Pant y Slade to Witches Point, Glamorgan

[SS 870 741]–[SS 890 726]

Introduction

The Pant y Slade to Witches Point GCR site is a coastal section, some 2 km in length (Figure 3.5) and (Figure 3.6) that exposes, better than any other site, the lateral and vertical transitions from 'marginal' facies unconformable on Carboniferous Limestone in the west through to more 'offshore' Blue Lias Formation facies in the east. As such it is one of the classic British examples of lateral facies changes in ancient sediments. Three distinct sedimentary units, the Sutton Stone Member, the Southerndown Member and the Blue Lias Formation (Porthkerry Member), can be recognized along the section although precise boundaries between them are diachronous and difficult to define. A gentle easterly dip brings the marginal facies, exposed in the upper part of the cliff above the Carboniferous Limestone at Pant y Slade, down to beach level at Southerndown. Between there and Witches Point (Trwyn y Witch) the cliffs are formed in alternating limestones and mudstones of Blue Lias Formation facies. Faults on the western side of Witches Point bring the Carboniferous Limestone into the lower part of the cliff; with the marginal facies forming the cliffs above and descending to beach level a short distance to the east. This site is a key locality for demonstrating, through faunal evidence, the diachronous relationships of facies.

The oldest Jurassic rocks, termed the 'Sutton Stone' by Henry De la Beche (1846), comprise coarse bioclastic calcarenites with reworked limestone lithoclasts and rest on an irregular surface of Carboniferous Limestone. This passes up gradationally into more thinly bedded bioclastic calcarenites with fewer and smaller limestone lithoclasts, and a higher clay content. These were termed the 'Southerndown Beds' by Tawney (1866). In turn this passes up into offshore Blue Lias Formation facies of the Porthkerry Member. The succession fines upwards from the coarsely conglomeratic base of the Sutton Stone Member to the mudstones and argillaceous limestones of the Blue Lias Formation. There is a corresponding increase in faunal diversity upward through the succession. The striking transition from marginal facies to offshore Blue Lias Formation sediments has been the focus of considerable discussion since it was first noted by De la Beche (1846). Publications that have been concerned with the age of the sediments and their fossil content included Tawney (1866), Bristow (1867), Duncan (1867a,b, 1886), Moore (1867a), Tate (1867), Tomes (1878, 1884) and Hodges (1986). One of the most comprehensive descriptions of the section is that of Trueman (1922b): useful summaries were provided by Woodward (1888a, 1893), Strahan and Cantrill (1904), Arkell (1933), Thomas (1970), Wilson *et al.* (1990) and Warrington and Ivimey-Cook (1995). Accounts by Hallam (1960a), Wobber (1965, 1966, 1968a,b), Ager (1986a,b), Fletcher (1988) and Johnson and McKerrow (1995) have focused on the palaeoenvironments deduced from the sedimentology and palaeoecology.

Description

The Lias succession exposed along the coast between Pant y Slade and Witches Point shows vertical and lateral changes that demonstrate the transgressive nature of the basal Lias in this area. The unconformity between the Lias marginal facies and the Carboniferous Limestone is best exposed at Pant y Slade (Figure 3.7) but can also be seen at Witches Point. The two lithofacies divisions of the marginal facies, the Sutton Stone Member and the Southerndown Member, also are most accessible at Pant y Slade since their outcrop farther east is tidally restricted. The transition from marginal facies to the offshore facies of the Porthkerry Member is most easily examined in the cliffs below Southerndown whereas the progressive increase in the proportion of mudstone to limestone upwards through the succession can be seen in Dunraven Bay.

The surface on the Carboniferous Limestone beneath the marginal facies of the Lias is mostly smooth or gently undulating. The unconformity is particularly striking below Southerndown, where it truncates a steep monocline in the Carboniferous Limestone. At Pant y Slade the unconformity forms a broad trough, approximately 150 m wide and more than 10 m deep, cut into the limestone (Figure 3.6). It was termed the 'Slade Trough' by Fletcher (1988). The margins of the trough are steep and terraced, particularly on its western margin where the unconformity surface ascends steeply from beach level (Figure 3.7). On the platform just to the north-west of the Slade Trough, Fletcher (1988) described a low, irregularly scalloped scarp beneath which a series of broad channels and ridges descend the dip of the unconformity surface for several metres before becoming more subdued as the unconformity surface levels out. The surfaces of the ridges and troughs are intensively bored, as are the roof and walls of occasional crevices; most of the borings are narrow and elongate (*Trypanites*) but flask-shaped lithophagid bivalve crypts also occur. Johnson and McKerrow (1995) also described corals and oysters encrusting the unconformity surface at this locality.

Resting directly upon this irregular unconformity surface is the Sutton Stone Member, which may be formally assigned member status (Cox *et al.,* 1999), and comprises thickly bedded, coarsely bioclastic calcarenites and conglomerates. The Sutton Stone Member is 10–13.5 m in thickness, being greatest where banked against the western margin of the Slade Trough (Hallam, 1960a). Hallam (1960a) recognized two subdivisions within the Sutton Stone Member which he claimed were separated by an irregular bored surface. The lower unit, up to 10 m thick, is markedly conglomeratic towards the base with abundant pebbles of Carboniferous Limestone (Figure 3.8). Coarse breccias are restricted to the lower part of the Slade Trough, where irregular Carboniferous Limestone lithoclasts, up to 2 m across, are encrusted and bored by fossil marine organisms and set in a matrix of smaller clasts and shell debris (Bed 1 in (Figure 3.8)). An impersistent calcarenite unit (Bed 2) lies between this and an overlying breccia (Bed 3) in which the clasts, generally smaller than those in the lower breccia, are supported in a coarse bioclastic matrix. Irregular colonial coral masses up to 0.5 m across occur in the lower part of Bed 3. Massive- to thinly bedded polymictic framework-supported conglomerates with a sparry calcite cement are conspicuous a little higher in the succession (Bed 8). Above this, fragments of limestone and chert are rarely more than 0.03 m across and tend to be confined to discrete layers above irregular partings. Within the conglomerates the sphericity of limestone clasts (up to 0.90) consistently is higher than that of chert clasts (0.40–0.70). Many elongate or discoidal clasts have a preferred orientation, with some exhibiting imbrication. Hallam (1960a) described the upper unit as about 4 m of thinly bedded calcarenites with abundant gravel-grade lithoclasts of limestone and chert. Wobber (1965) considered that this division could be recognized only locally and that east of Pant y Slade Hallam's upper division could not be distinguished from the overlying Southerndown Member. Bands of pseudo-oolite, sand-sized lithoclasts with semi-opaque rims of micro-crystalline calcite, are common throughout the Sutton Stone Member (Hallam, 1960a; Wobber, 1965).

The Sutton Stone Member passes vertically and laterally into the succeeding Southerndown Member but the transition is gradational and, locally, there is no distinct boundary between the two units. The Southerndown Member, like the Sutton Stone Member, comprises lithoclastic and bioclastic sands and gravel-grade conglomerates but these contain a lower proportion of limestone lithodasts, a higher day content and are more thinly bedded. The succession includes occasional thin (less than 0.03 m) argillaceous units separating the limestone beds. Locally the upper part of the Southerndown Member contains bands of oolitic limestone which are associated with, and gradational from, underlying conglomerates. Ooid nuclei are formed of calcarenite grains, shell fragments and quartz grains.

There is a gradation, both vertically and laterally, from thinly bedded conglomeratic limestones of the Southerndown Member into shales and nodular limestones of the typical offshore facies of the Porthkerry Member. The lateral changes, although visible, are inaccessible in the sheer cliffs between Pant y Slade and Seamouth but the vertical transition can be examined at some localities. At Seamouth [SS 883 733] an oolite bed at the top of the Southerndown Member has a hummocky surface overlain by shale in which occur abundant boulders of this same oolite, often encrusted by fossil oysters. About 400 m west of this point the 'boulder bed' is absent and there is a transition between facies, with an increase in mean chert lithoclast size followed by a sharp decrease in lithoclast abundance in passing into the shale and limestone of the more offshore facies of the Porthkerry Member. There is a corresponding upward increase in pyrite abundance.

The Porthkerry Member is of typical Blue Lias Formation facies, with centimetre- to decimetre-scale alternations of mudstone and argillaceous limestone. Argillaceous micritic limestones, from 0.04 m to 0.76 m thick, comprise from 45% to 75% of rock volume in different parts of the Porthkerry Member exposed at the eastern end of the GCR site. The limestone–mudstone ratio is useful as a broad lithostratigraphical indicator and enabled Wilson *et al.* (1990) to recognize four distinct lithostratigraphical units in the Porthkerry Member. Units A to C are limestone-dominated while Unit D has a significantly higher proportion of mudstone. Limestones vary from bands of isolated ellipsoidal nodules through to continuous semi-nodular or tabular beds. A few of the tabular limestones are laminated, as are some of the ellipsoidal nodules. Some distinctive limestone beds or groups of beds can be traced for several kilometres along the main coastal exposures of the Porthkerry Member to the east of this GCR site, but Wilson *et al.* (1990) found it difficult to correlate any of these with the succession exposed at Dunraven Bay. A few of the limestone beds can be recognized by their distinctive fossil content, for instance corals or brachiopods (Wobber, 1968a). A limestone exposed on the foreshore in Dunraven Bay contains abundant *Montlivaltia haimei* (Trueman, 1922b), and this same coral occurs in lower abundance in several of the adjacent limestone beds. The fossil content of the limestones varies from rare to more than 50%, mostly as bioclastic debris. Based on this Wobber (1965) recognized four dominant limestone types; micrite, pelmicrite, fossiliferous micrite and biomicrite. Most of the bioclastic debris is randomly distributed and orientated, and highly fragmented. Winnowed accumulations commonly occur on the top of limestone bands. Fossils within the limestone typically are uncrushed.

Most of the mudstone units within the Porthkerry Member are bioturbated calcareous shales containing a moderate to abundant benthic fauna. Fossils are commonly fragmentary or, where intact, distorted by compaction around irregular limestone nodules beneath them. Thin lenses of fibrous calcite, or 'beef', occur locally and they too may be distorted around fossils or nodules. Organic-rich laminated shales occur throughout the succession but are rare; they are characterized by pyritized ammonites, fish debris and an impoverished bivalve fauna.

The striking facies changes which occur upwards through the Lias Group succession at this GCR site are reflected in substantial faunal differences between the Sutton Stone Member, Southerndown Member and Porthkerry Member. Fossil material is common in the Sutton Stone Member, but is mostly fragmentary or poorly preserved. The finer-grained units of the Sutton Stone Member are characterized by a great abundance of the bivalves *Chlamys valoniensis* and *Terquemia arietis,* both of which are minor elements of the offshore facies. Other common taxa in the Sutton Stone Member are *Lima succincta, Pseudolimea hettangiensis, Cardinia* sp. and the patellid gastropod *Acmaea schmidti.* Large poorly preserved colonial corals occur in the lower part of the Sutton Stone Member, especially in the Slade Trough, and include *Heterastraea latimeandroides, Isastraea globosa* and *Stylophyllopsis murchisoniae.* Several large thecosmiliid colonies at the base of the Sutton Stone Member immediately west of the Slade Trough have been replaced by barite. Their poor preservation has led to their mis-identification as serpulid reefs (Cope, 1971; Ager, 1986a; Johnson and McKerrow, 1995; Simms *et al.,* 2002). The coastal exposures of the Sutton Stone Member do not preserve the rich and diverse fauna of corals, bivalves, gastropods, serpulids and bryozoa which was described from 19th century collections at inland quarries near Brocastle [SS 93 77] and Ewenny [SS 91 77] (Duncan, 1867b; Beauvais, 1976; Negus, 1983). The fauna of the Southerndown Member has a closer resemblance to that of the offshore facies, but gastropods are more common and larger with several genera represented, among them *Coelostylina, Katosira, Proceritbium* and *Pseudomelania.*

The succeeding offshore facies of the Porthkerry Member contains a fairly rich and diverse fauna similar to that of the Blue Lias Formation elsewhere. Bivalves are especially common. *Gryphaea arcuata* occurs profusely at some stratigraphical levels and specimens from Dunraven Bay formed the basis for part of the classic investigation into the evolution of this bivalve by Trueman (1922a), and more recent studies by Jones and Gould (1999). Large examples of *Pinna* in life position also form a conspicuous element of the fauna. Ammonites are common in the Porthkerry Member and provide good biostratigraphical control.

Ammonites are rare in the Sutton Stone and Southerndown members and seldom well-preserved, and precise biostratigraphical correlation with the offshore facies of the Blue Lias Formation has proved difficult. Tawney (1866) assigned both the Sutton Stone and the Southerndown members to the Rhaetic (= Upper Triassic, Penarth Group) despite recording *Ammonites suttonensis* and *A. dunravenensis* (subsequently re-identified by Tate, 1867), which demonstrably were Jurassic taxa, from the Sutton Stone Member. Hodges (1986) and Wilson *et al.* (1990) have summarized the known ammonite records recovered from the marginal facies. Within the GCR site the oldest dated marginal deposits are of Johnstoni Subzone age. On the south side of Witches Point the youngest marginal facies is of Portlocki Subzone age and is succeeded by offshore facies of proven Laqueus Subzone age at the base of the Porthkerry Member. However, on the northern side of Dunraven Bay, at Dancing Stones, the youngest marginal facies is of Angulata Zone age and the base of the overlying Porthkerry Member lies within the Conybeari Subzone. Trueman (1922b), Hallam (1960a) and Hodges (1986) established that inland from this GCR site the marginal facies extends up into the Bucklandi Zone and possibly even into the Semicostatum Zone.

Mineralization occurs to an unusual extent in the Lower Jurassic succession of this area. Silicification is widespread, both in the marginal and offshore facies and particularly in the upper part of the Porthkerry Member. Primary chert nodules are not uncommon and fossil material frequently is beekitized, although preservation is often poor. Septal chambers of ammonites and other cavities may be lined with drusy quartz crystals, occasionally amethystine. A striking feature of the marginal facies is the widespread occurrence of barite in the conglomerates and breccias. The barite occurs either as a microcrystalline buff-coloured replacement of fossils and geopetal sediments or as a white, more coarsely crystalline, interstitial cement or cavity fill, which often is associated with white, coarsely crystalline calcite. Galena crystals up to 15 mm across are common and concentrated particularly at the barite–calcite boundary. This barite–calcite–galena mineralization is particularly evident at the western margin of the Slade Trough where it fills cavities dissolved in the bioclastic matrix of the basal breccia as well as many of the biogenic borings in the Carboniferous Limestone clasts (Fletcher, 1988). Shell coquinas and corals in this area also have experienced extensive replacive mineralization (Simms *et al.,* 2002). There is a clear relationship between barite–calcite–galena mineralization in the base of the marginal facies and the presence of mineral veins in the Carboniferous Limestone beneath (Fletcher, 1988). Although little sulphide mineralization is evident in the offshore facies of the Porthkerry Member, there is a frequent and conspicuous association between small crystals of galena and pieces of coalified driftwood.

Interpretation

The vertical and lateral (diachronous) changes exposed within this GCR site, from the conglomeratic Sutton Stone Member, through the Southerndown Member into typical Blue Lias Formation mudstones and limestones of the Porthkerry Member, confirm the observation of Trueman (1922b) that wherever the Lias of this region is in contact with the underlying Carboniferous rocks it is of Sutton Stone Member facies, regardless of age. Hence it is impossible to assign any biostratigraphical significance to a particular marginal facies. The Sutton Stone Member passes laterally and vertically into Southerndown Member-type facies which, in turn, passes into typical offshore Blue Lias Formation facies. Clearly the boundaries between these units are diachronous and were determined by the interplay between local topography and the transgression of the early Jurassic sea over the irregular surface of the Palaeozoic rocks beneath. The Sutton Stone and Southerndown members should be regarded as no more than local names given to distinctive types of marginal facies (Hodges, 1986). Even at this site, the type locality, the two units interdigitate in a complex manner and often do not show a clear relationship to each other; Wobber (1965) noted the difficulty at Dunraven of applying Hallam's (1960a) two-fold division of the Sutton Stone Member. Diachronous changes from Sutton Stone Member marginal facies through the Southerndown Member to fairly typical offshore facies of the Porthkerry Member occur over quite short distances. For instance at Black Rocks Quarry, just beyond the north-west limit of the site, the Laqueus Subzone is in Sutton Stone Member facies with the onset of offshore facies not occurring until early in the Bucklandi Zone; yet less than 2 km to the southeast, on the south side of Trwyn-y-Witch, the Laqueus Subzone is in offshore facies (Hodges, 1986). The vertical and lateral changes seen in the Blue Lias Formation at this site therefore represent an exceptionally clear example of Walther's Law, in which facies occurring in a conformable vertical sequence were deposited in laterally adjacent environments.

The depositional environment of the marginal facies has long been the subject of discussion. Trueman (1922b) considered that the marginal facies of the Sutton Stone and Southerndown members were littoral deposits that accumulated close to the shore of an island archipelago which gradually was submerged by the transgression of the early Jurassic sea. These 'islands' of Carboniferous Limestone represent parts of the breached and eroded Cardiff–Cowbridge Anticline against which the marginal facies are, in general, banked. However, elsewhere in south Wales the marginal facies may overlie Triassic rocks or be interbedded with typical offshore facies of the Porthkerry Member, as was found in the St Fagans Borehole farther east, near Cardiff (Waters and Lawrence, 1987). Wilson *et al.* (1990) observed that facies boundaries appeared broadly to parallel several major faults, among them the Slade and Dunraven faults, which define the margins of the narrow Dunraven Graben extending ENE towards Cowbridge. It would appear that periodic movement on these faults in early Jurassic times had a major influence on sedimentation in this area. Not only did it maintain the high-energy shorelines that sustained the marginal facies but it probably exerted an influence on sedimentation patterns within the offshore facies of the Porthkerry Member sufficient to disrupt attempts at bed-by-bed correlation of limestones between the Dunraven Graben and the main coastal exposures. Significantly, the NW-trending coastline in this area lies virtually on the strike of the Napton and Nash faults that Kamerling (1979), Miliorizos and Buffett (1998) and Chadwick (in Peacock and Sanderson, 1999) have proposed as the northward extension of the Watchet–Cothelstone–Hatch Fault System (see (Figure 2.1), Chapter 2). This has been interpreted as a major transfer fault between southern and northern areas of extension in Mesozoic times. Its obvious proximity to the Slade Trough, which also parallels the trend of the Bristol Channel Basin as a whole, suggests that movement on the Watchet–Cothelstone–Hatch Fault System would have had a profound influence both on sedimentation immediately adjacent to it as well as in the Slade Trough. The evidence seen in the Slade Trough would seem to support this.

Hallam (1960a) considered the Sutton Stone Member to have been deposited in very shallow, clear water subject to strong current or wave action and experiencing periodic emergence. He ascribed the change to Southerndown Member facies to a marked deepening, with the localized oolite boulder bed at the transition to the offshore facies providing clear evidence for a further episode of emergence immediately prior to this. The poorly sorted conglomerate bands elsewhere in the Southerndown Member he attributed to rapid deposition from density currents, though graded bedding is absent. Wobber (1965) considered the Sutton Stone Member sediments to derive from the mechanical and biological abrasion of shell debris and Carboniferous Limestone, with seaward winnowing of any terrigenous silt or clay. The environment clearly was a high-energy one, with rock slivers indicating that impacts sometimes were sufficient to shatter clasts. Wobber ascribed the presence of the coarse breccias in the Slade Trough to subaqueous slides and the undercutting of the Carboniferous Limestone. Some of the minor erosion surfaces and associated textural and sorting anomalies seen elsewhere in the marginal facies he attributed to slumping of debris off the flanks of the islands as well as to tidal and wave scour. He interpreted the Southerndown Member as merely a more seaward correlative of the Sutton Stone Member, with the increased representation of chert lithoclasts reflecting preferential destruction of limestone clasts. Wobber (1968b) identified three subdivisions of his marginal biofacies, along with five offshore biofacies. He attempted to correlate these with marginal and offshore lithofacies, linking them all to relative water depth.

Ager (1986a,b) compared the Sutton Stone Member at Panty Slade with coarse breccias, of presumed Triassic age, at Ogmore-by-Sea, little more than 1 km farther to the north-west. These latter breccias rest upon a highly irregular unconformity surface, with fissures, steps and steep faces cut into the Carboniferous Limestone. They are absent to the east, where the marginal Sutton Stone Member facies is developed. Furthermore, the unconformity surface on the Carboniferous Limestone beneath the Sutton Stone Member has a more subdued relief. Ager (1986a) interpreted these differences as due to the contrast between debris flows emplaced subaerially onto a karstified limestone surface, in the case of the Ogmore breccias, and those emplaced onto a marine planation surface following the onset of the early Jurassic transgression. On this basis he considered the lower, breccia-rich, part of the Sutton Stone Member to have been deposited catastrophically as a single debris-flow generated by a major storm, with succeeding units in the Sutton Stone and Southemdown members representing subsequent lesser events. This interpretation was challenged by Fletcher *et al.* (1986) who considered storms to be just one of several factors involved in deposition of the Sutton Stone Member over a prolonged time period. In a subsequent paper, Fletcher (1988) attributed the morphology of the unconformity surface beneath the Sutton Stone Member, with its stepped series of low scalloped scarps and dip-parallel ridges and troughs, to tidal erosion and cliff-line retreat associated with still-stands during the early Jurassic transgression. He considered that the collapse of overhangs led to the accumulation of coarse angular debris which now lies adjacent to the low scarps, this being buried beneath bioclastic debris and calcarenites as the transgression progressed. Hesselbo and Jenkyns (1998) broadly supported Ager's (1986a) debris-flow model and suggested a deeper-water origin for these marginal facies. In contrast, Johnson and McKerrow (1995) considered the Sutton Stone Member to have been deposited during transgression across a rocky shore, on which a range of encrusting and boring organisms were preserved, and they did not support Ager's (1986a) contention that it was a mass-flow deposit. However, the restriction of *Trypanites* borings to only the underside of the large blocks would seem to favour Ager's (1986a) debris-flow theory for the basal breccia. It indicates that the blocks reached their present position within the breccia in an unbored state, as would be the case for material transported into a shallow marine environment by a debris flow originating subaerially, and only then did boring organisms commence to colonize their undersurfaces. If, as Fletcher (1988) maintained, these large blocks originated from collapse of overhangs in a marine environment then we might expect to find at least a moderate proportion of the blocks to have overturned before reaching their final position and hence have a significant number of borings on their present upper surfaces, relics from when they were actually on the underside of these overhangs. This seems not to be the case.

The Dunraven Bay section is particularly important since the offshore facies at the Lavernock to St Mary's Well Bay GCR site, the only other Lower Jurassic GCR site in south Wales, does not extend above the Angulata Zone. Both Hallam (1960a) and Wobber (1965) considered the environment of deposition of the offshore facies in some detail. Hallam (1960a) noted the apparent independence from terrigenous influence of the calcareous 'mud' component of both marginal and offshore facies, from which he concluded that much of the calcium carbonate in the limestones was inorganically precipitated rather than derived from bioclastic debris swept offshore. However, Wobber (1965) maintained that fine bioclastic debris was a significant component of these same limestones and contributed to substrate firmness, a significant factor in his biofacies subdivisions. Hallam (1964a) considered initially that the limestones were, to a large extent, primary in origin but more recently (Hallam, 1986) suggested that many could originate solely from early diagenetic segregation of calcium carbonate, citing the south Wales succession in evidence. This view has since been contested by Weedon (1987) who maintained that the limestones were, to a significant extent, primary in origin. The difficulty of correlating limestone 'marker bands' from the main coastal exposures into the Dunraven Graben is further evidence for the predominantly primary origin of the limestones, indicating that local subsidence rates exerted a significant influence. Lenses of fibrous calcite, or 'beef', are only a minor component of the Porthkerry Member by comparison with correlative strata in the Dorset Lias, suggesting that sedimentation rates did not increase markedly in the latter part of early Jurassic times.

The limestone–mudstone rhythms described by Hallam (1964a) from the Blue Lias Formation of Dorset are, on the whole, rather poorly developed in the Porthkerry Member. Most of the mudstone units are bioturbated and contain a benthic fauna; laminated, organic-rich shales are comparatively rare and this suggests that the Porthkerry Member was deposited in shallower water than correlative strata in Dorset, thereby preventing the development of significant sea-floor anoxia. Bivalves are the most abundant element of the fauna in the Porthkerry Member. *Gryphaea* is more common in the mudstones than in the limestones and may constitute up to 60% by volume of some mudstone units at Seamouth [SS 883 733], with 60–95% of these in life position. Strongly ribbed bivalves are more common than in the more offshore facies of the Blue Lias Formation, such as the Lavernock Shale Member. *Pinna* in life position is conspicuous at certain levels in Dunraven Bay and indicates periods of stable sedimentation rate. The presence of the coral *Montlivaltia haimei* indicates very slow sedimentation rates, reaching a minimum in the limestone band in which this species occurs in profusion. Considerable bioturbation of this limestone band, as of others, is indicated by many specimens lying at a considerable angle from the horizontal. Wobber (1968a) analysed several gastropod taxa and found that, in general, they were more common and grew to a larger size on fine sand than on the finer sediments of the offshore facies. While some species are very facies restricted, others have a eurytopic distribution.

Poorly preserved patellids (*Scurriopsis*) are associated with cobbles and shelly sand in the Sutton Stone Member facies whereas *Pleurotomaria* is widespread in both offshore and marginal facies. *Coelostylina, Zygopleura* and *Pseudomelania* were more common where shale partings, indicating slight deepening, were present in the Southerndown Member.

Hallam (1960a) compared the offshore facies at this site with correlative successions on the Dorset coast, at Tolcis Quarry near Axminster, and with the Saltford Railway Cutting near Bristol. Palmer (1972) made a similar comparison of the Dorset and Glamorgan successions with that of the north Somerset coast. The Porthkerry Member is substantially thicker than the correlative strata in Dorset, though slightly thinner than the north Somerset coast succession. In the offshore facies exposed between Panty Slade and Witches Point this is attributable to an increase in the limestone–mudstone ratio compared with Dorset and Somerset. Hallam (1960a), Palmer (1972) and Whittaker and Green (1983) have all commented on the correlation of distinctive limestone or mudstone units along considerable stretches of coastline, with some being broadly traceable from south Wales through Somerset to Dorset, implying that controls on offshore facies were not merely regional in their extent. The limestone–mudstone diagrams of both Hallam (1960a) and Palmer (1972), in which they correlate the successions in south Wales, Somerset and Dorset, imply that the Bucklandi Zone in both Dorset and Somerset is substantially thicker than in south Wales. However, it is well established (Cope *et al.,* 1980a) that the Bucklandi Zone in Dorset is significantly thinner than that of either Somerset or south Wales, a fact more in keeping with the generally more attenuated succession in Dorset.

No precise correlation is possible between the marginal facies of south Wales and those of other regions, such as the Mendip–Radstock area or the western Scottish sites. The broad similarity of facies found in these marginal environments reflects the influence of local factors rather than the broader-scale influences which are evident in the offshore facies.

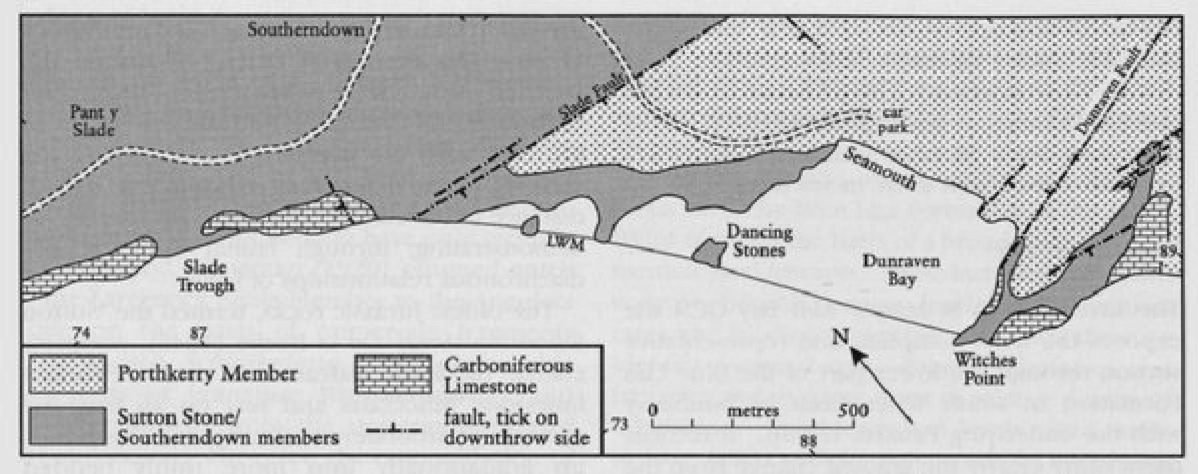
Most marginal facies share a common prevalence of massive bioclastic carbonate units with only minor mudstone development. The fauna of such facies typically is dominated by corals and molluscs adapted to high-energy environments; ammonites invariably are rare or absent. Nonetheless, attempts have been made to correlate the marginal facies of the Pant y Slade to Witches Point GCR site with the offshore facies of the Lavernock section farther east. The earliest proven age for the marginal facies is Johnstoni Subzone, thereby correlating with the upper part of the St Mary's Well Bay Member. On the north side of Witches Point the overlying Liasicus Zone, largely equivalent to the Lavernock Shale Member, is entirely in marginal facies that extends up into the Angulata Zone. However, to the south of Witches Point only the lower part of the Liasicus Zone, the Portlocki Subzone, is in marginal facies and passes up into more offshore facies in the succeeding Laqueus Subzone. However, this 'offshore' facies of alternating limestones and mudstones is still strikingly different from the mudstone-dominated Lavernock Shale Member. The only attempt at lithostratigraphical correlation between the marginal facies at Pant y Slade and the offshore facies of the Lavernock outlier was by Wobber (1968b) who suggested that the degree of lithoclast rounding and sorting in the marginal facies was, in some way, analogous to the limestone–mudstone ratio of the offshore facies. More specifically, he suggested that the decrease in lithoclast percentage and sparite cement, and the presence of clay partings in part of the marginal facies, could be correlated with the general increase in dominance of mudstone during the Liasicus Zone at Lavernock and elsewhere.

The calcite–barite–galena mineralization which pervades the marginal facies at Pant y Slade is one of the most intriguing features of this site. The association of more intensively mineralized areas of marginal facies with mineral veins cutting the Carboniferous Limestone directly beneath, described by Fletcher (1988), suggests that 'cold seeps' may have existed in this area in early Jurassic times. Fletcher (1988) noted that this mineralization was particularly evident in the Slade Trough, and elsewhere along the outcrop it is clear that there was a direct association between active faulting and mineralization. The close proximity of these marginal sediments to the north-westward extension of the Watchet–Cothelstone–Hatch Fault System, which lies just offshore and virtually parallel to the coast, may well account for the presence of fairly extensive mineralization along this stretch of coast. The barite–calcite mineralization appears to have favoured open framework sediments and cavities, being particularly evident where it replaces fossil material in shell coquinas and corals, and in the *Trypanites* borings. The association of galena with driftwood in the Porthkerry Member is clear evidence that the mineralizing fluids pervaded the sediment pile for some distance above the unconformity, precipitating sulphides in the reducing environment represented by the wood. The sulphide mineralization in the marginal facies has been considered, on isotopic evidence, to be early Jurassic in age (Jenkins *et al.,* 1990) although field relationships indicate only a post-Hettangian date. Fletcher *et al.* (1993) obtained isotopic evidence for at least two phases of lead mineralization in the Mendip and south Wales orefield, with the later of these being of early Jurassic age. The existence of cold seeps here seems quite plausible, therefore, if the sea floor was breached by faults or fractures along which mineralizing fluids were migrating. However, Haggerty *et al.* (1996) favoured a single mineralizing episode, probably of Middle Jurassic age (see also Simms, 1997), for the Mississippi Valley-type deposits in the Mendip Hills. They attribute this to fluid expulsion from adjacent Mesozoic sedimentary basins, which in the case of Ogmore would be the Bristol Channel Basin to the south, as a result of overpressuring associated with rapid subsidence in Triassic and Jurassic times. A post-early Jurassic age for the mineralization would seem to preclude the existence of cold seeps in the Ogmore area although different rates and timing of subsidence in the Bristol Channel, as compared with the Somerset and Wessex basins which border the Mendip Hills, may have led to the earlier onset of mineralization in south Wales.

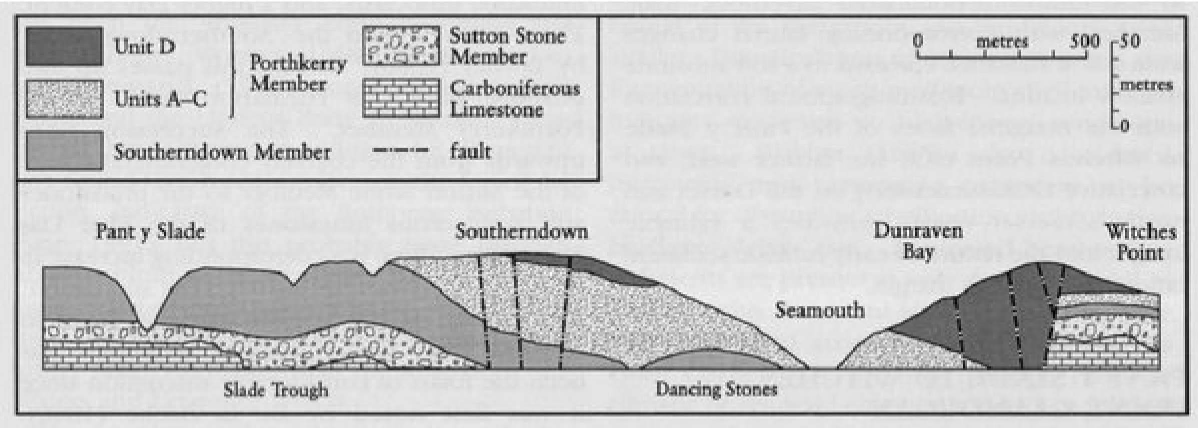
Conclusions

The coastal cliffs between Pant y Slade and Witches Point expose the finest sections anywhere in Britain that show the transition from coarse marginal facies to much finer offshore facies of the Hettangian Stage. The succession is of crucial importance for demonstrating the early Jurassic transgression and for the interpretation of both marginal and offshore Lower Jurassic sediments in the Bristol Channel and Mendip region. The site also provides evidence of mineralization.

References

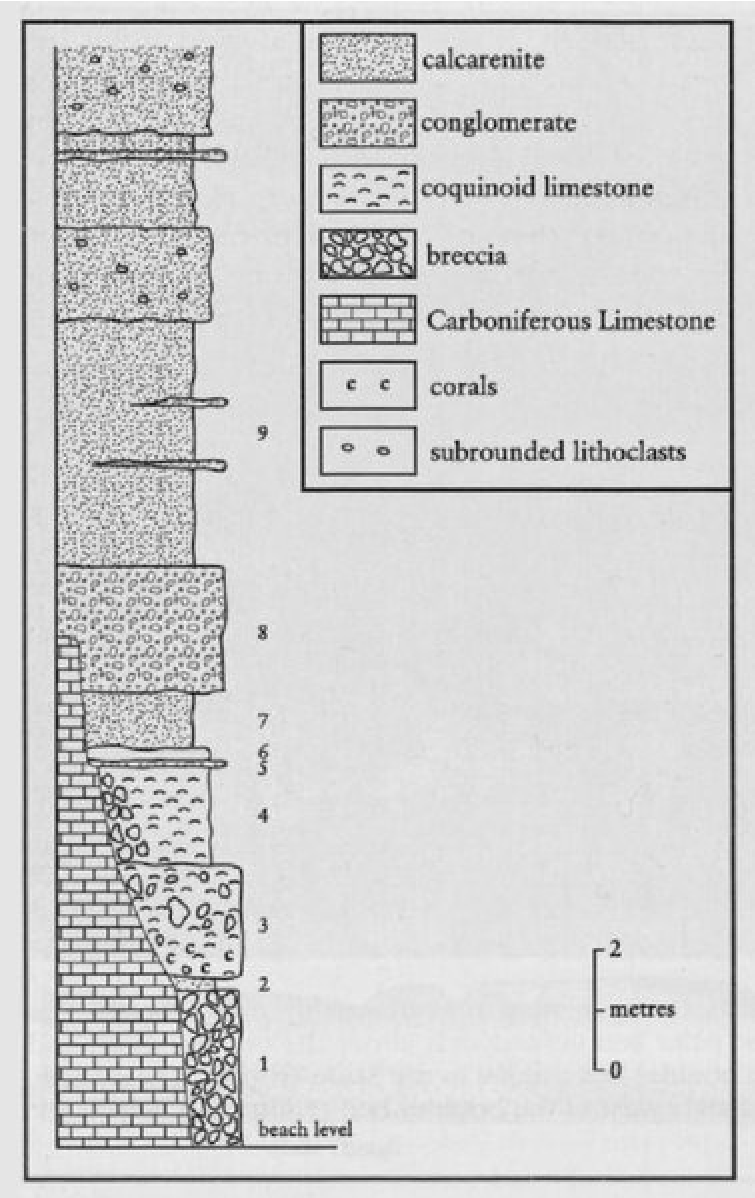


(Figure 3.5) Sketch map of the Pant y Slade to Witches Point GCR site. After Wilson et al. (1990).

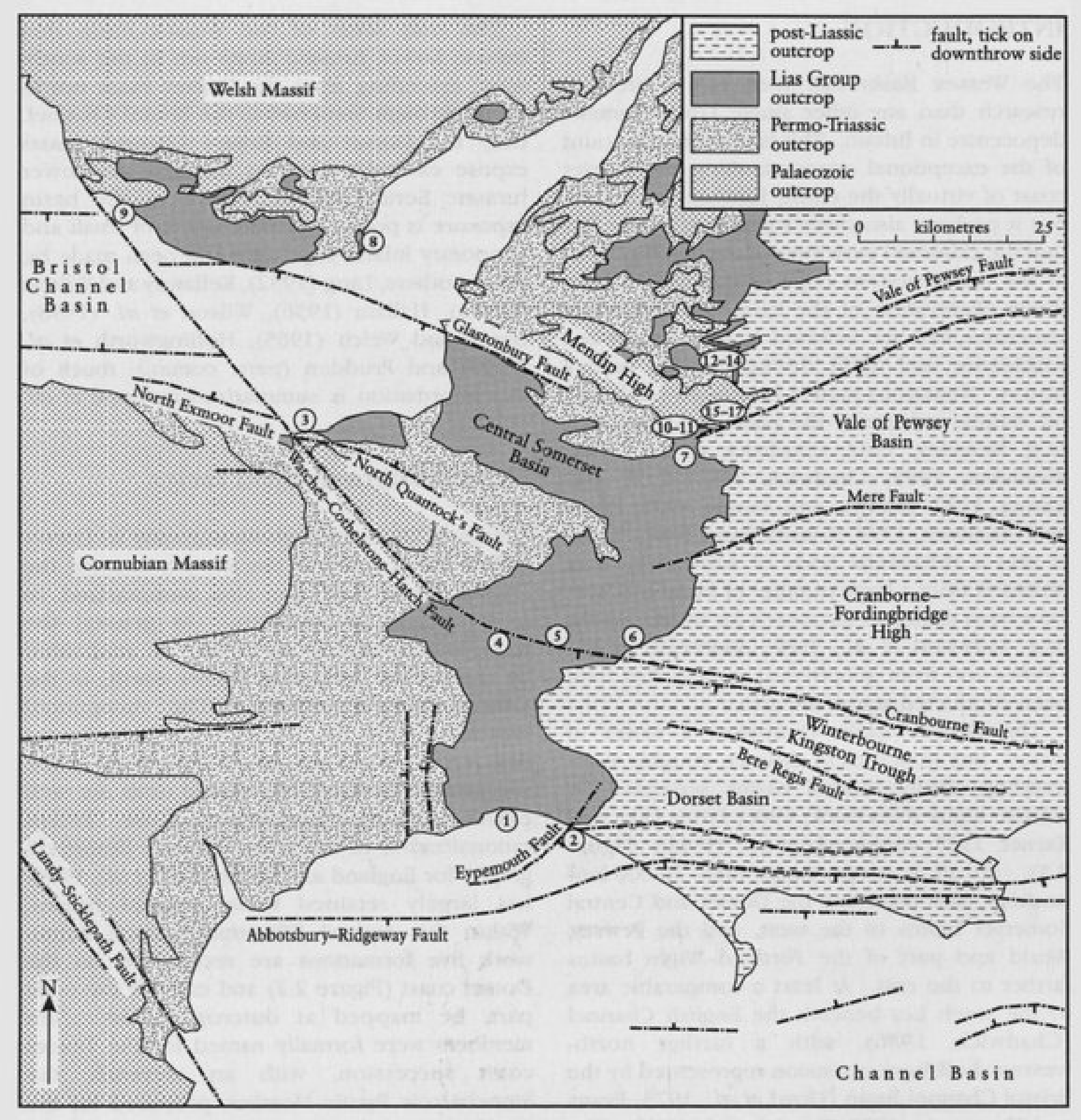


(Figure 3.6) Coastal section from Pant y Slade to Witches Point, showing lateral facies changes in the Lias Group. After Trueman (1922b).

(Figure 3.7) Coarsely bedded marginal facies of the Lias Group resting unconformably on Carboniferous Limestone at the western edge of the Slade Trough. The paler bed immediately above the unconformity, and wedging-out rapidly westwards, is the heavily mineralized boulder bed unique to the Slade Trough. The person, for scale, is standing on the *unconformity surface immediately west of the boulder bed (Photo: M.J. Simms.)*



(Figure 3.8) Lithological log of the lower part of the marginal facies of the Lias Group within and adjacent to the Slade Trough. After Fletcher (1988).



(Figure 2.1) The major structural elements and sub-basins of the Wessex Basin and its margins. Numbers correspond to the locations of the GCR sites: 1— Pinhay Bay to Fault Corner and East Cliff; 2 — Cliff Hill Road Section; 3 — Blue Anchor—Lilstock Coast; 4 — Hurcott Lane Cutting; 5 — Babylon Hill; 6 — Ham Hill; 7 — Maes Down; 8 — Lavernock to St Mary's Well Bay; 9 — Pant y Slade to Witches Point; 10 — Viaduct Quarry; 11 — Hobbs Quarry; 12 — Bowldish Quarry; 13 — Kilmersdon Road Quarry; 14 — Huish Colliery Quarry; 15 — Cloford Quarry; 16 — Holwell Quarry; 17 — Leighton Road Cutting. After Lake and Karner (1987).