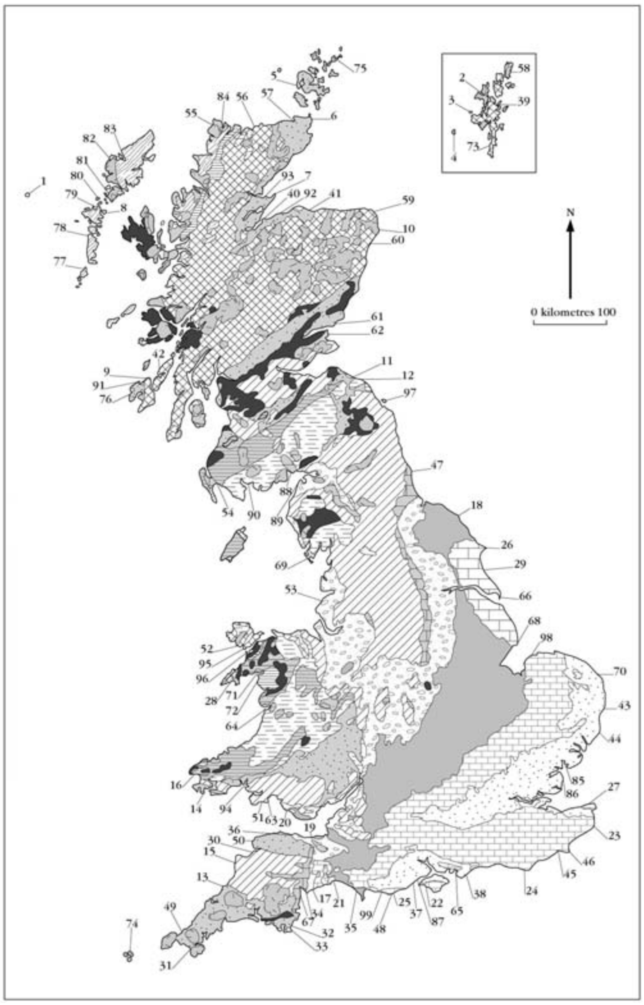
CARMARTHEN BAY

V.J. May

OS Grid Reference: SN220070–SN421868

Introduction

Carmarthen Bay is formed by the estuaries of the rivers Taf, Twyi and Gwendraeth where they enter the sea between the Carboniferous Limestone headland of Worms Head on the Gower Peninsula and Caldey Island (see Figure 1.2 for general location). The bay includes several subunits that would warrant selection as coastal geomorphology GCR sites in their own right. It is unusual, however, in containing features that are relatively uncommon in England and Wales and in being very little disturbed by human activity. At low tide, three interconnected units (Figures 11.12 and 11.13) are exposed:



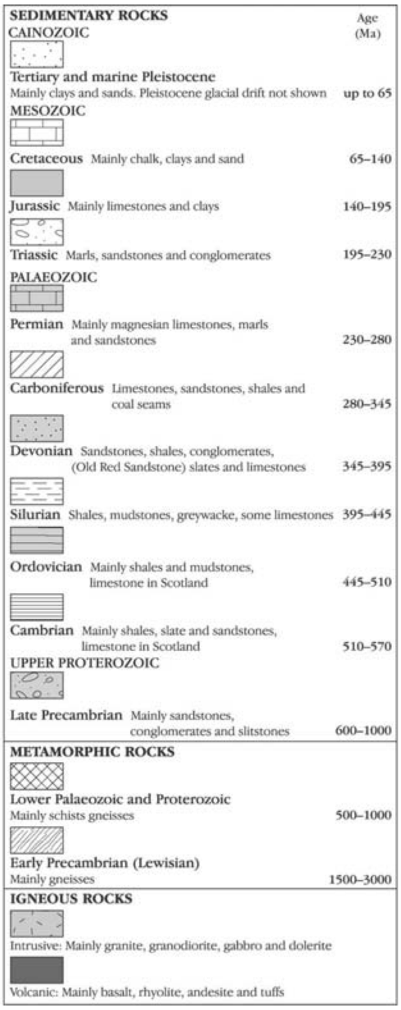


Figure 1.2: Geological map of Great Britain, also showing the locations of the Coastal Geomorphology GCR Sites. The map shows sedimentary rocks classified according to their age of deposition and igneous rocks according to their mode of origin. The numbers in the key indicate age in millions of years (Ma). (Permit number IPR/26-45C British Geological Survey © NERC. All rights reserved.)

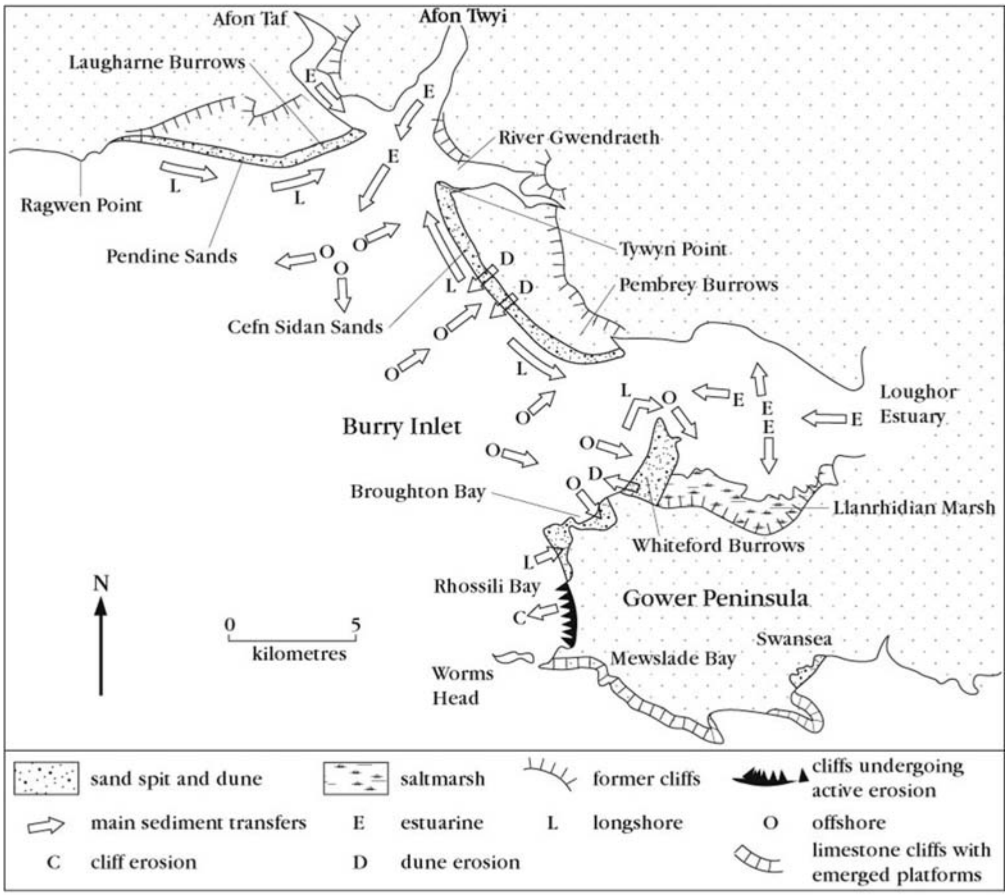


Figure 11.12: Sketch map of the key geomorphological features and sediment transfers of Carmarthen Bay. See also Figure 11.17 for details of the Rhossili Bay area. (Offshore transfers derived in part from Barber and Thomas, 1989.)

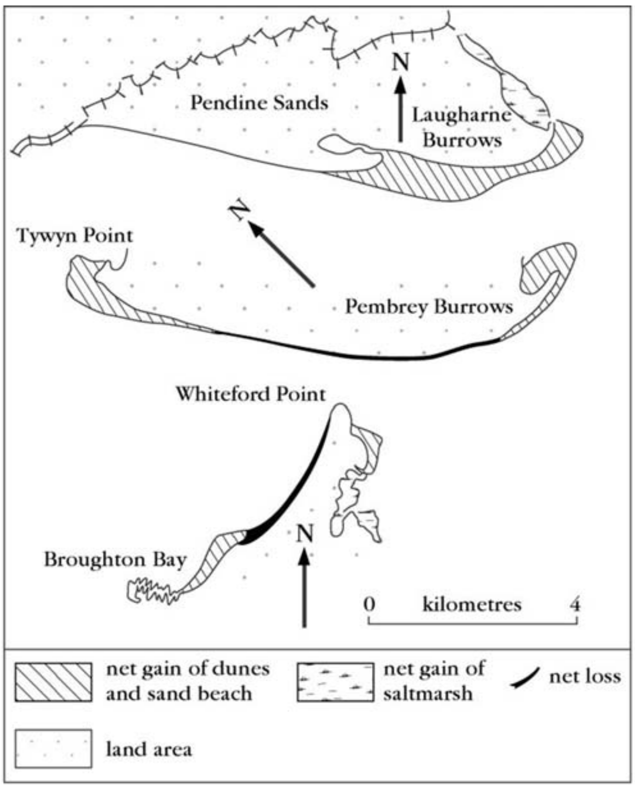


Figure 11.13: Variations in accretion and erosion since 1950, Carmarthen Bay.

1. Whiteford Burrows and Rhossili Bay (see Figures 11.17 and 11.18)

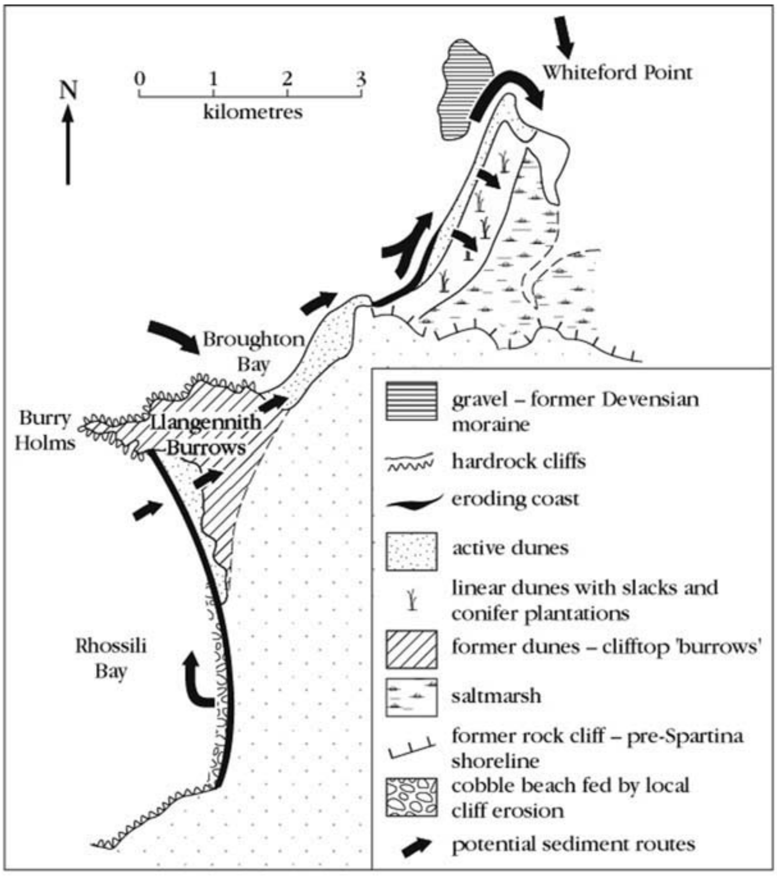


Figure 11.17: Geomorphological features of Rhossili Bay and Whiteford Burrows.

Figure 11.18: Rhossili Bay seen from the Carboniferous Limestone headland looking north towards Burry Holms and Llangennith Burrows. Rhosilli Down to the right of the photograph is fronted by low cliffs formed in periglacial head and fluvioglacial material. Erosion of these cliffs feeds the narrow fringing cobble beach. The wide intertidal beach is mainly sand. (Photo: J.D. Hansom)

2. Cefn Sidan Sands, Tywyn and Pembrey burrows (see Figure 11.15), and

Figure 11.15: Pembrey: older dunes can be seen to the right of the photograph – these are now conifer plantations. Post-19th century accretion is evident in the middle and left background. A blowthrough is present in the foreground. (Photo: V.J. May.)

3. Pendine Sands and Laugharne Burrows (see Figure 11.14).

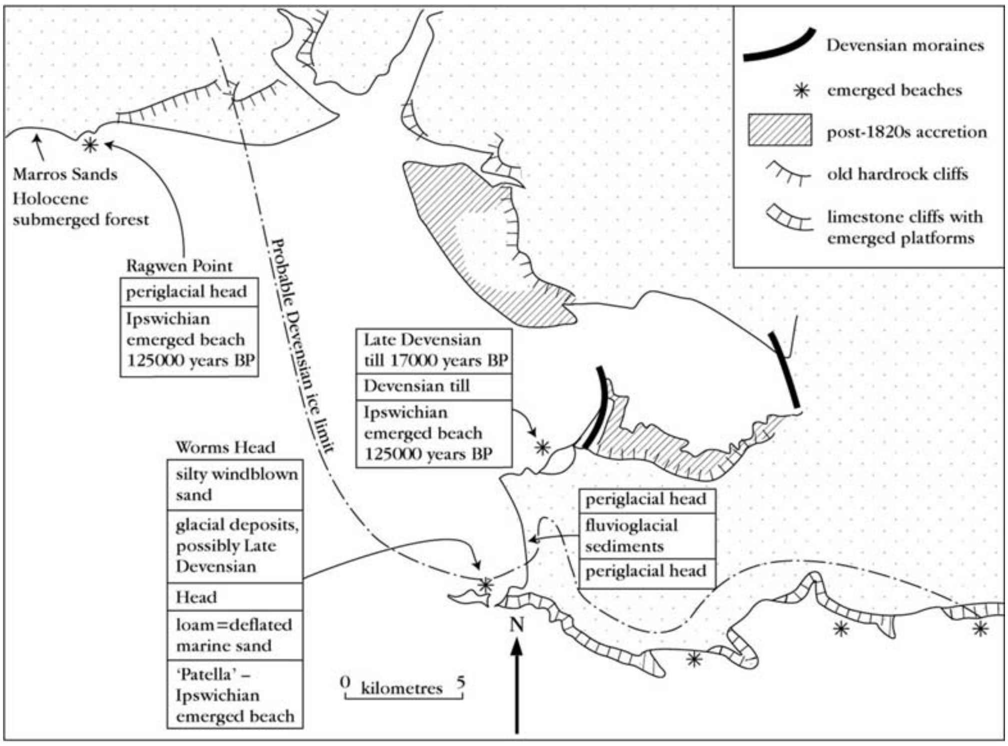


Figure 11.14: The Devensian geomorphology of Carmarthen Bay, with stylized sections through selected emerged beach sites. (After Campbell and Bowen, 1989.)

These three units can be further subdivided into 8 subsites (see 'Description' below).

The estuaries of the rivers Taf, Twyi and Gwendraeth separate units 2 and 3, whereas units 1 and 2 lie to the south and north of the Loughor estuary respectively. Parts of these estuaries are included in the site.

Both Pendine–Laugharne and Whiteford beaches form spits that trend away from a predominantly rocky cliffed coastline, whereas the barrier beach from Cefn Sidan to Pembrey links to the mainland only by former dunes and reclaimed marshland. This barrier feature is only one of three large barrier systems in England and Wales, the others being Scolt Head Island (North Norfolk Coast) and parts of the Holy Island, Northumberland, site. During the 20th century, the general trend has been for erosion at the proximal end of the spits, accretion at their distal ends and extensions of the forms into the estuaries (Figure11.13). Cefn Sidan–Pembrey has been an area of general progradation, with extension of the beach as spits into estuaries of the rivers Loughor and Gwendraeth.

Apart from the coasts of north Norfolk and Holy Island, Carmarthen Bay contains the largest assemblage of unmodified sandy beaches in England and Wales, but it has received very limited attention in the literature. North (1929) and Steers (1946a) concentrated mainly upon the hard-rock coastline and the evidence of changes in sea level. Savigear (1952) saw the eastward growth of the Pendine beach as controlling slope development on the abandoned cliffs behind the beach and marsh. Kahn (1968), Potts (1968), Jago (1980) and Jago and Hardisty (1984) described the sediments and the geomorphological processes that act upon individual parts of the site. Barber and Thomas (1989) have considered the whole bay in terms of sediment transport and its effects on the beaches. Emerged (‘raised') beaches and periglacial and fluvioglacial deposits occur at several points around the bay and many writers have considered the Quaternary history of the area and Campbell and Bowen (1989) provide a comprehensive summary.

Description

There are eight major subsites, each of which is described in turn from west to east. These sub-sites form parts of an integrated whole that is bounded in the south-east by Worms Head and in the north-west by Ragwen Point. The eight units (for locations see Figure11.12) are:

1. Pendine Sands and Laugharne Burrows

2. The estuaries of the Taf and Tywi

3. Cefn Sidan, Tywyn and Pembrey Burrows (including the Gwendraeth estuary)

4. The Loughor estuary (uncluding Llanrhidian saltmarsh)

5. Whiteford Burrows

6. Broughton Bay burrows and cliffs

7. Rhossili Bay

8. Worms Head and Mewslade Bay.

Consideration of processes at other GCR sites led to the decision to treat the whole of Carmarthen Bay as a single unit in the GCR, defined by the low-water limits of the intertidal zone at Ragwen Point and Rhossili. In addition, the cliffed coast around Worms Head, which is an important site in its own right, was integrated with the larger Carmarthen Bay GCR site. The site includes all the intertidal sand banks of the bay and the channels between them. The seaward boundary crosses the channels at their most seaward extent. Because the processes that affect the site extend into deeper water, an appropriate geomorphological boundary lies along a straight line from Ragwen Point to Worms Head.

The site comprises 32 morpho-sedimentological units of which ten are hard-rock cliffs, seven are saltmarsh, six are stable or prograding beaches and three are sandy beaches affected by erosion. The remainder are till cliffs undergoing erosion (one unit), estuary/ria (two units), shingle beach (two units), and pocket beach (one unit). Depending upon tidal and wave conditions, sediments can move between most parts of the site, with the possible exception of the area south of Worms Head (Figure 11.12). Very large areas of sand are exposed at low tide, especially at the mouth of the rivers Taf and Twyi. At high tide, the behaviour of waves crossing these intertidal flats is affected by changes in channel position and bathymetry. The site is macrotidal, with a tidal range in excess of 8 m and currents that exceed 1 m s^{-1}. The maximum fetch in the direction of prevailing and dominant winds from the south-west exceeds 4000 km. Fetch to the SSE, i.e. across the Bristol Channel, is 70 km.

The north-western extremity of the site at Ragwen Point (SN 220 070) forms the low-water boundary of the sandy intertidal zone. A small pocket beach separates Ragwen Point from Gilman Point (SN 228 074) whence the cliffs that reach up to 30 m in height trend northwards to Dolwen Point (SN 233 079). The Pleistocene sequence (including emerged beaches) at Ragwen Point (Bowen, 1970, 1974; John, 1971, 1973; Campbell and Bowen, 1989; Figure 11.14) indicates the long time period over which the rock cliffs of this site have developed. As elsewhere in the site, several caves are cut into the cliffs.

Pendine Sands and Laugharne Burrows are dominated by dunes up to 700 m wide that extend some 9.5 km to Ginst Point (SN 331 078). The dunes attain heights in excess of 15 m, except in the vicinity of Wickett Pill where a stream draining marshland and a shallow lake existed up to the 1950s. Since then, there has been considerable accretion of Laugharne Burrows, but the shoreline of Pendine has remained virtually static. The intertidal zone is up to 1 km in width, notably opposite Wickett Pill. As the dunes grew eastwards they protected the rocky cliffs (Savigear, 1952) and the intervening marshland was reclaimed. North of Ginst Point, saltmarsh has developed in the lee of the dunes and in front of artificial embankments. The eastern part of the reclaimed marshland drains via Railsgate Pill into the Taf estuary at SN 306 099.

The 0.5 km-wide Taf estuary is bounded by rock cliffs on its western side, but on its eastern side a cobble spit (Black Scar) narrows the channel, and there has been some development of saltmarsh. Vertical cliffs about 30 m high form the shoreline around Wharley Point (SN 340 093) to the Twyi estuary at SN 352 100. Both sides of this estuary are formed by low vertical cliffs, but the eastern side is much lower than the western side. On the eastern side, the low cliff (SN 361 082) is replaced by a cobble and gravel beach that widens southwards extending seawards into Salmon Point Scar (SN 355 070) and narrowing the estuary significantly at low tide.

The Gwendraeth estuary is dominated by sandflats and mudflats that merge into a growing saltmarsh in the lee of Tywyn Point (SN 357 065). The sand beach extends about 12 km from Tywyn Point through Tywyn and Pembrey Burrows to just south-west of Burry Port (SN 437 994). Intertidal sands extend seawards over 3 km at Cefn Sidan at the mouth of the rivers Taf and Twyi. Much of the area landward of the beaches of Cefn Sidan– Tywyn–Pembrey is dominated by former dunes in Tywyn Burrows, over 2 km-wide and reaching over 20 m in height (Figure 11.15). Much of the duneland is afforested. Seawards of the main zone of grey dunes, there is a zone of low-lying sandy hummocks, rarely higher than 2 m, fringed by a narrow ridge of younger, mainly active, dunes over 5 m in height, which extend into both the Gwendraeth and Loughor estuaries. Although the central part of the beach has suffered some retreat in recent years, the distal areas have extended several hundred metres during the last 150 years. This is a fine example of a progradational beach to which the supply of sediment is sufficient not only to allow the beach to grow in overall volume but also to be able to sustain the lateral growth of the spits.

The saltmarshes of the Burry Inlet comprise the most extensive area of saltmarsh in Wales: 2121 ha out of a total of 6712 ha (32%), and represent almost 5% of all British saltmarsh. Those of the south shore of the estuary from Whiteford Point to Loughor are of interest for the range of geomorphological features they display, particularly saltmarsh creeks, saltpans, erosion cliffs and range of sediments (Figure 11.16; Gillham, 1977). Berthlëyd, Llanrhidian and Landimore marshes have developed in a sequence from east to west. The mature marshes at Berthlëyd display well-developed terraces and a marsh cliff undergoing erosion: at Llanrhidian pans and creeks are present and display much dissection. At Landimore, an intricate and deep creek network is present. The sequence of marshes forms a key area for an understanding of saltmarsh dynamics, sediment transport and sea-level changes.

Figure 11.16: A deeply incised saltmarsh channel in the muds of Llanrhidian saltmarsh, Loughor Estuary. (Photo: J.D. Hansom.)

The marshes extend for about 15 km along the northern shore of the Gower Peninsula and are up to 1.5 km wide. Landimore Marsh in the west lies in the shelter of Whiteford Burrows and is the youngest of the marshes. Llanrhidian Marsh is more exposed to waves entering Burry Inlet from the west, but Berthlëyd Marsh is in the more sheltered upper part of the estuary. The marsh sediments have not been dated. The tidal range at springs is 6.6 m and at neaps 3.7 m (Pye and French, 1993). Fine-grained sediment deposition is restricted to the more sheltered upper intertidal zone and upper reaches of the estuaries. According toCarling (1981), grain size typically becomes finer with increasing elevation, andPye and French (1993) record the mean grain size on the upper tidal flat as sands, on the marsh edge as sandy silts, and on the upper marsh as clayey silts. The marsh-edge is widely marked by a low cliff formed during periodic storm activity. Gently sloping ramped margins occur in areas of pioneer marsh progradation. There are some weakly developed terraces, the transition being marked by low cliff, ramp or residual mud-mound topography. Many creeks on the upper marshes show infilling in response to a reduction in tidal capacity while the marshes grow both vertically and laterally (Pye and French, 1993), but common cord-grass *Spartina anglica* was introduced to Loughor in 1931 and colonized rapidly in the 1950s and 1960s, but appears to have declined since (Hubbard and Stebbings, 1967; Burd, 1989). Smith (1978) identified subsurface piping patterns in this area, and attributes the development of saltpans (Packham and Willis, 1997) to their presence. At Landimore, an intricate and deep creek network is present. Small-scale mass-movements in rills and creeks in the muddy intertidal zone play an important role in the changes in creek morphology, the supply of sediment into the creeks, and in intertidal drainage patterns (Allen, 1989).

Whiteford Burrows extends some 3 km northwards from the northern side of the Gower Peninsula to Whiteford Point (SN 450 968; Figures 11.12 and 11.17), where its distal end is associated with a cobble bank to seaward. The burrows are formed of several lines of dunes reaching a maximum height of 24 m in the north-east. The main dune ridge is generally between 10 and 16 m in height, widening towards its landward end. To the west, a line of dune slacks separate more recently accumulated dunes from the main ridge. On the seaward side of the main ridge, a line of slacks rest on partly rounded cobbles and shingle derived from Devensian till probably deposited by ice in the Loughor valley (Bridges, 1987). There has been some erosion of the proximal end in the recent past, but sand ridges have also extended into this area from Broughton Bay to the west.

The coast westwards to Burry Holms (SN 398 925; Figure 11.17) is dominated by vertical cliffs fronted by dunes up to altitudes of 50 m OD . At Broughton Burrows the dunes extend to sea level between Prissen's Tor (SN 425 937) and Twlc Point (SN 415 931) where the outlines of the bay appear to be fault-controlled. The cliffs are penetrated by several caves that have developed along joints in the Carboniferous Limestone. Since the late 1980s, marine erosion in Broughton Bay has exposed a very important Devensian multiple till sequence (Campbell and Bowen, 1989). Near Twlc Point, the base of this exposure is formed by an emerged beach conglomerate with fragments of marine shells, mainly flat periwinkle *Littorina littoralis,* resting on a Carboniferous Limestone platform (also probably marine in origin; Campbell, 1984). The emerged beach is overlain by head and tills that include some fragments of wood (willow/poplar Salicaceae). Shelly and stony tills in the upper part of the section show glaciotectonically-induced folds that are also exposed occasionally in plan form on the foreshore (Campbell and Bowen, 1989). The dunes that overlie this sequence are thought to have been in existence by Roman times (*c*. 2000 years BP) and to have been affected by renewed activity during intense late medieval storms (Lees, 1982, 1983).

Burry Holms, an island at high water, forms the northern end of Rhossili Bay, a *c*. 450 m-wide smoothly curving sandy beach directly aligned to the prevailing and dominant south-westerly waves (Figures 11.17 and 11.18). Just over 4 km in length, the bay has a northern shoreline formed by dunes. These rest on bedrock and reach altitudes of about 50 m OD, and are fed by sand blowing from the drying intertidal zone. The southern part of the bay is formed by low active cliffs in till and periglacial sediments (Campbell and Bowen, 1989). The shoreline is cut across the lithological change and is strongly wave-dominated. Shallow slides feed boulders and cobbles into a narrow fringing beach but the contribution of these cliffs to the beach sediment budget is slight. The beach appears to be in deficit, especially as there is no obvious sediment supply from either offshore or alongshore. Sand leaks from the beach via Llangennith and Broughton Burrows towards Whiteford Burrows.

The southern boundary of Rhossili Bay is formed by high limestone cliffs that are continued beyond a gap of 500 m to Worms Head (SN 384 878). Cliffs drop almost vertically into the sea on the northern side of the headland, but a shore platform is well developed around Worms Head and along the southern shoreline, where emerged beach, glaciogenic and periglacial head and colluvial sediments occur widely (Campbell and Bowen, 1989). Cemented '*Patella*' emerged beach deposits rest on the Carboniferous Limestone shore platform (Figure 11.15). Mewslade Bay, bounded to the east by the headland of Thurba (SN 421 868), has similar examples of a platform at present-day sea level and a higher platform planed across dipping strata with emerged beach sediments. The present-day platform is pitted by potholes and solution forms (Figure 11.19). The upper slopes have been severely weathered and screes cloak the lower part of the slopes resting, in places, on the emerged beach materials.

Figure 11.19: Limestone intertidal solution features near Worms Head, typically up to 0.3 m in height. (Photo: V.J. May.).

Interpretation

This old cliffed coastline preserves coastal forms of considerable age that have been retrimmed recently to provide the framework within which the extensive recent sedimentation has formed intertidal banks, beaches and saltmarshes. The interpretation of the coastline of Carmarthen Bay involves both explanation of the form and development of the coast during the Quaternary Period and the forms and processes that are active today.

Carmarthen Bay is an excellent example of a coastline whose outline was moulded by marine and subaerial processes throughout the Quaternary Period, but where the shoreline and its detail is much more recent in origin. Each subunit of the site is distinguished by features of major geomorphological interest. For example, the Loughor estuary saltmarshes form a key area for the understanding of saltmarsh dynamics, sediment transport, and sea-level changes, and the platforms and cliffs in Rhossili Bay are excellent examples of hard-rock erosional forms including features linked to former sea levels.

The Quaternary history of Carmarthen Bay indicates that it was affected by several phases of lower sea levels, glacial and glaciofluvial action, and periglaciation superimposed on a framework of river valleys. The interpretation of a number of cave and other sediments containing emerged beach deposits point to a sea level close to the present-day level about 200 000 years BP during Oxygen Isotope Stage 7 (Campbell and Bowen, 1989), and another period of emerged beach formation (sometimes referred to as the *Patella*' beach) about 125 000 years BP during the Ipswichian (Oxygen Isotope Substage 5e) in which two emerged beach facies have been identified at the western end of Carmarthen Bay at Gilman Point (Bowen, 1970). Extensive periglacial activity led to head deposits forming during the onset of the Devensian and point to considerable cliff instability on parts of the coast. For example, John (1971, 1973) regards the presence of very large quartzite boulders in the head around Ragwen Point as an indicator of an intensive period of slope instability (Figure11.14). At the time, there was apparently no mechanism removing this material beyond the cliff foot. The limit of Devensian ice probably crossed Carmarthen Bay from just south of Worms Head towards Pendine Point (Bowen, 1981a,b), since in-situ Devensian tills overlie the Ipswichian emerged beach at Broughton Bay (Bowen, 1984) but are absent farther west at Ragwen Point and Marros Sands. At Worms Head, glacial age deposits may be remnants of soliflucted pre-Ipswichian glacial materials or Late Devensian outwash (Bowen, 1970; Bowen *et al*., 1985; Bowen and Sykes, 1988; Figure 11.14). At Rhossili, two phases of periglacial head are separated by fluvioglacial material. There is some doubt about the precise limit of the Devensian ice, although Stephens and Shakesby (1982) suggested that the bay might have been occupied by a large piedmont lobe. Its effect however was to leave substantial deposits of sand and gravel that were re-worked by a rising postglacial sea, and from which the sand of the coastal dunes and spits was blown. A loam lying above the Ipswichian emerged beach at Worms Head has been interpreted as deflated marine sand. Although there have undoubtedly been periods of localized erosion and trimming of the hard-rock slopes, the distribution of the Ipswichian emerged beach suggests that the broad outline of the bay was in place during the Ipswichian and that the Devensian saw only limited change in the hard-rock coasts, largely as a result of the protection offered by deposition of the Holocene sediments.

Modern processes have served to erode or protect parts of the older shoreline, although there is some doubt as to the extent that protection has lead to significant recent change in the older hard rock slopes. Savigear (1952), for example, argued that as the Pendine beach grew eastwards it protected former rocky cliffs and that the slope profiles demonstrate the effects of progressive protection of the cliff foot on slope profile. Attractive though this interpretation is, there are some difficulties: the slope profiles are not a simple progression from steep at the distal end to gentle at the proximal end of the spit; they have probably been affected by subaerial processes over a much longer time than the period of the extension of the spit, and more recent interpretations of the Pleistocene history of the area indicate that most change in these slopes occurred during intense periglacial conditions during Devensian times. Basal removal would have begun again with sea levels attaining present-day levels about 6500 years BP and would have then ceased sequentially from west to east. This may have done little more than exhume older cliffs.

The modern shoreline is a very dynamic one, as a result of the growth of spits, dune and saltmarsh development, changes in intertidal and deeper water bathymetry and erosion of both beaches and cliffs.

There are few sites in Britain that have been so little affected by anthropogenic interference and which contain such a fine assemblage of coastal forms. Carmarthen Bay is the only coastal assemblage GCR site that is directly affected by the Atlantic wave systems; it also contains four estuaries. Like the other coastal assemblage GCR sites, it gains its greatest importance from its completeness and the fact that it can be defined as a single unit in terms of its overall sediment dynamics.

It is apparent from the field studies that the individual parts of the site are interconnected with sediment moving between intertidal sands and the beaches, and therefore able to move from one subunit to another. Similarly there is evidence of sand movement from Rhossili Bay to the Whiteford Burrows spit and beyond.

In recent years concern about erosion of parts of the beaches, particularly at Pembrey, led the Coast Protection Authorities responsible for to commission studies of the bay treating it as a single coastal ‘cell'. The Carmarthen Bay Study (Barber and Thomas, 1989) shows that the shape of the modern coastline is dominated by the high-energy, south-westerly wave regime interrupted by the discharges of the two major estuaries. Tidal streams in the bay have three dominant effects:

1. On the ebb tide they produce significant refraction of waves,

2. direct scour by currents occurs at the distal end of spits, particularly at Ginst and Tywyn

Points, and

3. currents are also important mechanisms for moving sediments stirred up by wave action on the intertidal banks.

Waves are affected by refraction especially over the shallow areas of the estuaries, and by currents. Over the shallow inlets there is some partial breaking of waves, and the effects of bottom friction and shoaling on waves are particularly strong over the wide intertidal areas. As a result there is considerable stirring of sediments that can then be moved by tidal streams. Wind action also plays a major role in the movement of sand between intertidal drying areas and the dunes. This is especially important with dominant and prevailing westerly winds. There are distinct differences in the recent patterns of accretion on the three main beaches (Figure 11.13). Pendine Sands and Laugharne Burrows show no change along its proximal half where it is not protected by offshore intertidal banks, but substantial growth along the distal half at Laugharne where the effects of the offshore banks become significant. Pembrey Burrows shows a tendency to periodic retreat and advance along its main central section that faces directly into the main direction of wave approach, but persistent gain at the distal ends where sand appears to be transported from the intertidal banks. The accretion here is more than can be accounted for by longshore transfers from the erosion of the central section. Whiteford spit has shown most gain at its distal end within the Burry Inlet, probably by transfers from the offshore banks and by redistribution alongshore. Rhossili beach is a fine example of an Atlantic swell-dominated beach of considerable width (Figure11.18), but for which there are very limited local sources of sediment, other than coarse shingle and cobbles from the till cliffs and sand from offshore.

Modelling of wave conditions in Carmarthen Bay (Barber and Thomas, 1989) showed that changes in bathymetry between 1977 and 1988 had significantly changed both the direction and the intensity of wave attack within the Loughor estuary and the joint estuary of the rivers Taf and Tywi. Sediment transport was also affected. According to the model, nearshore wave conditions were critically affected by the direction of approaching waves and the magnitude and direction of tidal streams. For example, during a model SSE storm with significant wave height (H_s) = 2.7 m and wave period (T_s) = 6.3 s), wave attack was concentrated on the central part of Cefn Sidan–Tywyn–Pembrey area two hours before high water. This could account for the observed erosion on this beach and the tendency for transport towards both ends of the beach. However, the most significant feature of both the model and the empirical studies is their definition of the bay as a single sedimentary unit.

Barber and Thomas (1989) argued that the approach of the Carmarthen Bay Study provides a ‘modern' tool to aid decision-making regarding development and conservation proposals affecting a specific shoreline and its neighbours within a recognizable coastal ‘cell' (Figure 11.12). From the point of view of coastal geomorphology, this recognition of the integrated characteristics of coastal processes within a large site provides considerable support for the designation of this area as a single site.

Further interest is added by the saltmarsh morphology. The saltmarshes of the Burry Inlet comprise the most extensive area of saltmarsh in Wales, and those of the south shore of the estuary from Whiteford Point to Loughor are of particular interest for the range of geomorphological features that they display, particularly saltmarsh creeks, saltpans, marsh terraces, erosion cliffs and the range of sediments. Understanding of the long-term dynamics of saltmarshes in the Bristol Channel has been focused mainly in the Severn estuary and there has been comparatively less attention given to those of the Burry Inlet. Within the Severn marshes, geomorphological and sedimentological techniques were used by Allen and Rae (1987, 1988) to elucidate the oscillations of late Holocene shorelines and to describe vertical saltmarsh accretion since the Roman period (*c*. 2000 years BP). Allen (1990a) has, however, voiced caution about relying upon saltmarsh sedimentation rates as a source of estimates of sea-level change especially because reworking of muddy intertidal sediments is an important process (Allen, 1987). Compaction, the intricate patterns of sedimentation, and local changes of elevation can each lead to errors. Postglacial stratigraphy of the Severn estuary indicates a long-term sea-level rise (about 3–4 m during the last 2000 years (Allen and Rae, 1988; Heyworth and Kidson, 1982) upon which are superimposed several periods of still-stand (Kidson and Heyworth, 1976; Allen, 1990a–c, 1991b, 1992). These interpretations probably also apply to the Burry Inlet, but there has been very limited investigation of them and the magnitude of change is thought to have been less in the Burry Inlet. Relative sea level continues to rise in the region: mean sea level at Avonmouth increased by 1.12 ± 0.62 mm a^{-1} between 1925 and 1980 (Woodworth *et al*., 1991) and relative sea-level rise in Carmarthen Bay is estimated at between 1 and 2 mm a^{-1} (Pye and French, 1993).

Conclusions

Carmarthen Bay has perhaps the most varied assemblage of coastal features in the British Isles and is one of the few sites with limited anthropogenic disturbance. There are major dunes, sand spits and barrier beaches, both hard-rock and easily eroded cliffs, rias, emerged ('raised') beaches, extensive intertidal sand-flats and some of the most important saltmarshes in England and Wales. Ages of features in the site range from about 245 000 years old to modern, and the site is crossed by the probable limit of the Devensian ice in Britain.

There is no other site in England and Wales that has such well-developed spit and barrier beaches in a macrotidal regime dominated by south-westerly Atlantic wave conditions, and the site can be regarded as a single sedimentary unit. The interest of the site is heightened by the well-documented Quaternary sequences that occur within it at Ragwen Point, Broughton Burrows, Rhossili Bay and Worms Head, since it is possible to relate the modern features to earlier ones. The comprehensive dating that confirms the longevity of many of the features, notably the cliff–platform sequences and some of the cliff-top dunes at the northern end of Rhossili Bay, is rare and of considerable significance to the understanding of glaciomarine margins and their subsequent development.

The saltmarshes of the Burry Inlet are of major regional and national interest for the range of geomorphological features they display, particularly saltmarsh creeks, saltpans, erosion cliffs and range of sediments, in a macrotidal environment.

Reference list

Allen, J.R.L. (1987) Dessication of mud in the temperate intertidal zone: studies from the Severn estuary and eastern England. Philosophical Transactions of the Royal Society of London, **B315**, 127–56.
Allen, J.R.L. (1989) Evolution of salt marsh cliffs in muddy and sandy systems: a qualitative comparison of British west-coast estuaries. Earth Surface Processes and Landforms, **14**, 85–92.
Allen, J.R.L. (1990a) Salt-marsh growth and stratification: a numerical model with special reference to the Severn estuary, southwest Britain. Marine Geology, **95**(2), 77–96.
Allen, J.R.L and Rae, J.E. (1987) Late Flandrian shoreline oscillations in the Severn estuary: a geomorphological and stratigraphical reconnaissance. Philosophical Transactions of the Royal Society of London, **B135**, 185–230.
Allen, J.R.L. and Rae, J.E. (1988) Vertical salt-marsh accretion since the Roman Period in the Severn estuary, southwest Britain. Marine Geology, **83**, 225–35.
Barber, P.C. and Thomas, R.P. (1989) Case study at Carmarthen Bay. In Coastal Management: Proceedings of the Conference organised by the Institution of Civil Engineers and held at Bournemouth on 9–11 May 1989, Thomas Telford, London, pp. 243–62.
Bowen, D.Q. (1970) South-east and central south Wales. In The Glaciations of Wales and Adjoining Regions (ed. C.A. Lewis), Geographies for Advanced Study, Longman, London, pp. 197–228.
Bowen, D.Q. (1974) The Quaternary of Wales. In The Upper Palaeozoic and post-Palaeozoic rocks of Wales (ed. T.R. Owen), University of Wales Press, Cardiff, pp. 373–426.
Bowen, D.Q. (1981a) 'The South Wales end-moraine': fifty years after. In The Quaternary of Britain (eds J. Neale and J. Flenley), Pergamon Press, Oxford, pp. 60–7.
Bowen, D.Q. (1984) Introduction, Western Slade and Eastern Slade, Langland Bay, Abermawr, Fishguard–Newport–Cardigan. In Field Guide: Annual Field Meeting April 1984: Wales: Gower, Preseli, Fforest Fawr (eds D.Q. Bowen and A. Henry), Quaternary Research Association, Cambridge, pp. 1–102.
Bowen, D.Q. and Sykes, G.A. (1988) Correlation of marine events and glaciations on the north-east Atlantic margin. Philosophical Transactions of the Royal Society of London, **B318**,

619–35.

Bowen, D.Q., Sykes, G.A., Reeves, A., Miller, G.H., Andrews, J.T., Brew, J.S. and Hare, P.E. (1985) Amino acid geochronology of raised beaches in south-west Britain. Quaternary Science Reviews, **4**, 279–318.

Bridges, M. (1987) Classic Landforms of the Gower Coast, Classic Landform Guides, No.**7**, Geographical Association, Sheffield, 48 pp.

Burd, F. (1989) The Saltmarsh Survey of Great Britain: An Inventory of British Saltmarshes, Research and Survey in Nature Conservation, No. **17**, Nature Conservancy Council, Peterborough, 180 pp.

Campbell, S. (1984) The nature and origin of the Pleistocene deposits around Cross Hands and on west Gower, South Wales. Unpublished PhD thesis, University of Wales.

Campbell, S. and Bowen, D.Q. (1989) Quaternary of Wales, Geological Conservation Review Series, No. **2**, Nature Conservancy Council, Peterborough, 237 pp.

Carling, P.A. (1981) Sediment transport by tidal currents and waves: observations from a sandy intertidal zone (Burry Inlet, south Wales). In Holocene Marine Sedimentation in the North Sea Basin (eds S.D. Nio, R.T.E. Schuttenhelm and T.C.E. Van Weering), International Association of Sedimentologists Special Publication, No.**5**, Blackwell Scientific Publications, Oxford, pp. 65–80.

Heyworth, A. and Kidson, C. (1982) Sea level changes in southwest England and Wales. Proceedings of the Geologists' Association, **93**, 91–111

Hubbard, J.C.E. and Stebbings, R.E. (1967) Distribution, date of origin and acreage of Spartina townsendii (s.l.) marshes in Great Britain. Proceedings of the Botanical Society of the British Isles, **7**, 1–7.

Jago, C.F. (1980) Contemporary accumulation of marine sand in a macrotidal estuary, south-west Wales. In Shallow Marine Processes and Products (eds A.H. Bouma, D.S. Gorsline, C. Monty and G.P. Allen), Sedimentary Geology Special Issue, Elsevier, Amsterdam, No.**26**, pp. 21–49.

Jago, C.F. and Hardisty, J. (1984) Sedimentology and morphodynamics of a macrotidal beach, Pendine Sands, SW Wales. Marine Geology, **60**, 123–54.

John, B.S. (1971) Pembrokeshire. In The Glaciations of Wales and Adjoining Regions (ed. C.A. Lewis), Geographies for Advanced Study, Longman, London, pp. 229–65.

John, B.S. (1973) Vistulian periglacial phenomena in south-west Wales. Biuletyn Peryglacjalny, **22**, 185–211.

Kahn, A.S. (1968) The recent sediments of the area between the Loughor and Towy estuaries, Carmarthen Bay. Unpublished PhD thesis, Imperial College, University of London.

Kidson, C. and Heyworth, A. (1976) The Quaternary deposits of the Somerset Levels. Quarterly Journal of Engineering Geology, **M9**, 217–35.

Lees, D.J. (1982) The evolution of Gower coasts. In Geographical Excursions from Swansea. Volume 1, Physical Environment (ed. G. Humphrys), Department of Geography, University College, Swansea, pp. 15–32.

Lees, D.J. (1983) Post-glacial sand-dune history and archaeology at Broughton Bay, Gower. In British Geomorphological Research Group, Spring Meeting, May 13–15, 1983. Field Excursion Handbook, Swansea, pp. 27–9.

North, F.J. (1929) The Evolution of the Bristol Channel, with Special Reference to the Coast of South Wales, National Museum of Wales, Cardiff, 103 pp.

Packham, J.R. and Willis, A.J. (1997) Braunton Burrows in context: a comparative management study. In Coastal Dune Management: Shared Experience of European Conservation Practice (eds J.A. Houston, S.E. Houston and P.J. Rooney), Liverpool University Press, Liverpool, pp. 65–79.

Potts, E.A. (1968) The geomorphology of the sand dunes of south Wales, with special reference to Gower. Unpublished PhD thesis, University College, Swansea.

Pye, K. and French, P.W. (1993) Erosion and Accretion Processes on British Saltmarshes. Final Report to the Ministry of Agriculture, Fisheries and Food, Cambridge Environmental Research Consultants, Cambridge, 5 volumes.

Savigear, R.A.G. (1952) Some observations on slope development in south Wales. Transactions of the Institute of British Geographers, **18**, 31–51.

Smith, J.S. (1978) A new method of salt-pan formation in intertidal marshes. Transactions of the Botanical Society of Edinburgh, **43**, 127–30.

Steers, J.A. (1946a) The Coastline of England and Wales, Cambridge University Press, Cambridge, 644 pp.

Stephens, N. and Shakesby, R.A. (1982) Quaternary evidence in South Gower. In Geographical Excursions from Swansea. Volume 1: Physical Environment (ed. G. Humphrys), Department of Geography, University College, Swansea, pp. 33–50.

Woodworth, P.L., Shaw, S.M. and Blackman, D.L. (1991) Secular trends in mean tidal range around the British Isles and along the adjacent European coastline. Geophysical Journal International, **104**, 593–609.