# *British Lower Carboniferous Stratigraphy*


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Chapter 8

# North Wales Shelf

A.E. Adams and P.J. Cossey

## INTRODUCTION

Up to 900 m of Dinantian strata, mostly shallow marine limestone, occur in North Wales, deposited on the North Wales Shelf on the southern side of the Irish Sea Basin and bordering the Wales–Brabant Massif. The Lower Carboniferous succession also includes the lower part of the Namurian sandstone–shale succession which heralded the terrigenous clastic deposition of the Upper Carboniferous sequence.

Lower Carboniferous strata outcrop in a number of separate areas (Figure 8.1). These include a strip running southwards from Prestatyn, along the east side of the Clwydian Mountains to Llandegla, then offset eastwards by faulting to continue from Minera to Llangollen, and offset eastwards again, terminating at Llanymynech north of the Afon Vyrnwy. A second outcrop runs south-eastwards up the west side of the Vale of Clwyd from Llanddulas to Denbigh and Ruthin. The Little Orme and Great Orme, to the east and west of Llandudno respectively, are composed of Carboniferous Limestone, and on Anglesey there are outcrops in three areas, known as the Principal, Penmon and Straitside areas. There are also small outcrops in Arfon on the mainland opposite the Straitside area of Anglesey, and in an inlier near Corwen.

There are good coastal exposures of Lower Carboniferous strata in Anglesey and on the Little Orme and Great Orme, but these are not always easily accessible. Natural inland exposures occur where there are steep hillsides, such as on the Great Orme and on Eglwyseg Mountain, but many important exposures are in the numerous, mainly disused, quarries.

### History of research

The first detailed descriptions of the Carboniferous Limestone in North Wales are contained in a series of papers by G.H. Morton (1870, 1878, 1886, 1897, 1898, 1901). Morton proposed a basic three-fold classification of the limestones, with more locally developed units at the base and top. At around the same time, the area was being mapped by the [British] Geological Survey and the first memoirs were

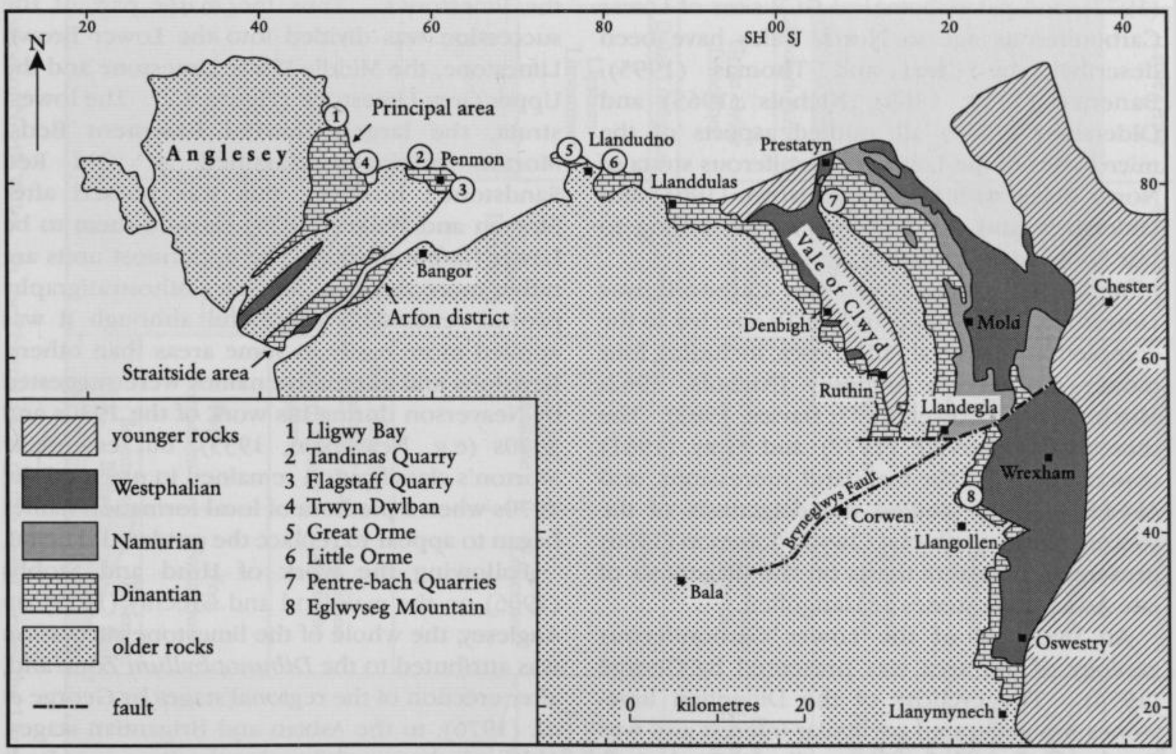



**Figure 8.1** Geological map of North Wales illustrating the distribution of Carboniferous rocks and the locations of GCR sites described in the text. Based on [British] Geological Survey maps of the area (principally Institute of Geological Sciences, 1979b).

published (Strahan, 1885, 1890). Vaughan's (1905) faunal zones were applied to the mainland area by Hind and Stobbs (1906) and to Anglesey by Greenly (1919). Jones (1921) was the first to describe the petrography of the limestones, using thin-sections, and he also made some environmental interpretations. Sargent (1923, 1927) reviewed the stratigraphy of the uppermost part of the succession in the east of the area, and Smyth (1925a) described the succession on the Great Orme. Papers of this period devoted to the Lower Carboniferous fauna and flora include those of Jackson (1925b), Smyth (1925b) and Walton (1928, 1931).

Further [British] Geological Survey memoirs with descriptions of Lower Carboniferous rocks include Wedd and King (1924) and Wedd *et al.* (1927, 1929). Neaverson authored a series of papers on the Carboniferous Limestone of mainland North Wales (Neaverson, 1929, 1930, 1935, 1937, 1943, 1945, 1946) and was the first to provide a general interpretation of depositional environments. Floras from parts of the succession were described by Lacey (1952a,b, 1962), Hibbert and Lacey (1969) and Pettitt and Lacey (1972), and palaeobotanical GCR sites of Lower Carboniferous age in North Wales have been described by Cleal and Thomas (1995). Banerjee (1959, 1969), Nichols (1965) and Oldershaw (1969) all studied aspects of the microfacies of the Lower Carboniferous strata of North Wales, with Orme and Brown (1963) and Oldershaw and Scoffin (1967) contributing to our knowledge of their diagenesis.

Renewed interest in the Carboniferous Limestone in the 1960s and 1970s also led to the completion of several PhD theses, including four mostly devoted to Anglesey (Nichols, 1962; Mitchell, 1964; Power, 1977; Davies, 1982). The theses of Somerville (1977) and Gray (1981) concentrated on the mainland successions, and Al-Fadel (1983) studied the diagenesis of the successions in north-east Clwyd. Solomon (1986) presented a Masters thesis on the diagenesis of late Asbian limestones at Llangollen.

An overview of the Lower Carboniferous geology of the area was presented by George (1974). The cyclicity of the Dinantian limestones has generated particular interest and was the focus of work by Somerville (1979a,b,c) in north-east Wales and by Davies (1984) in the Anglesey and Llandudno areas. In 1984, the [British] Geological Survey published the memoir for the area around Rhyl and Denbigh, which also includes the Lower Carboniferous rocks of the Little Orme and Great Orme (Warren *et al.*, 1984). A succession of fossil discoveries and some re-mapping of the outcrop between Prestatyn and Llandegla and in the Vale of Clwyd has led to major revision of the stratigraphy in these areas (Somerville and Strank, 1984a,b,c; Davies *et al.*, 1989; Somerville *et al.*, 1989).

Papers interpreting aspects of detailed local sedimentology include those of Walkden and Davies (1983) on the sandstone pipes of Anglesey, Solomon and Walkden (1985) on calcrete fabrics at Llangollen, Bancroft *et al.* (1988) on some unusual bryozoan buildups near Llandudno, Solomon (1989) on early cementation in cyclic limestones, and Davies (1991) on karstification and soil formation in the Anglesey succession.

## Stratigraphy

In his series of papers on the Lower Carboniferous rocks of North Wales, Morton (1870, 1878, 1886, 1897, 1898, 1901) applied a simple lithostratigraphy based on the colour of the limestones. Thus the major part of the succession was divided into the Lower Brown Limestone, the Middle White Limestone and the Upper Grey Limestone (Figure 8.2). The lowest strata, the largely detrital Basement Beds, Morton originally classified as 'Old Red Sandstone'; however, this was revised after Strahan and Walker (1879) showed them to be Lower Carboniferous. The uppermost units are rather more variable. Morton's lithostratigraphy proved remarkably successful although it was applied more easily in some areas than others. Revisions and alternative names were suggested by Neaverson during his work of the 1930s and 1940s (e.g. Neaverson, 1935), but essentially Morton's classification remained in use until the 1970s when a plethora of local formation names began to appear to replace the outdated scheme.

Following the work of Hind and Stobbs (1906) on the mainland and Greenly (1919) on Anglesey, the whole of the limestone succession was attributed to the ***Dibunophyllum*** Zone and, after erection of the regional stages by George *et al.* (1976), to the Asbian and Brigantian stages. Although the possibility that the Basement Beds were $S_2$ (Holkerian) was raised, older Dinantian strata were not generally recognized with certainty, despite the record of $S_2$ (Holkerian)

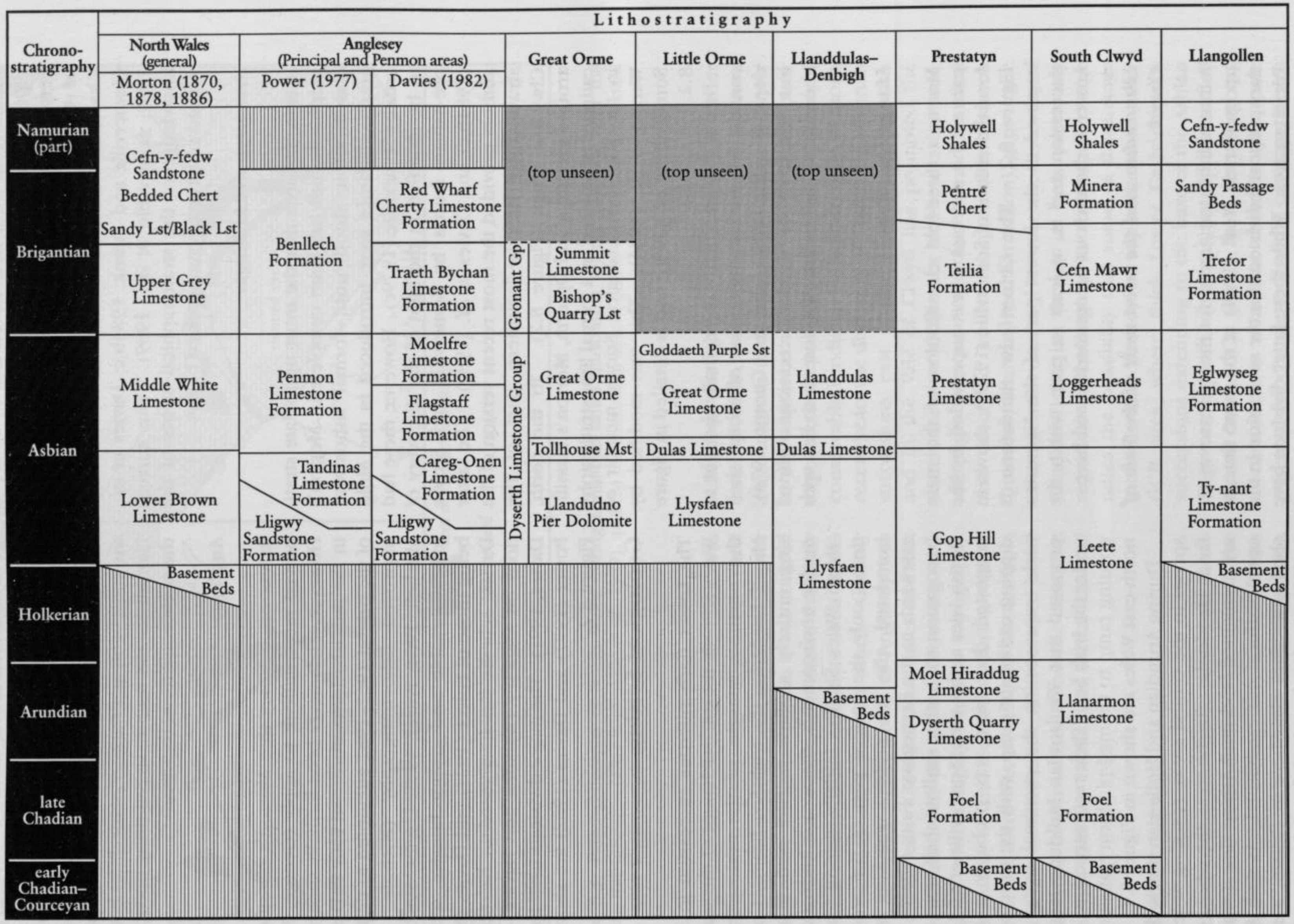



**Figure 8.2** Simplified stratigraphical chart for the Lower Carboniferous succession of North Wales. In the central areas of the Great Orme, the Little Orme and Llanddulas to Denbigh, Warren *et al.* (1984) placed Brigantian strata in the Gronant Group and Asbian strata in the Dyserth Limestone Group. Compilation based on information from Power (1977), Somerville (1979a), Davies (1982), Somerville and Strank (1984c), Warren *et al.* (1984), Somerville *et al.* (1986) and Davies *et al.* (1989). Areas of vertical ruling indicate non-sequences. Not to scale.

foraminifera from near Llanddulas by Simpson (1961), until detailed work on the outcrop between Prestatyn and Llandegla and in the Vale of Clwyd revealed the presence of beds of Chadian, Arundian and Holkerian age (Somerville and Strank, 1984b,c; Davies *et al.*, 1989; Somerville *et al.*, 1989). The current knowledge of the stratigraphical status of the various outcrops is summarized below.

### *Prestatyn to Llandegla*

It is in this area that the most up-to-date stratigraphical work has been completed. Morton's classification stood until formal lithostratigraphical names were introduced in the Mold area by Somerville (1979c). However, these had to be modified in the light of the discovery of pre-Asbian faunas by Somerville and Strank (1984b,c) and Davies *et al.* (1989). The latter authors provided the most recent version of the stratigraphy for the southern part of the Clwydian range (Figure 8.2). To the north, around Prestatyn and Dyserth, Morton's classification was replaced by a formal lithostratigraphy in the [British] Geological Survey memoir of Warren *et al.* (1984). This was modified by Somerville *et al.* (1986) and is detailed in Figure 8.2.

It was this area that was originally thought to contain the thickest succession of Asbian shelf deposits in the British Isles (e.g. George, 1974), but the discoveries of older successions outlined above bring the thicknesses closer into line with those of other similar areas.

### *Llangollen area*

Morton's three-fold classification of the main part of the succession was superseded by the formal divisions of Somerville (1979a), shown in Figure 8.2. The Cefn-y-fedw Sandstone is retained as the lowest part of the Namurian succession and is, at least in part, within the Lower Carboniferous succession as used here.

### *Llandudno and the area west of the Vale of Clwyd*

A formal lithostratigraphy for these areas was set up by Warren *et al.* (1984) at the same time as they proposed divisions for the succession in the Prestatyn area. While these latter divisions have been modified in the light of the more recent work described above, those for the Great Orme and Little Orme represent the most recent stratigraphical work in these areas and are shown in Figure 8.2. Somerville and Strank (1984c) recorded Arundian faunas from near the base of the succession at a number of localities between Llanddulas and Ruthin, so requiring updating of the nomenclature in this area.

### *Anglesey*

It was on Anglesey that Morton's classification proved most difficult to apply (George, 1974). However, it has never been formally superseded in the published literature. All four PhD theses of the period 1962–1982 attempted to define an improved lithostratigraphy (Nichols, 1962; Mitchell, 1964; Power, 1977; Davies, 1982), the most workable and comprehensive schemes being those of Power (1977) and Davies (1982). Davies' scheme has been used in his publications on Anglesey (Walkden and Davies, 1983; Davies, 1991). The major divisions used by both Power (1977) and Davies (1982) are shown on Figure 8.2.

## Geological Setting

The Lower Carboniferous succession in North Wales records the encroachment of the sea onto the northern margin of the Wales–Brabant Massif, bordering the Irish Sea Basin. Comprising entirely shallow marine and marginal marine environments, the area is known as the 'North Wales Shelf'. Initially, during Chadian times, only the eastern part of the area was inundated, the sea perhaps reaching south-eastwards to the Bryneglwys Fault (Figure 8.3a). In common with other shallow shelf areas of the British Isles at this time, Somerville *et al.* (1989) suggested that there was probably a gently dipping carbonate ramp, with the outcropping rocks representing the proximal end. They proposed that Waulsortian buildups might lie under the Irish Sea. Their reconstructions of the ensuing ramp to rimmed platform transition for north-east Wales are shown in Figure 8.4.

During Arundian and Holkerian times, the sea spread to the central areas, reaching at least as far as Llanddulas. To the west, the whole of the area remained land until Asbian times, when an open platform was established. As with Asbian shelf sequences elsewhere in Britain, a strong cyclicity is developed, defined by episodes of

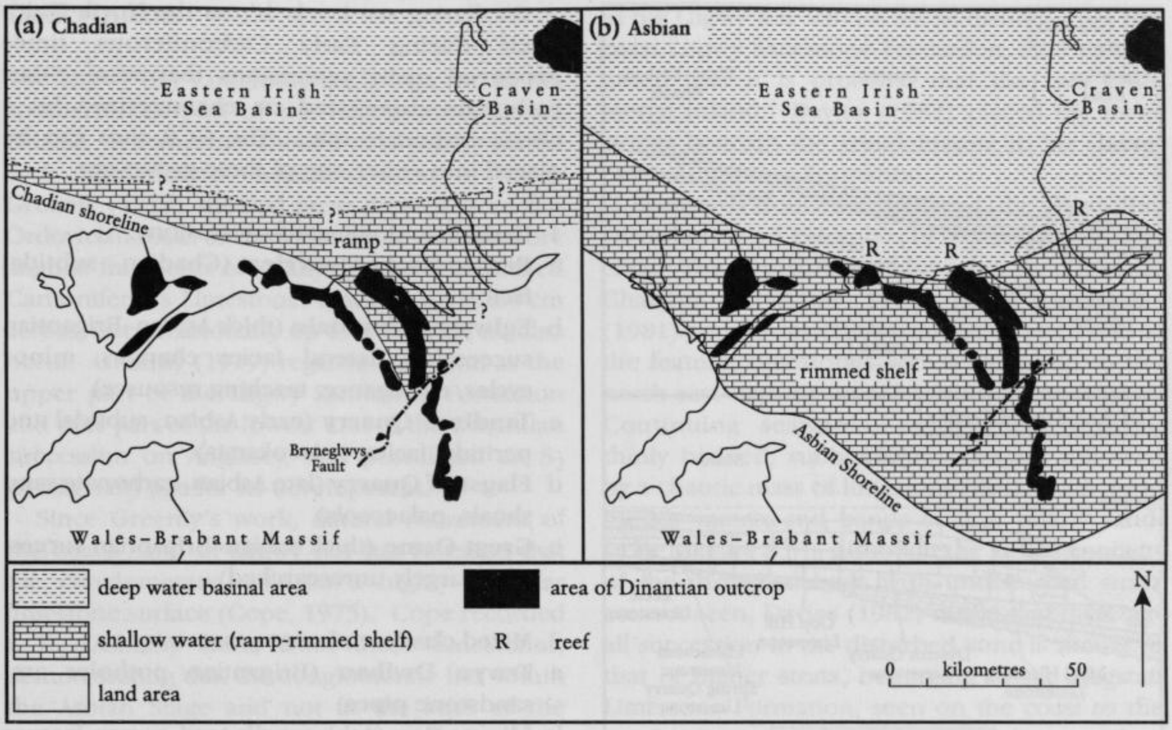



**Figure 8.3** Palaeogeography of North Wales during Dinantian times illustrating (a) the situation after the Chadian transgression (after Somerville *et al.*, 1989), and (b) the maximum extent of the shelf sea during Asbian times. After Warren *et al.* (1984).

subaerial exposure. Probably the area was exposed, with previously deposited shelf carbonates undergoing meteoric diagenesis, for as much of late Dinantian time as it was covered with shallow sea. Figure 8.3b shows the likely maximum extent of the carbonate shelf across North Wales in late Dinantian times. Greenly (1919) recognized that much of Anglesey was land during early Carboniferous times and that the strata recorded the partial drowning of a landscape with a highly irregular topography. The proximity of land meant that during relative sea-level fall there was an influx of clastics from the adjacent elevated areas. This resulted in the progradation of alluvial fans across the emergent carbonates and the incision of fluvial channel complexes (Davies, 1982).

## GCR site coverage

The choice of sites attempts to portray the stratigraphical and sedimentary evolution of the North Wales Shelf during Early Carboniferous times. Sites with Asbian and Brigantian successions are particularly well represented, reflecting the greater knowledge, broader outcrop width and better exposure of these stage intervals than those either higher or lower in the sequence. Restricted outcrop and poor exposure have so far prevented the selection of conservable Pendleian and Arnsbergian sites. In recent years the discovery of Chadian–Holkerian successions east of the Clwydian Mountains and in the Vale of Clwyd has prompted the search for new GCR sites in these areas and, although one new site has been identified and described in this chapter (**Pentre-bach Quarries**, Chadian, Foel Formation), gaps in the coverage still remain. However, the discovery of Chadian–Holkerian faunas in beds previously regarded as belonging to the Asbian Stage raises the possibility that some of these stage intervals may already be represented at other GCR sites, where thick Lower Carboniferous successions extending to the base of the Asbian Stage are reported (e.g. the poorly researched **Great Orme** GCR site). From the foregoing discussion it is clear that there is still some potential for change to the site coverage in this area.

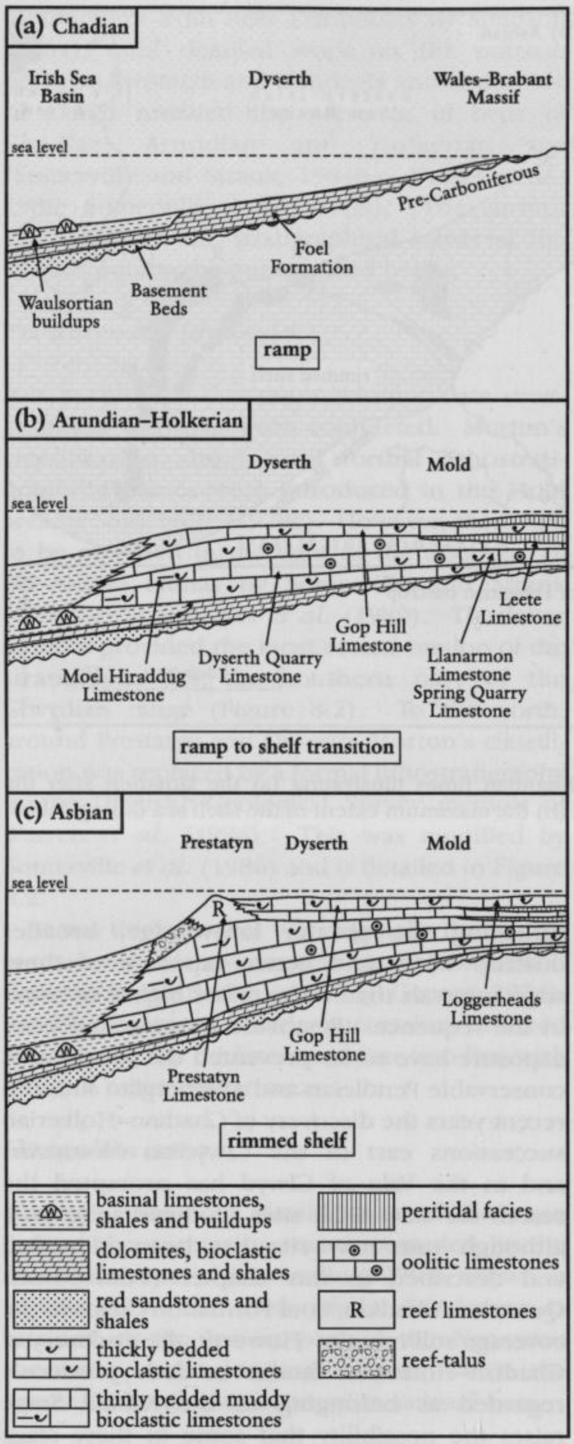



**Figure 8.4** A north to south section across north-east Wales showing the transition from carbonate ramp to reef-rimmed carbonate shelf during Dinantian times, with inferred facies for the Irish Sea Basin area: (a) Chadian, (b) Arundian–Holkerian, (c) Asbian. After Somerville *et al.* (1989). The approximate length of the sections is 50 km.

Oscillating sea levels across the North Wales Shelf during Early Carboniferous times produced cyclic successions that were either carbonate dominated or characterized by a clastic–carbonate mix. The GCR sites can be placed into either one of these groupings.

1. Carbonate-dominated successions:

a **Pentre-bach Quarries** (Chadian, subtidal facies)

b **Eglwyseg Mountain** (thick Asbian–Brigantian succession, lateral facies changes, minor cycles, emergence, teaching resource)

c **Tandinas Quarry** (early Asbian, subtidal and peritidal facies, palaeokarsts)

d **Flagstaff Quarry** (late Asbian, carbonate sand shoals, palaeosols)

e **Great Orme** (thick Asbian–Brigantian succession, largely unresearched)

2. Mixed clastic–carbonate successions:

a **Trwyn Dwlban** (Brigantian potholes and sandstone pipes)

b **Lligwy Bay** (Asbian collapsed cavern feature and Lligwy Bay Conglomerate)

A further site selected specifically for its sedimentological and palaeontological interest is the **Little Orme** in which rocks of reef facies are developed in the Great Orme Limestone (Asbian).

## LLIGWY BAY, ISLE OF ANGLESEY, GWYNEDD (SH 499 871–SH 502 872)

### Introduction

The Lligwy Bay GCR site consists of the south-east side of Lligwy Bay, from Carreg Ddafad (SH 499 871) ENE for about 500 m to the north-west side of the headland of Trwyn Gribin (SH 502 872), 1 km north-west of Moelfre, Anglesey. The locality is famous for its exposures of the impressive Lligwy Bay Conglomerate and of the Lligwy Bay Disturbance, features that are both unique to the Dinantian succession in Anglesey and critical to reconstructions of Lower Carboniferous palaeogeography in north-west Wales. Details of the site geology were originally presented by Greenly (1919), while more substantive and relatively modern accounts are provided by Cope (1975) and Davies (1982).

## Description

The Lligwy Bay Conglomerate is exposed in the southernmost part of the bay, around Carreg Ddafad. It comprises about 2 m of poorly sorted rock with rounded boulders, many of which Greenly (1919) showed were derived from the Ordovician rocks of Parys Mountain. Rather more angular fragments of locally derived dolomitized Carboniferous Limestone, typically up to 60 cm across, but occasionally up to nearly 1.5 m, also occur. Greenly (1919) regarded this unit as the upper part of the Lligwy Sandstone Formation and thus part of the lowest unit of the Dinantian succession on Anglesey, and postulated an $S_2$ (Holkerian) age for its development.

Since Greenly's work, natural movement of the beach sand in Lligwy Bay has revealed that the conglomerate rests on a highly irregular limestone surface (Cope, 1975). Cope recorded a $D_1$ (Asbian) fauna from these limestones, demonstrating that the conglomerate lies within the Asbian Stage and not at the base of the succession. Davies (1982) put the conglomerate in his Lligwy Bay Sandstone as distinct from the basal Lligwy Sandstone Formation, although he noted that it is probable that the two units merge inland. Davies (1982) placed the limestones beneath the conglomerate in his Careg-Onen Limestone Formation.

Eastwards from Carreg Ddafad, the Lligwy Bay Disturbance of Greenly (1919) is seen in the cliffs. The structure has also been described by Chalinor and Bates (1973), Bates and Davies (1981) and Davies (1982). At the western end of the feature, limestones with a steep dip to the north-east rest on near-horizontal sandstones. Continuing seawards, more-or-less vertical, thinly bedded, rubbly limestones are followed by a chaotic mass of limestone blocks with a red muddy matrix and bands of fine yellow sandstone (Figure 8.5). Although the lateral contacts of the disturbed beds with undisturbed strata are not seen, Davies (1982) noted that the overall succession in the disturbed zone is similar to that of higher strata, belonging to the Flagstaff Limestone Formation, seen on the coast to the south-east.

**Figure 8.5** Conglomerate at the eastern end of the Lligwy Bay Disturbance showing a chaotic array of limestone blocks set in a red shale matrix. The rucksack, for scale (left of centre), is approximately 50 cm in length. (Photo: P.J. Cossey.)

Beyond the disturbed zone, a normal bedded succession can be seen in the cliffs. Sandstones and shales are overlain by bioclastic and oolitic limestones and represent the first exposed cycle of the Flagstaff Limestone Formation (Bates and Davies, 1981; Davies, 1982).

## Interpretation

Cope (1975) interpreted the Lligwy Bay Conglomerate as a beach deposit, with the irregular limestone surface beneath being the remains of sea stacks and collapsed sea stacks. Bates and Davies (1981) and Davies (1982) regarded a fluvial origin as more likely, with the limestone surface beneath being intensely karstified. The Lligwy Bay Disturbance is also probably a karst-related feature, resulting from the collapse of a vadose cave system (Bates and Davies, 1981; Davies, 1982). It is tempting to relate this solution and collapse to one of the episodes of emergence higher in the Dinantian succession, but this is not proven and there remains the possibility that the collapse was much later, perhaps of Triassic or Tertiary age (Davies, 1982).

## Conclusions

Lligwy Bay is an important site for showing two unique features, the conglomerate and the disturbance. The age of the conglomerate and its relationships to the underlying limestone are now clear, but further work is needed to try to establish whether the collapse that led to the development of the Lligwy Bay Disturbance is related to intra-Dinantian emergence or whether it is a later phenomenon.

# TANDINAS QUARRY, ISLE OF ANGLESEY, GWYNEDD (SH 584 820–SH 587 822)

## Introduction

The Tandinas Quarry GCR site, located 2 km NNE of Llandona in eastern Anglesey, comprises the disused Tandinas Quarry (SH 584 820) and a sea-cliff section (SH 587 822) that extends for 500 m to the north-east of the quarry. It is the most complete section of early Asbian beds in Anglesey. The locality was chosen by Power (1977) as the type section for his proposed Tandinas Limestone Formation which broadly equates with the Careg-Onen Limestone Formation of Davies (1982) and the Lower Brown Limestone of the older nomenclature (Morton, 1870, 1878, 1901).

## Description

Details of the section are provided by Power (1977) who recognized 14 sedimentary cycles in a 42 m sequence of the Tandinas Limestone Formation (Figure 8.6). Each cycle is between 1 m and 8 m in thickness, with cycles 1–7 recognizable in the cliffs to the north-east of the quarry and cycles 7–14 and the base of the overlying formation found in the quarry itself. Cycles in the upper part of the formation tend to be thicker than those at the base. Each cycle comprises two major lithologies. At the base there is a unit of thinly bedded, dark-weathering bioclastic limestones with thin shaly interbeds and partings. This unit has little visible macrofauna with the exception of the brachiopod *Daviesiella llangollensis*, chaetetid sponges and gastropods. The second, or upper, unit consists of carbonate mudstones ('porcellanous limestones') with bird's-eye fenestrae and carbonaceous shales with little macrofauna visible apart from concentrations of gastropods in some limestones. Power (1977) regarded the irregular tops to the carbonate mudstones that cap cycles and mark cycle boundaries as erosional. The eroded carbonate mudstone of cycle 13 is overlain by a probable palaeosol clay.

The junction with the overlying formation is also visible in Tandinas Quarry 22.5 m above the main quarry floor (Figure 8.7). The top of the Tandinas Limestone Formation is marked by an unusually thick (7.7 m) development of white-weathering carbonate mudstones with fenestrae in the uppermost metre (Power, 1977). These are succeeded by more thickly bedded, pale-weathering bioclastic packstones and grainstones of the Penmon Limestone Formation (Power, 1977), which broadly equates with the Flagstaff Limestone Formation (Davies, 1982).

## Interpretation

The early Asbian age for the Tandinas Limestone Formation is confirmed by the presence of *Daviesiella llangollensis*. The cycle style and thickness is comparable to that of the Ty-nant Limestone Formation at Eglwyseg Rocks, also of

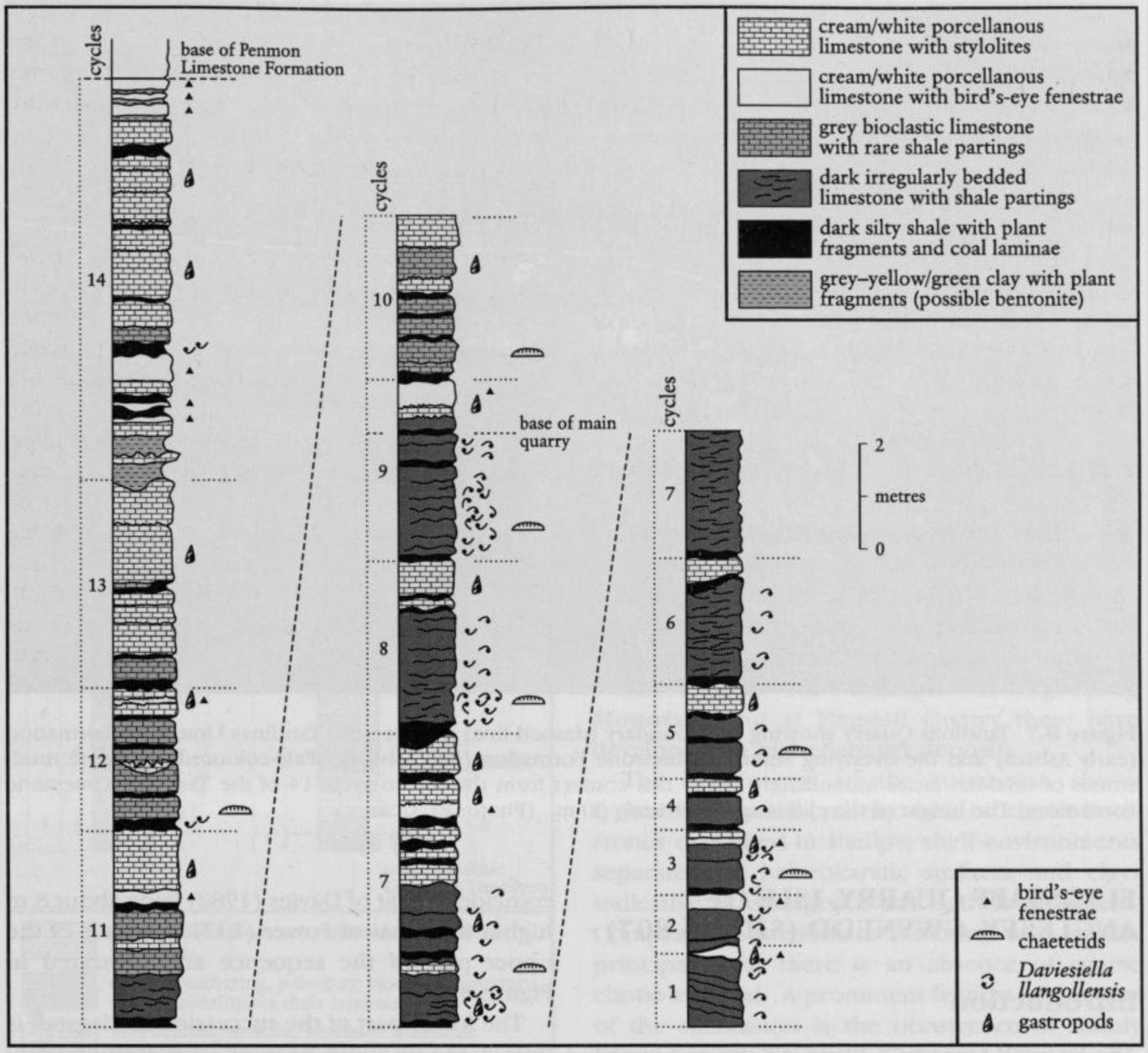



**Figure 8.6** Sedimentary log of the Tandinas Limestone Formation (early Asbian) at Tandinas Quarry. Sections shown are for the main quarry (cycles 9 to 14), the adjacent sea cliffs (cycles 1 to 7 plus) and the transition zone (cycles 7 to 9) that links the quarry to the coastal exposures. After Power (1977).

early Asbian age. Each cycle is interpreted as a small-scale shallowing-upwards succession, with the bioclastic limestones recording deposition in a shallow subtidal shelf or lagoon environment and the mudstones representing the shallowest, most sheltered parts of the lagoon. The presence of fenestrae, most typically in the white-weathering carbonate mudstones, indicates desiccation and deposition on tidal flats. The sparsity of the macrofauna suggests that salinities were different from normal sea water, confirming the interpretation that the environment was a restricted lagoon. The cyclicity reflected in the alternation of limestone rock types bears witness to a pattern of continuous sea-level change across Anglesey in late Dinantian times.

## Conclusions

Tandinas Quarry is particularly important for demonstrating the development of small-scale cyclicity in early Asbian strata. Exposures here and at **Flagstaff Quarry** provide the best available and most continuous section of cyclic Asbian carbonates on Anglesey. Together these two complementary sites are of paramount importance in monitoring sea-level and palaeoenvironment changes across the North Wales Shelf during late Dinantian times.

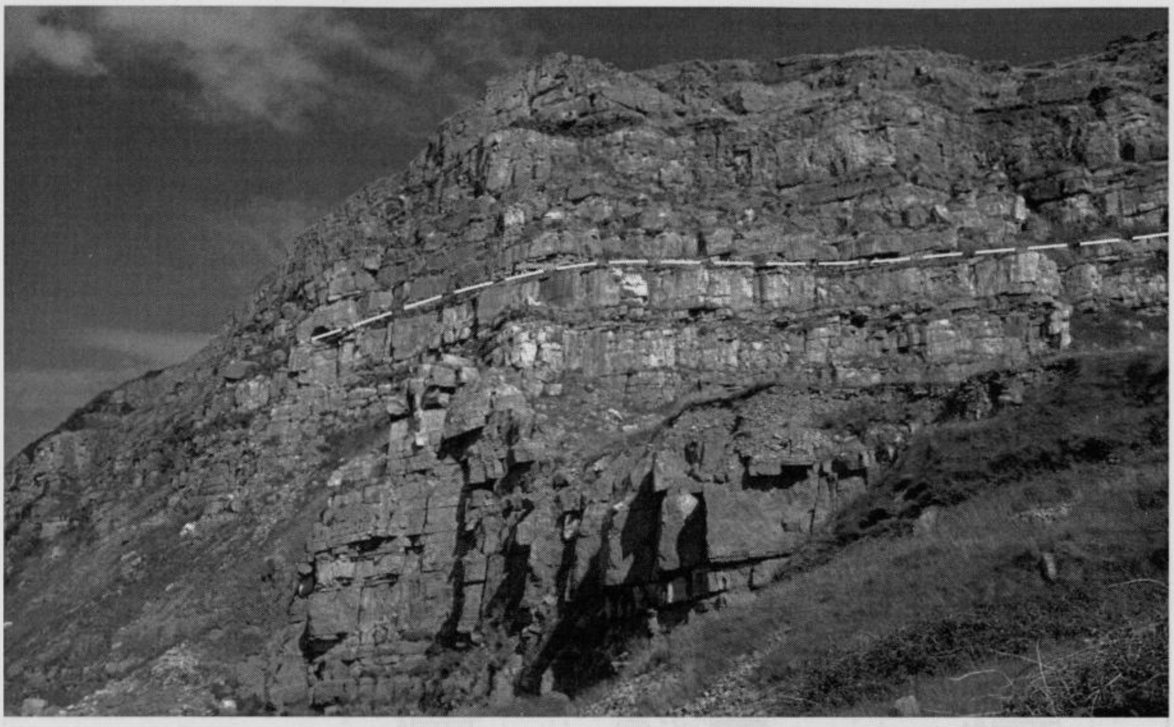


**Figure 8.7** Tandinas Quarry showing the boundary (dashed line) between the Tandinas Limestone Formation (early Asbian) and the overlying Penmon Limestone Formation (late Asbian). Pale-coloured carbonate mudstones of tidal-flat facies immediately below this contact form the top to cycle 14 of the Tandinas Limestone Formation. The height of the cliff is approximately 30 m. (Photo: P.J. Cossey.)

## FLAGSTAFF QUARRY, ISLE OF ANGLESEY, GWYNEDD (SH 636 807)

### Introduction

The Flagstaff Quarry GCR site is a disused quarry on the south side of the Penmon peninsula on the north-east tip of Anglesey (SH 636 807). It is the type section for the Penmon Limestone Formation, defined by Power (1977) and the approximate equivalent of the Flagstaff Limestone Formation of Davies (1982). Exposures here provide the best examples of late Asbian sedimentation and cycle development in the north-western area of the North Wales Shelf.

### Description

The section at Flagstaff Quarry is entirely of Asbian age and embraces the boundary between the Tandinas Limestone and Penmon Limestone formations of Power (1977) and the boundary between the Careg-Onen Limestone and Flagstaff Limestone formations of Davies (1982). However, these boundaries are apparently not coincident, that of Davies (1982) lying about 8 m higher than that of Power (1977). Details of the upper part of the sequence are illustrated in Figure 8.8.

The lower part of the succession at Flagstaff is dominated by about 14 m of cross-stratified bioclastic and oolitic grainstone. This is overlain by a more heterogeneous unit about 10 m thick, dominated by fenestrate carbonate mudstone. Power (1977) placed the top of his Tandinas Limestone Formation at a palaeokarstic surface near the top of this unit, whereas Davies (1982) included a further unit of cross-stratified grainstone in his Careg-Onen Limestone Formation, also capped by a palaeokarstic surface, probably on the basis of the occurrence of *Daviesiella llangollenensis*, indicating an early Asbian age, within it (see Figure 8.8). This unit forms the first cycle of the Penmon Limestone Formation according to Power (1977).

A further 25 m are exposed in Flagstaff Quarry comprising cycles 2–5 and part of cycle 6 of Power (1977), each cycle boundary marked by a palaeokarstic surface. Differences in interpretation led Davies (1982) to recognize three

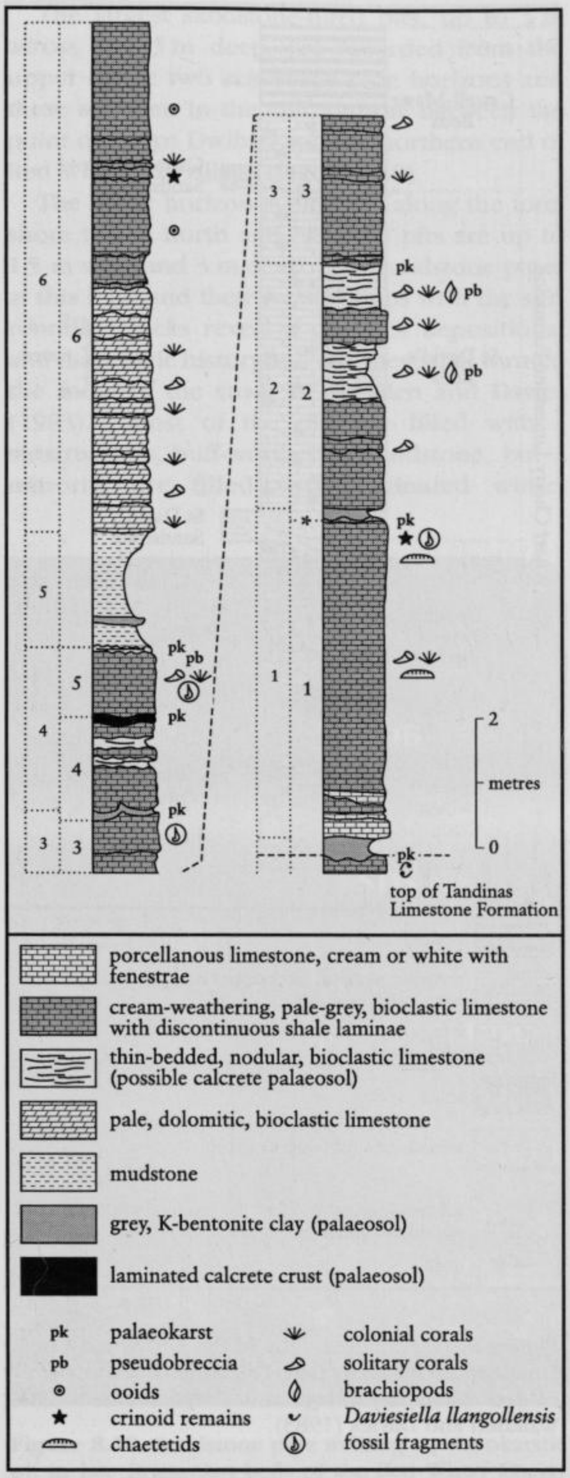



**Figure 8.8** Sedimentary log of the Penmon Limestone Formation (late Asbian) at Flagstaff Quarry. Cycles of Power (1977) indicated in large numbers. Cycles of Power and Somerville (1975) indicated by small numbers. An asterisk at the 1–2 cycle boundary of Power marks the approximate line of division between the Careg Onen Limestone Formation and the overlying Flagstaff Limestone Formation of Davies (1982). After Power (1977).

complete cycles and part of a fourth. The Flagstaff Limestone Formation or Penmon Limestone Formation is, as noted by Davies (1982), quite heterogeneous. It is distinguished by the dominance of pale-coloured bioclastic limestones, the extensive development of rubbly beds, the well-developed palaeokarstic surfaces often overlain by palaeosol clays and by the absence of porcellanous carbonate mudstones. The uppermost exposed unit is patchily dolomitized. The upper part of this formation is not seen in Flagstaff Quarry.

## Interpretation

The lower (early Asbian) part of the succession seen at Flagstaff Quarry, comprising cross-stratified grainstones and fenestrate mudstones, indicates carbonate shoal environments that periodically built up to sea level, allowing tidal-flat deposits to develop. Tidal-flat deposits are important elsewhere in rocks of this age in North Wales, for example at **Eglwyseg Mountain**, but at Flagstaff Quarry these have developed on higher-energy deposits.

The higher part of the succession shows typical late Asbian cyclicity, with bioclastic limestones deposited in shallow shelf environments separated by palaeokarstic surfaces and clays indicative of emergence and soil development. Compared to sections to the north-west, in the principal area, there is an absence of coarse clastic material. A prominent feature of this part of the succession is the occurrence of rubbly limestones. Their development is probably related to solution during emergence, enhanced by selective re-crystallization and pressure solution (Davies, 1982).

## Conclusions

Flagstaff Quarry is the most important site on Anglesey for the understanding of sedimentary processes operating during late Asbian times. The succession contains an extensive range of limestone rock types deposited as shallow marine carbonate sand bars and tidal-flat sediments that were, periodically, exposed above sea level and to the effects of subaerial weathering. Exposures here complement those at **Tandinas Quarry**, the two sites together giving the most complete and best exposed sections of Asbian marine shelf limestones with exposure surfaces on Anglesey.

## TRWYN DWLBAN, ISLE OF ANGLESEY, GWYNEDD (SH 531 821–SH 532 814)

### Introduction

The Trwyn Dwlban GCR site is a shoreline site, 1.5 km south-east of Benllech, Anglesey. It runs from the headland of Trwyn Dwlban (SH 531 821) 600 m southwards to Red Wharf Bay village (SH 532 814) and includes the quarried exposures of Castell-Mawr. In this area the latest Brigantian beds belonging to the Red Wharf Cherty Limestone Formation of Davies (1982), equivalent to the uppermost part of the Benllech Formation of Power (1977), are exposed. In common with other late Dinantian shelf carbonates, the succession is cyclic, with cycle boundaries defined by palaeokarsts and palaeosols formed during episodes of subaerial exposure. On Anglesey these exposure surfaces are frequently cut by channels filled with detrital material. Trwyn Dwlban is famous for its sandstone-filled pits, usually known as 'sandstone pipes', consisting of more-or-less cylindrical pits up to 3 m wide and 5 m deep, generally filled with sandstone and which are associated with the channels.

Channels and sandstone pipes are known from a number of horizons in Anglesey in the late Asbian and Brigantian succession, but are nowhere as well seen as at this locality. Greenly (1901) was the first to describe them in detail although both Henslow (1822) and Morton (1901) had recorded their presence. Suggestions as to their origin include sand volcanoes (Hobbs, 1907), soft-sediment loading (Greenly, 1919), mechanical potholing (Chalinor and Bates, 1973) and karstic solution (North, 1930; George, 1974; Power, 1977; Baughen and Walsh, 1980). The most detailed descriptions are those of Walkden and Davies (1983), who unequivocally demonstrated the solutional origin of the pits and it is on their work that this account is largely based.

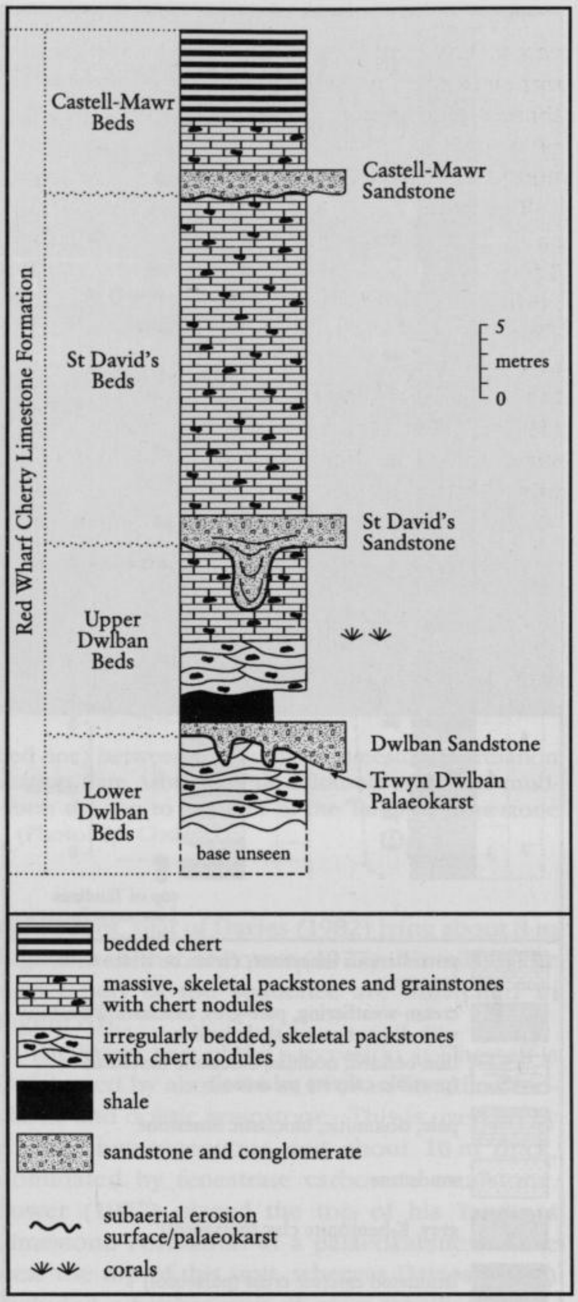



**Figure 8.9** Sedimentary log of the Red Wharf Cherty Limestone Formation (late Brigantian) in the vicinity of Red Wharf Bay village and Trwyn Dwlban. After Walkden and Davies (1983).

### Description

Just over 50 m of strata belonging to four depositional cycles are exposed at the site; three cycle boundaries occur, each marked by a sandstone, and the lower two associated with the sandstone-filled pits (Figure 8.9). The carbonates in the succession are mostly bioclastic packstones and grainstones with significant nodular chert. The cycle between the two horizons with the sandstone pipes contains numerous silicified colonies of the Brigantian coral *Lonsdaleia duplicata*. At the top of the succession, seen to the south of Castell-Mawr, bedded cherts occur.

The largest sandstone-filled pits, up to 3 m across and 5 m deep, are recorded from the upper of the two sandstone pipe horizons and these are seen in the cliff midway between the point of Trwyn Dwlban and the northern end of Red Wharf Bay village (Figure 8.10).

The lower horizon is exposed along the foreshore to the north and here the pits are up to 1.5 m wide and 3 m deep. The sandstone pipes at this level and their relationships with the surrounding rocks reveal a complex depositional and diagenetic history and it is these that formed the focus of the study of Walkden and Davies (1983). Most of the pits are filled with a structureless, buff-weathering sandstone, but a minority are filled with laminated white-weathering quartz arenite or with poorly sorted buff-weathering conglomerate. Walkden and Davies (1983) demonstrated that the white quartz arenite- and conglomerate-filled pits relate to an earlier period of karstification and infill than the more abundant ones filled with the buff sandstone. In all, the Trwyn Dwlban Palaeokarst records at least three episodes of karstification and one of fluvial channel incision. In each case the erosive episode was followed by lithification of the terrigenous clastic material. The depositional and early diagenetic history of this surface as interpreted by Walkden and Davies (1983) is shown in Figure 8.11.

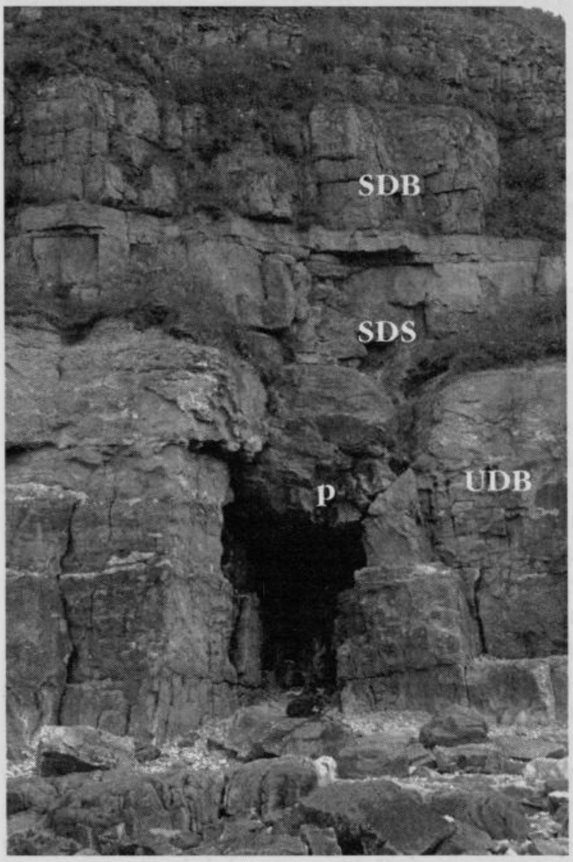



**Figure 8.10** Sandstone pipe infilling a palaeokarstic pit in late Brigantian beds of the Red Wharf Cherty Limestone Formation at Trwyn Dwlban. Note the pipe extension (p) from the base of the St David's Sandstone (SDS) into the underlying Upper Dwlban Beds (UDB) and the irregular nature of the subaerial erosion surface (palaeokarst) which separates the two units. (SDB – St David's Beds.) The rucksack, for scale, is approximately 50 cm in length. (Photo: P.J. Cossey.)

## Interpretation

The late Dinantian limestones of Anglesey record deposition on a shallow marine shelf. Deposition was interrupted by periods of emergence when terrigenous clastic sediment derived from the weathering of nearby highlands (composed of Precambrian, Lower Palaeozoic and Devonian rocks) was carried out over the exposed shelf, cutting channels into the partly lithified limestone. According to Davies (1982), the sandstones represent flood-generated fluvial deposits whose upper parts were reworked during the ensuing transgression.

The sandstone-filled pits are marginal features of the fluvial channels, and Walkden and Davies (1983) interpreted the pits as having formed by solution during overbank flooding rather than as a direct result of atmospheric weathering. In their model, the alternation of solution of limestone and lithification of pit-fills by the precipitation of cement could be accounted for by channel switching without the need to invoke climatic change, although the possibility of alternating wet and dry periods is not discounted.

The late Dinantian succession on Anglesey is unique in its interbedding of fluvial terrigenous clastics and marine limestones. Other exposed mixed carbonate–clastic successions of this age, such as the Yoredale cycles of northern England, are clastic-dominated, leading to significant components of marine clastics. During transgressions, clastic deposition on Anglesey appears to have been restricted to the shoreline. The closest parallel to the late Dinantian succession in Anglesey perhaps lies in successions of the same age in west Cumbria, although these are nowhere as well displayed as the succession at Trwyn Dwlban. In addition to its importance

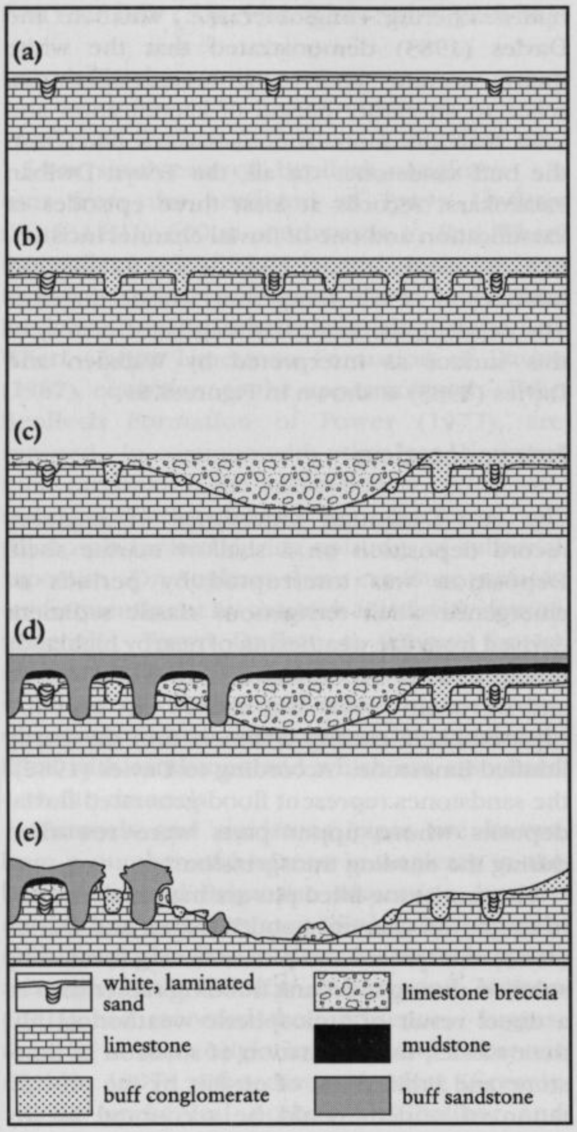



**Figure 8.11** Development of the Trwyn Dwlban Palaeokarst. (a) Uplift of carbonate sediments and lithification, followed by karstification and the deposition of white laminated sand. Further lithification produces resistant sandstone plugs. (b) Arrival of buff conglomerate and renewed solution forms conglomerate-filled pits. Some earlier formed plugs are liberated and some 'moating' takes place around others. Lithification of the conglomerate. (c) Channel formation and fill with limestone breccia. Renewed lithification. (d) Deposition of mud followed by buff sandstone. Renewed solution forms buff sand-filled pits lined with shale and some pits penetrate the breccia. Compaction and lithification of the shale. (e) Quaternary erosion of the surface. After Walkden and Davies (1983).

in demonstrating the style of mixed clastic–carbonate cyclicity, this site exposes bedded cherts characteristic of the uppermost Dinantian sequence in North Wales (Figure 8.2). However, its major importance lies in the record of alternating solution and lithification processes associated with subaerial exposure revealed by the sandstone-filled pits.

## Conclusions

This site provides a unique record of the development of solution pits and sandstone pipes formed by subaerial weathering and fluvial processes during late Dinantian times. The occurrence of these features in a mixed limestone–sandstone sequence is the best example of its kind in Britain.

# GREAT ORME, GWYNEDD (SH 750 841–SH 783 828)

## Introduction

The Great Orme at Llandudno is one of the classic Dinantian localities in Britain. The site includes the limestone cliffs around the Great Orme peninsula (Figure 8.12) and the quarried exposures near its summit. An almost complete succession of the Carboniferous Limestone in the area is seen, totalling about 400 m in thickness, although the basal unconformity with Lower Palaeozoic strata is not visible and uppermost Brigantian beds are not present.

Morton applied his classification of the Carboniferous Limestone in North Wales (Morton, 1870) specifically to the Llandudno area in 1898, and further detailed descriptions of the area can be found in Smyth (1925a) and Neaverson (1937). A more recent account of the key sections at the Great Orme, including the type sections of many newly recognized formations, is provided by Warren *et al.* (1984) who erected a formal lithostratigraphy for the Dinantian strata between Prestatyn and the Great Orme (Figure 8.2). The site offers the best available and most continuous section of late Dinantian carbonates in north-west Wales and is one of the most important research sites of Lower Carboniferous age in Britain.

**Figure 8.12** Cliff and escarpment sections in the bedded and cyclic Great Orme Limestone (Dyserth Limestone Group, Asbian) near Ogof Hafnant at the Great Orme GCR site, Llandudno. (Photo: P.J. Cossey.)

## Description

### *Dyserth Limestone Group*

Warren *et al*. (1984) defined three formations in the Dyserth Limestone Group, two thick carbonate units separated by a thin mudstone. The Dyserth Limestone Group in the Great Orme area has been attributed entirely to the Asbian Stage and is one of the thickest Asbian shelf successions in the British Isles (Warren *et al*., 1984). The lowest unit, the Llandudno Pier Dolomite, is about 140 m thick. Its type section is on the eastern side of the peninsula, from near the pier (SH 783 828) northwards to 200 m beyond the toll gate (SH 782 833). With the exception of a few areas of crinoidal limestone, the unit is made up of bedded medium- to coarse-grained dolomites with little preservation of depositional textures (Warren *et al*., 1984). Other exposures of this formation occur on the south-facing slopes overlooking the town (SH 771 823) and on the shore at the western extremity of the Great Orme (SH 750 841). Warren *et al*. (1984) recorded the brachiopods *Gigantoproductus* sp. *maximus* group and *Megachonetes* cf. *papilionaceus* from near the top of the formation, but other fossils are largely indeterminable.

The type section of the Tollhouse Mudstone lies on the landward side of Marine Drive some 200 m north of the toll gate (SH 781 823). Warren *et al*. (1984) recorded 1.2–2 m of calcareous mudstone and earthy limestone from this locality, containing *Gigantoproductus*, *Linoprotonia*, *Megachonetes*, *Schizophoria*, *Bellerophon*, *Aviculopecten* and ostracodes. The same mudstone is also exposed immediately below the Great Ormes Head Lighthouse (SH 756 843).

Much of the exposure in the steep cliffs around the Great Orme is of the Great Orme Limestone (Figure 8.12). The type section is on the eastern side of the Orme in the crags NNW of Happy Valley (SH 781 832–SH 779 834), where about 140 m of the total estimated thickness (175 m) are visible. The Great Orme Limestone develops a large-scale stepped topography on weathering, resulting from the cyclic alternation of resistant massive limestones and softer rubbly beds. Warren *et al*. (1984) recognized nine cycles at the type section, defined by the rubbly bands that lie at the top of each cycle. These cycles can be traced around the peninsula. Warren *et al.* (1984) provide a log showing the thickness of each cycle and the contained fauna. This includes typical Asbian fossils such as the corals *Dibunophyllum bourtonense* and *Palaeosmilia murchisoni*. The uppermost part of the Great Orme Limestone is not as well exposed, but does occur, on Craig Rofft to the west of Wyddfid (SH 776 832). Here a sandstone occurs in the succession, and above it a fine-grained limestone containing *Chaetetipora*, a calcareous demosponge first described by Smyth (1925b) as a meandrine form of *Chaetetes* (Warren *et al.*, 1984).

***Gronant Group***

Above the Dyserth Limestone Group are 70 m of limestone belonging to the Gronant Group within which Warren *et al.* (1984) recognized two units: the Bishop's Quarry Limestone (used by Smyth, 1925a), and the Summit Limestone.

The mostly dark-coloured and well-bedded Bishop's Quarry Limestone is markedly different from the massive or rubbly pale-coloured Great Orme Limestone beneath. Warren *et al.* (1984) estimated the thickness of the formation as about 20 m, with the best exposure, in Bishop's Quarry (SH 766 831), showing the upper 10 m. The section consists of limestones typically 0.15–0.5 m thick separated by mudstone partings, and has yielded a rich brachiopod fauna that is typical of early Brigantian times (Warren *et al.*, 1984). The bivalve *Posidonia becheri*, indicative of the $P_1$ Zone, is found in the lowest exposed beds in the quarry.

The basal 4 m of the Summit Limestone is present in Bishop's Quarry, with other exposures in old workings close to the summit of the Great Orme. The formation here comprises grey or brownish-coloured limestones with conspicuous chert. A coral–brachiopod fauna recorded by Warren *et al.* (1984) from these beds includes *Caninia cambrensis*, *C. juddi*, *Diphyphyllum lateseptatum*, *Antiquatonia*, *Gigantoproductus*, *Linoprotonia*, *Pugilis pugilis* and *Spirifer*.

## Interpretation

The entire Dinantian succession on the Great Orme has been regarded as Asbian and Brigantian in age (Warren *et al.*, 1984). However, the discovery of Chadian, Arundian and Holkerian strata along the eastern side of the Clwydian range between Dyserth and Llandegla (Somerville and Strank, 1984b,c; Somerville *et al.*, 1986, 1989; Davies *et al.*, 1989), together with the absence of diagnostic fossils through much of the Llandudno Pier Dolomite, raises the possibility that pre-Asbian strata may be present in the Carboniferous Limestone of the Great Orme. The presence of a brachiopod–bivalve fauna of probable $P_{1c}$ age near the base of the Bishop's Quarry Limestone (Brigantian) close above the top of the Great Orme Limestone (Asbian) has been taken to indicate the presence of an unconformity between these two formations and that the lowest Brigantian strata are missing on the Great Orme, as in the Prestatyn area (Warren *et al.*, 1984).

The Great Orme Dinantian succession lies on the North Wales Shelf close to the shelf margin (Figures 8.1 and 8.3). Little is known of the depositional characteristics of the Llandudno Pier Dolomite, although it was, at least in part, a bioclastic limestone. Warren *et al.* (1984) regarded the dolomite as secondary in origin, perhaps forming by the reflux of fluids during relative sea-level fall, and inferred that this mostly took place at the close of early Asbian times.

The Great Orme Limestone displays a cyclicity defined by the presence of rubbly bands and the stepped topography produced by weathering. By comparison with other late Asbian shelf successions in North Wales, it is likely that each cycle is capped by a palaeokarstic surface and a palaeosol clay, but in these natural exposures the cycle boundaries are grassed over. In the absence of modern sedimentological work, more detailed interpretations are not possible.

## Conclusions

The Great Orme is a classic Dinantian site and the type locality for a number of fossil species. Virtually the whole of the Lower Carboniferous succession in north-west Wales is exposed and the locality includes the type sections of the majority of its formations. Given the importance of the site, it is perhaps surprising that little, if any, modern sedimentological work has yet been undertaken. There is also the possibility that a micropalaeontological study would yield more precise information about the age of the Llandudno Pier Dolomite and hence its correlation with other units in North Wales. The site thus has great potential for future research.

## LITTLE ORME, GWYNEDD (SH 817 828–SH 819 826)

### Introduction

The Little Orme GCR site occupies a small area centred on the bay of Porth Dyniewaid on the north-eastern side of the Little Orme (SH 818 827), 3 km east of Llandudno. Inland, the site extends to include a disused quarry complex where important sections are located in what has been referred to as the 'Upper Quarry' area by Davies and Somerville (1986). The locality provides the best exposed section of the richly fossiliferous Asbian reef limestones which are thought to have formed on the northern margin of the North Wales Shelf during late Viséan times. Comprehensive site descriptions have been provided by Warren *et al.* (1984) and Davies and Somerville (1986).

### Description

The reef limestones can be best seen on the east side of the bay on the north-west facing slopes of Trwyn y Fuwch (Figure 8.12). Warren *et al.* (1984) describe the limestones as strongly jointed and obscurely bedded. Lithologies consist of patchily dolomitized fine crystalline limestones and carbonate mudstones. Davies and Somerville (1986) record two main reef lithologies: massive wackestones–packstones with reticulating areas of sparry calcite around bioclasts and lithoclasts, and wackestones–mudstones with lens- and sheet-like stromatactoid cavities floored with laminated and graded geopetal sediment and overlain by fibrous spar cements. Cavities in the reef, some of them vertical pipe-like structures, are filled with limestone breccia or with red calcareous sandstones and shales. In the steep cliffs of the western headland to Porth Dyniewaid, a lower and upper level of pale-coloured massive reef limestone occurs separated by thickly bedded dark-grey limestones. Inland, the lateral transition of the upper reef limestone into brecciated reef limestones and a bedded packstone shelf facies can be seen in the 'Upper Quarry' (Davies and Somerville, 1986).

The reef limestones have an abundant and diverse fauna that includes heterocorals, rugose corals, brachiopods, bryozoans, gastropods, bivalves, nautiloids, trilobites and crinoids together with the stratigraphically important goniatite *Bollandites castletonensis*. Detailed faunal lists are supplied by Warren *et al.* (1984).

### Interpretation

The massive, fossiliferous fine-grained limestones of the Little Orme are interpreted as reef limestones that formed at the margin of the North Wales Shelf where it sloped down into the Irish Sea Basin (see Figure 8.3b). The presence of *Bollandites castletonensis* indicates a $B_{2b}$ (late Asbian) age for the reef and Warren *et al.* (1984) included it within the Great Orme Limestone. Although an abundant macrofauna has been recorded from the reef, these organisms are unlikely to have been solely responsible for the construction of a reef framework. As with other Dinantian reef structures, the organisms responsible for reef construction are obscure, possibly microbial. Similar reef limestones are known from the Prestatyn area (Neaverson, 1930, 1965), but are otherwise absent from North Wales. These reefs are the same age as those in the transition zone between the Askrigg Block and the Craven Basin in the central Pennines (see Chapter 5) and those located around the northern and western margin of the Derbyshire Platform in the southern Pennines (see Chapter 7), but no work has been done to highlight the similarities and differences between these Pennine reefs and those of the North Wales area.

The reef limestones of the Little Orme are the lateral equivalents of the cyclic Great Orme Limestone seen on the Great Orme and in the more south-westerly exposures on the Little Orme. Unfortunately, faulting and the presence of probable collapse breccias mean that the exact relationships of the reef limestones to the normal bedded shelf limestones cannot be easily demonstrated (Warren *et al.*, 1984).

### Conclusions

The Little Orme displays arguably the best exposed section of one of the few outcrops of Asbian reef limestone on the northern edge of the contemporary North Wales Shelf and contains a rich and varied invertebrate fauna. Since little modern sedimentological or palaeoecological work has been undertaken on the Asbian reefs of this area, the site has great potential for future research.

## PENTRE-BACH QUARRIES, CLWYD, (SJ 061 783)

### Potential GCR site

### Introduction

Lying on the west side of Moel Hiraddug, 1 km south of Dyserth, the Pentre-bach Quarries site (SJ 061 783) comprises two overgrown quarries known as 'Pentre-bach North Quarry' and 'Pentre-bach South Quarry' (Somerville *et al.*, 1989). The importance of the site lies in the exposure of the Chadian Foel Formation and the base of the overlying Dyserth Quarry Limestone of Arundian age. Early descriptions of the site were by Strahan (1885) and Neaverson (1935). More recently, Warren *et al.* (1984) published a log of the succession and supplied palaeontological data, while Somerville *et al.* (1989) provided additional sedimentological and biostratigraphical information.

### Description

Pentre-bach North Quarry is the type locality for the Foel Formation of Warren *et al.* (1984), although the base of the formation and its contact with the Basement Beds are not seen. The exposed section is in two parts, the lower consisting of about 7.5 m of the Foel Formation and the higher comprising 2 m of the Foel Formation and about 12 m of the overlying Dyserth Quarry Limestone. The two sections are separated by a gap of about 3 m. The missing strata are mostly represented in the exposure in Pentre-bach South Quarry, 120 m to the SSE, where a 7.5 m section of the middle part of the Foel Formation is seen. Logs of the sections at the two quarries are shown in Figure 8.13.

The Foel Formation consists of mostly dolomitic and silty carbonates interbedded with grey or green mudstones. Lithologies reported by Somerville *et al.* (1989) include peloidal packstones and intraclastic and bioclastic grainstones. The fauna is dominated by brachiopods, especially *Composita* cf. *ficoidea*. Corals occur particularly in one bed in the middle of the formation, called the 'Coral Bed' by Somerville *et al.* (1989). Among the corals recorded from this bed by Somerville *et al.* (1989) were the typical Chadian forms *Caninia cornucopiae* and *Koninckophyllum cyathophylloides*. These occurred in association with *Carruthersella* cf.

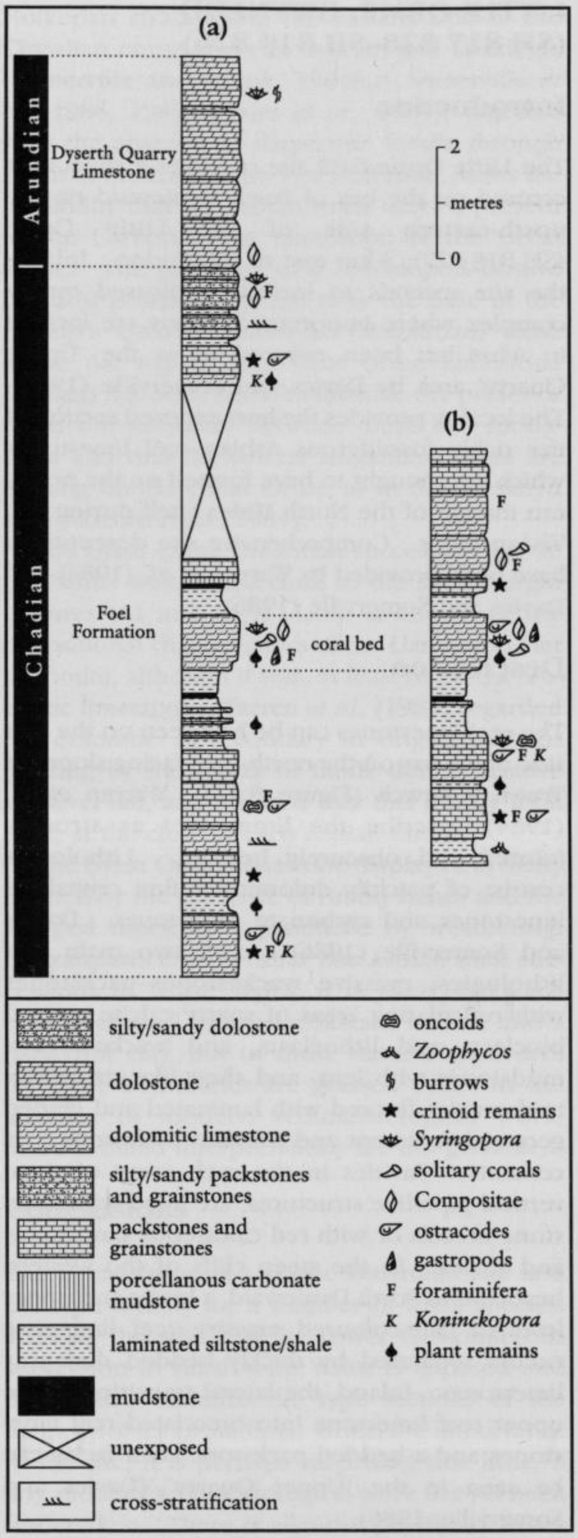



**Figure 8.13** Sedimentary logs of parts of the Foel Formation (late Chadian) and Dyserth Quarry Limestone (Arundian) at (a) Pentre-bach North Quarry, and (b) Pentre-bach South Quarry. After Somerville *et al.* (1989).

*compacta* and *Axophyllum* cf. *simplex* – forms that are known to span the Chadian–Arundian stage boundary (Mitchell, 1989; Riley, 1993). Somerville *et al.* (1989) also recorded a foraminiferal assemblage with abundant endothyrids and tournayellids, but lacking archaediscids. Pentre-bach is also famous for its Viséan floras (e.g. Walton, 1928; Lacey, 1952a,b, 1962), the significance of which is discussed in a companion GCR volume on Palaeozoic palaeobotany by Cleal and Thomas (1995).

The base of the overlying Dyserth Quarry Limestone is taken below a thick, coarse-grained dolomite unit towards the top of the face in Pentre-bach North Quarry (Figure 8.13). On the whole, this unit is more massive and lacks the interbedded mudstones of the Foel Formation. The fauna is sparse, but includes *Composita* and *Syringopora*.

## Interpretation

The lower part of the succession at Moel Hiraddug was included in the Lower Brown Limestone of Morton (1870, 1878, 1886) and was regarded as $D_1$ by Neaverson (1930, 1943). In their new lithostratigraphy for the area, Warren *et al.* (1984) placed the succession at Pentre-bach in the Foel Formation and the lower part of the Ochr-y-foel Limestone, which they continued to regard as being entirely Asbian in age (see Warren *et al.*, 1984). New discoveries in the south Clwyd and Prestatyn areas reported by Somerville *et al.* (1986, 1989) and Davies *et al.* (1989) led to a revision of the stratigraphy, although the name 'Foel Formation' was retained (Figure 8.2). Somerville *et al.* (1989) cast doubt on some earlier fossil identifications from the Foel Formation, especially an uncertain record of *Daviesiella llangollensis* reported by Neaverson (1929). Discarding this identification, the macrofauna indicates a Chadian–Arundian age. The foraminiferal assemblages of the Foel Formation lacking archaediscids are regarded as being of late Chadian age and broadly comparable with those obtained from the Stone Gill Beds and Coldbeck Beds of Ravenstonedale (Somerville *et al.*, 1989) (see Chapter 5). The Dyserth Quarry Limestone has a less diverse macrofauna than the Foel Formation, but a rich foraminiferal fauna which indicates an Arundian age (Somerville *et al.*, 1989).

Somerville *et al.* (1989) also supplied a sedimentological interpretation of the Foel Formation. They regarded it as predominantly the deposit of a wave- and storm-influenced shallow subtidal environment. Detrital material was continually being supplied from an adjacent source area, accounting for the impure nature of the limestones and the interbedded terrigenous clastic mudstones. The occurrence of carbonate mudstones suggests that back-barrier lagoonal conditions developed from time to time.

## Conclusions

For many years the Dinantian carbonate succession in North Wales was regarded as being entirely of Asbian and Brigantian age. Recent work, however, has shown that older Dinantian strata are present, at least in the outcrop east of the Vale of Clwyd and north of the Bryneglwys Fault (Figures 8.1 and 8.3a). Pentre-bach Quarries provide the best exposures of the late Chadian Foel Formation in the Prestatyn region and are therefore critical localities for the understanding of the revised stratigraphy and palaeogeography of the North Wales Dinantian shelf area.

# EGLWYSEG MOUNTAIN, CLWYD (SJ 235 478–SJ 240 428)

## Introduction

The Eglwyseg Mountain GCR site runs in an arc up to 0.8 km wide for 7.5 km from World's End (SJ 235 478) to Bron Heulog Quarry (SJ 240 428) near the Sun Inn at Trefor, 3 km east of Llangollen (Figure 8.14). It includes the W-facing scarp of Creigiau Eglwyseg and the SW-facing Trefor Rocks. The main scarp rises in a series of steps to a height of over 450 m and includes the finest continuous inland exposures of late Dinantian limestones on the North Wales Shelf. In addition to those of the scarp face, there are exposures in the sides of steep ravines and in disused quarries. The extent of the site is of particular importance in that it allows the lateral variation in the limestones to be studied as well as the vertical succession.

Morton (1878) applied his earlier (Morton, 1870) division of the Carboniferous Limestone in North Wales to the Eglwyseg scarp. He recognized three major divisions based on the colour of the limestones: the Lower Brown Limestone, Middle White Limestone and Upper

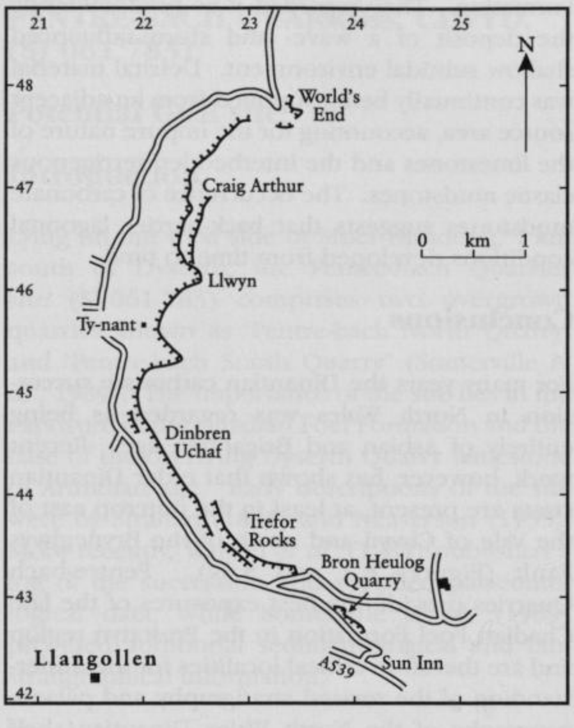



**Figure 8.14** Locality map for the Eglwyseg Mountain GCR site.

Grey Limestone (Figure 8.2). Hind and Stobbs (1906) recognized that all three units lay within the D Zone of the zonal scheme set up by Vaughan (1905) for the succession in the **Avon Gorge** (see GCR site report, Chapter 9). They also established that the boundary between the $D_1$ and $D_2$ subzones lay at the contact of the Middle White Limestone with the Upper Grey Limestone, a position confirmed by the further palaeontological work of Neaverson (1929, 1946), despite Wedd *et al.* (1927) having placed the boundary lower, within the Lower Brown Limestone.

Early reference to the site was made by Wills (1920) and Power and Somerville (1975) but the most important general sedimentological work in the area has been that of Somerville (1979a,b) and Gray (1981). Much of the description here is based on their work. In addition to studying the lithologies in detail and establishing the nature of the cyclicity in the succession, Somerville (1979a) proposed a formal stratigraphical scheme to replace Morton's original divisions. This stratigraphical framework and the earlier divisions, plus the assignment to the stages of George *et al.* (1976), are shown in Figure 8.2.

## Description

### Basement Beds

The Basement Beds, consisting of red and yellow sandstones and conglomerates, are very poorly exposed, but according to Morton (1878) reach their thickest development at the foot of the Eglwyseg escarpment. His estimate of their maximum thickness was 90 m (300 ft), but this was regarded as excessive by Wedd *et al.* (1927). In the absence of any firm palaeontological evidence the Basement Beds are tentatively assigned to the Holkerian Stage (Figure 8.2).

### Ty-nant Limestone Formation

The thickest development of the Ty-nant Limestone Formation (early Asbian) is in the type section seen in two old quarries (SJ 219 454 and SJ 219 457) north of Ty-nant farmhouse. Here some 60 m are exposed up to the contact with the overlying Eglwyseg Limestone Formation (Somerville, 1979b). The lower part of the Ty-nant Limestone and the contact with the Basement Beds are not exposed and Somerville (1979b) estimates the unexposed limestone thickness to be approximately 55 m.

Sedimentary cyclicity was recognized in the Ty-nant Limestone by Somerville (1979b). The cyclicity involves the alternation of two principal lithologies – a lower muddy bioclastic packstone or wackestone and an upper fenestrate carbonate mudstone or wackestone. These alternations make up 15 exposed cycles (Figure 8.15), the lower group (cycles 1–8) only being seen in the more northerly of the two quarries at Ty-nant (SJ 219 457). Here these cycles are 2–3 m thick and consist of brownish-weathering, dark-grey dolomitic bioclastic limestones with thin shaly partings, alternating with bluish-weathering carbonate mudstones. The bioclastic limestones commonly contain abundant *Daviesiella llangollenensis* (see Cope, 1940), usually in life position.

The upper group of cycles (9–15) vary in thickness from 1.5 m to 11 m, with generally thicker developments of bioclastic limestones and shales. At the top of cycle 10 there is a prominent hummocky surface overlain by an orange-weathering bentonite clay and a thin coal seam. In the uppermost three cycles the

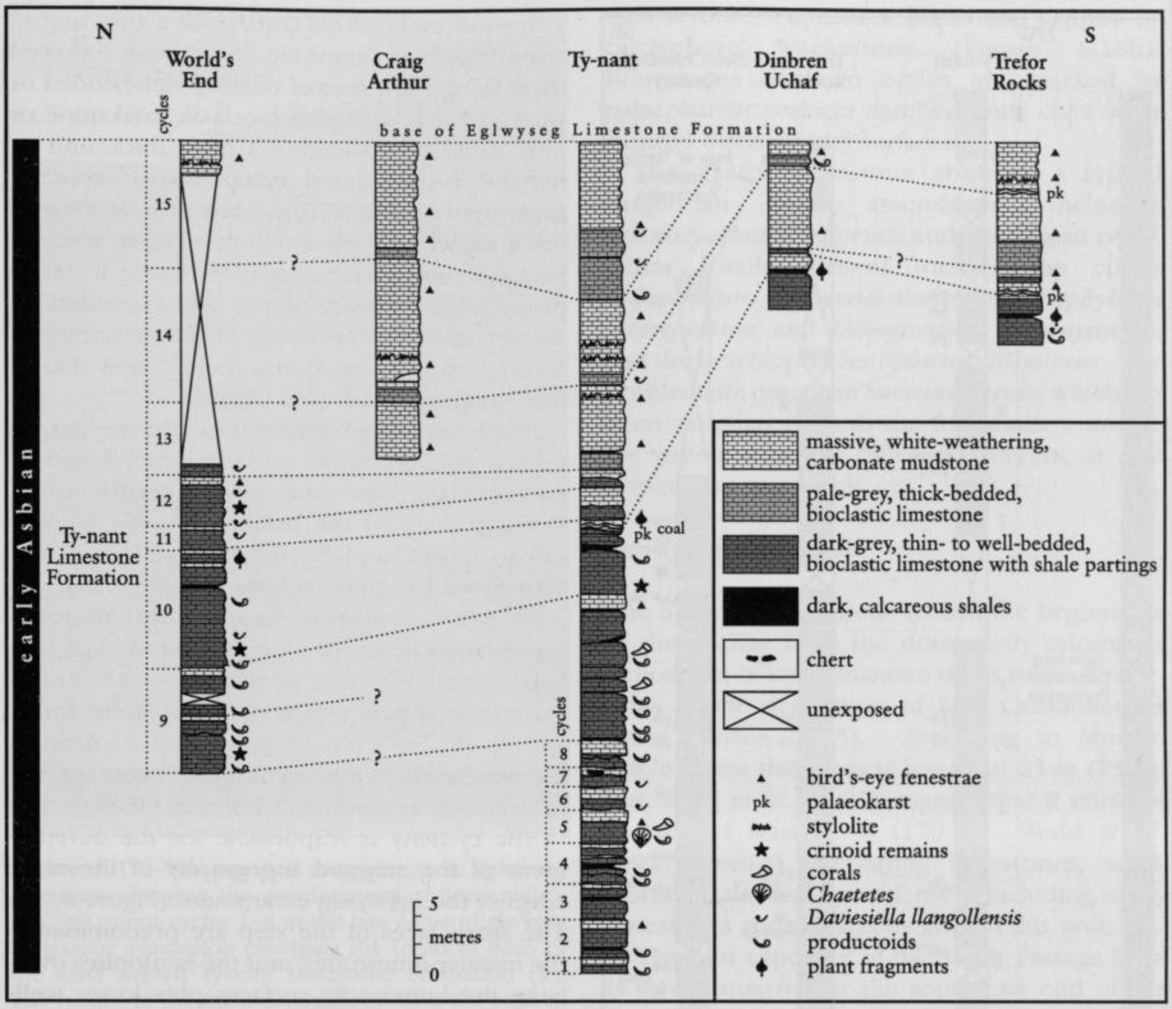



**Figure 8.15** Sedimentary logs of the Ty-nant Limestone Formation (early Asbian) at the Eglwyseg Mountain GCR site showing lateral facies variations and cycle-top correlations. After Somerville (1979b).

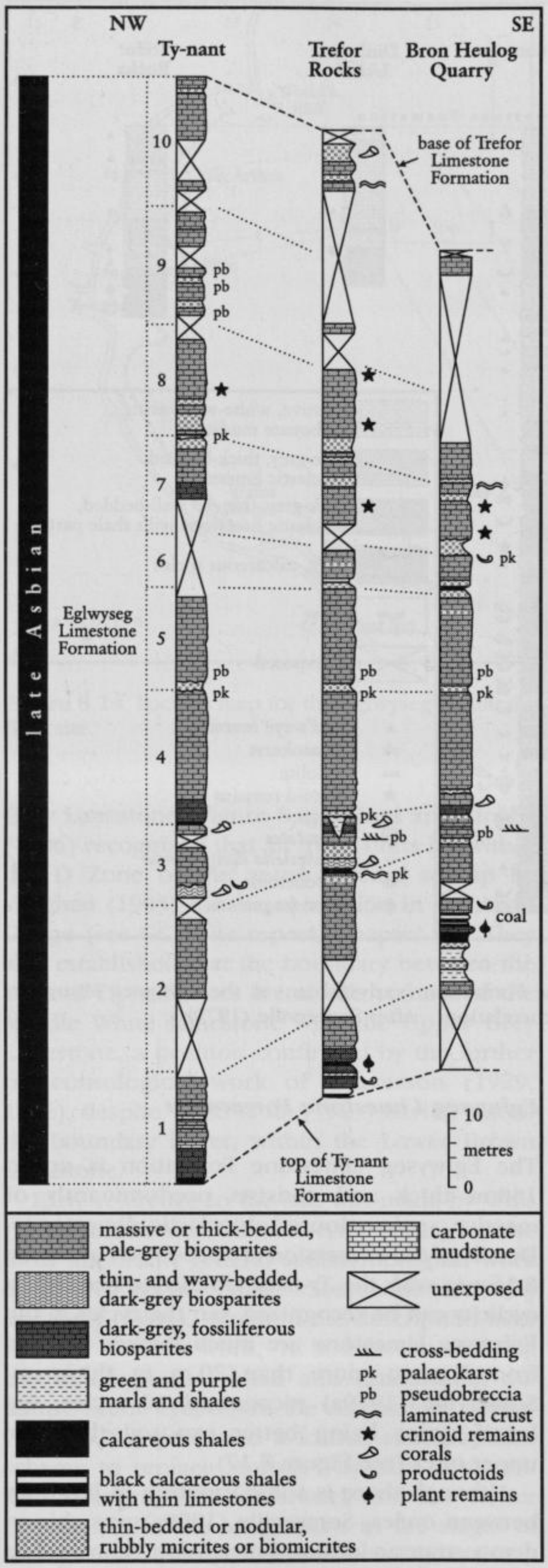
carbonate mudstones are thicker and the bioclastic limestones are purer carbonate with less shale. *D. llangollensis* is present throughout the upper cycles. Other notable fossils in the Ty-nant Limestone include *Linoprotonia*, *Syringopora* and *Siphonodendron sociale*, and the type specimen of *Chaetetes* (*Boswellia*) *mortoni* containing spicule pseudomorphs which Gray (1980) used to demonstrate the spongioid nature of Palaeozoic chaetetids.

It is clear that there is significant variation in the thickness of the Ty-nant Limestone and of individual cycles when traced along the outcrop. Figure 8.15 shows the sedimentary logs of Somerville (1979b) and his proposed correlations.

### *Eglwyseg Limestone Formation*

The Eglwyseg Limestone Formation is up to 150 m thick and consists predominantly of massive, pale-coloured bioclastic limestones. Details of the succession are presented in Figure 8.16. As with the Ty-nant Limestone beneath, a cyclicity can be recognized, but the cycles in the Eglwyseg Limestone are much thicker, ranging from 7 m to more than 20 m in thickness. Somerville (1979a) recognized 10 cycles, the lower cycles being better exposed than the upper ones (see Figure 8.17).

Although there is some variation in lithology between cycles, Somerville (1979a) was able to demonstrate an idealized succession, representing




◄**Figure 8.16** Sedimentary logs of the Eglwyseg Limestone Formation (late Asbian) showing cycle-top correlations in the central and southern areas of the Eglwyseg Mountain GCR site. After Somerville (1979a).

a 'typical' cycle. This consists of a thin unit of shale or rubbly limestone at the base, followed by at most a few metres of fairly well-bedded or wavy-bedded, dark-grey bioclastic packstone or grainstone and succeeded by a thick unit of massive pale-coloured bioclastic packstone or grainstone (Figure 8.18a). Some of these massive units show a colour mottling. These 'spotted' rocks or 'pseudobreccias' are similar to those found in limestones of this age elsewhere in Britain, such as north-west England (Garwood, 1913) (see Chapter 4) and South Wales (Dixon and Vaughan, 1911) (see Chapter 9).

The boundaries between the cycles are characterized by hummocky surfaces, interpreted as palaeokarsts, overlain by bentonite clays. Coating some of the palaeokarsts are laminar calcite crusts, and features indicative of root activity such as rhizocretions and alveolar-septal fabric can sometimes be found in the limestones immediately beneath. One well-exposed palaeokarstic surface is that at the top of the fourth cycle, and this is clearly seen in Trefor Rocks Quarry (SJ 231 433). Exposure phenomena in the limestones at the top of cycle 7 were studied in detail by Solomon and Walkden (1985).

The cyclicity is responsible for the development of the stepped topography of the main crags of the Eglwyseg escarpment (Figure 8.17). The steep faces of the step are predominantly the massive limestones, and the bentonites overlying the hummocky surfaces plus lower well-bedded limestones at the base of the next cycle form the slope break where natural exposures are generally covered by grass and scree. The hummocky surfaces and associated features are well seen at Bron Heulog Quarry.

The Eglwyseg Limestone contains a rich coral–brachiopod fauna characteristic of late Asbian times, including *Dibunophyllum bipartitum*, *D. bourtonense*, *Lithostrotion portlocki*, *L. verticale*, *Palaeosmilia murchisoni*, *Siphonodendron junceum*, *S. martini*, *S. sociale*, *S. pauciradiale*, *Delepinea* aff. *comoides* and *Linoprotonia hemisphaerica*. Towards the top, in the poorly exposed uppermost cycles, *Gigantoproductus giganteus* makes its first appearance.

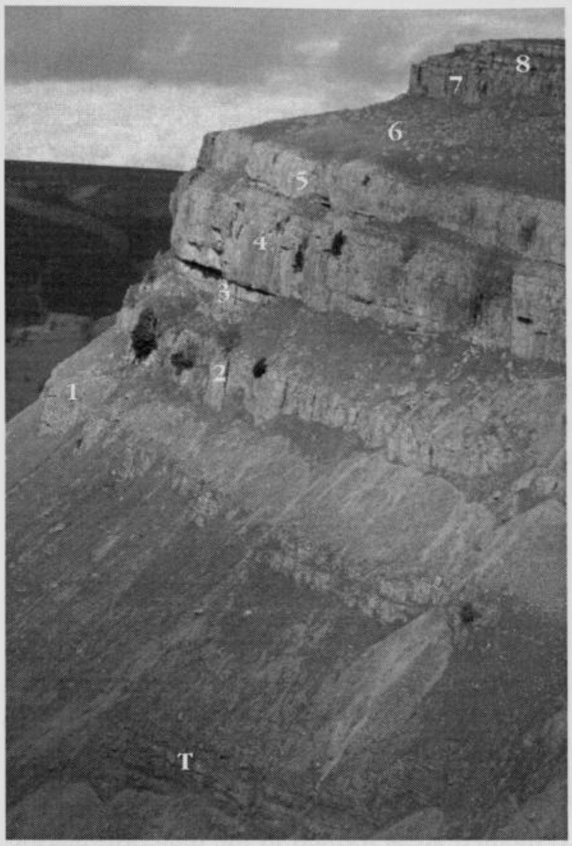



**Figure 8.17** The stepped escarpment at Eglwyseg Mountain showing the development of Somerville's (1979a) minor cycles 1–8 in the late Asbian Eglwyseg Limestone Formation overlying the topmost beds of the early Asbian Ty-nant Limestone Formation (T). The height of the main escarpment from the base of the Eglwyseg Limestone to the top of minor cycle 5 is approximately 80 m. (Photo: P.J. Cossey.)

### *Trefor Limestone Formation*

The Trefor Limestone Formation comprises about 90 m of thinly bedded dark-grey crinoidal packstones and wackestones. The formation is best seen in the area around Trefor Rocks (SJ 230 433). Cyclicity is again present, with cycles intermediate in thickness between those of the Ty-nant Limestone and those of the Eglwyseg Limestone. The most important sedimentological study of the Trefor Limestone is that of Gray (1981), also reported by Tucker (1985). Gray (1981) identified a typical cycle consisting of a basal unit of microfossil (algal) packstone and wackestone with brachiopods and corals often abundant and preserved in life position. This is overlain by algal grainstone with a more fragmented fauna and capped by calcisphere wackestone (Figure 8.18b). Boundaries between cycles are marked by palaeokarstic surfaces and bentonite clays or by sutured discontinuity surfaces.

The Trefor Limestone contains a typical Brigantian coral assemblage, including *Actinocyathus floriformis* and *Palastraea regia*. Other fossils present include the corals *Aulophyllum pachyendothecum*, *Diphyphyllum lateseptatum* and *Lithostrotion maccoyanum*, and the brachiopod *Semiplanus latissimus*. The problematic organism *Saccaminopsis*, which has been assigned to both the foraminifera and to the green algae by different workers, is also present at some levels.

### *Sandy Passage Beds*

The Sandy Passage Beds record the beginnings of the change from the dominantly calcareous deposition of late Dinantian times to the terrigenous clastic deposition of Late Carboniferous times (Taylor, 1973). According to Morton (1878) their thickness is less than 25 m (75 ft), but Wedd *et al.* (1927) suggest that it must be greater, at least 50 m (170 ft). Wedd *et al.* (1927) record alternating limestones, sandstones, shales and 'mixed' rocks including sandy limestones and calcareous grits in this unit.

The best exposure of the Sandy Passage Beds is in old quarries at the south-east end of the exposure, north of the road above Bron Heulog Quarry (SJ 241 429). In these quarries several metres of sandy limestone with large-scale cross-stratification occur. The dune foresets are defined by an alternation of brown-weathering and grey-weathering bands, each 1–2 cm in thickness. The brown-weathering layers consist of fine sand-sized angular quartz grains cemented by calcite. The calcite contains some iron (ferroan calcite) which results in the brown colour on weathering. The grey layers consist of small ooids and superficial ooids with quartz grain nuclei set in a calcite cement containing much less iron than that in the quartz sand layers.

## Interpretation

Each of the three limestone formations is characterized by cyclicity. Cycle boundaries are either defined by palaeokarstic surfaces with attendant bentonite clays, and sometimes with calcretization features in the limestone beneath the palaeokarstic surfaces, or by 'sutured discontinuity surfaces' interpreted by Gray (1981) as the products of intertidal solution and erosion. In either case a degree of subaerial exposure is involved, more profound and prolonged in the case of the palaeokarsts than in the case of the discontinuity surfaces.

The cycles are interpreted in terms of shallowing-upwards successions culminating in subaerial exposure. Somerville (1979b) interpreted the muddy bioclastic limestones of the Ty-nant Limestone as the deposits of sheltered lagoons or subtidal mudflats. The abundance of *Daviesiella llangollensis* in life position supports the idea of a quiet environment below wave-base. The mudstones and wackestones have a restricted fauna and are interpreted as the deposits of back-lagoons and tidal flats. The presence of fenestrae at some levels is diagnostic. Both laminar fenestrae elongate parallel with bedding and more rounded structures ('bird's-eyes') are present; the former may represent decayed cyanobacterial mats, characteristic of high intertidal and supratidal environments, and the latter entrapped gas bubbles, also characteristic of supratidal flats. The absence of any evidence for evaporites suggests that the climate was relatively wet, and more akin to that of the Bahamas today than that of the Arabian Gulf.

The cycles of the Eglwyseg Limestone are quite different in character, being much thicker than those of the Ty-nant Limestone, but with less evidence for well-developed tidal flats (Figure 8.18a). Somerville (1979a) interpreted the basal rubbly limestones as shallow subtidal deposits, with the deepest water represented by the dark-grey well-bedded bioclastic limestones. Shallowing is recorded by the massive pale-coloured packstones and grainstones with their rich faunas. Evidence of shoaling within this unit is occasionally provided by increased burrowing activity and the presence of cross-stratification towards the top of cycles. Finally, with lowering of relative sea level, each cycle was exposed to meteoric waters and underwent solution, probably beneath a bentonite soil formed from weathered volcanic ash. Limestones beneath these surfaces suffered from intense early diagenesis with multiple generations of solution and cementation (Solomon and Walkden, 1985).

The colour mottling ('pseudobrecciation') in the massive limestones was the subject of detailed investigation by Solomon (1989). He interpreted the mottles as being early cemented areas formed in the meteoric–marine mixing zone during the repeated episodes of deposition followed by regression and emergence.

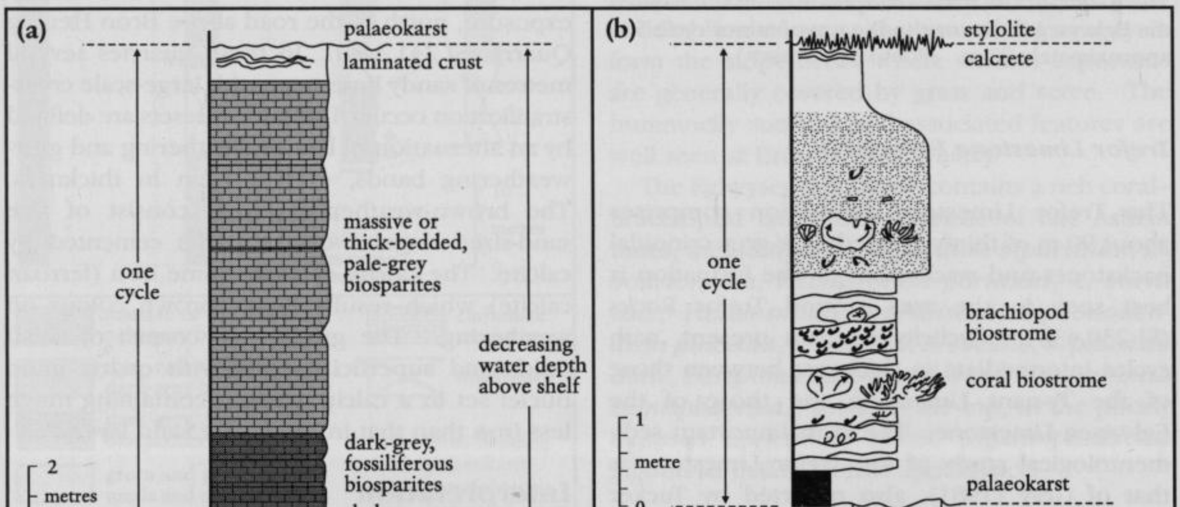



**Figure 8.18** Styles of cyclicity in late Dinantian limestones at Eglwyseg Mountain. (a) A typical Eglwyseg Limestone (late Asbian) cycle. After Somerville (1979a). (b) An ideal Trefor Limestone (Brigantian) cycle. Based on Gray (1981) and Tucker (1985).

The Trefor Limestone shows a cyclicity that is closer in style to that of the Ty-nant Limestone than that of the Eglwyseg Limestone (Figure 8.18b). Gray (1981) interpreted the Trefor Limestone cyclicity in terms of different depths of shelf flooding and regarded the microfossil packstones and wackestones as subtidal below-wave-base deposits, the algal grainstones as shoreface deposits, and the calcisphere wackestones as tidal-flat deposits. The Trefor Limestone cycles, with a greater subtidal component, may represent cycles developed farther from the contemporary shoreline or under a regime of greater relative sea-level change compared to the thinner cycles of the Ty-nant Limestone with a more poorly developed subtidal facies.

It is generally accepted that eustatic variations were at least partly responsible for late Dinantian cyclicity (see, for example, Walkden, 1987). As Somerville (1979b) pointed out, in the area represented by this site, eustatic fluctuations *could* account for the cyclicity, but the variations in cycle thickness, particularly evident in the Ty-nant Limestone, suggest the involvement of local tectonism.

## Conclusions

The superbly displayed succession at Eglwyseg Mountain shows the different styles of late Dinantian cyclicity developed in entirely carbonate facies better than at any other site in Britain. A unique feature of the site is the geographical area covered, which allows study of lateral variation in cycles and in cycle bounding surfaces. These features make Eglwyseg Mountain an essential resource for teaching and for further research.