Dinantian succession beneath and the marine shales of the Namurian sequence above. Descriptions of the site feature in Dixon and Vaughan (1911) and Thorne (1978).

Description

The site shows a succession of dark-coloured limestones and shales (Figure 9.31) dipping approximately 25° eastwards, this more-or-less representing the plunge on the Colts Hill Anticline (Owen, 1971). This unit was originally known as the 'Upper Limestone Shales' (e.g. Strahan, 1907a), and has also been called the 'Black Lias' because of the resemblance of the bedding style to that of the Jurassic Blue Lias. It was attributed to the topmost division of the Carboniferous Limestone, the 'D_2–D_3' interval by Dixon and Vaughan (1911). In its re-survey of the Swansea district, the [British] Geological Survey (Institute of Geological Sciences, 1973) used the name 'Oystermouth Beds' to replace the term 'Upper Limestone Shales' in this area.

About 25 m of succession can now be seen, close to the top of the unit according to Dixon and Vaughan (1911). The limestones are argillaceous, sometimes crinoidal and often cherty, and are rather thicker than the inter-bedded calcareous shales. They were described as dark packstones by Ramsay (1989, 1991). Some levels are notably rich in sponge spicules, and finely crystalline dolomite is also locally present (Thorne, 1978).

The richest faunas have been collected from the shales (Owen, 1971) and include many brachiopods, notably *Martinia multicostata*, *Spirifer oystermouthensis*, *Schellwienella* cf.

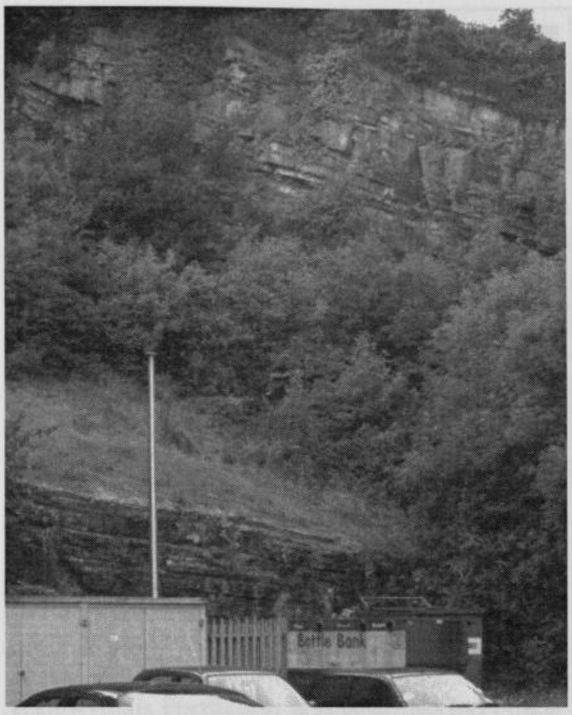


Figure 9.31 General view of the Brigantian Oystermouth Beds at Oystermouth Old Quarry, near Swansea. (Photo: P.J. Cossey.)

crenistria and *Eomarginifera longispina*. Solitary rugose corals are also present, including *Triplophyllites oystermouthensis* and *Amplexizaphrentis enniskilleni*, plus the trilobite *Paladin* '*Griffithides*' cf. *barkei*. The section was also searched for conodonts, but found to be almost completely barren (Rhodes *et al.*, 1969).

Interpretation

The dark packstones and interbedded shales of latest Brigantian age are regarded as offshore deposits by Ramsay (1991). They suggest an overall deepening of the environment towards the end of Dinantian times and also record the increasing input of terrigenous clastic material which, by the beginning of the Namurian Epoch, had terminated carbonate deposition in South Wales. George (1958) notes that this is a widespread late Dinantian facies; it can be recognized in Pembrokeshire (Bosherston) and the Mendips and extends as far as Belgium. On the north crop the facies extends as far east as the Vale of Neath where it is still known as the 'Upper Limestone Shales' (e.g. Barclay *et al.*, 1988). It is not known throughout the area covered in this chapter, partly because of post-Dinantian erosion and partly because the facies is replaced by sandstones in the Bristol district.

Conclusions

This site shows the best exposure of the uppermost unit of the Carboniferous Limestone in South Wales, the Oystermouth Beds. These beds represent offshore deposits with a higher concentration of fine-grained land-derived sediments than earlier formed parts of the Lower Carboniferous succession. The site is also important for its well-preserved late Dinantian brachiopod–coral–trilobite fauna and occasional ammonoids which confirm its late Brigantian age.

TONGWYNLAIS ROAD SECTION, SOUTH GLAMORGAN (ST 127 825–ST 131 824)

Introduction

The Tongwynlais Road Section GCR site consists of the road cuttings in the Taff Gorge on the east side of the road, 8 km north-west of Cardiff (ST 127 829–ST 131 824). The importance of the site lies in the exposure spanning the Devonian–Carboniferous boundary, which coincides at this locality with the change from predominantly non-marine terrigenous clastic deposition to marine carbonate deposition. The most detailed descriptions of the site can be found in Gayer *et al.* (1973), Burchette (1977) and Waters and Lawrence (1987).

Description

The most important part of this site is at the southern end where beds dip SSE on the southern limb of the Castell Coch Anticline. Gayer *et al.* (1973) recorded 19.3 m of Old Red Sandstone in the core of the anticline, overlain by at least 44.9 m of Carboniferous Limestone, now ascribed to the Lower Limestone Shale Group. The contact was taken at the base of the lowest limestone of the marine succession. Later workers placed the boundary differently: according to Waters and Lawrence (1987), the base of their newly defined Tongwynlais Formation (the lowest part of the Lower Limestone Shale Group) lies 2.6 m beneath the horizon chosen by Gayer *et al.* (1973) and 5 m lower than the base as taken by Burchette (1977, 1987).

The Upper Old Red Sandstone here consists of red and greenish-grey, micaceous, cross-bedded sandstones of the Quartz Conglomerate Group, becoming increasingly calcareous upwards (Gayer *et al.*, 1973). Waters and Lawrence (1987) recorded that the contact with the Tongwynlais Formation is sharp but conformable. Much of the Tongwynlais Formation comprises interbedded bioclastic limestones and shales, but with a more varied unit, 12 m thick, at the base. This basal unit comprises three divisions (Waters and Lawrence, 1987); the lowest, with calcretized sandy limestones and calcareous sandstones, is within the top of the Old Red Sandstone of Gayer *et al.* (1973). The middle unit consists of interbedded bioclastic limestones and shales, and the uppermost unit comprises red bioclastic grainstones resting on an erosive contact with the limestones beneath, overlain by oolitic and bioclastic grainstones (Figure 9.32) (Gayer *et al.*, 1973; Waters and Lawrence, 1987). The red unit contains haematite and is known as the 'Rhiwbina Ironstone' (Rogers, 1861; Squirrell and Downing, 1969). Haematite occurs as a replacement of skeletal grains, infilling pores within crinoids and bryozoans, as coatings on grains and as irregular rounded masses (Gayer *et al.*, 1973).

The remaining 30 m of the Tongwynlais Formation consists of bioclastic packstones and grainstones interbedded with micaceous, calcareous shales. Fossils include crinoids, ostracodes, brachiopods, bivalves, gastropods, orthoconic nautiloids and fish debris (Waters and Lawrence, 1987). The topmost-exposed bed is an oolitic and crinoidal grainstone attributed to the Castell Coch Formation by Waters and Lawrence (1987).

Gayer *et al.* (1973) made a detailed study of plants, spores and brachiopods in the Upper Old Red Sandstone, together with conodonts and brachiopods from the Lower Limestone Shale Group. They also provided detailed faunal and floral lists. Limited further sampling for conodonts was reported by Waters and Lawrence (1987). According to Gayer *et al.* (1973), the conodonts indicate the *Patrognathus variabilis–Spathognathodus plumulus* and *Siphonodella–Polygnathus inornatus* assemblage zones as recognized in the Avon Gorge succession by Rhodes *et al.* (1969).

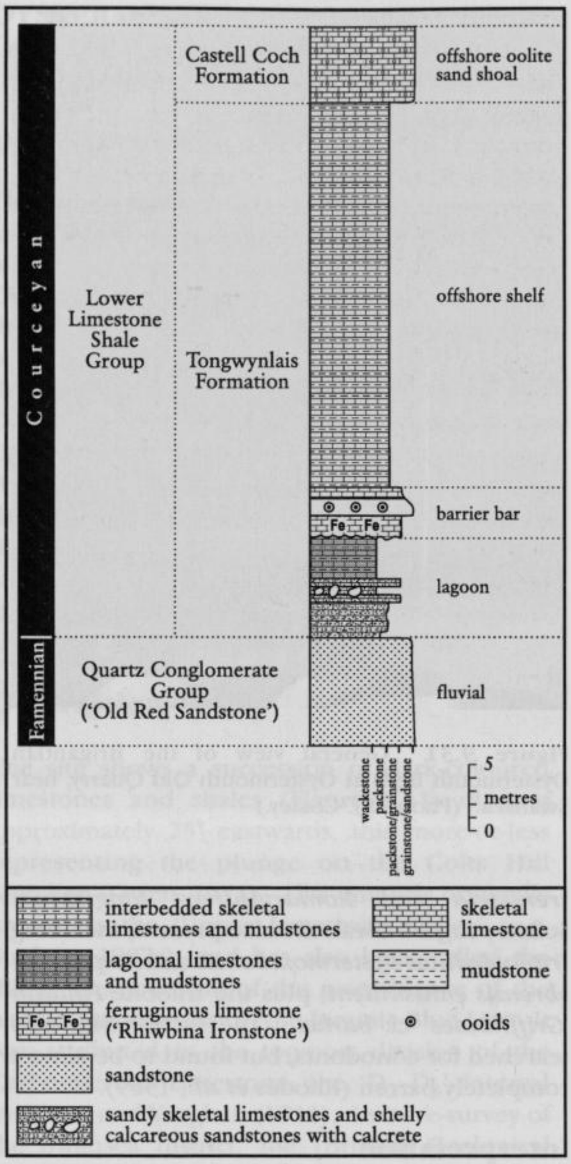


Figure 9.32 Sedimentary log of the Courceyan Tongwynlais Formation (Lower Limestone Shale Group) at Tongwynlais Road Cutting. After Waters and Lawrence (1987), with interpretations based on information from Burchette (1987) and Burchette *et al.* (1990).

The northern limb of the Castell Coch Anticline is less well exposed in the road cutting and is eventually truncated by the Castell Coch Thrust (Gayer *et al.*, 1973). Farther north, dolomitic limestones, probably belonging to the Black Rock Limestone Group, can be seen dipping northwards and passing into brecciated mineralized dolomites whose structure is obscure (Gayer *et al.*, 1973).

Interpretation

The succession on the southern limb of the Castell Coch Anticline records the transition from the dominantly fluvial environment of the Old Red Sandstone to the dominantly marine environment of the Lower Limestone Shale Group–Tongwynlais Formation, although the exact position of the boundary has varied by a few metres according to different workers. Gayer *et al.* (1973) recorded spores which they attributed to the early Tournaisian within the upper part of the Old Red Sandstone and placed the Lower Limestone Shale–Old Red Sandstone boundary in the lower part of the Belgian Tn1b spore zone. However, as recorded by Waters and Lawrence (1987), Conil *et al.* (1977) revised the Famennian–Dinantian boundary in Belgium such that these floras now lie within the Famennian Stage. Waters and Lawrence (1987) recorded an earliest Courceyan conodont fauna between 1.5 m and 3 m above the base of the Tongwynlais Formation and thus the Devonian–Carboniferous boundary must lie very close to the lithostratigraphical boundary. Waters and Lawrence (1987) also discussed the significance of the conodont faunas recorded by Gayer *et al.* (1973) from the Lower Limestone Shale Group and cast doubt on the validity of the correlation of the upper part of the exposed section with the zones derived from the Avon Gorge succession, suggesting that the distribution of species was facies controlled.

The environment of deposition of the Tongwynlais Formation has been discussed by Burchette (1977, 1987). In the road section a channelled surface separates lagoonal deposits from the Old Red Sandstone (Burchette, 1987). These lagoonal deposits themselves are cut by a major channelled horizon representing a 'ravinement' surface that developed during transgression and the establishment of a barrier bar (Figure 9.32). The remainder of the succession records a transition to an offshore shelf environment where storm processes were important (Burchette, 1987).

Conclusions

This site is invaluable for its section across the Old Red Sandstone–Carboniferous Limestone boundary and for the biostratigraphical data it has yielded which suggest that the lithostratigraphical boundary is more-or-less coincident with the boundary between the Famennian (uppermost Devonian) and Courceyan stages. The locality is also important for allowing the study of the faunas, floras and strata developed during the transgression that established marine conditions in the area after deposition of the largely fluvial Old Red Sandstone.

BROFISCIN QUARRY, MID GLAMORGAN (ST 070 813)

Introduction

The Brofiscin Quarry GCR site is a disused quarry (ST 070 813), 3 km south-east of Llantrisant. It is the type section for the Courceyan Brofiscin Oolite (Black Rock Limestone Group), a widespread unit in South Wales that represents a shallowing of the early Carboniferous seas. The section begins in the Barry Harbour Limestone, contains the whole of the Brofiscin Oolite and ends in the lower part of the overlying Friars Point Limestone. The Brofiscin Oolite was originally named the 'Candleston Oolite' by George (1933), and the succession in the area was documented by Dixey and Sibly (1918). The most recent descriptions with biostratigraphical data have been provided by Waters and Lawrence (1987) (see also Wilson *et al.*, 1990).

Description

This is a disused quarry that is commonly stated to have been the site of toxic waste disposal. The quarry floor is very poorly drained and appears to be composed of clay-rich material covering a layer of large oil drums which are leaking. Much of the area is at times flooded with water containing leachate, which may be dangerous, and therefore care should be taken in these areas. Great care should also be taken when approaching the rock faces, as there is a gap between the quarry floor and the vertical faces in some areas. Waters and Lawrence (1987) record a 70 m succession at this locality. At its base is approximately 17 m of the Barry Harbour Limestone, with some oolitic units. Lithologies in this unit consist of dolomitized, fine-grained, laminated and cross-laminated bioclastic limestones, with bryozoans and crinoid remains. The unit has a sharp contact with the overlying Brofiscin Oolite, which is a massive to thickly bedded unit (13.6 m thick) of pale- to dark-grey, well-sorted, oolitic, skeletal grainstones (Figure 9.33) with local planar cross-stratification. A distinctive feature is the localized reddening of the ooids. The unit is heavily dolomitized and contains some chert pods together with crinoid and brachiopod debris. This unit is sharply overlain by approximately 38 m of the Friars Point Limestone, which is composed mainly of dolomitized, muddy bioclastic limestones. There is no evidence of a subaerial surface at the top of the Brofiscin Oolite as occurs in the Gower (Burchette *et al.*, 1990). The lower part of the Friars Point Limestone comprises fine, pale- to dark-grey, laminated and cross-laminated dolostones (*c.* 5 m) overlain by graded beds of dark bioclastic packstone with mudstone partings and erosive-based, brachiopod–crinoid lags with planar and cross-stratified layers, and hummocky cross-stratification (*c.* 13 m). The upper part of the unit (*c.* 20 m) consists of black, foetid, bioturbated and bioclastic packstones–wackestones with shaly interbeds, crinoid lags and a fauna of bryozoans, brachiopods, corals and gastropods.

Interpretation

Lithostratigraphical correlations equate the Black Rock Limestone Group in the Llantrisant area with the Penmaen Burrows Limestone Group farther west in the Gower Peninsula (see Figure 9.2, and **Three Cliffs Bay** and **Caswell Bay** GCR reports, this chapter). Similarly the Barry Harbour Limestone appears to be the lateral equivalent of the Shipway Limestone, while the Friars Point Limestone correlates broadly with the Tears Point Limestone (see Figure 9.2). Conodont studies by Waters and Lawrence (1987) indicate that the Barry Harbour Limestone and the lower part of the Brofiscin Oolite lie within the *Siphonodella–Pseudpolygnathus multistriatus* Interzone, whereas the uppermost beds (5–6 m) of the 'Oolite' and lowermost 4–5 m of the Friars Point Limestone fall within the overlying *Ps. multistriatus* Zone. Thus the Brofiscin Oolite is Courceyan in age. The remaining part of the Friars Point Limestone is ascribed to the *Polygnathus mehli* Zone (Waters and Lawrence, 1987).

Figure 9.33 The Brofiscin Oolite (left) and the Friars Point Limestone (top centre and right) at Brofiscin Quarry near Groes Faen. The development of the oolitic and shelly beds of the Brofiscin Oolite, with its prominent chert nodules, records a regional shallowing event across the South Wales area during Courceyan times. (Photo: P.J. Cossey.)

The nature of the outcrop does not allow any detailed facies analysis beyond the fact that the Brofiscin Oolite marks a regional shallowing phase. The Barry Harbour Limestone, by analogy with coastal outcrops, represents a mid-ramp storm-influenced setting. Shallowing took place allowing ooid generation, but a subsequent transgression brought the return of deeper offshore, mid-ramp deposition as the Friars Point Limestone. The Brofiscin Oolite thins southwards, and Burchette *et al.* (1990), based mainly on data from the Gower, speculated that the formation was a storm and longshore current-influenced, shoreline-detached sand-body, unlike the barrier-island oolites found at other levels in the local Lower Carboniferous rocks. The unit can be traced southwards into the Yorke Rock Bed, a 3–5 m-thick well-sorted crinoidal grainstone in the Barry area (Waters and Lawrence, 1987). In the Gower, the unit is sharp-based and this might indicate that it represents a forced regressive event rather than a simple highstand shallowing phase, as may well be the case at this site. In both areas, however, the development of a mid-ramp facies immediately above the formation is indicative of a rapid transgressive event.

Conclusions

The site is the type section for the Brofiscin Oolite, an oolitic sand-body of Courceyan age that marks a regional shallowing across the gently dipping carbonate ramp that developed across South Wales in early Carboniferous times.

DANYGRAIG, GWENT (ST 234 908)

Introduction

The Danygraig GCR site is a disused quarry and landfill site (ST 234 908), immediately west of Risca. It exposes a section in the Rudry Formation (George *et al.*, 1976) of probable late Chadian–Arundian age, which may provide a critical link between sections in the Vale of Glamorgan and Gower to others in the Abergavenny–Penderyn region. The main section contains a variety of very shallow-water limestones and clays that were deposited on storm-influenced intertidal flats, in shallow lagoons and as soils. The formation appears to be an equivalent of the Cheltenham Limestone Member of the Llanelly Formation, a unit cropping out from Gilwern to near Penderyn to the north and north-west (see **Llanelly Quarry**, **Clydach Halt Lime Works**, **Cwar yr Ystrad and Hendre**, **Baltic Quarry**, **Odynau Tyle'r Bont** and **Blaen Onneu Quarry** GCR site reports, this chapter). However, the section at Danygraig is at least three times thicker than its possible northern equivalent. The original, extensive section was discussed by George (1956a) and the only recent work has been that on the dolomites from the quarry by Hird *et al.* (1987).

Description

Two sections are available in the Rudry Formation. The southern exposures comprise thickly bedded to massively bedded dolomites and may be of Chadian age. Those in the western part of the site are probable Llanelly Formation equivalents, and are therefore likely to be Arundian in age. The latter crops out in two sections. The smaller of the two sections is located close to the site entrance. This section reveals the higher part of the succession, which comprises approximately 10 m of medium- to thin-bedded limestones and dolomites, with shale and clay partings. The lower part of the Llanelly Formation equivalent, higher up the slope, is a larger, continuous section (Figure 9.34) exposing 28 m of mainly medium- to thick-bedded limestones and dolomites, with a variety of clays. Many of the carbonates exhibit prominent fine wavy lamination. Hird *et al.* (1987) note microbial laminites with fine bioclastic units and intraformational breccias, fenestral fabrics and pseudomorphs after gypsum. They also presented detailed mineralogical and geochemical data on the associated dolomites. The present outcrop does not contain any obvious contacts with other units, nor any of the distinctive palaeokarst horizons associated with the Llanelly Formation in its main outcrop area. Also absent from this site is the distinctive fluvial lithofacies of the Llanelly Formation with its thick calcrete palaeosols that form the basal and top members of the formation in its type area.

Interpretation

The western section closely resembles the Cheltenham Limestone Member of the Arundian Llanelly Formation except in two respects. Firstly, typical thickness values for this member

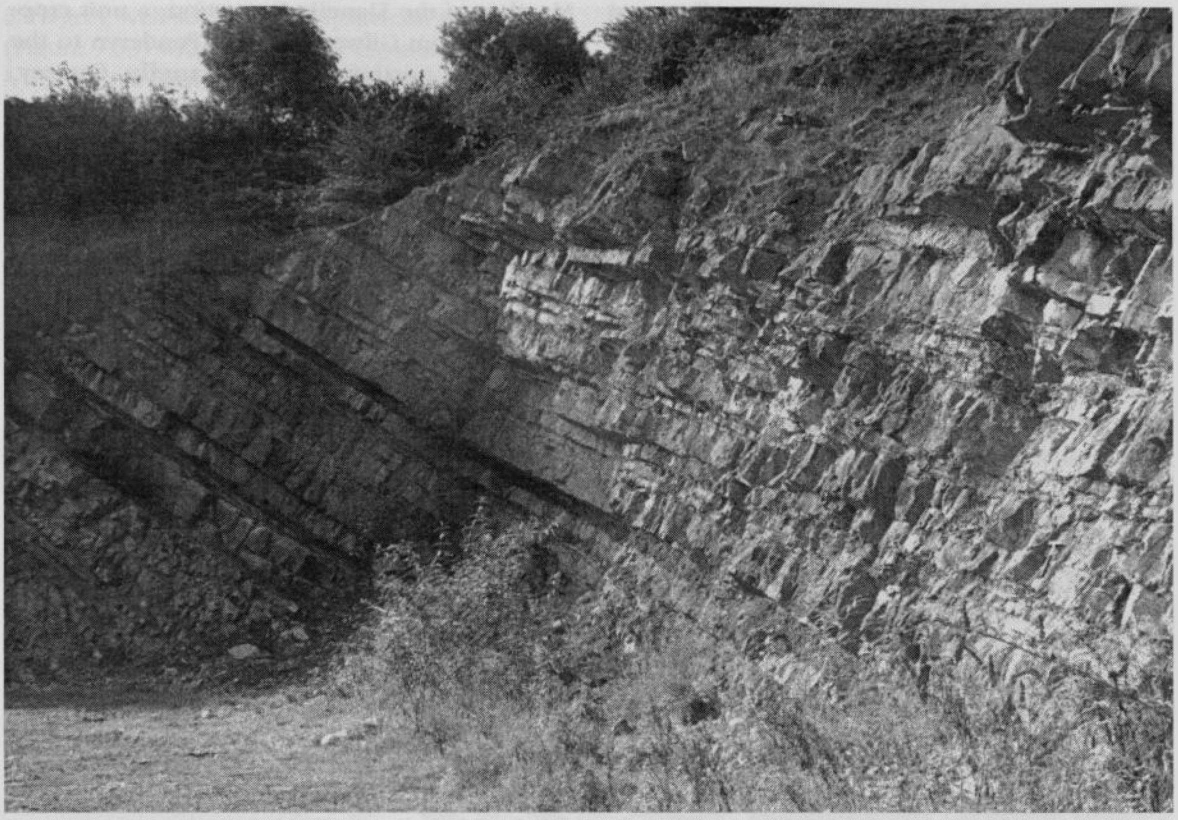


Figure 9.34 General view of Danygraig, Risca, illustrating shallow marine and peritidal deposits of the Rudry Formation. This site forms an important link between the Caswell Bay Mudstone of southern outcrops and the Llanelly Formation of the North Crop. (Photo: P.J. Cossey.)

range from 1.75 m to 8.5 m, not 28 m as at this site. Secondly, laminated rocks are not a common lithology in the Cheltenham Limestone Member, making up only 12.5% by thickness (Wright, 1981a). There are also significant differences with the Caswell Bay Mudstone of the Vale of Glamorgan and Gower, which, although commonly well laminated (Riding and Wright, 1981; Waters and Lawrence, 1987) does not exhibit common clay beds, and is also not as thick as the unit at Danygraig. There are, however, similarities with the Arundian Clifton Down Mudstone of the Chipping Sodbury–Tytherington area (Weedon, 1987).

The Danygraig succession was deposited in very shallow waters and a significant proportion was formed in a variety of intertidal settings. The preservation of fine lamination with thin bioclastic layers is typical of lower intertidal, storm-influenced settings. The presence of brecciation and gypsum pseudomorphs probably relates to upper intertidal to supratidal conditions. Hird *et al.* (1987) interpreted the finely crystalline dolomites in this section to be of peritidal origin. The clay beds, by analogy with the more studied Cheltenham Limestone Member, may represent thin palaeosols, but this assertion requires further investigation.

A clue to the origin of the Danygraig section might come from a sequence stratigraphical approach. In this context, the Caswell Bay Mudstone may represent a transgressive unit developed during the early Arundian sea-level rise, whereas the Cheltenham Limestone Member has the characteristics of a mainly high-stand systems tract (Wright, 1996). It is possible that the Danygraig section represents an intermediate setting. To the south, down ramp, the combined effects of real sea-level rise and subsidence led to the drowning of the peritidal systems of the Caswell Bay Mudstone and to the development of a relatively thick set of offshore bioclastic limestones, the High Tor Limestone. In the more northern areas, where the rate of accommodation space creation was reduced, partly as a result of low subsidence rates, only a thin, broadly regressive peritidal unit formed (Llanelly Formation), associated with prominent palaeosol development. At the intermediate setting represented by Danygraig, the rate of accommodation space creation was in balance with sediment production, allowing the peritidal deposits to stack and not to be drowned and transgressed, as in the case of the Caswell Bay Mudstone. This might also explain the apparent lack of well-developed palaeosols in the Danygraig section.

The dolomitized sections to the south probably equate to the Chadian Gully Oolite or Gilwern Oolite, assuming that these outcrops are in sequence and that no fault exists between them and the peritidal limestones to the west.

Conclusions

This site contains peritidal carbonates, of probable Arundian age. It is unique in that it may represent an important link between well-documented sections in South Wales, to the south-west and north. The site is therefore a key site for future sedimentological and stratigraphical research and pivotal to the understanding of late Chadian–Arundian palaeogeography in the South Wales area.

STENDERS QUARRY, GLOUCESTERSHIRE (SO 659 182)

Introduction

The Stenders Quarry GCR site is situated 0.5 km south-west of Mitcheldean in Gloucestershire. This disused quarry (SO 659 182) provides arguably the finest section of the early Courceyan Lower Limestone Shale Group in the Forest of Dean area. Sandwiched between the top of the Old Red Sandstone (Tintern Sandstone) and the base of the Lower Dolomite (George *et al.*, 1976), the sequence includes a significant part of both the Castell Coch Formation (the Castell Coch Limestone, Astridge Wood Member and Mitcheldean Member) and the Cwmyniscoy Formation (Burchette, 1987) a unit which equates with the Cwmyniscoy Mudstone Formation of the Clydach and Cardiff districts (Waters and Lawrence, 1987; Barclay, 1989) (Figure 9.2). The succession was formed in a variety of nearshore and offshore settings as sea water flooded across the exposed southern margin of the Wales–Brabant Massif during early Carboniferous times. An early site description by Sibly and Reynolds (1937) includes a detailed log of the section and a significant amount of palaeontological data. Much of this work was later reproduced in summary form by Welch and Trotter (1961). Details relating to the sedimentology are given by Burchette (1977, 1987).

The site is also referred to as the 'Cement Works Quarry' (Sibly and Reynolds, 1937), the 'Cementstone Quarry' (Burchette, 1977) and 'Wilderness Quarry' (Welch and Trotter, 1961). It is not, however, the locality referred to by Wethered (1888) as 'Wilderness Cement Works'.

Description

The Lower Limestone Shales at this site comprise an attenuated and fossiliferous succession (*c.* 56 m thick) of mudstones, thin-bedded micritic limestones and a few developments of thicker-bedded calcarenites. The sequence, which dips steeply (*c.* 50°–60°) to the south-west, lies on the eastern limb of the southward-plunging Wigpool Syncline (Figure 9.35). At its base and immediately overlying the upper part of the Tintern Sandstone, a lower unit (*c.* 9 m) representing part of the Castell Coch Limestone (Burchette, 1987) begins with locally conglomeratic sandstones and quartzose grainstones which grade upward into thick-bedded, cross-stratified oolitic and crinoidal calcarenites. While brachiopods (especially *Macropotamorhynchus 'Camarotoechia' mitcheldeanensis*), ostracodes and bryozoans are common in this unit, 'spirorbids' are also known at some levels (Sibly and Reynolds, 1937). Poor exposure and the gradational change from the Tintern Sandstone to the Castell Coch Limestone make it difficult to define the position of the Old Red Sandstone–Lower Limestone Shale Group boundary.

The overlying Astridge Wood Member (*c.* 11 m) is characterized by thinly bedded and occasionally sandy, bioclastic (crinoidal) limestones and thin mudstone horizons. From some particularly fossiliferous limestones near the top of this unit, Sibly and Reynolds (1937) recorded an abundant fauna of ostracodes, bryozoans, brachiopods (atrypids, rhynchonellids and small productoids) and crinoids together with modiolid bivalves, the 'calcareous algae *Solenopora* and *Mitcheldeania*', *Parachaetetes*, sparse echinoids (*Palaechinus*), a fish tooth (*Psephodus*) and evidence of bioturbation. A

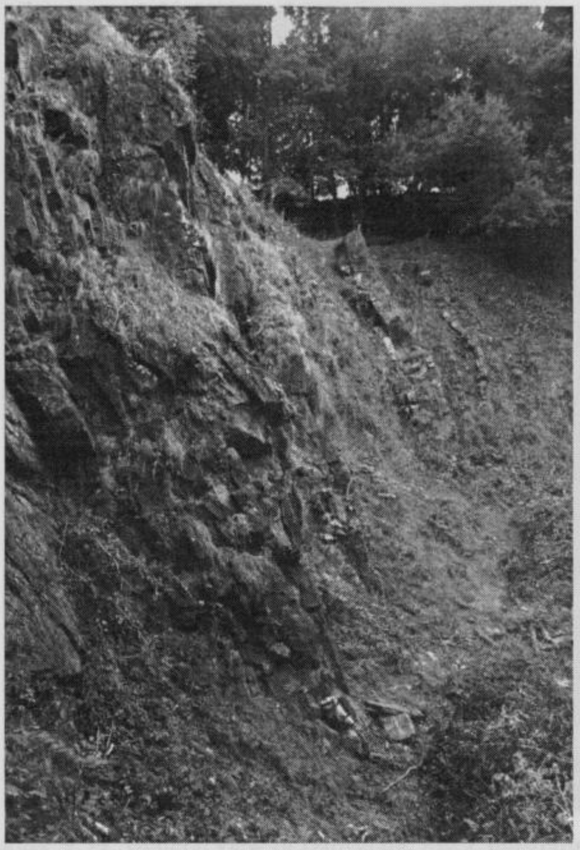


Figure 9.35 Interbedded limestones and shales of the Courceyan Lower Limestone Shale Group at the Stenders Quarry GCR site in the Forest of Dean. (Photo: P.J. Cossey.)

loose specimen of the early Courceyan index coral *Vaughania vetus* may also have come from this level (see Sibly and Reynolds, 1937).

Above this, the Mitcheldean Member (*c.* 13 m) comprises a shale-dominated interval containing a number of thin limestone beds sandwiched between two prominent skeletal calcarenite bands. Both Sibly and Reynolds (1937) and Burchette (1977) gave a detailed description of this part of the sequence. Close to its base are micritic limestones with fenestrae. Immediately overlying this, a distinctive nodular oncoid horizon contains the 'calcareous algae – *Mitcheldeania, Solenopora* and *Spongiostroma*' (Sibly and Reynolds, 1937) in close association with the vermiform gastropod '*Serpula*' *advena* (a form now re-assigned as a microconchid; see Weedon, 1990), ostracodes and fragmented bivalve shells. A similar association between possible microconchids and a microbial laminite occurs higher in the sequence. The significance of such 'biostromal' associations recorded at other Lower Limestone Shale localities in southern Britain and from Border Group successions in the north of England is discussed by Burchette and Riding (1977).

The prominent and brachiopod-rich calcarenite band (3 m) at the top of the Mitcheldean Member is the lateral equivalent of the topmost part of the Stowe Oolite Member. This is directly superseded by a poorly exposed shale-dominated interval (*c.* 20 m) representing the upper part of the Cwmyniscoy Formation. At its base is the prominent 'Bryozoa Bed' (Sibly and Reynolds, 1937), a ferruginous and partly dolomitized crinoidal limestone that contains brachiopods and bryozoans in abundance. The remaining part of the formation includes a few thin, sharp-based and fossiliferous limestones which also contain a bryozoan–brachiopod fauna. The higher of these limestone intervals is dolomitized. The top of the Cwmyniscoy Formation is overlain by the massive dolomitized calcarenites of the Lower Dolomite, but only the base of this unit is seen in the quarry.

Interpretation

Burchette (1987) interpreted the Lower Limestone Shale Group as a transgressive unit that developed as a depositional response to the major (and possibly eustatic) sea-level rise that took place at the beginning of the Carboniferous Period. Within it he recognized several depositional cycles formed during periods of shoreline advance (regressive phase) and retreat (transgressive phase). Considered in this context, the lower beds of the Castell Coch Limestone are interpreted as part of a littoral sand-sheet formed by a northward-advancing shoreline, and the higher oolitic beds part of a southward-prograding subtidal carbonate sand-body behind which sediments of the Astridge Wood Member accumulated in a shallow marine embayment or open lagoon (Burchette *et al.*, 1990). The characteristic features of the Mitcheldean Member are regarded as more typical of deposition in a restricted and hypersaline lagoon. Burchette (1987) suggested this unit developed in the lee of another southward-prograding sand-body (the Stowe Oolite) that formed a NE–SW-trending barrier complex and as part of a later depositional cycle (Figure 9.4a). The prominent calcarenite at the top of the Mitcheldean Member probably represents a washover fan deposited as the Stowe Oolite barrier was drowned during a further transgressive episode that later resulted in the deposition of the Cwmyniscoy Formation in a deeper water offshore setting.

The occurrence of *M. 'C' mitcheldeanensis*, *Cleiothyridina roissyi*, *Pugilis 'Dictyoclostus' vaughani* and *Syringothyris cyrtorhyncha* and a possible record of *V. vetus* (Sibly and Reynolds, 1937) confirm an early Courceyan age for the Lower Limestone Shale sequence at this site (see Riley, 1993).

Outcrops of the Lower Limestone Shale Group also occur at **Tongwynlais Road Section** and **Maesbury Railway Cutting** (see GCR site reports, this chapter). While the Mitcheldean (Stenders Quarry) section is clearly younger than that at Tongwynlais in the Taff Gorge (see Burchette, 1987), its relationship to the section at Maesbury, in the Mendips, remains unclear, though a broadly comparable age is suspected. Together these complementary sections provide detailed evidence of the palaeogeographical changes that resulted from the major marine transgression that swept northwards across parts of southern England and South Wales at the beginning of the Carboniferous Period.

Conclusions

The Lower Limestone Shale Group at Stenders Quarry offers an outstanding section of nearshore peritidal and lagoonal deposits in complex association with barrier–shoreline and offshore deposits. The succession represents part of a transgressive 'start-up' phase of carbonate ramp sedimentation (Kendall and Schlager, 1981) and provides critical evidence for the understanding of the palaeogeographical evolution of southern England during early Carboniferous (Courceyan) times.

SCULLY GROVE QUARRY, GLOUCESTERSHIRE (SO 657 187)

Introduction

The Scully Grove Quarry GCR site is located on the eastern limb of the Wigpool Syncline, 0.5 km west of Mitcheldean. This disused quarry (SO 657 187) provides an important but attenuated Lower Carboniferous succession that extends from the top of the Lower Dolomite, through to the base of the Drybrook Sandstone (Figure 9.2). The section, which includes the Crease Limestone (C_1) and arguably the 'finest' exposure of the Whitehead Limestone (C_2S_1) in the Forest of Dean area (Welch and Trotter, 1961), was deposited in a shallow and mostly marginal marine environment on the South Wales–Mendip Shelf during Chadian and Arundian times. Regrettably, at the time of writing the lower part of this succession was badly overgrown. A detailed description of the site geology was presented by Sibly and Reynolds (1937), much of which has been reproduced in a later publication by Welch and Trotter (1961).

Description

The site includes an elongate N–S-trending strike section (*c.* 120 m long) of the Whitehead Limestone, and a section of the Lower Dolomite and Crease Limestone which is indifferently exposed in a disused NW–SW-trending tramway cutting (*c.* 80 m long) that connects with the quarry at its southern end. Across the site, beds dip consistently to the west at approximately 40°.

Poor exposure and the occurrence of dolomitized beds in both the Crease Limestone and the Lower Dolomite currently make it difficult to define the boundary between these two units. Details of the Lower Dolomite are scant, but a description of the upper part of this unit exposed close by (see Sibly and Reynolds, 1937) refers to the occurrence of finely crystalline dolomites with partially dolomitized crinoidal layers and a fauna consisting of spiriferoids, chonetoids and *Euomphalus*. The overlying Crease Limestone (*c.* 23 m thick) is an incompletely dolomitized crinoidal limestone, containing *Syringopora*, *Bellerophon*, *Psephodus*, a rich brachiopod fauna and variable amounts of oolitic material. The base and top of this unit are more pervasively dolomitized in the Mitcheldean area than its middle section (Sibly and Reynolds, 1937).

Above this, the Whitehead Limestone (*c.* 13 m thick) comprises a mixed and partially dolomitized sequence of massive to well-bedded 'algal' (oncoidal) limestones, oolitic and micritic limestones, vari-coloured clays, thin sandstones and calcareous grits, with a restricted marginal marine and 'lagoonal' biotic assemblage dominated by microbial oncoids containing *Garwoodia 'Mitcheldeania'* sp. (see Wethered, 1886; Wood, 1941; Welch and Trotter, 1961), *Spongiostroma*, *Aphralysia*, spirorbids and ostracodes. Rare bivalves (*Lithodomus* cf. *lingualis*), nautiloids (*Cycloceras*), foraminifera and 'worm-casts' are reported from some layers (Sibly and Reynolds, 1937). The inclusion of terrigenous sand in a number of the limestone beds is a prelude to the deposition of the overlying Lower Drybrook Sandstone, which is no longer exposed in the quarry.

Interpretation

Lithostratigraphical correlations broadly equate the Lower Dolomite, Crease Limestone, Whitehead Limestone and Drybrook Sandstone of the Mitcheldean area respectively with the Black Rock Dolomite, Gully Oolite, Clifton Down Mudstone and the Cromhall Sandstone in the Cromhall, Avon Gorge and Mendips region to the south (George *et al.*, 1976; Green, 1992; Kellaway and Welch, 1993; and see Figure 9.2). Regional sequence thickness variations (northerly thinning) and faunal evidence indicate that the Forest of Dean succession may be punctuated by a number of stratigraphical breaks, both within and at the base of the Whitehead Limestone and at the base of the Crease Limestone (George *et al.*, 1976; Green, 1992). However, conclusive evidence for all of these discontinuities has yet to be demonstrated because of the combined effects of dolomitization and poor exposure.

Despite the lack of modern sedimentological research on the Crease Limestone and Whitehead Limestone, an appreciation of the regional palaeogeography (see Green, 1992) allows a general palaeoenvironmental interpretation of the Scully Grove succession to be made. Coral and brachiopod evidence suggests that the Crease Limestone was formed in an open marine environment, but the restricted faunas, microbial ('algal') oncoids and lithologies of the Whitehead Limestone indicate that this unit was deposited as a 'lagoonal' (Sibly and Reynolds, 1937) and back-barrier facies to the peloidal grainstone barrier facies of the High Tor Limestone (Wilson *et al.*, 1988; and see Figure 9.4b). The general character of the succession, its reduced thickness and suspected stratigraphical breaks (Green, 1992), are a reflection of its proximal depositional setting on a slowly subsiding southward-dipping carbonate ramp on the southern margin of the Wales–Brabant Massif during early Carboniferous times.

Conclusions

The site provides one the most important Chadian–Arundian sections in the Forest of Dean area. The succession, which is thin in comparison with equivalent sections to the south, represents a marginal marine and nearshore facies deposited close to the northern margin of the South Wales–Mendip Shelf during the early to middle part of the Dinantian. The Whitehead Limestone contains an outstanding biostromal development of 'algal nodules' (microbial oncoids) – arguably the finest example of its kind in the Carboniferous rocks of southern England.

EDGEHILL SAND QUARRY, GLOUCESTERSHIRE (SO 661 168)

Introduction

The Edgehill Sand Quarry GCR site is located on the steeply dipping eastern limb of the Wigpool Syncline, 0.5 km to the south-west of Plump Hill in the Forest of Dean. This disused quarry (SO 661 168) contains a stratigraphically important section of the Drybook Sandstone and the Edgehills Sandstone. The site has been the focus of some detailed palynological research by Sullivan (1964b) and Spinner (1984), the results of which were re-evaluated by Cleal (1986) following the discovery of stratigraphically significant plant fossils. Although various ages have been suggested for different parts of the sequence, the balance of evidence would appear to favour a middle to late Viséan (Holkerian–Asbian) age for this section.

Description

The currently exposed sequence includes approximately 40 m (Cleal, 1986) of vari-coloured sandstones and conglomerates with subordinate developments of finer siliciclastic deposits (Figure 9.36). While the lower part of the section is ascribed to the Drybrook Sandstone (Sibly, 1912), the higher beds form part of the Edgehills Sandstone (Sullivan, 1964b). A thin coal (the Edgehills Coal) occurs close to the top of the Edgehills Sandstone. Uncertainty regarding the position of the Drybrook Sandstone–Edgehills Sandstone boundary (see below) makes it difficult to

Figure 9.36 Thick-bedded sandstones and finer siliciclastics of the Drybook Sandstone at Edgehill Sand Quarry, Gloucestershire. The upper part of the section seen in the background (top right) includes part of Sullivan's (1964b) Edgehills Sandstone and the Edgehills Coal (see text for further details, and Cleal, 1986). (Photo: P.J. Cossey.)

determine the exposed thickness values for these two units. The succession dips steeply (*c.* 60°) to the west (Figure 9.36).

Sullivan (1964b) recorded a somewhat greater total sequence thickness than the 40 m indicated by Cleal (1986). This difference is attributed to the difficulty in establishing the true thickness of the exposed succession, for when Sullivan's work was undertaken only two small quarries were present at the site, but when Cleal's work was undertaken the two quarries had been enlarged to form the single quarry face that is seen today (Cleal, 1986).

The Drybrook Sandstone is dominated by massively bedded, red, white and speckled and bioturbated medium-grained sandstones (some poorly consolidated and locally conglomeratic) with sparse siltstone bands and mudstone lenses. Near the base, a thin 'coaly shale' layer once generated a rich miospore assemblage including *Lycospora uber*, *Punctatisporites platyrugosus*, *Schultzospora ocellata*, *Convolutispora mellita*, *Leiotriletes tumidus*, *Waltzispora planiangulata*, *Vallatisporites ciliaris* and *Cribrosporites cribellatus* (Sullivan, 1964b). An S_2 Zone (Holkerian) age for this assemblage was suggested by Sullivan (1964b) thus confirming the earlier held view (Sibly, 1918) of an S_2 Zone age for the Drybrook Sandstone based on the discovery of *Davidsonina carbonaria* in the Drybrook Limestone. A slightly younger TC miospore zone (Asbian) age for this assemblage was later suggested by Neves *et al.* (1972). Subsequently, the discovery of the TC Zone megaspores *Carbaneuletes circularis* and *Didymosporites* *scotti* by Spinner (1984), from the same horizon as Sullivan's, apparently confirmed an Asbian age for this part of the sequence. Regrettably these lower beds of the Drybook Sandstone are no longer exposed at the site.

The Edgehills Sandstone, by contrast, consists of coarser purple and grey sandstones (some pebbly) and conglomerates. At its top, a finer mudstone–siltstone interval (3 m) includes the Edgehills Coal (15–25 cm) from which Sullivan (1964b) recorded a 'Westphalian A' miospore assemblage that included *Granulatisporites* cf. *micrograntfer*, *Lycospora pusilla*, *Savitrisporites nux*, *Dictyotriletes sagenoformis*, *Knoxisporites stephanephorus*, *Cirratriradites saturni*, *Apiculatisporis variocorneus*, *Crassispora kosankei*, *Florinites* spp., *Raistrickia* spp., *Fabasporites pallidus* and *Calamospora mutabilis*. The discovery of further 'Westphalian A' megaspores, including *Cystosporites varius*, *Triangulatisporites regalis* and *Tuberculatisporites apiculatus*, from the same horizon (Spinner, 1984) appeared to support Sullivan's view of the age of these beds. However, Cleal (1986) recorded a drifted plant macrofossil assemblage from a purplish-grey mudstone immediately below the Edgehills Coal that included the horsetail *Archaeocalamites radiatus*, the lycopods *Tomiodendron variabilis* and *Lepidostrobus lanceolatum*, and possible pteridosperm stem fragments which he regarded as Viséan age.

The Drybrook Sandstone–Edgehills Sandstone boundary was originally defined by Sullivan (1964b) at the base of the 'first ... thick conglomerate band ... above the massively bedded sandstones'. However, the absence of this boundary from Sullivan's log and the subsequent re-shaping of the quarry make this boundary difficult to place in the section as it is currently exposed. Careful consideration of Sullivan's log indicates that it may lie either 14 m or 24 m below the level of the Edgehills Coal (as seen in the quarry at present) although Cleal (1986) placed the boundary higher in the section, some 3–5 m below the Edgehills Coal.

Interpretation

Miospore evidence from the lower of the two assemblages described by Sullivan (1964b) indicates a Viséan (Holkerian–Asbian) age for this part of the Drybrook Sandstone succession. However, the occurrence of Westphalian A spore assemblages in the Edgehills Coal (Sullivan, 1964b; Spinner, 1984), in a part of the sequence formerly assigned to the Drybrook Sandstone, led Sullivan (1964b) to conclude that a significant unconformity existed within the sequence, and this unconformity was used to mark the local base to the overlying Edgehills Sandstone succession. Later, following the discovery of plant macrofossils immediately below the Edgehills Coal, Cleal (1986) was able to challenge Sullivan's view. Considering the time ranges of the plant taxa he recorded and re-evaluating the palynological evidence, Cleal (1986) concluded that the Edgehills Sandstone was also of Viséan (and probably Asbian) age, and not of lower Westphalian age as previously thought. He also noted that the character of the plant horizon bore a striking resemblance to the classic Drybrook Sandstone flora of Puddlebrook Quarry (Lele and Walton, 1962), from which NM Zone (Asbian) miospore assemblages were subsequently recorded (Rowe, 1988; Cleal and Thomas, 1995). Following this argument, a major stratigraphical break in the sequence at Edgehill Sand Quarry now seems unlikely. Thus the Edgehills Sandstone may simply represent a distinctive lithofacies that developed locally towards the top of the Drybrook Sandstone over broadly the same time period.

While a braid stream origin is suggested for much of the Drybrook Sandstone, littoral strand plain deposits comprising 'planar or sheet sandstones with a trace fauna' and supratidal mudflat and swamp deposits (carbonaceous mudrocks and thin coal horizons) are also recognized in the unit (Jones, 1984). Although each of these environments may be represented at Edgehill Sand Quarry, their precise definition within the section has yet to be demonstrated.

Regional assessments of the Drybrook Sandstone and its lateral equivalent east of the River Severn, the Cromhall Sandstone, indicate that these units formed part of a marine-influenced fluvial complex (Atta-ntim, 1984) that extended south towards the Bristol district during middle and late Viséan times; a complex that developed in response to a period of contemporary earth movements (uplift) along the line of the Malvern Axis (see Dixon in Smith, 1930; Jones, 1984; Wilson *et al.*, 1988; Kellaway and Welch, 1993).

Conclusions

This locality provides one of the most important and easily accessible sections of the Drybrook Sandstone and Edgehills Sandstone in the Forest of Dean area. The rocks most probably represent a combination of ancient river, coastline and swamp deposits formed in middle to late Viséan times as a result of localized uplift along an ancient fault line (the Malvern Axis). Uncertainty regarding the precise age of parts of the sequence make this one of the most stratigraphically contentious sites of Lower Carboniferous age in southern England.

AVON GORGE, BRISTOL, AVON (ST 554 748–ST 566 727)

Introduction

The Avon Gorge site lies 3 km west of Bristol city centre. The GCR site includes exposures on both banks of the river and in the surrounding cliffs and old quarries from near Sneyd Park (ST 554 748) to Clifton (ST 566 727). Here almost all of the Dinantian succession of the region is exposed. This classic stratigraphical site assumed national and international significance as a result of the pioneering work undertaken by Vaughan (1905), who established the first biostratigraphical zonation scheme for the Carboniferous Limestone based on the distribution of coral–brachiopod faunas taken largely from the Avon Gorge section. This work, with various subsequent modifications, proved to be the standard for the correlation of Lower Carboniferous shelf limestone successions in Britain for the next 70 years. Its significance has recently been evaluated by Riley (1993). Aspects of the succession were also considered by Vaughan (1906) and Reynolds (1920, 1921, 1926, 1936). One of the more critical of these contributions was by Reynolds (1921) in which the lithological succession in the gorge was first defined. The most informative recent account is by Kellaway and Welch (1993) who record all the significant changes at the site since Vaughan's work was published and who also provide an abundance of modern and high-quality annotated outcrop illustrations. Conodont faunas from the section were described by Rhodes *et al.* (1969).

Description

Kellaway and Welch (1993) summarize the changes that have affected the Avon Gorge section since the work of Arthur Vaughan. Overall there has been some deterioration in the section, with parts becoming overgrown and inaccessible. The nature of the exposure also changed when a railway line along the right bank was closed and a road (the Portway) opened. The uppermost part of the succession has always been poorly exposed and the Ashton Park Borehole (Kellaway, 1967) was drilled to examine that part of the succession. The construction of new deep tunnels has also added to our knowledge of the stratigraphy of the area. The account here is based on the work of Kellaway and Welch (1993) and a summary stratigraphical column based on their work is illustrated in Figure 9.37. Strata dip south-eastwards at an average of 25°–35°, although there are considerable structural complications especially in the more southerly part of the section, some of which were not recognized by earlier workers. A map of the gorge illustrating the distribution of lithostratigraphical units is presented in Figure 9.38.

In the Bristol area the non-marine beds of the Upper Old Red Sandstone 'pass imperceptibly upwards into the wholly marine sequences of the Carboniferous Limestone' (Kellaway and Welch, 1993). The Shirehampton Beds, which record this passage, are said to possess a mixed Devonian–Carboniferous fauna. For convenience, the base of the Carboniferous Limestone Series is taken at a pebbly sandstone containing fish remains, known as the 'Sneyd Park Fish Bed', at the base of the Shirehampton Beds. The Shirehampton Beds consist of a heterolithic assemblage of impure limestones, mudstones and sandstones. Much of this part of the succession on the right bank of the river is now obscured, but the upper part of the unit, consisting of shale and sandstone overlain by a red crinoidal and bryozoan limestone, known as the 'Bryozoa Bed', can be seen (ST 558 747). This part of the section was placed in the *Modiola* Zone by Vaughan (1905) and is recognized as a shallow-water phase at the base of the Carboniferous succession. In his zonal scheme, Vaughan (1905) recognized discrete intervals in which the zonal indices of two contiguous zones could be found. Vaughan designated these with

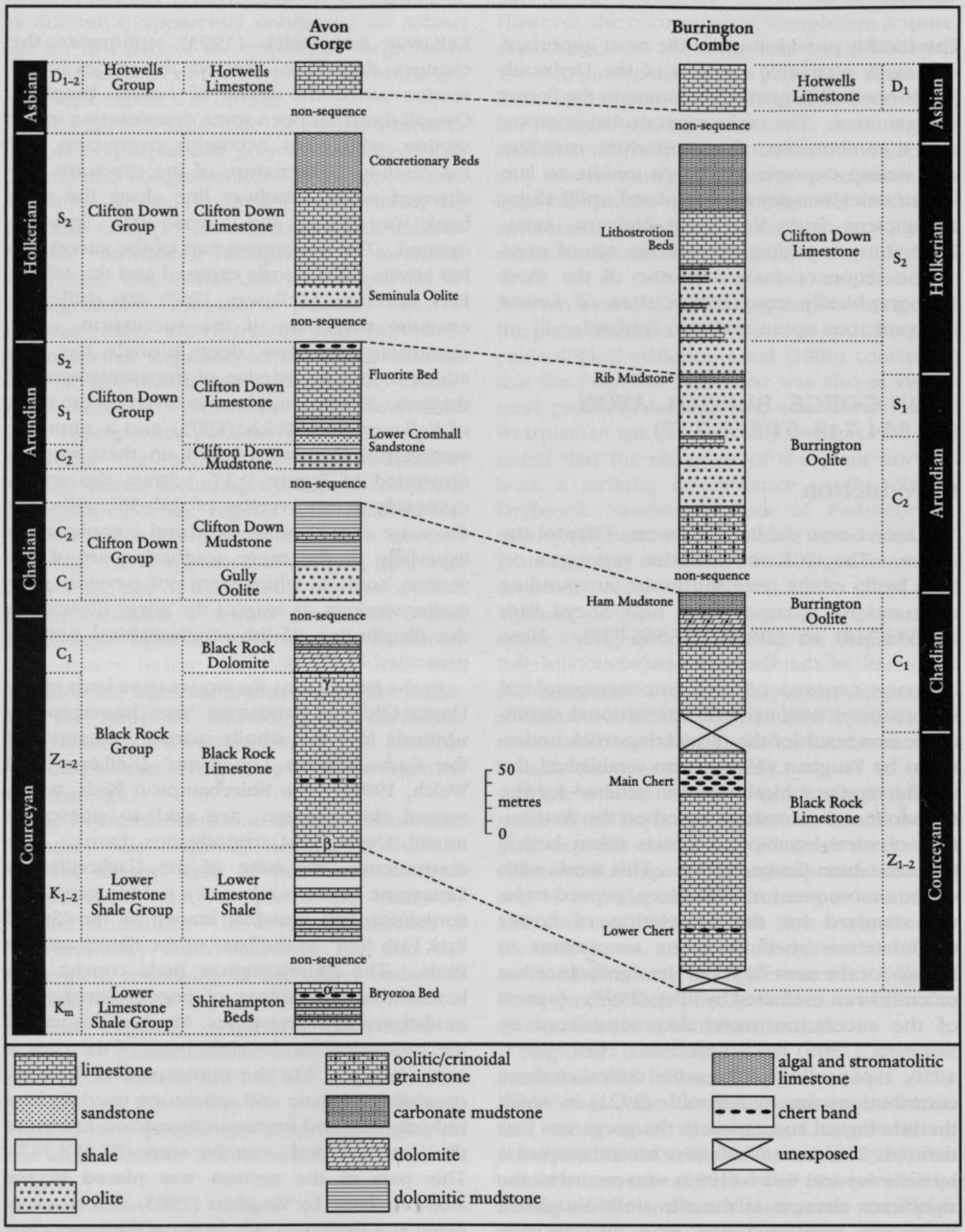
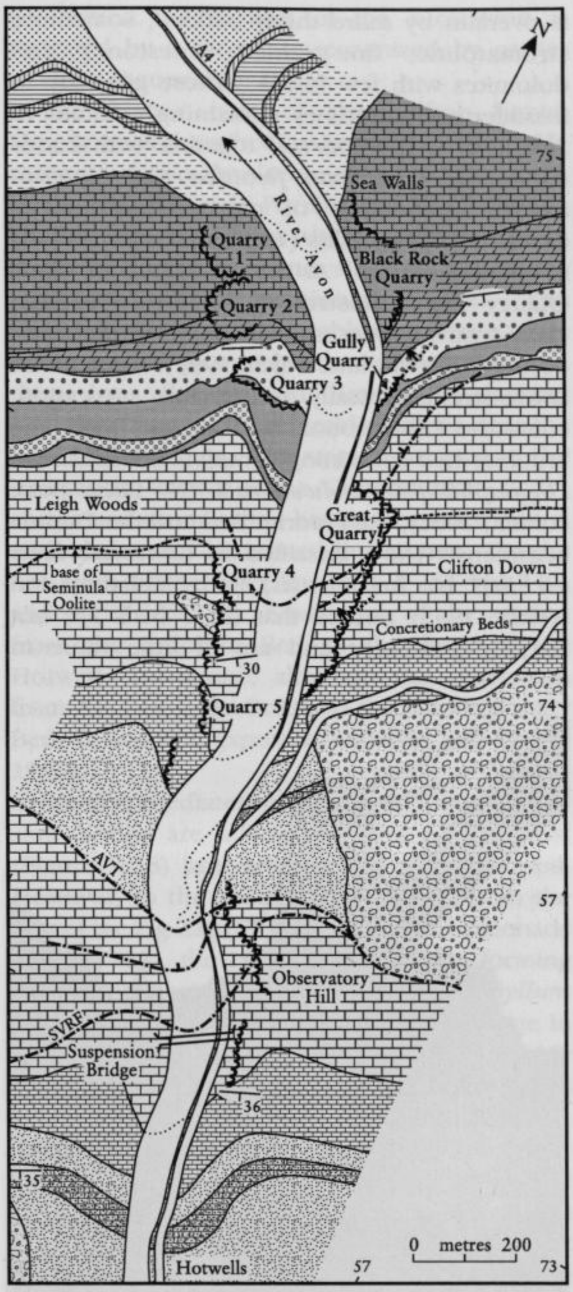


Figure 9.37 Comparative sections of Dinantian strata exposed at the Avon Gorge and **Burrington Combe** GCR sites. After Kellaway and Welch (1993) and including non-sequence information from Ramsbottom (1973) and George *et al.* (1976). Biostratigraphical information is from Vaughan (1905, 1906), Reynolds and Vaughan (1911) and Reynolds (1921). Horizons α, β and γ are based on Vaughan (1905).



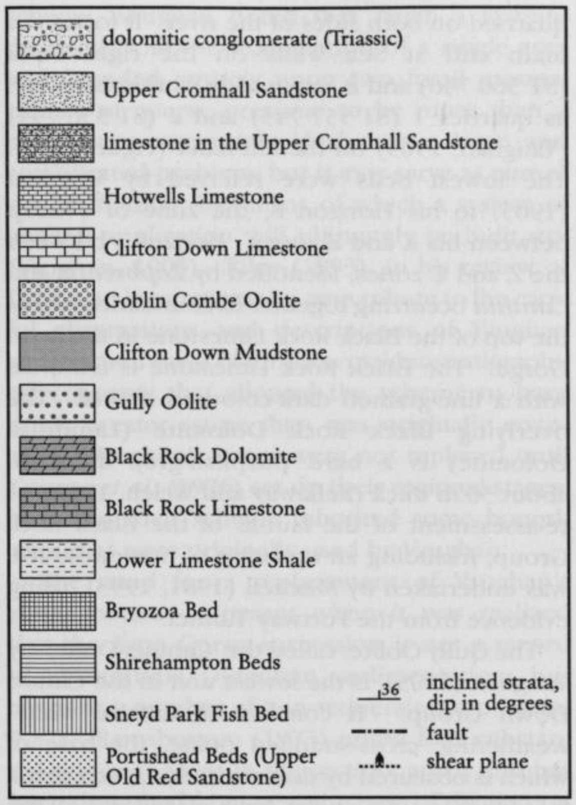


Figure 9.38 Simplified geological map of the Avon Gorge showing the position of localities referred to in the text. AVT – Avon Thrust Fault; SVRF – St Vincent's Rocks Fault. After Kellaway and Welch (1993).

a Greek letter, the Bryozoa Bed becoming Horizon α. On the left bank of the river, some 25 m of shale, sandstone and limestone, succeeded by the Bryozoa Bed, overlie a conglomerate thought to mark the top of the Old Red Sandstone (Kellaway and Welch, 1993). The palynology of the Shirehampton Beds was described by Utting and Neves (1970). Their evidence confirms that the Devonian–Carboniferous boundary lies close to the Sneyd Park Fish Bed.

The Lower Limestone Shale is now poorly exposed in the gorge. On the left bank, about 15 m of thinly bedded mudstones and fine-grained limestones can be seen overlying the Bryozoa Bed (ST 556 746). The lowest bed, resting on an eroded surface of the Bryozoa Bed, is a thin conglomeratic and phosphatic unit containing *Lingula* and fish remains. This was called the 'Palate Bed' by Stoddart (1876). *Vaughania vetus* has been recovered from the upper part of this succession (Kellaway and Welch, 1993). Conodonts from this level were reported by Butler (1973), who also recorded caliche development in the Bryozoa Bed. On the right bank of the river, thinly bedded bioclastic limestones attributed to the top of the Lower Limestone Shale can be seen immediately beneath the more massive limestones (Black Rock Limestone) at the base of the overlying Black Rock Group (ST 559 747).

The succeeding limestone-dominated units are better exposed than the muddy facies below. The Black Rock Limestone has been extensively quarried on both sides of the river. It forms the main cliff at Sea Walls on the right bank (ST 560 746) and is exposed in workings known as quarries 1 (ST 557 745) and 2 (ST 558 744) (Vaughan, 1905) on the left bank (Figure 9.38). The lowest beds were referred by Vaughan (1905) to his Horizon ß, the zone of overlap between his K and Z zones. Horizon γ between the Z and C zones, identified by *Zaphrentis* and *Caninia* occurring together in abundance, lies at the top of the Black Rock Limestone in the Avon Gorge. The Black Rock Limestone is crinoidal with a fine-grained dark-coloured matrix. The overlying Black Rock Dolomite (Laminosa Dolomite) is a hard purplish-grey dolomite about 30 m thick (Kellaway and Welch, 1993). A re-assessment of the faunas of the Black Rock Group, including an updating of nomenclature, was undertaken by Mitchell (1981, 1993), using evidence from the Portway Tunnel.

The Gully Oolite, called the 'Caninia Oolite' by Vaughan (1905), is the lowest unit in the Clifton Down Group. It consists of massive white-weathering, cross-stratified oolite, the base of which is obscured by dolomitization, such that a fossiliferous unit at the base elsewhere in the Bristol area – the 'Sub-Oolite Bed' – cannot be recognized (Kellaway and Welch, 1993). The Clifton Down Mudstone consists of well-bedded or lenticular, pale-grey carbonate mudstones and stromatolites with very few fossils. The upper part contains three beds of more massive, cross-stratified, oolitic and crinoidal limestone, correlated with the Goblin Combe Oolite found to the south of Bristol (Figures 9.2 and 9.3b). These are succeeded by 15 m of hard grey limestones with brachiopods including productoids, spiriferoids and rhynchonelloids, as well as the gastropod *Bellerophon* (Kellaway and Welch, 1993). The occurrence of the latter led to Vaughan (1905) naming this part of the succession the 'Bellerophon Beds', although he did not recognize this unit in the Avon Gorge. The Bellerophon Beds can be seen in a crag between quarries 3 and 4 on the left bank (ST 560 742) (Kellaway and Welch, 1993).

The Clifton Down Limestone is seen particularly well in sections at Great Quarry (ST 563 740) and is repeated by faulting farther south under Brunel's suspension bridge (Figure 9.39). The base of the Clifton Down Limestone is a bed of sandy limestone correlated with the Lower Cromhall Sandstone seen to the north of Bristol (Kellaway and Welch, 1955, 1993). This is overlain by more thinly bedded, sometimes stromatolitic, fine-grained limestones and dolomites with few fossils. These give way to fossiliferous limestones containing colonies of *Siphonodendron martini* together with bands containing *Composita ficoidea* and *Linoprotonia*. A number of named fossil bands described by Reynolds (1921) occur in this part of the succession. At the north end of Great Quarry the Lithostrotion Band of Vaughan (1906), now known as the 'Diphyphyllum Band', occurs (Kellaway and Welch, 1993). Some 30 m above stratigraphically, and in close succession, come the Lithostrotion basaltiforme Band, the Trilobite Bed containing complete specimens of *Linguaphillipsia holwellensis* (N. Riley, pers. comm., 2002), the Fluorite Bed and the Caninia bristolensis (now classified as *Caninophyllum archiaci* var. *bristolensis*) Bed. Kellaway and Welch (1993) remark that these beds are not laterally persistent and are of little value in

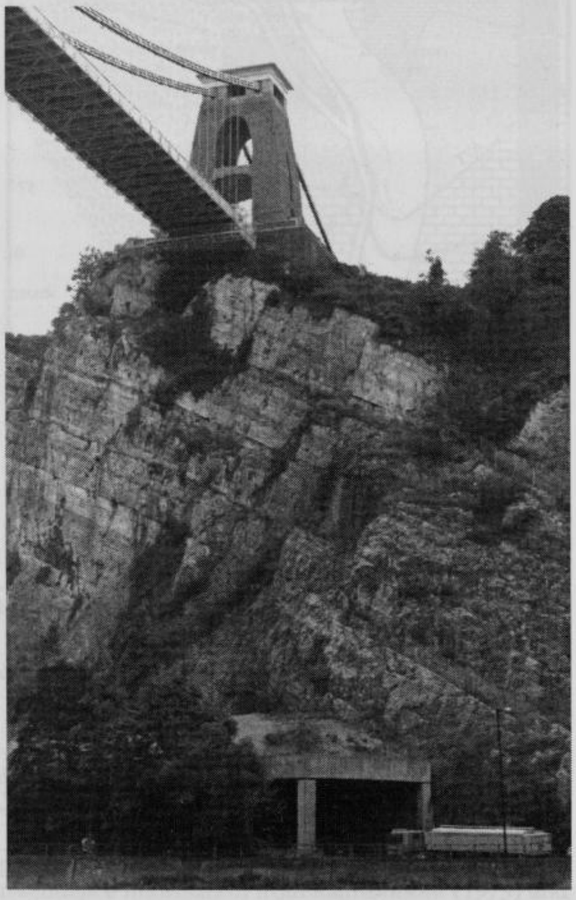


Figure 9.39 The spectacular outcrops of the Clifton Down Limestone at the Clifton Suspension Bridge in the Avon Gorge. (Photo: P.J. Cossey.)

correlation. This part of the succession is repeated by a thrust, unrecognized by earlier workers (Loupekine, 1953).

The higher part of the Clifton Down Limestone is described by Reynolds (1921). He recognized two developments of 'oolitic' limestone, the Seminula Pisolite and the Seminula Oolite, separated by a vuggy dolomite 1.5 m thick. Chert bands and silicified fossils are prominent in the Seminula Pisolite. The Seminula Oolite has a notably sharp base. The oolite grades up into bioclastic limestones and then into fine-grained limestones lacking abundant faunas and resembling those near the base of the group. The uppermost part of the succession, known as the 'Concretionary Beds', comprises stromatolitic limestones interbedded with shales and brecciated limestones. On the left bank of the river, quarries 4 (ST 561 739) and 5 (ST 562 738) show much of the section from the Trilobite Bed to the base of the Hotwells Limestone, although the succession from the Seminula Oolite to the Concretionary Beds is not well exposed (Kellaway and Welch, 1993).

Strata immediately to the north of the suspension bridge are affected by the Avon Thrust (Figure 9.38) and are sheared and distorted. However, to the south of the bridge, from the foot of the Zig-Zag (ST 565 730) to the Colonnade (ST 566 728), the Hotwells Limestone, forming the lower part of Vaughan's *Dibunophyllum* Zone, can be seen. The Hotwells Limestone in the Avon Gorge is about 50 m thick and notably fossiliferous. Gigantoproductid brachiopods and the corals *Dibunophyllum bourtonense*, *Palaeosmilia murchisoni* and *Siphonodendron martini* are particularly evident (Kellaway and Welch, 1993). This part of the section on the left bank is presently overgrown and the higher part of the Hotwells Group, represented by the Upper Cromhall Sandstone, is not seen at all in the gorge.

Interpretation

The Vaughan zonal scheme for the shelf limestones of the Lower Carboniferous succession, as outlined in his work on the succession of faunas in the Avon Gorge (Vaughan, 1905), became, with some modifications (e.g. Reynolds, 1921), the reference section to which other sections in the British Isles were compared. However, although he set out to produce a workable zonal scheme, Vaughan noted that 'Such a system, deduced from the examination of a single area and founded entirely upon two fossil groups, cannot of course presume to be more than a preliminary attempt to deal with a large and complicated problem; but it may serve as part of the scaffolding, by means of which a system of general application will ultimately be built up' (Vaughan, 1905). Riley (1993), in his review of Dinantian biostratigraphy, pays tribute to the careful observations and descriptions of Vaughan and his awareness of fundamental biostratigraphical concepts that allowed the scheme to have much greater scope than was originally envisaged. Vaughan's zones were not replaced until George *et al*. (1976) set up their regional stages, but even their scheme inherited some boundaries that were originally used by Vaughan.

The need for a replacement of Vaughan's zones became apparent when it was realized that the Avon Gorge succession is not a record of continuous Dinantian sedimentation, but contains a number of non-sequences (see Figure 9.37). Ramsbottom (1973) noted four substantial non-sequences in the section, and a fifth has been described from near the base of the section (Butler, 1973), all corresponding with times of sedimentation elsewhere in the British Isles. The first of these non-sequences lies at the top of the Shirehampton Beds, where the Palate Bed rests on an eroded surface of the Bryozoa Bed (Butler, 1973). The second non-sequence occurs at the top of the Black Rock Group and has been discussed by Mitchell (1971, 1972, 1981) who suggested that both the uppermost Tournaisian and the lowermost Viséan successions are not represented. Evidence for the absence of the uppermost Tournaisian succession comes from a comparison of faunas from the Avon Gorge with those of **Burrington Combe** (see GCR site report, this chapter). Mitchell (1971) inferred that about 130 m of strata seen at the top of the Black Rock Group of Burrington Combe are not represented in the Avon Gorge. The absence of lowest Viséan strata in the Avon Gorge is inferred from a comparison of faunas with those of south Cumbria (Mitchell, 1972). Mitchell concluded that, at least where the Sub-Oolite Bed is missing, the basal Viséan sequence is unrepresented.

The third non-sequence lies at the top of the Gully Oolite where the Clifton Down Mudstone rests on an irregular erosive surface cut in the oolite. George *et al*. (1976) record that much of the lower part of the Arundian Stage is missing, although with the impoverished faunas of the Clifton Down Mudstone the extent of this non-sequence is difficult to establish. Ramsbottom (1973) recorded three faunal horizons of northern England that were absent from the Avon Gorge section at this level. The base of the Holkerian Stage in the Avon Gorge succession is taken at the base of the Seminula Oolite, which has also been interpreted as an erosion surface indicating a stratigraphical break (Kellaway and Welch, 1993) and forms the fourth non-sequence. The fifth non-sequence occurs at the base of the Hotwells Limestone. Although the early Asbian brachiopod *Daviesiella llangollensis* is absent from this unit, the late Asbian form *Davidsonina septosa* is known from the base of the Hotwells Limestone in the Mendips (Kellaway and Welch, 1993).

Apart from 200 thin-sections examined by Reynolds (1921) during his work on the lithological succession, there is an absence of detailed petrographical work and facies analysis of the section in the Avon Gorge. However, Kellaway and Welch (1993) provide a summary of the palaeoenvironments represented. The whole succession was deposited on the Mendip Shelf, which, at least for the earlier part of Dinantian times, was probably a southerly dipping ramp (Figure 9.3b) continuous with that inferred for South Wales (Wright, 1986a). The Avon Gorge was in a fairly proximal position on this ramp, an aspect that accounts for the development of numerous non-sequences here, in contrast to those sections farther south in the Mendips where deposition was more continuous.

The largely terrigenous Shirehampton Beds were deposited in restricted marine or brackish water environments (Kellaway and Welch, 1993). Their accumulation was followed by a period of non-deposition or erosion represented by a non-sequence. The Lower Limestone Shale marked a change to more open marine conditions, but still with a significant supply of fine-grained detrital material. This supply of detritus was reduced during deposition of the overlying Black Rock Group, which contains a diverse fauna in a fine matrix, and probably represents open marine below wave-base environments. The Gully Oolite was deposited in shallower high-energy conditions with shifting, perhaps tidal, sand-bodies providing a habitat inimical to most organisms (Kellaway and Welch, 1993). In contrast, the Clifton Down Mudstone represents low-energy, restricted, sometimes stagnant, lagoonal environments with an impoverished fauna. This gives way to more open marine conditions again, characterized by bioclastic limestone in the lower part of the Clifton Down Limestone. Shallow, agitated water oolitic deposits (the Seminula Oolite and Pisolite) are succeeded by a return to lagoonal deposits at the top of the Clifton Down Limestone. Following a break in sedimentation, the Hotwells Limestone was deposited in open-shelf conditions of fairly high energy, supporting a diverse and abundant fauna (Kellaway and Welch, 1993).

Conclusions

Despite the deterioration in some parts of the succession since the early part of the 20th century, when the classic work of Vaughan and Reynolds was undertaken, the Avon Gorge still provides the best section through much of the Dinantian sequence of the Bristol area. Its importance lies partly in its historical association with one of the most important developments in Carboniferous stratigraphy, but also it continues to provide a valuable resource for research into the stratigraphy and sedimentology of Lower Carboniferous shelf limestones in southern England.

BURRINGTON COMBE, SOMERSET–AVON (ST 477 590–ST 476 582–ST 485 582)

Introduction

The Burrington Combe GCR site provides the most complete section through the Carboniferous Limestone in the Mendips. The site extends from the entrance to the combe (ST 477 590), south to Goatchurch Cavern (ST 476 582), with an eastwards extension up the combe to ST 485 582. Although the base and top of the Lower Carboniferous sequence are not seen in the site, some 800 m of strata are exposed. The section is notably fossiliferous and, compared to the Avon Gorge succession, is more complete, being sited in a more distal position on the Dinantian carbonate ramp. Detailed accounts of the site geology are provided by Sibly (1905a), Reynolds and Vaughan (1911) and Mitchell and Green (1965).

Description

The Burrington Combe section is located on the northern limb of the Black Down Pericline. Beds dip northwards at between 50° and 65°, and the combe sides provide a section at right angles to strike through much of the succession. A summary lithological and stratigraphical log for the area is shown in Figure 9.37. The Lower Limestone Shale Group is not exposed within the boundaries of the site, but is partially exposed on the hillside to the south. The Black Rock Limestone, however, is extensively exposed, in dip sections at the southern end of the combe and at the entrances to the tributary valleys known as the Eastern and Western Twin Streams, as well as in a strike-section along Great Scarp on the northern side of the east–west part of the combe. Mitchell and Green (1965) provide a measured section of the interval which, including the dolomite at the top, the Laminosa Dolomite of Reynolds and Vaughan (1911), totalled 943 feet (288 m). Much of the undolomitized part of the succession comprises fine-grained, dark-coloured limestone with variable amounts of coarse crinoidal debris. Notable chert developments occur at two levels, 30 m and 150 m above the base of the Black Rock Limestone. Both contain chert nodules and silicified fossils and the upper also shows well-defined bands of chert. These were designated the Lower Chert and Main Chert beds by Reynolds and Vaughan (1911). The Lower Chert forms a well-marked topographical feature on the hillside on the south side of the combe and the Main Chert is well seen in Great Scarp (Reynolds and Vaughan, 1911; Mitchell and Green, 1965).

The Black Rock Limestone is the most fossiliferous part of the Mendips succession, with a particularly diverse and abundant coral–brachiopod fauna. This is described in detail by Mitchell and Green (1965) who recognized three main faunal assemblages, which they referred to as the Lower, Middle and Upper faunas. Important elements of the faunal assemblages are summarized by Kellaway and Welch (1993). The Lower Fauna is characterized by zaphrentoid corals and includes *Fasciculophyllum omaliusi*, *Sychnoelasma clevedonensis* and *Zaphrentites delanouei*. Common brachiopods are *Cleiothyridina glabristria*, *Dictyoclostus multispiniferus*, *Pugilis vaughani*, *Rhipidomella michelini*, *Rugosochonetes vaughani* and *Syringothyris cuspidata cyrtorhyncha*. The Middle Fauna is characterized by the first appearance of a number of corals: *Caninophyllum patulum*, *Caninia cornucopiae*, *Cyathaxonia cornu*, *Cyathoclisia tabernaculum*, *Fasciculophyllum densum* and *Sychnoelasma konincki*. The appearance of the coral *Siphonophyllia cylindrica* marks the beginning of the Upper Fauna, which is also characterized by the brachiopods *Eomarginifera* aff. *derbiensis*, *Megachonetes magna*, *Pustula pustuliformis*, *P. pyxidiformis*, *Schuchertella* cf. *wexfordensis* and *Syringothyris* aff. *elongata*.

The lower part of the overlying Clifton Down Group is known as the 'Burrington Oolite', measured by Mitchell and Green (1965) as 680 feet (208 m) thick. It consists of grey, grainy, sometimes oolitic, and crinoidal limestones with some intercalations of fine-grained limestone. Parts of the succession, particularly near the base, are strongly dolomitized. Two dolomitic mudstone marker bands which have some stratigraphical significance have been named by George *et al.* (1976). These are the Ham Mudstone 6 m above the base, and the Rib Mudstone 38 m below the top (Figure 9.40). The most common corals in the Burrington Oolite are *Palaeosmilia murchisoni* in the lower part and *Siphonodendron martini* in the upper part (Mitchell and Green, 1965). Amongst the brachiopods, *Megachonetes papilionaceus* and *Rhipidomella michelini* are common in the lower beds (Mitchell and Green, 1965). *Davidsonina carbonaria* has been found in the upper part of the Burrington Oolite (Mitchell and Green, 1965).

The Clifton Down Limestone is about 150 m thick, but the basal 40 m is poorly exposed in Burrington Combe. The lowest exposed beds comprise oolites interbedded with fine-grained limestones. These are overlain by darker cherty beds, often containing silicified corals. The topmost part consists of dark fine-grained limestones (Mitchell and Green, 1965; Kellaway and Welch, 1993). The most common coral in the Clifton Down Limestone is *Siphonodendron martini*, with *Axophyllum* '*Carcinophyllum*' *vaughani* also widely distributed (Mitchell and Green, 1965). *S. martini* is particularly common in the middle part of the unit and this part of the succession has been used as a mappable marker known as the '*Lithostrotion* Beds' (Green and Welch, 1965). *Megachonetes papilionaceus*, *Composita ficoidea* and productoids characterize the brachiopod fauna of the Clifton Down Limestone (Mitchell and Green, 1965).

Figure 9.40 General view of the upper part of the Burrington Oolite at Burrington Combe. A thin band crossing the centre of the figure (top right to bottom left) marks the position of the dolomitic 'Rib Mudstone' and the Arundian–Holkerian boundary (see text for further details). (Photo: P.J. Cossey.)

Only about 30 m of the Hotwells Limestone can be seen at the north end of Burrington Combe. It consists mostly of massive crinoidal limestone, but contains a fauna distinct from the Clifton Down Limestone below. This includes the first appearance of the coral *Dibunophyllum bourtonense* and the brachiopods *Gigantoproductus maximus* and *Linoprotonia hemisphaerica*.

Interpretation

Mitchell and Green (1965) discuss the relationships of the faunas, the mapped formations and the application of the Avonian zones to the Burrington section as described by Reynolds and Vaughan (1911). Much of this data is incorporated in Figure 9.37. The Burrington Combe section offers a thicker section with fewer non-sequences than the Avon Gorge (Figure 9.37). This is exemplified by the Black Rock Limestone with its Lower, Middle and Upper faunas, of which the Upper Fauna and part of the Middle Fauna are missing in the Avon Gorge. Ramsbottom and Mitchell (1980) replaced these three faunas with assemblage biozones. Thus the Lower Fauna became the *Zaphrentites delanouei* assemblage biozone, the Middle Fauna became the *Caninophyllum patulum* assemblage biozone and the Upper Fauna became the *Siphonophyllia cylindrica* assemblage biozone. The two lower biozones were equated with the later part of the Courceyan Stage and the *Siphonophyllia cylindrica* assemblage biozone with the early part of the Chadian Stage.

In Burrington Combe the base of the Chadian Stage lies in an unexposed interval some 20–25 m thick between the limestones bearing the Middle and Upper faunas, and the top of the stage has been taken at the top of the Ham Mudstone which lies just above the base of the Burrington Oolite as defined by Green and Welch (1965) (George *et al.*, 1976). That part of the Burrington Oolite beneath the Ham Mudstone was attributed to the Gully Oolite by George *et al.* (1976). Basal Arundian beds may be missing in Burrington Combe even if there is less of a non-sequence at this level than there is in the Bristol area (George *et al.*, 1976). The top of the Arundian Stage at this site was taken at the top of the Rib Mudstone 38 m below the top of the Burrington Oolite of Green and Welch (1965) (see Figure 9.40). That part of the Burrington Oolite between the Ham Mudstone and the Rib Mudstone was called the 'Aveline's Hole Limestone', and the part above the Rib Mudstone was called the 'Quarry Two Limestone' by George *et al.* (1976). The appearance of *Davidsonina carbonaria* above the Rib Mudstone indicates that the upper part of the Burrington Oolite (i.e. the Quarry Two Limestone) is Holkerian in age (George *et al.*, 1976). The remainder of the Holkerian Stage is represented by the Clifton Down Limestone. The Hotwells Limestone contains an Asbian fauna, although, as in the **Avon Gorge**, *Davieseilla llangollensis* is not present, suggesting that the early part of the stage is not represented (George *et al.*, 1976).

Despite little modern sedimentological work on the section in Burrington Combe having been published, the environments represented here appear to be broadly similar to those inferred for the Avon Gorge succession.

However, the more distal situation of Burrington on the Dinantian ramp means that the succession has fewer non-sequences and that open marine environments are better represented than restricted lagoonal environments. In particular, the Arundian and Holkerian successions are dominated by 'grainy', sometimes oolitic, limestones at Burrington Combe, which are less significant in the Avon Gorge.

Conclusions

Burrington Combe is now arguably the best section through the Carboniferous Limestone in the Mendips and Bristol area, even though the lowest and highest parts of the succession are not included in the site. The section is especially valuable for the rich coral–brachiopod faunas of the Black Rock Limestone, the study of corals, in particular, leading to notable refinements in the stratigraphy of the area. Although little of the sedimentology has been studied in detail, the site offers great opportunities for future research.

MAESBURY RAILWAY CUTTING, SOMERSET (ST 607 476)

Introduction

The Maesbury Railway Cutting GCR site is situated 5 km ESE of Wells in Somerset. This disused railway cutting (ST 607 476) offers an almost complete if partly overgrown Courceyan section that extends from the middle of the Lower Limestone Shale Group through to the lower part of the Black Rock Limestone Group – arguably the finest section of this interval in southern England. Early reference to the site was made by Sibly (1906) and Welch (1929), but the more significant accounts are those of Green and Welch (1965) who provided a list of the macrofauna, Butler (1972, 1973) who noted the distribution of conodonts and considered sedimentological aspects, and Higgs and Clayton (1984) who recorded the distribution of miospores.

Description

The section is located on the northern limb and at the western end of the Beacon Hill Anticline (Welch, 1929). The succession dips gently to the north and is best exposed on the west side of the cutting (Figure 9.41). Here, both Green and Welch (1965) and Butler (1972, 1973) identified three units in the middle and upper parts of the Lower Limestone Shale with a total thickness of approximately 85 m. The lowest of the exposed units (*c.* 20 m) comprises thick, fine-grained limestones with laminations of a possible microbial origin and lenses of coarser material interbedded with fissile siltstones and shales. Overlying this, the shale-dominated middle unit (*c.* 40 m) includes siltstones with thin stringers of bioclastic debris and a few limestones, some of which, near the base of the unit, contain phosphatic nodules. The upper unit (*c.* 25 m) comprises a sequence of irregularly shaped lenticular limestones interbedded with micaceous siltstones and shales. Butler (1972, 1973) and Matthews *et al.* (1973) recognized two types of limestone in this unit: limestones with a laminated top and an erosive channel base, and

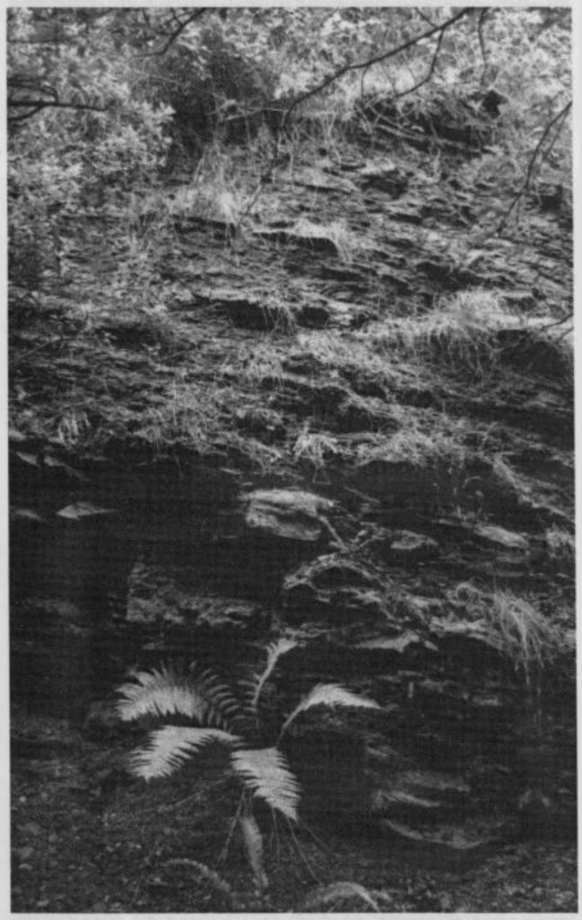


Figure 9.41 Outcrop of the Lower Limestone Shale Group at Maesbury Railway Cutting. (Photo: P.J. Cossey.)

limestones with a mega-rippled top surface. Structures resembling hummocky cross-stratification and bioturbation features also occur in these beds. In the higher parts of the unit where the 'channeled limestones' are missing from the sequence, limestones with mega-ripples increase in abundance and eventually 'coalesce to produce the Black Rock Limestone' (Matthews *et al.*, 1973). Butler (1973) described this lower part of the Black Rock Limestone (*c.* 60 m) as being composed of lenticular and well-bedded packstones and grainstones with some mud flasers.

The fauna from the Lower Limestone Shale includes a variety of brachiopod taxa namely *?Spinocarinifera 'Avonia' bassa*, *Plicochonetes stoddarti*, *Macropotamorhynchus 'Camarotoechia' mitcheldeanensis*, *Pugilis 'Dictyoclostus' vaughani*, *Unispirifer tornacensis*, *Schellwienella* cf. *aspis* and *Rhipidomella michelini* (Green and Welch, 1965) and a rich conodont assemblage with *Pseudopolygnathodus dentilineatus*, *Polygnathus symmetricus*, *Patrognathus variabilis*, *Siphonodella isosticha* and *Polygnathus inornatus* (Butler, 1973). Miospores extracted from the Lower Limestone Shale and Black Rock Limestone at Maesbury include *Verrucosisporites nitidus*, *Krauselisporites hibernicus*, *K. mitratus*, *Spelaeotriletes balteatus*, *S. pretiosus*, *Hymenozonotriletes explanatus*, *Umbonatisporites distinctus*, *Rugospora polyptycha*, *Vallatisporites vallatus*, *Raistrickia clavata* and *R. condylosa* (Higgs and Clayton, 1984). Consideration of the time ranges given for these taxa (see Riley, 1993) indicates the presence of *Siphonodella* Zone conodont faunas, a VI–PC Zone miospore assemblage and a brachiopod fauna typical of the *Vaughania vetus–Zaphrentites delanouei* assemblage biozones, thus confirming an early Courceyan age for most of the Maesbury section.

Interpretation

Although an early Carboniferous (K–Z) age (Sibly, 1906; Welch, 1929) for the Maesbury section is widely accepted, it was not until Butler (1972, 1973) completed his detailed biostratigraphical work on the distribution of conodonts in Tournaisian sections from the Bristol–Mendips area that a more complete picture of the stratigraphical significance of the site was established. In conjunction with other sites, Butler (1973) used the Maesbury section as a test-bed for the assertion that the Lower Carboniferous successions in the Mendips might be stratigraphically more complete than those of the **Avon Gorge** area (see GCR site report, this chapter) in which several non-sequences had been identified (Mitchell, 1972; Ramsbottom, 1973). While Butler (1973) recognized notable differences in the conodont assemblages obtained from the Maesbury and Avon sections (see Rhodes *et al.*, 1969), these differences were attributed to the existence of unexposed intervals in the Avon section and facies-controlled faunas. However, although unequivocal evidence of a major stratigraphical gap in the Lower Limestone Shale sequence at Bristol could not be demonstrated, Butler (1973) indicated that missing beds associated with a discontinuity at the level of the Palate Bed in the Avon Gorge might have some representation in the lower unit of the Lower Limestone Shale at Maesbury. His attempt to correlate the eastern Mendips succession with that of the Avon Gorge was reasonably successful, but efforts to correlate the former with equivalent sections in Europe and North America proved less conclusive.

Regional studies indicate that the Lower Limestone Shale sequence of southern Britain was deposited on a southward-dipping carbonate ramp (Wright, 1986a, 1987a; Leeder, 1992) in a variety of nearshore and offshore environments (Burchette, 1987; Burchette *et al.*, 1990). Its formation was a depositional response to the major and globally recognized sea-level rise that took place at the beginning of Carboniferous times. Whereas the existence of limestones of a possible microbial origin indicates that part of the Maesbury section may have been deposited in a nearshore setting, the general character of the remaining part of the succession, with its open marine faunas and its possible storm-generated limestone beds, suggests deposition in deeper water. The succession compares closely to a particular lithofacies (LAIII) of the Lower Limestone Shale that Burchette (1987) interpreted as an offshore deposit formed in moderately deep water below fair-weather wave-base. An outer-ramp setting is therefore envisaged for most of the Maesbury section. This interpretation stands out in marked contrast to the interpretation of Lower Limestone Shale sequences at **Tongwynlais Road Cutting** (see GCR site report, this chapter) in South Wales and at **Stenders Quarry** (see GCR site report, this chapter) in the Forest of Dean, where a more marginal, peritidal and back-barrier–lagoonal facies is recognized (Burchette, 1977, 1981, 1987; Davies *et al.*, 1991). Although Burchette (1987) demonstrated the presence of a number of transgressive–regressive depositional cycles in the Lower Limestone Shale, their recognition in outer-ramp facies, as at Maesbury, may prove difficult (see Wright, 1986a). A broadly similar ramp setting is envisaged for the Black Rock Limestone at this site. Further sedimentological research on this important section is clearly warranted.

Conclusions

This locality affords the finest section of the middle and upper parts of the Lower Limestone Shale in the Mendips. The section extends upwards to include the lower part of the Black Rock Limestone. The sequence records the progressive sedimentary response to changes associated with the earliest phase in development of an extensive carbonate ramp (Ahr, 1973, 1985; Wright, 1987a) that stretched across the South Wales–Mendip Shelf during early Carboniferous (Courceyan) times. The site is an important reference section for regional and international stratigraphical correlations as well as a valuable resource for future sedimentological research.

VALLIS VALE, SOMERSET (ST 755 494–ST 757 492 and ST 754 491–ST 757 486)

Introduction

The Vallis Vale GCR site comprises a series of disused quarries on the valley sides of the Mells and Egford stream systems (ST 757 492–ST 755 494 and ST 757 486–ST 754 491), and is situated between the villages of Egford, Hapsford and Bedlam, 2 km north-west of Frome in Somerset. The locality is widely known for its spectacular and historically important exposure of the angular unconformity between the Carboniferous Limestone and the Middle Jurassic (Bajocian) Inferior Oolite (Conybeare and Phillips, 1822; De la Beche, 1846; Arkell, 1933). The site also includes a thick Lower Carboniferous succession of Courceyan–Arundian age encompassing much of the Black Rock Limestone and the type section of the Vallis Limestone. Whereas general descriptions of the Vallis Vale unconformity are presented by many authors (Macfadyen, 1970; Savage, 1977; Duff *et al.*, 1985; Prosser and King, 1999) and details relating to the Middle Jurassic section are documented in a companion GCR volume (Cox and Sumbler, 2002), modern works on the Lower Carboniferous section at this site are generally lacking. The report that follows therefore relies heavily on the accounts of Bush (1925), Welch (1933), Kellaway and Welch (1955) and Butler (1973).

Description

The Lower Carboniferous succession at Vallis Vale lies on the northern limb of the Beacon Hill Pericline. Beds dip consistently to the NNW, with dips progressively increasing from low to moderately steep angles as the sequence is traced from south to north across the site. The Black Rock Limestone is particularly well exposed in an old quarry on the eastern side of Egford Brook at the southern end of the site. Its outcrop continues northwards (albeit poorly), in a series of overgrown quarries mainly on the western side of Egford Brook. North-west of the Egford and Mells stream confluence and either side of the upstream section of the Mells River, the Vallis Limestone is exposed in partly overgrown quarries on the valley sides.

The most comprehensive (if dated) description of the lithological and palaeontological succession is by Bush (1925), who recorded an extensive section ranging from the Z_2 Subzone to the S_1 Subzone that was substantially thicker and more complete (see Butler, 1973) than the equivalent section described by Vaughan (1905) from the **Avon Gorge** (see GCR site report, this chapter). The lower part of this succession (Z_2–C_1 subzones) is represented by the Black Rock Limestone (Figure 9.42) while the upper part (C_2–S_1 subzones) is represented largely by the Vallis Limestone. Making allowance for the exaggerated outcrop widths due to thrusting (see Welch, 1933), the upper Black Rock Limestone here is approximately 200 m thick. It comprises dark crinoidal wackestones with a prominent chert development in its lower part (the 'Main Chert' of Butler, 1973, and others). Towards the top of the unit, massive pale-coloured packstones and dolomitized beds become more common. Bush (1925) recognized three of Vaughan's (1905) faunal subdivisions in this part of the succession (Z_2, Horizon γ and

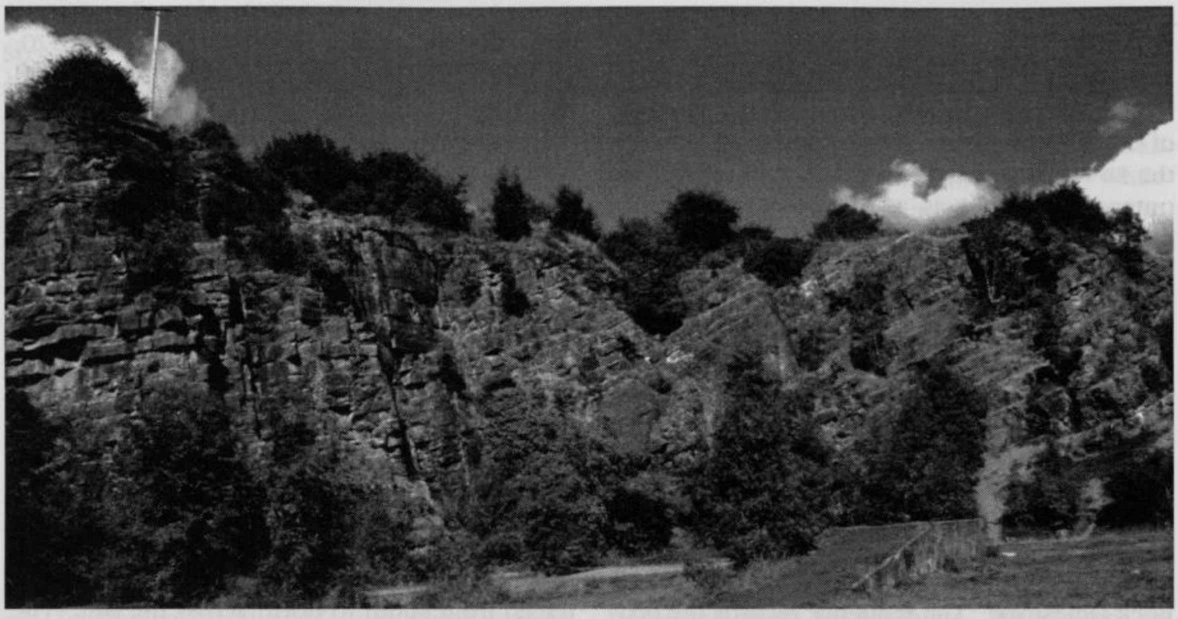


Figure 9.42 Quarry section in the Black Rock Limestone (Courceyan) at the southern end of the Vallis Vale GCR site. (Photo: P.J. Cossey.)

C_1) and from each of them he recorded rich fossil assemblages dominated by solitary rugose corals, tabulate corals and brachiopods.

Notable records from the Z_2 Subzone include the brachiopods *Unispirifer tornacensis*, *Leptaena analoga* and the coral *Zaphrentites delanouei* with *Siphonophyllia cylindrica* 'appearing low in the subzone' (Bush, 1925). In Horizon γ, other corals, including *Michelinia favosa*, *M. megastoma* and *Caninophyllum patulum*, enter the sequence (the latter reaching its acme at this level) accompanied by *S. cylindrica* and *Sychnoelasma konincki* in abundance. At the base of the overlying C_1 Subzone, large *S. cylindrica* are apparently particularly common (Bush, 1925). A somewhat similar faunal distribution was noted in the Black Rock Limestone at **Burrington Combe** (see GCR site report, this chapter) by Mitchell and Green (1965) who recognized three faunal subdivisions in the formation referred to as the 'Lower Fauna', the 'Middle Fauna' and the 'Upper Fauna' respectively. These three faunal subdivisions, later elevated by Ramsbottom and Mitchell (1980) to assemblage biozone status as the *Zaphrentites delanouei*, *Caninophyllum patulum* and *Siphonophyllia cylindrica* assemblage biozones respectively, broadly correspond to the faunal subdivisions Z_2, Horizon γ and C_1 recognized by Bush (1925) at Vallis Vale.

Whereas the precise position of critical stratigraphical boundaries remains uncertain, the recognition of diagnostic conodont and coral taxa confirms a Courceyan–Chadian age for much of the Black Rock Limestone at this site. Typical Courceyan conodonts recorded by Butler (1973) from a low position in the sequence include *Polygnathus communis carina*, *Gnathodus delicatus* and *Pseudopolygnathus multistriatus*, whereas higher in the sequence the occurrence of *S. cylindrica* in abundance (Bush, 1925) and *S. garwoodi* (Sibly, 1906; see Ramsbottom and Mitchell, 1980, p. 62) confirms that the upper part of the Black Rock Limestone extends from the Chadian Stage into the Arundian Stage (see Riley, 1993) – a view also supported by evidence from Halecombe Quarry 6 km to the west where *Delepinea carinata* has been recorded at the base of the Vallis Limestone and *Siphonophylum garwoodi* has been recorded approximately 20 m lower in the sequence (Butler, 1973; George *et al.*, 1976; Kellaway and Welch, 1993).

Above the Black Rock Limestone, the Vallis Limestone comprises approximately 110 m of massive, pale-coloured crinoidal limestone. The term 'Vallis Limestone' was first introduced by Kellaway and Welch (1955) to describe a lateral facies equivalent of the lower part of the Burrington Oolite dominated by bioclastic and crinoidal limestones and seemingly devoid of ooids. The formation is widely regarded as Arundian in age (Wilson *et al.*, 1988; Green, 1992; Kellaway and Welch, 1993). At Vallis Vale it includes those beds originally referred to by Bush (1925) as belonging to the C_2 Subzone, towards the top of which bellerophontid gastropods, large corallites of *Amplexus* and *Sychnoelasma konincki* are common. The formation may also include some of those beds Bush (1925) ascribed to the S_1 Subzone, which include carbonate mudstones containing other Arundian corals (*Siphonodendron martini*) and oolitic beds, although the [British] Geological Survey (Institute of Geological Sciences, 1965) appear to regard a significant part of Bush's (1925) S Zone at Vallis Vale as belonging to a unit above the Vallis Limestone in the Clifton Down Group. The uncertainty regarding the extent of the Vallis Limestone arises because its boundaries appear to be poorly defined in many areas.

Interpretation

Regional mapping and biostratigraphical studies have indicated that the Lower Carboniferous successions of the eastern Mendips are thicker and stratigraphically more complete than they are farther north in the Bristol district where a number of non-sequences are recognized in the sequence (Bush, 1925; Welch, 1933; Kellaway and Welch, 1955; Butler, 1972, 1973; Mitchell, 1972; Ramsbottom, 1973; Green, 1992; Kellaway and Welch, 1993). Bush (1925) in particular noted that the Z_2–C_1 subzonal interval at Vallis Vale was substantially thicker than the equivalent section in the Avon Gorge where the *Siphonophyllia cylindrica* assemblage zone at the top of the Black Rock Limestone (the approximate correlative of the C_1 Subzone at Vallis Vale) is missing from the sequence (Ramsbottom and Mitchell, 1980; Mitchell, 1981). Variations in the character of the conodont assemblages from the Vallis Vale and Avon Gorge sections would appear to support this view (Butler, 1973).

To a large extent the differences noted above are a reflection of the palaeogeography of southern England during early Carboniferous times and of the deposition of sediments on a southward-dipping carbonate ramp (Wright, 1987a; Leeder, 1992) that was subsiding at a greater rate and more continuously in the south than it was to the north (Figure 9.3b). In this context, the Black Rock Limestone, with its open marine faunas, is interpreted as an early Carboniferous offshore and relatively deep-water mid- to outer-ramp facies, while the Vallis Limestone probably formed as part of an E–W-trending and southward-prograding carbonate sand shoal, the Burrington Oolite–High Tor Limestone barrier complex (Figure 9.4b), which extended across parts of southern England and South Wales during Arundian times (Wright, 1987a; Wilson *et al.*, 1988).

Conclusions

This site offers a particularly well-developed and stratigraphically complete Courceyan–Arundian section that includes the middle and upper parts of the Black Rock Limestone and the type section of the overlying Vallis Limestone. Its rich macrofossil and microfossil assemblages make it an important reference section for stratigraphical correlations across the South Wales–Mendip Shelf in early Dinantian times. The locality also includes a historically significant angular unconformity which is widely regarded as the one of the most spectacular examples of its type in southern England.

COOK'S WOOD QUARRY, SOMERSET (ST 669 478)

Introduction

The Cook's Wood Quarry GCR site is situated close to Stoke St Michael and 6.5 km to the north-east of Shepton Mallet in the eastern Mendips. This disused quarry (ST 669 478) offers an outstanding section of the top part of the Clifton Down Limestone (Holkerian), and the Hotwells Limestone (Asbian). The succession displays a number of well-defined and glacio-eustatically controlled depositional carbonate cycles that record an important evolutionary phase in the development of the South Wales–Mendip Shelf during the earlier part of late Dinantian times. Regrettably, however, published details relating to this section are decidedly lacking.

Description

This site is located on the northern limb of the Beacon Hill Pericline. The exposed section dips steeply (*c.* 80°) to the north (see Welch, 1933), and includes approximately 200 m of massive and well-bedded bioclastic (crinoidal) and oolitic limestones, with subordinate developments of shale, carbonate mudstone and chert. Corals and brachiopods occur at various levels in the sequence.

Although the topmost beds of the Clifton Down Limestone are exposed at the southern end of the site, no formal detailed description of them has, to the authors' knowledge, ever been published. However, Green and Welch (1965) described the upper part of this formation approximately 2 km to the west as 'consisting predominantly of calcite-mudstone', a lithofacies widely recognized at this level elsewhere in southern England (Mitchell and Green, 1965; Murray and Wright, 1971; Green, 1992; Kellaway and Welch, 1993). Above these beds, the bulk of the section is represented by the Hotwells Limestone. This unit is characterized by the development of well-bedded and massive calcarenites and the development of several soft-weathering shale bands which occur in the prominent recesses of the quarry faces (Figure 9.43). Solitary and colonial rugose corals and productoid brachiopods occur in some of the limestone beds, and thin 'stringers' of coal may be found in some of the shale bands.

A key feature of the section is the development of sedimentary cycles, each approximately 10–20 m thick, in the Hotwells Limestone. In the lower part of the sequence this cyclicity is reflected by gradational changes in bed thickness and colour, the lower beds in each cycle appearing as thicker and paler coloured units than higher intervals. Higher in the succession, regularly spaced shale bands representing possible palaeosols define the position of cycle boundaries within the massive lithofacies (Figure 9.43). A similar pattern of cyclic sedimentation in the Hotwells Limestone was recognized throughout the northern Mendips by Green (1992).

Interpretation

Despite the lack of published information relating to the Cook's Wood section, comparisons made with other sections facilitate a general interpretation of the sequence. Wright (1987a), for example, regarded the Holkerian Clifton Down Limestone as the lateral back-barrier facies equivalent of the Dowlais Limestone which developed behind the Hunts Bay Oolite barrier complex in South Wales and part of the 'catch up' phase of ramp development. In addition, Wright (1987a) regarded the massive and thickly bedded calcarenites of the Asbian succession in southern Britain, i.e. the Hotwells

Figure 9.43 Minor cycles in the Hotwells Limestone (Asbian) at Cook's Wood Quarry. The height of the cliff face is approximately 18 m. (Photo: P.J. Cossey.)

Limestone (southern England) and the Oxwich Head Limestone (South Wales), as the deposits of a 'uniform, shallow, relatively flat' shelf area (see Figure 9.3). The Cook's Wood section therefore records a critical stage in the development of the South West Province, namely the ramp to shelf transition.

The character of the sedimentary cycles in the Hotwells Limestone strongly resembles those reported from other Asbian sections in Wales and England (Walkden, 1984, 1987; Somerville, 1979a; Horbury, 1989; Davies, 1991; Vanstone, 1998; and see **Ilston Quarry** GCR site report, this chapter, and **Eglwyseg Mountain** GCR site report, Chapter 8). Their formation bears testament to fluctuating sea levels across the Mendip Shelf during late Dinantian times and to periods of subaerial weathering when the shelf area was exposed above sea level. For a more detailed account of the origin and significance of these glacio-eustatically controlled cycles (Wright and Vanstone, 2001), see **Ilston Quarry** GCR site report (this chapter).

Conclusions

This site provides the finest and the most easily accessed section of the Hotwells Limestone (Asbian) in the Mendips, and reveals arguably the finest example of the development of sedimentary cycles in the Lower Carboniferous rocks of southern England. The succession was formed predominantly in a shallow marine environment as the Mendip Shelf was transformed from a gently dipping carbonate ramp to a broad flat-lying shelf. It is particularly important for understanding the changes in palaeoenvironment and palaeoclimate that occured south of the Wales–Brabant Massif during the later part of Dinantian times and as such it provides a valuable research site and teaching resource.

FLAT HOLM, BRISTOL CHANNEL (ST 218 650–ST 223 646)

Introduction

The Flat Holm GCR site lies in the Severn Estuary, 10 km south of Cardiff and 10 km west of Sand Bay, north of Weston-super-Mare. The locality includes the south- and west-facing cliffs of the island (ST 218 650–ST 223 646). The shoreline sections reveal excellent exposures of the Gully Oolite, Caswell Bay Mudstone and Birnbeck Limestone (Chadian–Arundian). The site is particularly important as the type locality for the Flat Holm Limestone Member of the Birnbeck Limestone; a distinctive facies of interbedded bioclastic limestones and thinly bedded dolomitic limestones and shales that is unique to the island. Details of the site geology are provided by Whittaker and Green (1983) and Weedon (1987).

Description

Flat Holm consists entirely of Dinantian strata that are folded and faulted such that the total stratigraphical thickness seen is less than 100 m. The oldest unit is the Gully Oolite (Chadian), the top of which is seen at Lighthouse Point at the south-eastern end of the site and in the core of an anticline on the west coast, north of Bottleswell Point. It comprises massive, pale-coloured, cross-bedded oolites capped by a particularly well-developed palaeokarst and calcrete (Spalton, 1982) (Figure 9.44). The Caswell Bay Mudstone is seen north of Bottleswell Point where it consists of 4.5 m of well-bedded, laminated and fenestrate dolomitic carbonate mudstones. Thin-walled bivalves and gastropods have been recorded from near the base and crinoidal debris is apparent near the top of the unit (Whittaker and Green, 1983).

The Flat Holm Limestone Member is best seen in southerly dipping sections north of Bottleswell Point and south of Lighthouse Point. A detailed description of the succession has been published by Whittaker and Green (1983). The member is 30 m thick and comprises six alternations of thickly bedded bioclastic and oolitic limestones alternating with thinly bedded dolomites and mudstones (Figures 9.45 and 9.46). The latter are in units 0.5–1.5 m thick and are lettered A to F from base to top by Whittaker and Green (1983). The intervening bioclastic units range from 1 m to 9 m in thickness. A coral bed, containing *Siphonophyllia caninia* sp. (?*caninoides* group) and *S. garwoodi*, occurs 10.5 m above the base. The higher part of the Birnbeck Limestone can be seen at the north-western end of the site where it comprises bioclastic and oolitic limestones with *Palaeosmilia murchisoni* and *Delepinea carinata* (Whittaker and Green, 1983).

Figure 9.44 Rhizocretion fabrics in a calcrete palaeosol at the top of the Gully Oolite (Chadian) on Flat Holm. (Photo: P.J. Cossey.)

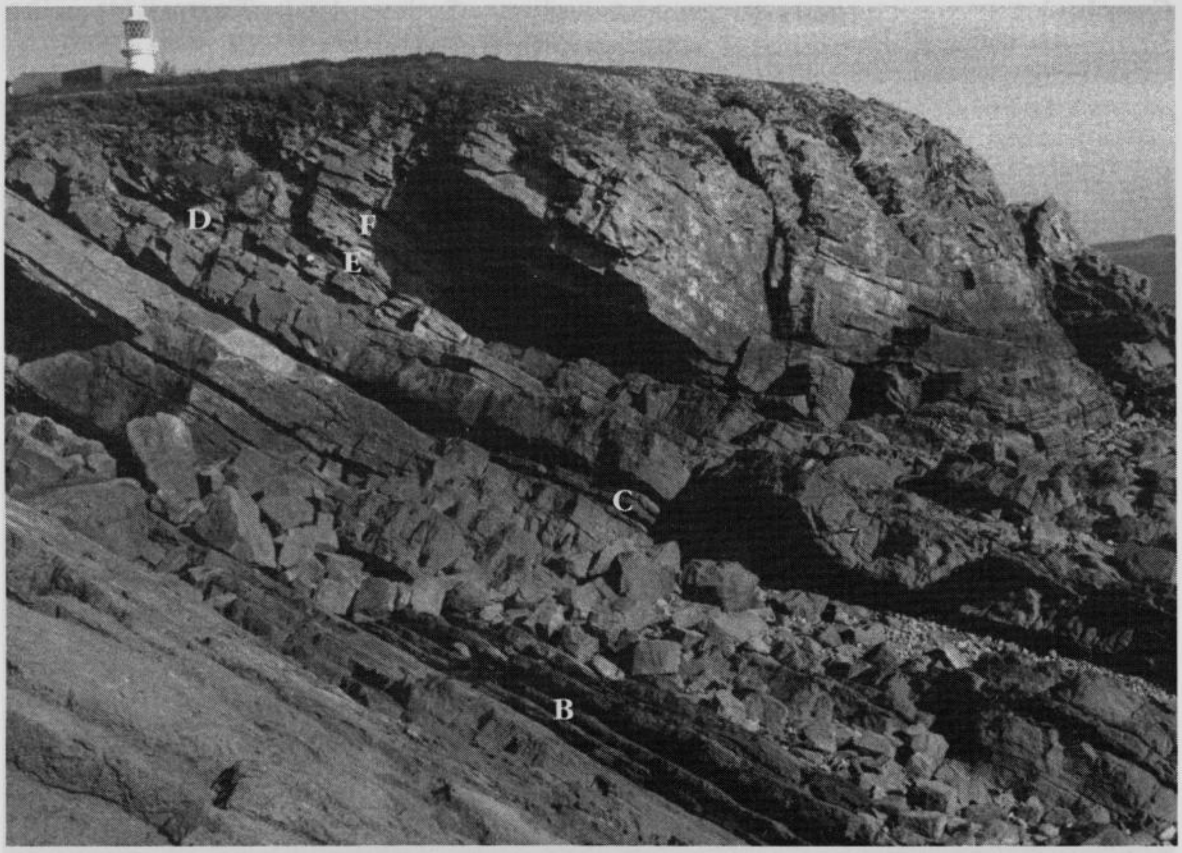


Figure 9.45 The Flat Holm Limestone Member of the Birnbeck Limestone (Arundian) at Flat Holm showing the development of the thinly bedded dolomitic mudstone units B, C, D, E and F referred to in the text. (Photo: P.J. Cossey.)

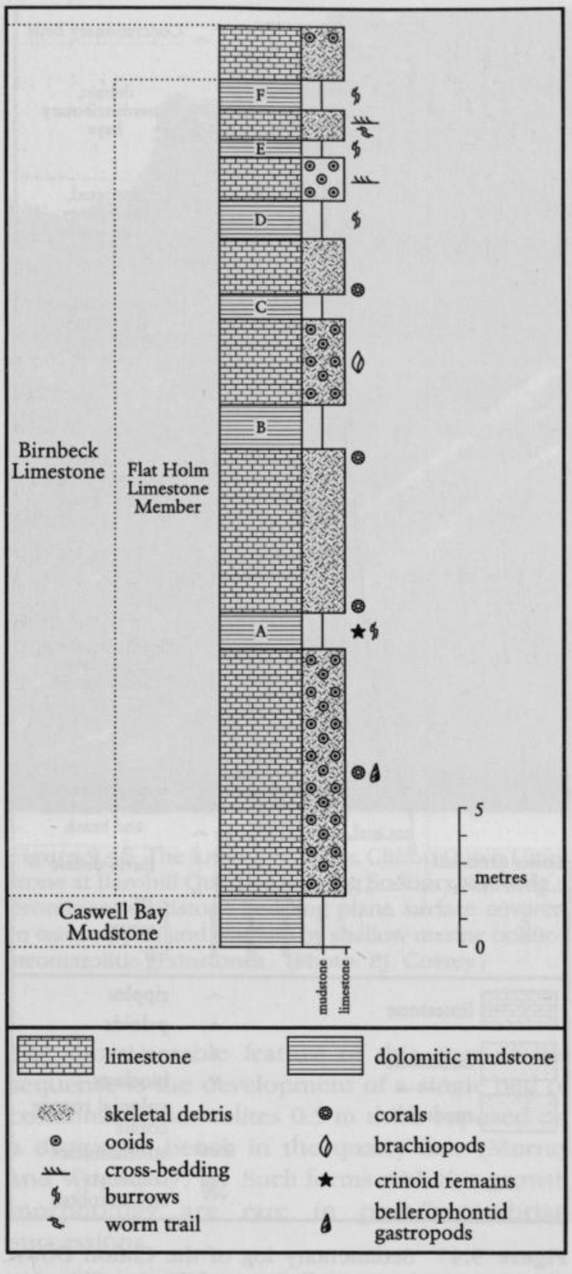


Figure 9.46 Simplified sedimentary log of the Flat Holm Limestone Member of the Birnbeck Limestone (Arundian) at Flat Holm. Note the intercalation of six thinly bedded dolomitic mudstone units (A–F) in a succession of bioclastic and oolitic limestones. After information in Whittaker and Green (1983).

Interpretation

The palaeosol at the top of the Gully Oolite has been compared with that at the top of the equivalent Caswell Bay Oolite in Gower (the Heatherslade Bed of George, 1978b) by Spalton (1982) and Whittaker and Green (1983). Although the Caswell Bay Mudstone has often been referred to as Chadian age (e.g. George *et al.*, 1976), Riding and Wright (1981) have made a sedimentological case for including it in the Arundian Stage (also see Figure 9.2). The Birnbeck Limestone (including the Flat Holm Limestone Member) is of Arundian age on the basis of its coral faunas (Whittaker and Green, 1983). The Birnbeck Limestone on Flat Holm differs from that on the mainland in the presence of the six intercalations of 'lagoonal' facies, resembling the Caswell Bay Mudstone beneath, in the normal marine limestone succession. Whittaker and Green (1983) indicate that detailed correlation of the Flat Holm succession with that of Weston-super-Mare is not possible, although it is probable that coral bands at a similar stratigraphical level in both successions are equivalent.

Conclusions

The value of the Flat Holm site lies in the exposure of the Flat Holm Limestone Member of the Birnbeck Limestone with its unique intercalation of lagoonal and normal marine deposits. The site is therefore of critical importance to the understanding of Lower Carboniferous palaeoenvironments and palaeogeography, as well as to future sedimentological research.

BARNHILL QUARRY, AVON (ST 724 825–ST 726 828)

Introduction

The Barnhill Quarry GCR site is a disused quarry (also referred to as 'Arnold's Quarry'; see Murray and Wright, 1971) lying immediately to the north of Chipping Sodbury in Gloucestershire (ST 7240 8250–ST 7260 8280). It provides an outstanding section of the Clifton Down Limestone (late Arundian–Holkerian). Note that since there is no clear differentiation between the Lower Clifton Down Limestone and the Upper Clifton Down Limestone in this area (Kellaway and Green, 1993; and see Figure 8.2, Chapter 8) the exposed limestone sequence at this site is simply referred to as the 'Clifton Down Limestone'. The section is the best outcrop illustrating the shallow-water sedimentary rocks and cyclic nature of this time interval in south-west Britain. It also exhibits spectacular sedimentary structures such as ripple-marked sandstones with trace fossils, and provides a rare opportunity to see a variety of stromatolites. These steeply dipping limestones are truncated at the top of the cliff by a planar unconformity capped by late Triassic desert deposits. Murray and Wright (1971) provide a detailed description of the succession but little biostratigraphical information is available for this site.

Description

There are two quarry faces running north to south, providing discontinous sections through the unit. The succession (see Figure 9.47) dips steeply to the west, the eastern side of the site covering a strike section of the lowest part of the Clifton Down Limestone. The west side exposes a section near the top of the formation. The base of the section is a huge bedding plane exposure of wave-rippled sandstone (Figure 9.48) covering an area of several hundred square metres, much of which is accessible with care. Locally the surface also displays abundant *Chondrites* trace fossils (Simpson, 1957), with some of these sediment-filled tubes having been reworked and concentrated into the troughs between ripples. This sandstone occurs approximately 1 m above the top of the Lower Cromhall Sandstone. It is also seen in the active quarry to the north of the site where a complete section of Courceyan–Holkerian age extending from the Black Rock Group to the Clifton Down Limestone and Middle Cromhall Sandstone is exposed (Vanstone, 1991).

Above the Lower Cromhall Sandstone, the lower part of the Clifton Down Limestone comprises approximately 8 m of cyclic bioturbated oolitic limestones alternating with small developments of stromatolitic limestone (Figure 9.49). Five such cycles occur and the stromatolites are typically overlain by rippled surfaces and by finely laminated dark-grey shales. The stromatolites occur as small columnar forms a few centimetres high, as small domes, or as undulating laminae just a few centimetres thick. Some are associated with fenestral fabrics, but not all. This part of the formation is overlain by a thick unit of oolitic, peloidal and bioclastic limestones with two more prominent domal stromatolite horizons but also with large colonial coral masses, some of which give the appearance of having been overturned and abraded. Detailed descriptions of this part of the succession are to be found in Murray and Wright (1971).

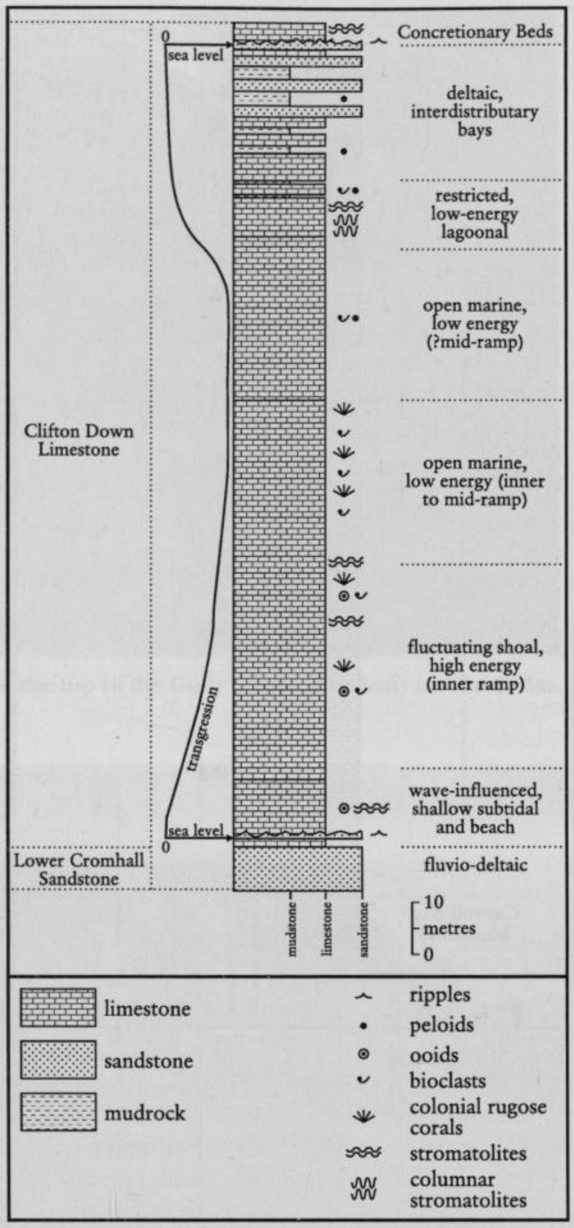


Figure 9.47 Sedimentary log of the Clifton Down Limestone at the Barnhill Quarry GCR site, Chipping Sodbury. The lower half of the succession is well exposed on the eastern side of the site (see Figure 9.48). The columnar stromatolites seen towards the top of the succession crop out on a quarry bench on the western side of the site. Note that the Lower Cromhall Sandstone is not exposed at this site. After, in part, information from Murray and Wright (1971).

The higher parts of the formation (see Figure 9.47) are poorly exposed on the western face of the quarry and where access to them is difficult.

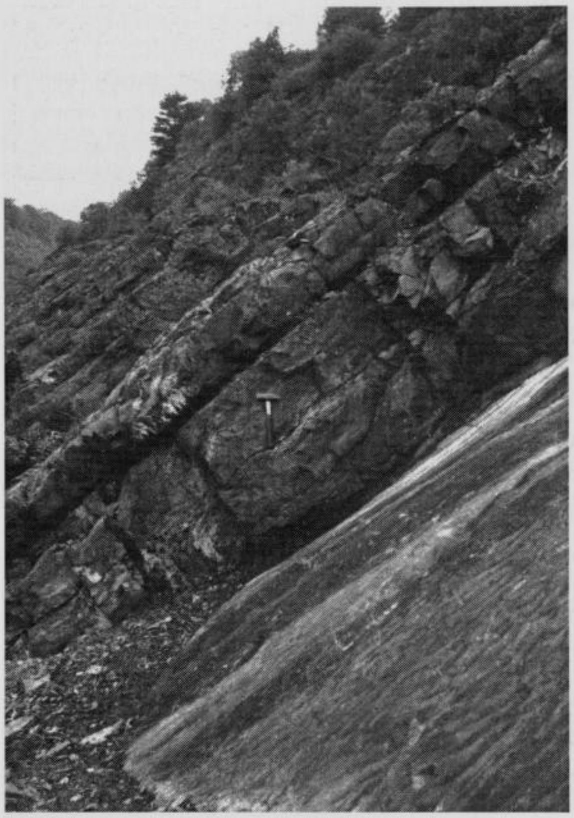


Figure 9.48 The lower part of the Clifton Down Limestone at Barnhill Quarry, Chipping Sodbury, showing a prominent sandstone bedding plane surface covered in wave ripples and overlain by shallow marine oolitic–stromatolitic grainstones. (Photo: P.J. Cossey.)

Figure 9.49 Stromatolitic domes on the top surface of a stromatolite unit near the base of the Clifton Down Limestone at Barnhill Quarry (see text for further details. (Photo: V.P. Wright.)

The most notable feature of this part of the sequence is the development of a single bed of columnar stromatolites 0.5 m thick exposed on a distinctive bench in the quarry face (Murray and Wright, 1971). Such forms with this growth morphology are rare in post-Precambrian successions.

Interpretation

The Clifton Down Limestone in this area appears to represent a single transgressive–regressive cycle (Figure 9.47). The rippled sandstones at the base of the section represent the marine reworking of the underlying fluvial Lower Cromhall Sandstone during a late Arundian–early Holkerian transgressive event.

The cyclic oolitic–stromatolitic limestones are mainly subtidal in origin and form part of the transgressive sequence. They could be regarded as small parasequences although their exact origin is unclear; they could simply represent stabilized storm sheets adjacent to an oolite shoal. The overlying coral-bearing limestones represent slightly deeper waters but still within wave-base depths. The stromatolitic bed on the west bench developed in restricted subtidal conditions.

Conclusions

This site preserves incomplete sections in the Clifton Down Limestone, but provides the finest section of shallow marine cyclic sediments in the Holkerian strata of southern England. The site also reveals some beautifully preserved sedimentary structures, including a spectacular ripple-marked bedding plane and a unique assemblage of microbial stromatolites.