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A MACRO REVIEW OF THE COASTLINE OF ENGLAND AND WALES

Volume 7. Wales. River Wye to the Great Orme, including Anglesey

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ABSTRACT

This report reviews the coastline of south, west and northwest Wales. In it is a description of natural and man made processes which affect the behaviour of this part of the United Kingdom. It includes a summary of the coastal defences, areas of significant change and a number of aspects of beach development. There is also a brief chapter on winds, waves and tidal action, with extensive references being given in the Bibliography.

This is the seventh report of a series being carried out for the Ministry of Agriculture, Fisheries and Food. For further information please contact Mr J M Motyka of the Coastal Processes Section, Maritime Engineering Department, Hydraulics Research Limited.

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1 INTRODUCTION

In 1985, the Ministry of Agriculture, Fisheries and Food commissioned Hydraulics Research, Wallingford to carry out a review of the coastline of England and Wales. The principal aim of this review is to provide information on various factors affecting the development of the coastline, including the physical processes, any coastal defences which may affect these processes, as well as natural factors such as the coastal geology, geomorphology, winds, waves and tidal action. Also included is a bibliography containing details of reports, studies and papers describing this particular coastline.

In this review the coastline of England and Wales has been sub-divided into regions, with each major region being covered by a separate report. The present report is Volume 7 of the series, and covers the Welsh coast from the mouth of the R. Wye to the Great Orme.

One of the fundamental objectives of this review is to identify those stretches of coast which can be treated, from a coast protection viewpoint, as individual units or cells. Such cells are judged to be self contained in those areas where it is found that beach or nearshore changes within a particular cell have no significant effect on processes taking place in adjoining cells. Identification of littoral cells is intended to help planners determine the length of coastline likely to be affected by coastal works in any particular area.

It is hoped that this type of 'overview' will assist in the understanding of the coastal system as a whole and may lead to a more unified approach to the planning of coastal defences.

Throughout these reviews the phrase 'Schedule 4 boundary' is often used. This is a term from the 'Coast Protection Act of 1949' which defines the boundary, chiefly on rivers and estuaries, upstream of which the Act ceases to apply. It is used here for convenience to establish a cut off point with regard to coast protection. Briefly the Coast Protection Act establishes relevant maritime authorities as the 'coast protection authority' giving them general powers to carry out coast protection work within their specified boundaries. The other relevant Act of Parliament is the 'Land Drainage Act of 1976'. This deals (among other things) with the prevention of flooding by the sea, ie 'sea defence', and is usually the responsibility of the Water Authorities. Both Acts now come under the jurisdiction of the Ministry of Agriculture, Fisheries and Food.

The major coastal units are set out in Chapter 2 and the more important coastal features highlighted. Chapter 3 describes the geology and recent coastal evolution. General information on winds, waves, tides and tidal currents is given in Chapter 4. The main body of the report is contained in Chapter 5, which describes the coastal defences and their effect on coastal processes.

2 EXECUTIVE SUMMARY

The coastline of Wales, though topographically and geologically very varied can still be divided into a number of larger coastal units within which coastal defences have common features.

The Wye to Lavernock Point

The low lying estuarial shoreline east of Lavernock is well sheltered from wave activity. The nett west to

east littoral drift is weak and only at high water are the embankments which protect the land from flooding subject to wave action. The intertidal zone is wide flat and muddy and its form is controlled by tidal current action. This frontage is largely undeveloped and has few serious coastal problems.

Lavernock Point to Nash Point

The coastline consists mainly of steep limestone or marl cliffs. These are subject to weathering but this generally does not pose coast protection problems. The upper foreshore is generally rocky with thin deposits of sand and some shingle storm beaches. Littoral drift is in a nett west to east direction and it is generally uninterrupted due to the sparsity of coastal defences. The lack of significant accumulation of material suggests that the drift is low. Coastal defences are centred around Barry and Aberthaw. To the west of Barry the shingle ridge called The Knap protects low lying urban land from flooding. Construction of coastal defences along the frontage to the west would have a detrimental effect on the ability of the ridge to protect the hinterland from flooding. There appears to be little need for coast protection westwards as far as Aberthaw. Here there is a large shingle delta and a wide shingle beach to the west of it. This frontage is owned by CEGB and protected by walls. The foreshore groyning has not been particularly successful in maintaining healthy beach levels. The weathering of cliffs westwards to Nash Point is believed to contribute pebbles to the beaches. This frontage is largely in a natural state and there has been little interruption of the material supply. The reasons for erosion of the Knap and at Aberthaw are unclear. Should the erosion become more of a problem than it is at present it would best be dealt with by renourishment. (More

extensive foreshore groyning would be detrimental to the adjacent coastline.)

Swansea Bay

The bay is strongly indented and there is generally a "clockwise" nett drift of material around its circumference. The coastal aspect is very variable. There are limestone cliffs and thin sand beaches overlying wide rock platforms between Nash Point and the mouth of the River Ogmore. This stretch is exposed to Atlantic waves but is partly protected from wave action by Nash Bank which is barely submerged at low tide.

The coast is largely undeveloped and apart from some cliff slippage near Dunraven there are no coastal problems. The central frontage of Swansea Bay is generally low lying and has extensive sand beaches. These have suffered erosion which is at least partly the result of large scale development and foreshore reclamation at Port Talbot and Neath. Falling beach levels have given rise to concern. Margam Sands and Kenfig Sands are eroding, as are the dunes which back them. Aberavon beach north of Port Talbot is also not particularly stable, despite being situated on the updrift side of Port Talbot harbour. Deterioration of the beaches is partly the reclamation of the foreshore, partly the cutting off the sand supply and also the result of beach mining for land fill. The western end of Swansea Bay is sheltered by the Gower Peninsula. The land is generally low lying and the wide foreshore consists of sand and mud. Coastal defences along this frontage are fragmented and consist mainly of embankments to protect the land from flooding.

The whole of the bay should be considered as one unit from a coast protection viewpoint.

The Gower Peninsula

The limestone and shale cliffs of the Gower peninsula separate the bays of Swansea and Carmarthen. The southward bays are strongly indented and the transfer of sand between adjoining bays is small. A number of major rock headlands act as barriers to movement of material within the intertidal zone. Some of the more notable are Mumbles Head, Pwlldu Head, Oxwich Point and Worms Head. The southward facing part of the Gower can be treated as one coastal unit. Problems along this frontage are relatively minor, mainly dune erosion due to public overuse.

Carmarthen Bay

The open coastline of Carmarthen Bay (including the west facing beaches on the Gower) is largely undeveloped and typified by wide sand beaches. The dune systems in the central part of the Bay (Pembrey and Pendine in particular) are eroding and this is giving rise to concern to the local authorities and the landowners. The two estuaries within the Bay (the Loughor and the Taf/Tywi estuaries) contain vast quantities of silt and sand. Low lying land within estuaries is protected from flooding by earth embankments. Some of the marshland is in a natural state. From Pendine westwards the coast is cliffed and the width of the foreshore is greatly reduced. There appears to be a free interchange of material although the rate and direction of littoral drift varies significantly in different parts of the Bay. The whole of the Bay clearly needs to be treated as one coastal unit. Although coastal defences are

fragmentary they clearly have a "knock-on" effect on adjoining stretches of beach.

The Pembrokeshire Peninsula

The greater part of the peninsula (ie from Giltar Point west to St David's Head and then north to Cemaes Head) is cliffed and forms a headland and bay coast formed by the differential erosion of rocks of varying resistance. Littoral drift is intermittent and variable in direction, depending on the orientation of various stretches of coast to the predominant south-westerly waves. There are many wide sand beaches which share similar problems, principally erosion of sand dunes where these are exposed to Atlantic storms. The whole stretch is generally unpopulated and has few coastal defences. It should be treated as one large coastal unit, within which there are many smaller independent cells. Because of the indented nature of the coast there is little interchange of beach material. The number of headlands which form barriers to littoral drift are too numerous to mention.

Cardigan Bay

The sparsely populated southern part of Cardigan Bay has coastal defences centred around the towns of New Quay, Aberayron and Aberystwyth. Elsewhere the coastal defences are very localised. From New Quay to Aberayron erosion of the boulder clay cliff produces beach building material ie sand and shingle. Erosion problems at New Quay are largely due to cliff instability. At Aberayron and Aberystwyth the supply of shingle appears to be reducing. (There are coastal erosion problems both updrift and downdrift of many coast protection structures along this frontage.

The coastline in the north part of Cardigan Bay is predominantly sandy as fine materials are swept northwards by wave action into an area increasingly sheltered by the Lleyn peninsula. Three estuary mouths have major sand and shingle spits extending northwards in the nett direction of littoral drift. These spits are dwindling and at Borth, Fairbourne, Shell Island and Morfa Harlech there are problems either due to coastline recession or dune erosion. The estuaries are only partial barriers to littoral drift and the whole part should be considered as one coastal unit. Coastal defences are concentrated at the areas of urban development which are generally at the estuary mouths. There is also extensive holiday development behind the duned areas of foreshore north of Barmouth. Within each of the estuaries the low lying land is liable to flooding and is protected by earth embankments.

The coastline along the whole frontage within Cardigan Bay should ideally be treated as one coastal unit from a planning viewpoint. Erosion of the boulder clay cliffs in the south part of the Bay results in material being transported northwards into the north part (although the southern stretch is rather more indented than the northern stretch).

Lleyn Peninsula

The south part of the Lleyn peninsula has many wide sand beaches separated by rock headlands. Many of the beaches are backed by dunes which are subject to erosion. Interchange of sand between adjacent beaches is small. Low lying areas in the eastern part of the peninsula are vulnerable to flooding. As in the north part of Cardigan Bay so the southern part of the Lleyn peninsula has much holiday development and defences are somewhat fragmentary parts being in private

ownership. The common nature of the coast protection problems makes it sensible that the whole area falls under one maritime authority.

The north face of the Lleyn peninsula, by contrast, is largely undeveloped. Coastal defences are few and are centred around a number of small towns eg Porth Dinllaen, Nefyn and Trevor. The coastal strip has a narrow foreshore except in a number of strongly indented embayments where there are wide sand beaches. Much of the cliff line consists of boulder clay which supplies sand and shingle which is transported northwards to the mouth of the Menai Strait.

The peninsula terminates in a massive sand and shingle spit backed by dunes and marshland at Dinas Dinlle. The shingle forming the crest of the spit is now eroding rapidly, despite the fact that there are few coastal defences to obstruct the northward movement of sediment. The whole of the north face of the peninsula and the low lying frontage extending to the Menai Straits should be treated as a coastal unit.

Anglesey

The rocky coastline forms a natural coastal unit in that the defences on the Island have a negligible impact on the mainland coast. The Island has one maritime authority. Coastal defences generally consist of short stretches of seawall or promenade at the heads of bays where urban development has taken place. There are areas liable to flooding in the south-west corner of the Island but unprotected with the exception of a rock breakwater at Abermenai Point. With the exception of this area (which includes the massive sand accretion at Newborough Warren) littoral drift around the coastline of Anglesey is very weak and sand is effectively contained within individual

bays by rocky promontories. Some properties may be at risk in the future on the eastern face of the Island where there are eroding boulder clay cliffs. Some of the walls are also used to protect coastal roads. The only area which has had a significant impact on coastal processes is at Holyhead Harbour. Construction of the harbour arms has increased the shelter against wave attack while the causeway connecting Holyhead to Anglesey has reduced tidal currents in the area. Siltation has therefore taken place to the north of the embankment.

Menai Strait

The southern shore of the Strait is well sheltered from wave activity and appears to have no serious coast protection problems. Both to the west and to the east of Carnaervon the coastal defences are mostly in private ownership and consist of short stretches of wall. The south shore of the Strait has few beach deposits and the construction of seawalls at Carnaervon and quay walls at Port Dinorwic has had little impact on the adjacent coast. Further east the coast is in private ownership. Formal defences are found at Bangor and Port Penrhyn. These too have had little impact on the adjacent coast. Tidal currents which can be as high as 8 knots are the predominant influence on the shaping of this coastal stretch, ie the frontage from the mouth of the Straits at Fort Belan eastwards to Port Penrhyn.

Conwy Bay

The frontage from Port Penrhyn to the Great Orme is partly sheltered from wave action and the Bay is effectively a sediment trap. The Bay is fed with sediment from the River Conwy with some input of material from offshore as well as from the Menai

Strait. Much of the coastline is low lying and sparsely populated, and some of the sea walls are privately maintained. Coast erosion problems are not serious in the western part of the Bay. Formal coastal defences are centred around Llanfairfechan, Penmaenmawr and on the east shore of the Conwy estuary between Llandudno Junction and the Great Orme. The headland east of Llanfairfechan acts as a partial barrier to littoral drift. However littoral drift is low and movement of sediment within the Bay is dominated by tidal current activity. The whole of the frontage should therefore be treated as one coastal unit.

The Great Orme forms a divide in the littoral processes operative to the west and the east and is therefore the limit of the coastline considered in this report.

3 COASTAL GEOLOGY AND TOPOGRAPHY

3.1 Geological background

The coastline of Wales from the Severn Estuary to Great Ormes Head is mainly composed of rocks ranging in age from the Pre-Cambrian (over 500 m years ago) to the Jurassic eras (ending 135 m years ago). The geological structure of Wales can be divided into two basic regions. The north and west coasts are formed in older Paleozoic rocks folded in a northeast/south-west direction. The south coast is formed in younger rocks folded later in an east/west direction.

An ancient core of Cambrian rock known as the Harlech Dome is exposed along the west coast between Barmouth and Tremadoc Bay. Surrounding this mass from the

Lleyn peninsula to Conwy on the northern coast and southwards to the Dyfi estuary are Ordovician rocks, mainly sedimentary shales but containing numerous and extensive outcrops of contemporaneous igneous rocks. Younger Silurian rocks sandstones and mudstones form the coastline in Cardigan Bay between Borth and New Quay while Ordovician rocks reappear to the south along the north coast of Pembrokeshire to St David's Head where once again there are many igneous intrusions. These rock strata form a great anticlinal (upfold) structure aligned north-eastwards and folded during the Caledonian (about 400 m years ago). Many of the rocks were altered or metamorphosed under the intense pressures and the igneous masses were intruded at the same time. The oldest Pre Cambrian rocks, mainly hard metamorphic schists and gneisses, are found on the Isle of Anglesey and on the Lleyn Peninsula. Outcrops of Carboniferous limestone form the headland of the Great Orme and parts of the east coast of Anglesey.

Along the south coast of Wales, from St Bride's Bay in Pembrokeshire running eastwards to Swansea Bay, are younger rocks mainly of the Carboniferous period (290-355m years ago) forming what is known as the South Wales Coalfield area. The coal basin is essentially a great syncline aligned in an east-west direction formed during the Armorican mountain building period (during the late Carboniferous period). The coal measures are bounded to the north and south by (older) Millstone grit, Carboniferous limestone and Old Red Sandstone. The less resistant rocks at the core of the downfold have been exposed in Carmarthen and Swansea Bays. Further south in the Gower Peninsula beyond Swansea and westwards into south Pembrokeshire the underlying Carboniferous limestone forms the coastal plateau. The relation between the geological structure and the coastal scenery is very clearly seen

here. Differential erosion by the sea of the folded Carboniferous strata has formed bays where the weaker shales and sandstones are exposed separated by headlands and cliffs of more resistant limestone.

In South Glamorgan and along the Severn Estuary east of Porthcawl the Carboniferous rocks are overlain by younger Triassic (New Red Sandstone) and Jurassic formations, mainly consisting of marls and limestones interbedded with shales.

The general configuration of the coastline of Wales was formed during the mid-Tertiary era (about 30m years ago) when the whole area was uplifted. This resulted in the flat-topped cliffs and inland plateaux characteristic of much of the west coast of Britain and which represent a number of former sea floor levels.

The coastal outline was further modified during the Pleistocene Ice Ages (commencing 1.8m years ago). Ice sheets covered the whole of Wales, the Irish Sea and St George's Channel at the time of the glacial maximum. The ice sheets deposited thick layers of unconsolidated sands, clays and gravels known as glacial drift or boulder clay. Where the boulder clay is now exposed at sea level the deposits offer little resistance to wave action and are rapidly eroded providing suitable beach material.

Sea level changes during and after the Ice Age have played an important role in the coastal development of Wales giving rise to great variation in the coastal environment over time. During the cold glacial phases the global lowering of the sea level caused the periodic exposure of extensive parts of the sea floor (of Cardigan Bay and the Bristol Channel) subsequently submerged by rising sea levels as the ice sheets

receded during the interglacial periods and in post glacial times. During periods of sea level rise large quantities of glacial sediments deposited over the sea floor were sorted by wave action and pushed shorewards as the surf zone advanced providing a major source of beach sand and gravel. The large sand banks in the Bristol Channel also originated in this way. This process is now largely complete and any contemporary sources of such material are very limited.

During periods of high sea levels coastal erosion proceeded rapidly. Former clifflines and shore platforms for example along the Gower and Glamorgan coasts represent the previous limits of wave action. Raised (fossil) beach deposits are often associated with such abandoned platforms and good examples of such deposits can be found on the Gower and in parts of Pembrokeshire. Evidence of lower sea levels is provided by submerged post glacial deposits such as estuarine and lacustrine clays, peats and forest deposits which are occasionally now exposed on the foreshore by erosion, for example in Swansea and Carmarthen Bays and also along the north coast of Cardigan Bay. River valleys which were deepened to lower base levels when the sea level was lower have now been drowned. The branching tidal inlet of the Daugleddau at Milford Haven was formed in this way and many of the rivers of south and west Wales exhibit wide estuary mouths which are now characterised by siltation.

The post glacial rise in sea level is still progressing at a rate of 1-2mm/year and this rate is likely to increase as a result of the so called 'greenhouse effect'. This effect combined with the fact that the contemporary supply of beach material appears to be insufficient to maintain beach levels implies that the coastal recession which is taking

place along Swansea, Carmarthen and Cardigan Bays is likely to continue in the long term.

3.2 Coastal processes

Bristol Channel and the Severn Estuary - The Wye to Lavernock Point

The Bristol Channel and the Severn Estuary together form a wide, shallow estuary with a large tidal range and strong tidal currents. The currents are generally rectilinear and have a residual westerly (ebb) flow along the northern side of the Bristol Channel and the South Wales coast and easterly (flood) flow along the south shore. To the east of Lavernock Point all fetch lengths are reduced excepting those from a narrow sector in the south-west leading to a significant reduction in wave activity. The overall easterly littoral drift, which is more apparent along the sections of the open coast to the west, decreases in magnitude upstream until the sediment movement becomes limited to the finest fractions and dominated by the tidal currents.

Much of the shoreline of the northern side of the Severn Estuary as far as Penarth and Lavernock Point is low lying and walls and clay embankments prevent flooding associated with exceptionally high tidal conditions when water becomes funnelled into the estuary. Large quantities of sediment originally derived from cliff erosion and glacial deposits together with river sediments are deposited as wide intertidal mudflats fringed with saltmarsh and offshore shoals of sand. The Upper Bristol Channel and the Severn Estuary appear to act as a sediment sink but where there is now only a relative small input of fresh sediment and existing sediments are reworked and recirculated by tidal currents.

In places exposures of bedrock, mainly mudstones and marls of the New Red Sandstone, form low eroding cliffs, for example at Penarth. At Laverock Point the marls are overlain by Liassic limestones. The shoreline between Penarth and Lavernock Point faces east with limited fetch and is therefore well sheltered from waves generated in the open sea. At low water spring tides Cardiff Grounds dry out and the effective fetch is further reduced. The low cliffs experience little active wave erosion and the beaches are strewn with boulders and pebbles and lack sand cover of any quantity.

Glamorgan Coast - Lavernock Point to Porthcawl

From Lavernock Point to Porthcawl the cliffs are rarely higher than 30m but are very steep and are broken only where valleys reach the coast. The rocks forming the cliffs are mainly horizontally bedded Lower Jurassic Lias formations (interbedded limestones and shales) or New Red Sandstone (marls) as at Penarth but in the west at Southerndown and Dunraven more resistant older Carboniferous limestone forms the foreshore. The three south pointing headlands at Barry are made of thick steeply dipping Carboniferous limestone capped by nearly horizontal beds of New Red Sandstone.

The limestone that forms so much of the foreshore of Glamorgan has a weak geological structure, being intersected by many faults and joints and in the Liassic areas the limestones are interbedded with less resistant shales. Cliff recession is mainly effected by rockfalls which are frequent where wave action undermines the cliff face already weakened by subaerial weathering. An average rate of recession of 6.8 cm/yr has been calculated from stake measurements taken over an 8 year period (Ref 1) but on major

rockfall localities 30cm/yr may be more appropriate. In 1983 a large rockfall at Nash Point involved some 20000m³. However, the rock is rapidly removed by wave action and the wavecut platform, which may be 300m wide in places, is often coincident with the bedding planes forming numerous step-like terraces. Some controversy exists as to whether ledges above high tide level provide evidence of former higher sea levels. Studies by Trenhaile have shown that the platforms are more likely adjusted to present wave activity. In general the junction of the cliff and platform is related to spring high water levels, the platform width and gradient is related to the magnitude of the tidal range and the variation in profile is related to local lithology (Ref 2). However, the varying aspect of the coastline is the dominant factor influencing the rate of cliff erosion along this part of the Glamorgan coast.

At Lavernock Point the gently dipping limestone strata are clearly seen in the cliffs. The more resistant strata form ledges with pavement features and have little material cover. To the west the harder limestone bands dip below sea level. Lavernock Spit extends south-westwards from Lavernock Point, probably under the influence of residual ebb flows since tidal currents in this area are high. From Lavernock Point westwards to Nash Point the coast trends east-west. The cliffs are rugged and are exposed to a high storm environment. The high tidal range, long Atlantic fetch and oblique wave approach promote a high potential for littoral transport in an easterly direction. The rock wave platforms are generally bare of beach material but pebble beaches exist where the material is trapped between headlands such as at Porth Kerry and Aberthaw. The only point on this coastline where sand is found on the lower foreshore in any large quantities is at St Mary's Well Bay. The small

bays and headlands reflect the differential erosion of softer shaley rocks brought down to sea level by faulting such as at St Donat's Bay and Stradling Well Bay.

The high rate of littoral movement along this coastline was underestimated in a scheme to stabilise the cliffs at LLantwit Major to the east of the Colhugh River (Ref 3). In 1969 remedial cliff blasting of Lias limestone cliffs was carried out to realign the cliff face and reduce the angle of the upper cliff to minimise rockfalls. It was hoped that the debris fan would also provide protection to the toe of the cliff against wave action. However cliff stability was not attained and the talus material was rapidly removed by waves such that wave attack now occurs at the base of the cliffs. Several rockfalls have occurred since the blasting which has probably exacerbated the structural weakness of the cliffs. Since subaerial weathering is an important contributary factor to the devepoment of rockfalls, any basal protection would therefore have little effect in preventing their occurrence. Approximately 28000cu yds were blasted away and this was supposed to prevent cliff undercutting for 20 years. Ten years later only 8000cu yds remain. Various efforts have been made to bulldoze pebbles and stockpile sand in order to form a recreational beach.

North of Nash Point to the mouth of the River Ogmore there are also steep crumbling cliffs but mobile sand beaches overlie the rock platform. At Treath Yr Afon north of the River Ogmore the sand beach is much wider and is backed by extensive mature sand dunes at Merthyr Mawr. Thus there is a general increase in the volume of beach sand northwards of Nash Point. The stretches of sand are separated by headlands and the net littoral drift is low.

The Nash Bank is some 12km long and trends east-west offshore of Nash Point. This bank provides shelter from severe wave activity during south-westerly storms and it is speculated that sand which is drawn seawards under storm conditions may be returned shorewards in the vicinity of Nash Point by clockwise tidal currents. Current dredging activities on the Nash Bank have been reviewed since any significant reduction in the height of East Nash would cause more wave action at the shoreline and could result in a reduction of beach deposits (Ref 4). The sheltering action of the bank is reduced for the coastline further north and the frontage at Porthcawl has suffered serious damage by wave action in the past.

Swansea Bay

Swansea Bay forms a large shallow embayment along the South Wales coast extending from Sker Point in the east to The Mumbles in the west. The bay was formed during the post glacial transgression at which time the rivers entering the bay became drowned and wave action eroded the less resistant Coal Measure rocks of the Upper Carboniferous. The intertidal sediments consist of recent beach sands overlying a post glacial sequence of brown peats and forest deposits, clays silts, sands and gravels. A group of linear, drying sand banks, namely the Nash and Scarweather Banks, trend approximately east-west along the southern margin of the bay. The banks are 8 - 12 m thick and are Holocene in origin formed from wave eroded glacial deposits during a period of lower sea level. The inner floor of the Bay is covered with finer silts and clays. The banks have a significant influence on the sedimentary circulation within the Bay and due to their location the tidal volume of Swansea Bay is partly isolated from the main tidal volume in Bristol Channel.

Much of the present undeveloped shoreline consists of sand dunes with a foreshore of sand and increasing proportions of muds in the more sheltered western part of the Bay. The bay is relatively sheltered from severe wave activity resulting in a generally weak littoral drift from west to east. The large tidal range (8.5 m on mean spring tides) has favoured large scale industrial development and construction of port facilities at Swansea and Port Talbot and much of the natural coastline has been obscured by land reclamation.

The Institute of Oceanographic Studies has undertaken detailed studies of the hydrodynamic processes and sedimentation regime within Swansea Bay prompted by falling beach levels which are exposing areas of peat clay and cobbles along the eastern shore (Ref 5). From Sker Point to the River Neath the shoreline consists of long, wide sandy beaches with some shingle at high water and backed by vegetated sand dunes such as at Kenfig Sands, Margam Sands and Aberavon Sands. Map studies show a history of long term coastal variation, while recent changes since the mid 19th century are associated with the construction of the Neath training wall and Port Talbot docks. There is a general tendency for the landward migration of the low water mark with local areas of accretion such as at Crymlyn Burrows to the west of the Neath Estuary. The offshore banks have progressively changed their relative positions but there have been no significant changes in their volume for the same period. It has been calculated that foreshore extraction (from 1934 to 1973) amounts to a reduction of the beach level by up to 0.25 m assuming uninterrupted longshore drift between Port Talbot and Sker Point and no gain or loss offshore.

More recent beach changes have been studied by IOS surveys taken along 11 lines between the Neath Estuary and Sker Point over a period of 2 years (1975-1977), (Refs 6 and 7). While considerable fluctuations in beach levels existed between surveys, there was no significant net change in volume of sediment present over the period and tracer experiments showed no preferential direction of sand movement. The shoreline is protected by the offshore banks such that most of the wave energy is dissippated and refraction produces waves aligned almost parallel to the coast thus excluding any predominant direction of sediment movement along the beach. At Sker Point a more oblique wave approach fron the south-west may account for the net losses of sand from the beach here during the study period. The beaches in Swansea Bay did not display the expected seasonal pattern of winter drawdown and build up during the summer months and the variability appeared to be related more to alongshore variations in wave energy. The extremes shown by the beach profiles usually occurred during the winter months and the stability (least fluctuation) of the beaches tended to decrease from north to south.

Clearly this evidence points to the sedimentary system in the Bay being virtually closed and the beach being in a state of dynamic equilibrium with the prevailing wave climate. The supply of appropriate grades of material to the beach from offshore is limited while alongshore movements of sediment appear to be weak and variable in direction.

The possible causes of erosion appear to be related to artificial changes in the natural beach system such as land reclamation near Swansea, natural accretion on the north side of the Bay, construction of the training walls along the Neath estuary, interruption of the longshore sediment transport due to the

building of the Port Talbot tidal harbour and the effect of the dredged channel there, the extraction of sand and gravel from the foreshore and the offshore banks and the inhibiting effect on coarse sediment bedload transport of silt spoil deposited within the Bay. As a result it was not possible to identify a single major cause for the erosion of the foreshore on the eastern side of Swansea Bay but there was evidence that the rate of loss of sand closely corresponded to the rate of removal by sand winning which was prohibited in 1973.

The area immediately offshore of Port Talbot is an area of low tidal energy and is therefore an area of potential deposition of fine sediments. Further offshore there are stronger tidal currents and therefore movement on the banks shown to be in a clockwise direction. There is a westward movement of sediment close to the coast south of Porthcawl and across the southern extremity of the Bay through the sand bank system comprising the Scarweather Sands and possibly Nash Bank towards the Gower coast. The rate of movement of material in this are is estimated to be 2 tonnes/m/day (Ref 8). Moving inshore there is a reduction in the rate of transport reflecting the diminishing tidal energy until in the vicinity of Port Talbot the transport rate is approximately 0.02 tonnes/m/day. These differences indicate that the Bay is effectively by-passed by the offshore westward movement of sand sized sediment. The observed sediment transport pattern suggests that the only movement of sand sized material into the Bay occurs in the vicinity of Mumbles head and at the western extremity of the Scarweather Sands. Some wave induced transfer may be possible during strong south-westerly winds but amounts are likely to be small and tracer studies do not indicate any appreciable shoreward movement of material even over long periods of time

when appreciable wave activity is known to have occurred (Ref as above).

The Gower Coast - Mumbles Head to Burry Holms

The Tertiary Carboniferous limestone plateau of the Gower Peninsula separates the bays of Swansea and Carmarthen which are cut in less resistant Carboniferous strata. The coastline of the Gower is strongly influenced by the lithology and local geological structure, such as folding and faulting. The bays at Oystermouth, Oxwich and Port Eynon are formed in the less resistant shales exposed in the synclines (or downfolds) whereas the harder limestone along the upfolds forms the headlands at the Mumbles, Oxwich Point and Worm's Head. The smaller bays at Caswell, Brandy Cove and Pwll-du are the produce of faulting in the limestone. The high limestone cliffs from Port Eynon Point to Worm's Head reach over 60m and are fronted by a narrow rocky foreshore. The large bays at Port Eynon and Oxwich are sandy and backed by sand dunes. Although the net direction of littoral drift is from west to east the movement of sediment is limited by the marked indentation of the coastline restricting the actual transfer of sediment between bays.

The limestone cliffs of the Gower are stable and show an extremely slow rate of erosion. Steep relic cliffs not formed by present marine action are found behind raised beach platforms which can be traced along the Gower coast particularly in Port Eynon and Oxwich Bays. The fossil beach deposits, which consist of a conglomerate cemented by lime, are resistant to present wave action and form a low bluff above the present wavecut platform.

Carmarthen Bay

The combined estuaries of the Taf, Tywi and Gwendraeth flow into Carmarthen Bay between extensive sandy beaches backed by dunes or marsh. Since the Ice Age rising sea levels have encouraged sedimentation in the estuaries. The erosion of the local sandy glacial deposits and the landward movement of glacial material as high water mark advanced have contributed to the sandy beaches around the bay. Further sedimentation within the estuaries has been accelerated in places artifical reclamation.

The Burry Inlet is the estuary of the River Loughor and opens into the eastern side of the Bay around Whiteford Point at the tip of the Gower. Many aspects of the development and history of the estuary are considered by a symposium in 1976 (Ref 9). Much of the north shore of the estuary is built up in contrast with the south Gower side where vast expanses of mud and sands with saltmarsh on the upper foreshore form the Llanrhidian Sands. This area has developed in the sheltered lee of the sand spit at Whiteford Point east of Burry Holms. The building of a training wall to form a deep water channel on the northern side of the estuary has also had the effect of favouring sedimentation on the southern shore which was increased later by the introduction of spartina anglia. The wall has long since breached and fallen into disrepair.

At Pembrey siltation and the eastwards encroachment of Pembrey Burrows threatens to close the harbour and has been the subject of various studies by Hydraulics Research (Ref 10). The eastward edge of Pembrey Burrows, called 'The Nose', already threatens to silt up the low water channel which at present drains the marshland and then runs eastward past the harbour

entrance. The spit has grown by the easterly drift of sand under the prevailing south-westerly waves and accumulation of windblown sand as dunes. The growth of the spit is of fairly recent origin. Before 1830 the coast immediately west of Pembrey was open to the sea. By 1872 a sand spit (The Nose) began to develop eastwards from Pembrey Sands and marshland began to form in the sheltered area behind. This marshland now drains eastwards as far as the Burry Port approach channel.

The development of Pembrey Burrows coincides with large scale changes in the configuration of the channels at the mouth of the Burry Inlet and are associated with the reduced tidal flows brought about by the closure of the north channel. At low tide large drying sand banks (the Hooper and Lynch Sands) are exposed at the entrance to the Burry Inlet, separated by meandering low water channels. It is likely that in the past sand carried eastwards by wave action was then redistributed by tidal currents on the ebb flow onto the sand banks. However, once the north channel deteriorated these currents were unable to transport the sand out of the area and allowed the formation of the spit fronted by an intertidal zone up to 1km wide.

Pembrey Burrows is at the southern end of a large tract of sand dunes fronted by a wide sandy foreshore that extends for 9km north-eastwards to the Gwendraeth estuary. The dune belt is fully exposed to the Atlantic storms and serious erosion is occurring along the frontline of the dunes.

On the western side of the estuaries a similar area of sand dunes known as the Laugharne and Pendine Burrows stretch for 9km from Ginst Point as far as Dolwen Point. Ginst Point is the tip of a recurved spit

which has developed within the river estuaries under an easterly littoral drift. However the dunes from Ginst Point to Wycthet are suffering from very severe erosion. Erosion in the 1960's and 70's resulted in the recession of the dune line east of Wytchet by 120m in places and the lowering of the beach level up to as much as 3m so that the dunes were in danger of breaching. It appears that the movements of the deep tidal river channels, mainly the Taf which flows west close to Ginst Point and parallel to the shoreline, may interrupt the processess of littoral drift. Once beach levels are lowered the deep water channel is allowed to approach still nearer the dunes. This erosive sequence is exacerbated by pedestrian and vehicular use of the dunes. It appears that the growth of a sand spur at the western end of the frontage is acting as a groyne and very little sand is moving eastwards to renourish the beach leading to Ginst Point.

Further recession of the dune line has been prevented by the construction of a 2km rip-rap embankment from Ginst Point to the Wytchet spur and fronted by a beach of quarry waste. However erosion of the beach has remained a problem along this frontage requiring continual monitoring and the recycling of material from Ginst Point when necessary. The eastern part of the beach remains at greatest risk where exposure to waves from the south-west is greatest. West of Wytchet the beach is accreting with the development of foredunes on the beach and eventually being stabilised by the natural colonisation of vegetation.

Further west Pendine beach receives very little sand from sources to the west as the net easterly drift is limited at this point. The wave approach is generally parallel to the beach and thus the movement of beach sediment is generally onshore/offshore. For the most

part the waves break well out to sea over the gently shoaling seabed and the only danger is stormy weather associated with exceptionally high tides.

A series of shallow embayments form the western part of Carmarthen Bay to the west of Pendine. Saundersfoot Bay and Tenby Roads are cut in the weaker shales and sandstones of the Carboniferous Coal Measures while Ragwen Point and Castle hill headlands to the east and west respectively are composed of more resistant Carboniferous limestones. The intense folding of the Coal Measures can be clearly seen in the soft cliffs. Exposure to the south-westerly waves decreases to the east where the coastline is protected by the southwards projection of the Pembrokeshire Peninsula. Thus the amount of sand and width of the intertidal zone increases westwards towards Tenby. At Amroth to the west the sand foreshore is backed by a storm ridge of pebbles which fills the small bay. The littoral drift here is strongly in a west to east direction causing erosion and beach lowering especially along the western frontage. The bay is particularly vulnerable during severe storms and high tides causing flooding and damage. A beach nourishment scheme and some recycling of shingle from the eastrn end of the ridge has done little to alleviate this problem as observed by the effects of the storms on 9 March 1989.

The Pembrokeshire Peninsula

Many of the details of the Pembrokeshire coast are influenced by geology. In general outline the Pembrokeshire coast comprsies three westerly projecting peninsula. The greater part of the coastline of Pembrokeshire is cliffed and forms a headland and bay coastline formed by the differential erosion of rocks of varying resistance. Beaches are

therefore located at the head of embayments or at the seaward end of valleys. Storm beaches are found in exposed bays such as at Newgale in St Bride's Bay, Abermawr and Aberbach on the north coast and Manorbier and Lydstep Haven on the south coast. There are also wide sandy beaches backed by sand dunes where these are exposed to strong onshore winds for example at the mouth of the Teifi estuary, Newport, Whitesand, Freshwater West, Barafundle Bay, Broad Haven, Freshwater East, Lydstep Haven and Penally.

In general the littoral drift along the whole of the Pembrokeshire coast is variable in direction and depends on the orientation of the coastline and its exposure to wave action. The actual movement of beach sediments tends to be low and fragmentary and limited to individual embayments. The major peninsula and the estuary at Milford Haven effectively form boundaries of zero net drift.

Many excellent examples of coastal features relating to varying Pleistocene and Holocene sea levels may be found along the coast of Pembrokeshire. Raised beaches, formed at higher sea levels, are found perched above the level of present wave action at Poppit on the Teifi estuary, near Porth Clais and Broad Haven near Bosherton. The large tidal estuary at Milford Haven and other smaller examples at Solva harbour, Newport Bay, Porth Clais and Aber-rhigian were formed by submergence after a period of lower sea levels. Submerged forest deposits are occasionally exposed in the intertidal zone at Amroth, Saundersfoot, Lystep, Manobier, Frestwater East, Freshwater West, Newgale, Whitesand, Abermawr and Newport especially after winter storms.

Between Tenby and Stackpole Quay the bay and headland coastline is a direct reflection of the differential

erosion of a complex geological sequence resulting from the folding of the rock strata along a north-west/south-east axis similar to that found on the Gower Peninsula. Lydstep Haven is bounded by Carboniferous limestone headlands of Giltar Point and Lydstep Point while the bay is formed in weaker sandstones and shales exposed in the core of a downfold. Freshwater East is eroded in weak Ordovician shales and sandstones outcropping in the core of an upfold and is bounded by headlands of more resistant Old Red Sandstone. Swanlake and Manobier Bays are result of erosion along groups of small faults.

Coastal features associated with Carboniferous limestone dominate the South Pembrokeshire coastline west of Stackpole Quay and in particular from St Govan's Head to Linney Head. The cliffs are almost vertical and form a plateau 30 - 50 m above sea level. This plateau is interpreted as an ancient wavecut platform uplifted during the Tertiary period. Natural weaknesses such as joints, faults, fissures and dry water courses have been exploited by the erosive action of the sea to form caves and blow holes. Huntsman's Leap just west of St Govan's Head is a deep indentation influenced by faults and fissures. It may have developed by the collapse of the roof of a sea cave. The Green Bridge of Wales near Flimston is a natural arch formed where two caves from opposite sides of a headland have united. Other arches are found at Shrinkle Haven, Haroldston Bridge near Broad Haven and at Pwll-y-Wrach near Ceibwr. The eventual collapse of arches leads to the formation of stacks for example the Elegug Stacks near Flimston.

Milford Haven is the estuary of the Daugleddau River and forms a deep, branching tidal indendation along the coastline. In the lower reaches the deep

sheltered waters have provided suitable berths for tankers and the development of oil terminal facilities along the banks. In the upper reaches finer sediments are deposited forming inter-tidal mudflats.

The broad west-facing St Bride's Bay is cut in relatively soft Coal Measure shales and sandstones exposed in the core of a major downfold or syncline and is bounded to the north and south by the St David's and Marloes-Dale peninsulas respectively. At Newgale there is a notable storm pebble beach 2.5 km long which dams back Newgale Marsh and Bathesland Water. The stones are mainly of Cambrian and Old Red sandstones derived from the cliffs to the north-west and south respectively but also erratics which have probably been washed out of glacial deposits flooring St Brides Bay.

Between St David's Head and Strumble Head on the north coast of Pembrokeshire the cliffs are high, precipitous and deeply indented. The large number of igneous intrusions form the headlands and the intervening bays are cut in the weaker sedimentary sandstones and shales. The cliffs become higher to the east of Fishguard and reach over 150 m between Pen-yr-afr and Cemaes Head.

Cardigan Bay

The coastline of Cardigan Bay is gently curved. The direction of greatest fetch is westward and the most effective storms are also from this direction. Consequently there is a northerly drift of beach material. The cliffs northwards to Aberystwyth consist of sandstones and siltsones with a fairly uniform resistance to erosion. The Hog's Back cliffs are remnants of cliffs cut by marine erosion and degraded by sub-aerial weathering. Raised beach

platforms occur at various levels. Boulder clay and solifluction deposits cover the cliffs and formerly did so to greater extent. This is being removed by current marine erosion exposing the steep preglacial cliffs to active wave erosion at their base. The complicated denudation chronology of this coastline has been studied in detail by Wood (Ref 11). Despite active erosion of the cliffs, the beaches are relatively thin with shingle ridges overlying sand.

Erosion along the beach at Aberystwyth is a serious problem. The bay is divided into four crescentic storm beaches separated by rocky headlands and reefs and the mouths of the Rivers Ystwyth in the south and Rheidol in the North. The littoral drift is predominantly south to north and the beaches are composed of cobbles from local gritstones and shales derived from the erosion of glacial terraces seawards of the preglacial cliffs to the south. The supply of material to the beaches at Aberystwyth has been reduced by human activity within the estuaries of the Rivers Rheidol and Ystwyth and with the interruption of natural coastal processes (Ref 12). This coastline is also subject to a high storm environment being directly exposed to the Atlantic and the prevailing and dominant westerly waves.

The long southern beach at Aberystwyth forms a shingle ridge under the northerly drift of material and so deflecting the mouth of the River Ystwyth northwards. The ridge is subject to erosion and 'rolling back' under storm conditions particularly at the proximal end. While some artificial armouring has been used to prevent breaching the ridge is unprotected for most of its length. The beaches to the north are fronted by promenades which to some extent have exacerbated erosion and falling beach levels. On the beach north of the Castle (north of the river estuaries) the high

water mark of ordinary tides has moved markedly landwards between 1889 and 1937. This recession has been attributed to the construction of a promenade around the Castle in the early 1900's thus preventing the natural erosion of the cliffs which were contributing sand and pebbles to the beach to the north. Over the same period there was also a reduction in the beach volume to the south presumably as a result of the diversion of the Ystwyth and the building of harbour defence works in the last century. Falling beach levels along the North Beach have continued to threaten existing walls and defences necessitating various remedial measures. Abrasion by the cobbles in this high energy environment has also caused constant maintenance problems. Various attempts have been made at nourishment but material along the North Beach is very mobile and can move away in both northerly and southerly directions. In 1977 14000m^3 of hard rock was imported as an initial charge over a 200m frontage and this has been followed by an annual recharge of 1000m^3 of stone (Ref 13). The area continues to pose problem with respect to wave overtopping.

North of Aberyswyth to Portmadoc three wide river estuaries, the Dyfi, Mawddach and Glaslyn, enter shallow embayments which are separated by stretches of steep rocky cliffs of slates, grits and sandstones. These cliffs form a coastal plateau up to 200m high and rise further inland to over 600m. Boulder clay deposits cover the cliff in places and these are the remains of a much wider cover that covered large areas of Cardigan Bay. The sarns or pebble banks exposed in the Bay at low tide probably originated as glacial moraine ridges submerged and modified by post glacial rising sea levels. Sarn Badrig is perhaps the most significant example and extends for some 30km south-westwards of Morfa Dyffryn.

The northern part of Cardigan Bay gradually shallows towards Tremadoc Bay as fine materials are swept north-eastwards by wave action while the Lleyn peninsula provides increasing shelter from the north-west and western sector. Extensive accumulations of recent sand and marsh form the coastline. A number of large accretionary spit features have developed across the estuary mouths under the influence of the prevailing northerly littoral drift. The estuaries act as partial barriers to the continual movement of beach sediment along this coastline and therefore each feature is supplied with sediment derived only by the wastage of the coastline immediately to the south. It is clear that these spit features are presently undergoing erosion. Parts of coast are now artifically protected and the rate of alongshore movement of material is exceeded by the present rate of supply. But it is also likely that this recession is part of a natural longer term trend related to rising sea levels. The following features have been studied and are described in some detail by Steers (Ref 14).

The village of Borth north of Aberystwyth is situated on a great storm beach of large pebbles capped by sand dunes. The ridge extends northwards into the Dyfi Estuary and recurves forming laterals at the distal end. Large expanses of sand and mud are exposed at low tide in the sheltered leeward areas of the estuary. This spit feature is of recent origin formed under present conditions of northward longshore drift of material and has developed over and incorporates the remains of earlier post glacial environments. Deposits of clay, forest and raised bog (called the Cors Fochno) lie under the spit and are now exposed in places on the foreshore seaward of the ridge face indicating the slow long term recession of this feature.

On the south side of the Mawddach estuary there is a similar but much smaller feature. The Rowen is a typical storm beach of coarse pebbles with minor recurve ridges and covered by simple but eroding dunes. The source of the material is undoubtedly the large gravel fans at Llwyngwril to the south. North of the river estuary at Barmouth the direction of littoral drift is not so obvious and is variable in direction depending on the prevailing wave conditions. The beach material is probably derived from the coast to the north at Llanaber by a local drift reversal and it is unlikely that shingle is able to move northwards across the mouth of the Mawddach. However the removal of beach material northwards during prolonged spells of south-westerly winds is often not replenished by a subsequent supply from the north leading to beach lowering along the Barmouth frontage and causing problems for coastal defence.

Morfa Dyffryn is a cuspate feature in front of the old cliffline built out into Cardigan Bay at a slight angle to the general trend of the coast. It comprises an extensive sand flat fringed on the outer margin by dunes. At the northern end the dunes surround Mochras Island an area of boulder clay material, probably the remains of a moraine feature, which provides beach material for the shingle spit extending to the north-east and recurving at the mouth of the River Artro. Shingle is exposed at low tide across the shallow river mouth and it is likely that some material reaches the northern shore at Llandanwg. The outer dunes are suffering erosion while the inner dunes are maintained by a cover of marram grass. Recession and breaching have occurred at the southern end of the dunes.

On the southern side of the Glaslyn estuary Morfa Harlech forms a broad triangular-shaped foreland

fringed by dunes on its seaward side. The old relic cliffline cut in hard and resistant Cambrian rocks of the Harlech Dome runs inland of Morfa Harlech to Talsarnau. The former island of Llanfihangel y Traethau is now incorporated in the sands and marshes of Morfa Harlech. The outer dunes are being eroded by the strong onshore winds forming blow-outs and slacks while the inner dunes are encroaching on the reclaimed marshland behind. At Harlech Castle and to the south the boulder clay covered cliffs are protected from erosion by the railway embankment and its associated defences. The reduction and interruption of supply of material from the south is likely to lead to recession in the long term.

The northern part of Cardigan Bay is enclosed by the Lleyn Peninsula. The southern shoreline from Portmadoc to Abersoch is well protected from wave action excepting from the south-west sector. Coastal sediments are generally transported to the east. The low cliff line forms a number of smooth gently curving bays between locally resistant rock promontories. Where boulder clay and glacial gravels are exposed at the coastline the cliffs are vulnerable to erosion for example between Criccieth Castle and Pen-ychan. However, at Pwllheli the cliffs are sufficiently protected from erosion by beach sediments. The bays are sandy but there is an increase in the amounts of shingle forming storm beaches and ridges towards the east where there is greater exposure to wave action. At Morfa Buchan to the north of the Glaslyn estuary there are considerable accumulations of sand dunes infront of the old cliffline. Some of these dune areas are liable to erosion.

The rugged coastline of the Lleyn peninsula is composed of Ordovician, Cambrian and Pre-Cambian rocks (shales and sandstones). Resistant igneous intrusions

form many of the headlands which separate isolated bays and the interchange of coastal sediments is low. Porth Neigwl is a large embayment at the southwestern tip of the peninsula, formed in boulder clay and largely filled with glacial deposits. North of Trevor the cliffs of boulder clay are lower. Extending north-eastwards from Dinas Dinlle into the Menai Straits is a large sand and shingle spit about 1.5.km long. This feature has grown as a result of the south to north littoral drift along the Lleyn coast and is aligned at right angles to the prevailing waves from the south- west. Falling beach levels at Dinas Dinlle and a reduction in the height of the ridge crest suggest that the rate of supply of sediment alongshore has diminished.

The Isle of Anglesey

The final separation of the Isle of Anglesey from the Welsh mainland and the formation of the Menai Straits took place during the Flandrian transgression. The Straits follow the same north-east/south-west drainage pattern on the island and therefore probably represent pre-glacial valleys deepened and connected when the barriers between them were removed during the Ice Age.

The hard Pre-Cambrian rocks which form most of the coastline are resistant to erosion and form low rugged cliffs and reefs. Where the cliffs are covered by boulder clay and reached by wave action these are preferentially eroded providing a source of beach material.

Newborough Warren at the western entrance to the Menai Straits forms one of the largest areas of sand dunes in Britain. A narrow sand and shingle spit extends eastwards into the Strait due to the effects of beach

drifting under the influence of the south-westerly winds and strong tidal currents terminating in a recurved feature at Abermenai Point. The exposed west coast of the island comprises rocky cliffs, headlands and reefs enclosing sandy coves such as Rhosneigr and Trearddur Bay. More extensive sand beaches backed by sand dunes are found at Malltraeth and Aberffraw Bays. The net littoral drift is very weak being locally variable in direction and the movement of sediment is essentially confined to individual embayments. Along the north coast the hard rock coastline is indented to form numerous small coves such as Cemlyn Bay, Cameas Bay, Hells Mouth, Porth Wen Bull Bay, Amlwch Harbour and Porth Eilian. At the head of Cemlyn Bay a storm beach of fine shingle has formed a bay-bar impounding a tidal lagoon. The east coast of Anglesey is more sheltered and long sandy beaches backed by sand dunes are found at Dulas Bay, Lligwy Bay, Benllech and Red Wharf Bay. These bays have formed where the boulder clay is exposed at sea level and provides little resistance to erosion by wave action whereas the cliffs separating the bays comprise more resistant Carboniferous limestone.

Conwy Bay

Conwy Bay forms a large shallow north facing embayment between the Isle of Anglesey and the Great Orme headland. The predominant north-westerly direction of wave attack combined with an easterly residual tidal flow in Liverpool Bay produces a general drift of foreshore material from west to east along the North Wales coast towards the Dee estuary and the Wirral Banks. But this pattern is interrupted by the Great Orme headland which projects sufficiently far seaward of the general coastline to cause a localised flow and drift reversal in the eastern part of the bay and to form a barrier to the transport of sediment.

In the western part of the bay the coast is well sheltered from the prevailing westerly waves and expansive intertidal sands known as the Lavan Sands are exposed at the entrance to the Menai Straits. Much of the bay is fringed by a wide flat sandy foreshore and bars towards the low water mark indicate that onshore/offshore movement of sand takes place while the net easterly littoral drift is low. However as exposure to wave activity increases towards the east so the width of the foreshore is reduced and the sand is backed by shingle storm beaches and windblown sand dunes. The beach material has been derived from the sorting of glacial material deposited in the bay area by wave action during the post glacial submergence and by the erosion of boulder clay where it exposed in the cliffs such as west of Penmaenmawr, Dwygyfylchi, Deganwy and on the Great Orme. Some of these areas are now artifically protected thus contributing to a reduction in the supply of beach material and a general slow recession of the coastline. The River Conwy supplies large quantites of finer sediments which are deposited in the more sheltered western area on the Lavan Sands.

At Llanfairfechan beach lowering may be attributed to tidal scour related to the strong tidal flows in the Menai Straits. Eastwards towards Penmaenmawr the Snowdonia hills rise steeply behind the town and the railway follows close to the shore. The present construction of the A55 (North Wales Coast Road) alongside the railway line and across the upper part of the foreshore at Penmaenmawr is involving the reconstruction of a new promenade 30 m to the seaward fronted by a placed storm beach of sand and cobbles won from the existing shoreline. The new beach will be groyned to retain the material in its new alignment. A study by Hydraulics Research (Ref 15) into beach changes as a result of the works concluded

that the effects would not be significant and would not endanger coastal stability. The original storm ridge appears to have been a relatively stable feature and the beaches in this part of the bay are in a state of dynamic equilibrium with the wave environment such that any net drift is very small and variable in direction.

Penmaenbach Point is a small rocky headland formed of resistant igneous rock. Extending eastwards of Penmaenbach Point is Conwy Morfa, a natural sand and shingle beach backed by sand dunes and terminating in a spit at the mouth of the River Conwy. On the eastern shore of the Conwy, between Deganwy and LLandudno West Shore, the sand and shingle beaches are also backed by well establised dunes stablised with vegetation. Some erosion is taking place here but is more serious to the north along the frontage at Llandudno West Shore. The boulder clay cliffs on the south side of the Great Orme have provided the source of the beach material but this supply is now insufficient to prevent the reduction of beach levels along the sea wall.

The coastal promontory of the Great Orme is formed of resistant Carboniferous limestone. The limestone outcrop was once an island but is now joined to the mainland by recent Holocene sediments forming a narrow isthmus between Conwy Bay to the west and Colwyn Bay to the east. Great Ormes Head forms a divide in the littoral processes operative to the west and east and is therefore the limit of the coastline considered in this report. The North Wales coast to the east of Great Orme is considered in the wider context of the coastal processes operating in Liverpool Bay and is covered in the next volume of this series.

4 WINDS, WAVES AND TIDAL CURRENTS

4.1 Wind and wave climate

There are a number of ways in which wave data can be derived for offshore locations around the coastline of England and Wales. Weather observation stations have measurements of mean hourly wind speed and direction and the data for the more exposed sites can then be converted to "over the sea" wind information. This wind information can then be used to reproduce wave data by means of computer simulation techniques (Refs 16 and 17). Such information can be obtained from the Meteorological Office, Bracknell, in a number of variable formats. The format being dependent upon the type of analysis which is to be carried out. For example a statistical analysis may require the data to be "grouped" while for simulation of real time wave conditions hour by hour listing of data may be required.

One can also use measured wave data which may come from a number of sources. Offshore wave data is collected by weather ships, light vessels and visual ship observations. In the present report a listing is provided of instrumentally recorded data, see below. There is no doubt that visually observed wave information, usually from vessels or lightships, can be valuable in the open sea. Although individual observations may not be particularly accurate the large mass of data usually provides ample compensation. Around the coastline of the United Kingdom, however, there are considerable difficulties in using visually observed wave data for coastal engineering purposes. This is because ship observations are grouped into "sea areas". For the varied exposure around the UK coastline these areas

are too large to be applied with any confidence at a particular location.

A report has been prepared for the Department of Energy which uses both existing wave observations and numerical techniques to predict maximum extreme wave heights for a 1 in 50 year storm (Ref 18). The predictions indicate that the maximum wave height in the 50 year storm is likely to be about 14 metres at the entrance to the Bristol Channel, reducing rapidly upstream. The open coast of North and West Wales has a 14-16 metre wave height as the 50 year value. These predictions thus bear little information to the inshore wave climate and only give a general picture of the relative severity of wave action around different parts of the Welsh coast. Listed below are the known records of the offshore wave climate obtained from an as yet unpublished HRL report (Ref 19).

Offshore wave data for the Welsh Coast

Location	MIAS Ref	Lat (N)	Long (W)	Instrument	Mean Water Depth	Period of Data recording From	To
Severn Site A	31	51°19'12"	3°34'24"	wrb	27m	10.4.78	Mar 79
Severn Site A	683	51°20'48"	3°34'30"	wrb	27m	Dec 80	Apr 81
Scarweather	443	51°27'	3°55'	wrb	27m	30.7.74	31.12.77
Helwick	179	51°30'30"	4°25'30"	swr	28m	Aug 60	Jul 61
Milford Haven	138	51°42'	5°05'	pg	20m	Nov 59	Aug 60
Saint Gowan	139	51°30'30"	4°59'48"	swr	55m	Aug 74	31.12.83
Off Cardigan	170	52°12'	4°50'	wrb	40m	1.1.73	31.12.73
Wylfa, Anglesey		53°25.3'	4°29.3'	wrb	21m	1.7.85	30.6.86

swr - Shipborne wave recorder

wrb - Wave rider buoy

flwr - float level wave recorder

pg - pressure gauge or sensor

The above information, which has been recorded in relatively deep water (taken as the 20m depth contour

or deeper) can be considered as typical for relatively large stretches of coast. However, in order to determine the wave conditions at any particular coastal location requires the use of wave refraction models (Ref 20) to transform the information from offshore to the inshore location. There is also a certain amount of inshore wave data. Such data is usually very site specific and should not be used to extrapolate to conditions at adjacent stretches of coast without the refraction models referred to above. For it to be used at an adjacent site the data would need to be refracted outwards into deep water and then transformed back to the new position on the coastline. This type of transformation is complex and expert advice should be sought as to the suitability of records at any particular site for use at adjacent sites.

Inshore wave data for the Welsh Coast

Location	MIAS Ref	Lat (N)	Long (W)	Instrument	Mean Water Depth	Period of Data recording From	To
Cardiff Harbour	1513	51°26.8'	3°9.8'	wrb	7.8m	Dec 86	Cont Feb 87
Cardiff Harbour	1513	51°27.4'	3°10.5'	pg	0m	8.1.86	Cont Mar 87
Porthcawl	1556	51°28.2'	3°42.5'	pg	4.8m	June 82	Present
Port Talbot	137	51°34'	3°48'	flwr	8m	Oct 62	Jul 66
Port Talbot	442	51°34'	3°48'	pg	12m	16.5.75	30.11.77
Burry Port	1486	51°41'	5°47'	pg	3.5m	13.11.84	-
Hells Mouth	36	52°47'42"	4°32'36"	pg	3m	8.11.75	23.7.77
Hells Mouth	37	52°47'42"	4°32'36"	pg	3m	12.7.78	Sept 86
Wylfa, Anglesey	146	53°25'	4°27'	pg	5m	Dec 61	Nov 65
Wylfa, Anglesey		53°25.2'	4°28.0	wrb	16.4m	1.7.85	30.6.86
Llandudno				wrb		Dec 83	Mar 84
Penrhyn Bay				wrb		Dec 83	Mar 84
Rhyl	1507	53°25.2	3°30'	wrb	15m	5.2.85	7.5.86

4.2 Tides and tidal currents

Tidal range

By contrast to the variable and unpredictable nature of wave activity the rise and fall of the tide is both regular and predictable. The effect of the tidal range is considerable in that the breaking point of the waves will vary in position at different stages of the tidal cycle. Thus the effect of wave action can be exerted over a considerable width of the beach. From the viewpoint of the design of coastal defences the magnitude of the tidal range is important in determining the crest elevation of coast protection structures, the likelihood of embankments being overtopped etc.

As a result of the funnelling action in the approaches to the Severn Estuary the tidal range increases in an "upstream" direction. By contrast the west coast of Wales has a relatively small tidal range, which then increases from the Lleyn peninsula eastwards into Liverpool Bay. Details of the predicted tides can be found in the Admiralty Tide Tables (Ref 21) but the mean spring tidal and neap ranges at a number of locations around the Welsh coast are as follows:-

Mean Tidal Ranges - Bristol Channel and Severn Estuary

Location	Spring Range (m)	Neap Range (m)
Beachley (near mouth of Wye)	12.4	6.8
Cardiff	11.1	5.6
Porthcawl	9.0	4.2
Tenby	7.5	3.7
Milford Haven	6.3	2.8

Mean Tidal Ranges - West Coast of Wales

Location	Spring Range (m)	Neap Range (m)
Fishguard	4.2	1.5
New Quay	4.2	1.8
Barmouth	4.3	2.2
Pwhelli Road	4.3	2.2
Porth Dinllaen	4.0	1.7

Mean Tidal Ranges - Anglesey and North Coast of Wales

Location	Spring Range (m)	Neap Range (m)
Holyhead	5.0	2.5
Amlwch	6.5	3.5
Menai Bridge	6.5	3.4
Puffin Island	6.9	3.6
Llandudno	6.9	3.5

Tidal currents

On the open coast tidal currents are rarely sufficiently high to enable them to initiate sediment motion but even if they are weak they can transport material which has been put into suspension by wave action. In river mouths and estuaries the currents alone may have sufficient velocity to carry sand and even shingle sized material. Within the Severn Estuary maximum tidal current velocities during mean spring tides are as high as 4 knots. Such currents can transport sand sized material in suspension. The formation of Nash Bank is essentially the result of sand being transported "offshore" from Nash Point by the high inshore tidal currents in that area.

The open coastline of Wales is unlikely to be affected by tidal current activity to any significant degree, littoral movement being dominated by waves breaking at an angle to the beach contours. However within the Menai Straits tidal currents during spring tides can reach 8 knots and these are even capable of

transporting shingle sized material. It is not surprising that the sea bed here is scoured "clean" by tidal current action and that the foreshore deposits are generally sparse.

This type of general information can be found from the relevant Admiralty Charts and tidal stream atlasses. Usually much more detailed information giving the spatial and the temporal distribution of tidal currents is needed for sediment transport or for navigational studies. Where such information is needed recourse has to be made to numerical modelling techniques (Refs 22 to 25). Some of these models are able to predict the movement of sediment in suspension, dispersion of sediment or effluent from its source of origin and are able to predict rates of siltation or erosion.

Surges

Wind induced surges can play an important part in raising water levels above that predicted by "astronomic" tide tables. Recent studies by the Institute of Oceanographic Sciences give predictions on maximum sea levels that can be expected for various return periods (Ref 26). In these predictions both astronomical tides and surges are included in the analysis. For the coastal engineer often it is the joint probability of occurrence of wave overtopping by both waves and tidal levels that is necessary for design purposes. A number of such analytical techniques have been developed at Hydraulics Research and have been used in the design of major flood defence schemes in Britain (Refs 27 and 28).

5 REVIEW OF THE COASTAL DEFENCES

5.1 The South Coast

This coastline varies from the muddy foreshores and the low lying land of the Severn Estuary, the sand beaches and dunes of Swansea Bay and Carmarthen Bay, to the cliffs of the Gower and Pembrokeshire. The level of coastal protection is not high with long stretches of cliff line being unprotected. Coastal defences are mainly the responsibility of Welsh Water in low lying areas and of the Maritime Local Authories elsewhere. In the following description of defences the local coast protection authority (the District, Borough or City Council) can be assumed to be responsible, except where it is otherwise stated in the text.

5.1.1 The Wye to Lavernock Point

The estuarial frontage between the River Wye and Magor is within Monmouth District but the majority of the defences along this stretch are in fact maintained by Welsh Water. The frontage is well sheltered from wave action and since the foreshore consists largely of mud flats the littoral drift is low. The drift on the upper beach is generally in a west to east direction though tidal current activity dominates the movement of sediments on the lower part of the foreshore. There are no serious coastal erosion problems although some parts of the coastline are liable to flooding.

One of the largest areas of saltings in Wales lie on the north bank of the Severn Estuary between Chepstow and Cardiff. The coast is low lying, with the major proportion reclaimed at some stage from the sea.

The frontage from the Wye to Magor is within Monmouth District. The shoreline is low lying and most of the defences are protection against flooding and are maintained by Welsh Water.

Southwest from the mouth of the Wye, the first 3Kms or so of coastline are protected along most of the length by earth embankments, the responsibility of Welsh Water. As elsewhere along the greater part of the frontage the foreshore is mud. Further west from Red Cliff to Sudbrook, the shoreline is unprotected except for a short stretch of gabion protection and a stone sea wall east of Black Rock. This particular stretch of coast is eroding, but not posing serious problems. Beyond Sudbrook to Magor, Welsh Water maintain a continuous earth embankment, fronted by saltings. Part of this embankment is faced with a stone pitching.

The shoreline from Magor to Peterstone Great Wharf lies within Newport District, but the responsibility for protecting this frontage lies almost entirely with Welsh Water. From Magor Pill to Usk Power Station the levels (ie low lying reclaimed land) are protected by earth embankments. At the more exposed western end of this frontage, at the mouth of the Usk, the embankment is topped by a concrete wave wall. There is also some protection at the landward edge of the saltings, consisting of stone rubble. Because of the large tidal range here the saltings exist on two levels and in places stone rubble has been placed at the cliffed interface between the two levels. Some 2.5Kms of river bank at the confluence of the Usk and Ebbw have some local rubble protection.

From the Ebbw to beyond Peterstone Great Wharf the levels are again protected by earth banks, which are the responsibility of Welsh Water. There is some

additional stone protection towards the eastern end while in the central part the stone cladding is grouted with bitumen.

From Peterstone Great Wharf to the River Ely the frontage lies within the Cardiff City boundary, coast protection being also the responsibility of Welsh Water, B.T.D.B. and private landowners.

The eastern part of the frontage is low lying agricultural land protected by the Rumney Great Wharf, the responsibility of Welsh Water. This consists of an earth bank with some walling and faced with stone pitching. To the west as far as Lamby Bridge the industrial frontage is partly the responsibility of Cardiff City and part private. This area is protected by dumping slag and hardcore onto the upper beach.

The British Transport Docks Board are responsible for the frontage of Cardiff Docks. A rock revetment protects the outer face of the docks. The rest of the dock frontage (within the River Taff) consists of masonry walls.

A proposal to build a 900m long bund across the mouth of Cardiff Docks (between Bute Town and Penarth Pier) is awaiting approval. The proposed barrier would be part of a large scheme designed to reduce the flood risk in the lower reaches of the River Taff. A further aim of the barrage would be to produce electricity, provide leisure amenities and link Bute Town with Penarth.

Further upstream on the east bank of the Taff Estuary, old timber piles, some masonry walls and earth embankments (the shared responsibility of Cardiff City and Welsh Water) protect the river bank and a small length of urban frontage up to Clarence Bridge. The

west bank of the Taff, called Cardiff West Moors, is an industrial frontage. It has no formal coast protection.

South of this frontage, Cardiff City Council have responsibility for the shoreline fronting Penarth Moors. Here the pebble beach is backed by a rough concrete apron with stone pitching near Estuary Point.

The coastline is generally one of accretion with no serious problems. A Private Members Bill is currently going through Parliament to obtain permission to build a barrier across the entrance to the Taff.

From the River Ely to Traeth Mawr, north of Nash Point the shoreline is within the Vale of Glamorgan District.

South of the Ely the ground rises to Penarth Head. This massive unstable limestone and shale layered cliff is eroding and fronted by a shingle foreshore over a wide rock platform. The shingle beach around the headland is groyned. South of the Head the land drops down to Lower Penarth. Here concrete sea walls (topped by a wave wall) and a masonry revetment, backed by a promenade, protect the urban frontage for a distance of 1.5Kms south of the pier. The sea wall has been refurbished recently and is now mass concrete. The beach consists of boulders, shingle and sand overlying a marl rock platform.

South of Lower Penarth the unstable eroding limestone and shale cliffs rise and extend to Lavernock Point. Boulders, shingle and a thin sand cover form the foreshore deposits. Although the cliffs are eroding, they front a rural area, so cliff falls are of little significance.

5.1.2 Lavernock Point to Porthcawl

From the point of view of wave exposure, Lavernock Point can be considered a boundary between the muddy shallow foreshore of the Severn Estuary and the open coast in the Bristol Channel. The exposed coastline from Lavernock Point to Nash Point has generally sparse beach deposits and hence the nett west to east littoral drift is low. Tidal currents off Nash Point are sufficiently strong to result in the formation of a submerged sand spit several kilometres long, trending eastwards from the land. Swansea Bay is strongly indented. There is some evidence of a nett north to south littoral drift at Porthcawl at the south end of the bay.

The frontage from Lavernock Point to Traeth Mawr lies within the Vale of Glamorgan District.

Between Lavernock and Sully Island the eroding cliffs are fronted by wide rock platforms forming flat, wide terraces. In the shelter of St Mary's Well Bay a fine sand beach has developed but elsewhere there are small deposits of pebbles and boulders. Except at the head of St Mary's Well Bay (where there is a holiday camp), the coastline is undefended and requires little protection.

West of St Mary's Well Bay, the high cliffs drop to Swanbridge and beyond that the coast is fronted by a low lying flat rocky ledge overlain by pebbles. The only coast protection is at Swanbridge, opposite Sully Island. Here a privately owned wall is in a state of disrepair and gabions have been placed in front of it. Some protection is being given to the car park area by dumping builders rubbish onto the upper foreshore. The County Council have also built a wall to the east to protect the coast road. Off the coast is Sully

Island, a limestone outcrop connected to the mainland at low tide. The causeway is rocky, being scoured by the rapid inshore tidal currents in this area. Beyond Swanbridge the coastal fringe is rural giving way to industrial development near Barry.

Barry Docks, the property of the British Transport Docks Board are protected by about 1.25Km of rock armoured breakwaters. West of the Docks is Barry Island. This rocky headland is privately owned and is a leisure and holiday camp complex. There is a small sand beach (with mud further offshore) between the Docks and Barry Island, called Jackson's Bay.

Whitmore Bay has Barry Island to the east and Friars Point to the west. This sandy amenity beach is backed by some 750m of masonry sea wall fronting the promenade.

West of Friars Point is the site of the old Barry harbour. Flanked by the limestone headlands of Friars Point and Cold Knap Point this bay of sand and mud is the site of a proposed marina. Coast protection around it consists of old masonry walling. From Cold Knap Point west to Bulwarks Fort, the coastal fringe is fronted by a large shingle beach called The Knap. This is essentially a shingle spit which now joins Cold Knap Point (once an island) to the mainland at Porthkerry. To the landward (i.e. north east of this ridge) the land which is reclaimed from the sea is low lying. Some erosion is taking place in the centre of the embayment between Cold Knap Point and the Bulwarks Fort.

From the Bulwarks (an iron age promontory fort) to Aberthaw, the coast consists of unstable limestone cliffs fronted by a shingle and sand foreshore overlying a rock foreshore platform. There is a large

shingle 'delta' at the mouth of the river Thaw, with sand at low tide. It would appear that the shingle ridge is eroding.

Aberthaw is dominated by the large power station built next to the silted up harbour at the mouth of the River Thaw. For some 2.5Kms around the delta and then in front of the station, the C.E.G.B. maintain the defences. These are an earth embankment and a groyned shingle beach around the delta. The power station is fronted by a concrete sea wall while the shingle beach is groyned.

From Aberthaw to the boundary with Ogwr Borough at Traeth Mawr, the coastline consists of limestone cliffs and small sand and shingle beaches overlying rock platforms. At Nash Point the coastline trends north but a large sandspit (Nash Bank) runs westwards out from the coast, protecting the coast from Nash Point to Ogmore against wave action. The coastline is unprotected except for the the 125m length of rock revetment near Llantwit Major. Tidal currents off Nash Point are extremely fast and have led to the development of Nash Bank which is aligned to the major axis of tidal movement. There is scientific opinion that the large clockwise eddy which develops in the lee of the spit transfers sand in suspension to the beaches north of Nash Point.

From Traeth Mawr northwards to the River Kenfig the frontage lies with the Ogwr Borough. In practice coast protection is shared with the Mid Glamorgan County Council and private landowners.

From Traeth Mawr to the River Ogmore, the coastal fringe comprises an undeveloped cliffed coastline similar to that to the south. The unstable limestone cliffs are intersected by small streams and hanging

valleys, with the cliffs reducing in height near Ogmore and Southerndown. The cliffs, fronted by substantial sand beaches overlying a rock platform, are unprotected and suffer erosion both from the sea and from weathering. Attempts to stabilise the soft mudstone/limestone cliffs at Southerndown have met with little success. The erosion however is only affecting footpaths.

The cliffs end at Ogmore-on-Sea on the south bank of the River Ogmore. On the north bank is the large sand beach of Traeth-yr-Afon. It lies at the east end of a deep embayment, which finishes at Newton Point. The beach is backed by the eroding dunes of Merthyr Mawr. Work has started on a pipeline running in front of the dunes connecting to the sewage works to the north east. At the west end of the embayment the beach is backed by a rubble revetment and a concrete retaining wall, protecting land which is liable to flooding. There is a terminal scour problem at the eastern end of this wall and Welsh Water who own the wall have carried out maintenance work here recently.

From Newton Point to Porthcawl the rocky coastline has two bays which front a holiday complex. These, Trecco Bay and Sandy Bay, both have wide sandy beaches flanked by rocky headlands.

Porthcawl Harbour is situated south of the town frontage. There is an old masonry wall and a rock revetment east of the harbour entrance. Extensive repairs have been made the masonry walls forming the harbour frontage.

The urban frontage at Porthcawl has suffered damage by wave action and serious beach lowering has taken place in the past. In the embayment between Porthcawl Point and Irongate Point abrasion of the near vertical

concrete sea wall has been a problem for a number of years. At one stage abrasion of the concrete had hollowed out the surface to such an extent as to expose the reinforcing rods. An asphalt apron has been constructed at the toe of the wall so as to dissipate wave energy in a gradual manner and thus reduce future damage. The improvement from the point of view of reducing reflected wave energy has been substantial and beach sand is now beginning to settle out again within the embayment. At the southern end of this apron a rock groyne has been installed to encourage the nett southerly drift of sand to be retained in front of the asphaltic protection.

5.1.3 Swansea Bay

The strong indentation of the bay gives a varying exposure to wave activity but there is generally an easterly drift over the frontage. At the east end of the bay however the nett drift is southerly. Along the coastline in the centre of the bay large scale industrial development and reclamation masks the natural beach. There are four maritime councils with in Swansea Bay; Ogwr Borough, Afan Borough, Neath Borough and Swansea City. Along this south eastern section of Swansea Bay, falling beach levels have given rise to considerable concern though the considerable research that has been carried out into the hydrodynamic processes taking place in the bay has not as yet led to an overall management strategy for the problem areas.

From Hutchwns Point (which marks the north end of the Porthcawl urban area) to Sker Point the frontage is known as Rest Bay. Here low rocky cliffs are fronted by a foreshore of eroding sand beaches. There are no coastal defences and the rocks are subject to aerial weathering in places. From Sker Point to the Ogwr

Borough boundary at Afon Kenfig there is a massive dune system known as the Kenfig Burrows. This forms the Kenfig Burrows Nature Reserve, which is managed by the Mid Glamorgan County Council. The beach, which is subject to erosion, is of fine sand with shingle at high water.

The frontage from Afon Kenfig to the River Neath lies with Afan Borough. About half of this industrialised coastline is owned either by British Steel or the British Transport Docks Board. North of Afon Kenfig, extending to Port Talbot are Margam Sands which are backed by the sand dunes of Margam Burrows. Both the beach and the dunes here are suffering erosion principally the result of industrial development. The first 1.5Km are the responsibility of the Afon Borough. Along the rest of the frontage, coast protection consists of a shingle bank which is maintained by British Steel. The dunes behind the bank have been badly damaged due to the heavy industrial use of the hinterland. Immediately northwest of Margam Sands is the B.T.D.B. new deep harbour and docks complex of Port Talbot. Here the 3Km frontage is protected by rock armouring and concrete sea walls. The design of the new facility used both numerical and hydraulic studies which were carried out by Hydraulics Research, see Bibliography.

Between the docks and the Aberavon beach Afon Borough Council maintain about 500m of rubble revetment at the mouth of the Afon river. Along the Aberavon frontage, a large expanse of sand dunes been levelled and the area developed into a large leisure complex. Reclaimed sand has been used to form a man-made beach. Coast protection here is the responsibility of the Afon Borough Council and consists of a concrete wave wall with a stepped revetment. The beach level at Aberavon is slowly falling at the southern end and

possibly building up to the north. Coal is being washed ashore in this area to the detriment of beach amenity, and Swansea University are studying ways of improving the situation. Estuarial salt marsh backed by dunes forms natural protection to the promontory of Witford Point to the north of Aberavon. The saltings extend into the mouth of the river Neath.

The estuarial frontage from Witford Point across the river Neath to Crymlyn Sands lies within Neath Borough. To the north of Witford Point over 1Km is unprotected and is made up of sand dunes with a sand and mud foreshore. Beyond that an area of reclaimed salt marsh is protected by 2Kms of earth embankments, wharfs etc. This industrial frontage is protected by Neath Borough.

On the west bank of the River Neath and still within the estuary mouth there is a 2Km unprotected frontage consisting of amenity land. Here the mud banks are fronted by saltings. From the mouth of the estuary to the Borough boundary at Crymlyn Burrows, the unprotected backshore consists of sand dunes with a foreshore of sand and mud.

The frontage from Crymlyn Burrows to Mumbles Head and beyond lies within the boundary of Swansea City. From the boundary with Neath for a distance of about 500m, a dune system fronts an industrial area owned by British Petroleum. Beyond that to Swansea Docks, coast protection consists of a long rock revetment fronting the main dock area (owned by B.T.D.B).

Flood protection in front of the South Docks is being improved as part of development of the Swansea marina. Upgrading of the flood defences is also taking place upstream near the new County Hall. These defences lie upstream of the Schedule 4 boundary.

From Swansea West Pier east over a frontage of about 500m the mud/sand foreshore is backed by sand dunes and is unprotected. Further west to Brynmill the coast is protected by a mixture of concrete, stone or masonry walls and revetments. The beach here is of sand and mud with some shingle.

From Brynmill to Black Pill the City Council are responsible for the duned sandy shoreline, which is eroding. This erosion is due to trampling of the sand dunes. The erosion of the dunes is not causing any serious problems.

From Black Pill to Mumbles Head the largely urban frontage is protected by stone and concrete revetments. There is a proposal in hand to upgrade the defences. The foreshore is sandy at Black Pill giving way to shingle at the south end. The high limestone headland of the Mumbles forms the southern limit of the bay. The coastline to the west is rocky and there is probably little interchange of beach material on either side of Mumbles Head.

5.1.4 Mumbles Head to Worms Head

The cliffed coast of the Gower Peninsula is largely in a natural state. It is strongly indented and whilst the nett direction of littoral drift is potentially from west to east, the actual interchange of material between adjacent bays is minimal. There is little evidence, for example of the large sand deposits in Oxwich Bay being transported past Pwlldu Head. The possibility of a transfer of material in the opposite direction (i.e.westwards past Oxwich Point) is even more remote.

The frontage from Mumbles Head to Worms Head and beyond lies within the Swansea City boundary. It is

either in the hands of the Nature Conservancy Council, the National Trust, or is in private ownership.

From Mumbles Head to Pennard Pill the coastline is mainly in private ownership and comprises a series of small sandy bays separated by headlands. Limeslade Bay has some minor masonry sea wall protection. Langland Bay to the west has a wider sandy beach backed by limestone cliffs. Here also some minor protection is afforded by masonry sea walls.

Between the headlands of Whiteshell Point and Pwlldu Head are a number of bays separated by rocky promotories. There are no coastal defences in these bays. Beyond Pwlldu Head west to Pennard Pill, the coastline consists of high, unprotected limestone cliffs.

West of Pennard Pill the low lying coastline within Oxwich Bay is protected from southwesterly waves by the rocky headland of Oxwich Point. The bay is backed along its western side by the high sand dunes of Nicholston and Oxwich Burrows. Erosion of the sand dunes in Oxwich Burrows is due to public overuse. These dunes are the primary protection of the low lying land against flooding. The coastline in Oxwich Bay has various owners and both the Nature Conservancy Council and the National Trust are involved.

From here to Worms Head the coastline is in private ownership. At the south end of the bay around Oxwich Point and extending east to Horton, high limestone cliffs reappear. These cliffs are fronted by a rocky foreshore. Littoral drift along this frontage is negligible. For about 1.5Kms west of Horton to Porteynon Point the coastline is again low lying and has a sand beach backed by dunes. These dunes, prior to 1978, were also eroded, largely by human traffic.

Since then, however, a management scheme has helped in their stabilisation. A coast protection scheme has been devised by a local archaelogical society to protect the Salthouse at Port Eynon.

From Porteynon Point to Worms Head the coastline again consists of high limestone cliffs with a rocky foreshore and some small sandy coves. There are no coastal defences along this frontage.

5.1.5 Carmarthen Bay

Carmarthen Bay is exposed to the action of Atlantic waves. It is intersected by two major estuarine systems within which sediment movement takes place by the combination of waves and currents. No general statements can be made about the nett direction of littoral drift except that the movement of material causes spits to extend into the mouths of the estuaries. This very large bay comes under five separate coast protection authorities. These are Swansea City Council, Lliw Valley District Council, Llanelli Borough Council, Carmarthen District Council and the South Pembrokeshire District Council.

The south east corner is within the boundaries of Swansea City whose jurisdiction extends north into the estuary of the River Loughor. In practice just over 1Km (the frontage of East and West Penclawdd) is the direct responsibility of the City Council, the rest is in private ownership.

North of Worms Head is Rhossili Bay a long sweep of sand which faces into the Atlantic. From Rhossili to Hillend the coastline comprises the low cliff platform of Rhossili Down, with high cliffs rising further landwards. From Hillend to Burry Holms in the north half of Rhossili Bay and (beyond that) north east to

Whiteford Point the sand beach is backed by dunes which form the primary sea defence. There has been severe dune erosion along this stretch of coast and Swansea City Council have introduced management schemes at Hillend and in Broughton Bay to the north. There appears to be no strong nett drift within Rhossilli Bay. Sand movement along Whiteford Sands is in a northeast direction. This has led to the gradual extension of Whiteford Point and the creation of mature dunes and the establishment of salt marsh in the lee of the Point. The marshes extend up the estuary from Whiteford Point east to Loughor.

The foreshore from Whiteford Point into the estuary is known as Llanrhidian Sands. These are large expanses of mud and sand with salt marsh on the upper foreshore. There are no coastal defences here and the roads may be flooded at high tides.

The frontage at East and West Penclawdd is protected by masonry and concrete sea walls and revetments which are there to prevent the flooding of the low lying hinterland.

From East Penclawdd to the City boundary at Wern-olau the low lying coastline comprises estuarial marshland.

The coastline further upstream is within Lliw Valley District. It comprises of marshland with a muddy foreshore. There are no coastal defences and little flood risk.

The boundary between Lliw Valley District and Llanelli Borough is the River Loughor.

The shoreline within Llanelli Borough extends westwards from the Loughor to the Gwendraeth Estuary.

The estuarial frontages consists of mud and sand with sand being dominant on the open coast.

From Loughor Bridge to Machynys the coastal area is owned by the Llanelli Community Council. There are no coastal defences for the first 1Km west of Loughor Bridge, while the remainder of the frontage has grassed earth embankments maintained by Welsh Water. These defences which are presently discontinuous and in need of repair, are being upgraded..

Llanelli harbour is now badly silted up and some parts of it have been reclaimed using industrial waste. Protection consists of grassesd embankments and on the eastern margin there is Armorflex mat protection. A spit forms the western "arm" of the harbour. This too is protected by grassed embankment with some rock armouring on the exposed outer face. The area north of the spit is also subject to wave attack and is protected by a 900m stretch of concrete/stone revetment.

The foreshore, of mud and sand, is groyned although at the present time a meandering tidal channel is undercutting the groynes, putting the Council's embankment and sea wall at risk from undermining. West of this point 3kms of rock revetment protect the railway line and are maintained by British Rail. At the western end of this revetment, 2Kms of shoreline fronting a disused power station are protected by an earth/slag embankment.

Beyond that (just east of Burry Port), some 300m of coastal embankment is protected by a somewhat dilapidated Maccaferri Reno mattress. This mattress protects an area of reclaimed land and is fronted by a foreshore of sand littered with slag. Although the mattress is impregnated with bitumen, this tends to

spall off. Abrasion has also resulted in the breaking up of layers at the revetment toe and the loss of the 'rock fill'. Between Burry Port and Pembrey Harbour to the west, the coastline has eroding sand dunes which are protected at the eastern end by 200m of recently constructed concrete sea wall. Littoral drift along this frontage is from west to east but is relatively low.

West of the old silted up harbour of Pembrey an area of saltings is protected by a 4Km long belt of sand dunes. These dunes, called Pembrey Burrows, are extending eastwards towards Pembrey as a result of wind action and the easterly drift. However sand movement on the lower part of the foreshore is more complex and is governed by the combined action of waves and tidal currents. A study by H.R. showed that the eastward growth of Pembrey Burrows has coincided with the decline of the estuary's North Channel and the eastward migration of the South Channel leading to increasingly more 'quiescent' conditions on the north shore. A wide sand beach backed by high dunes and grassland extends north to the mouth of the estuary formed by the rivers Gwendraeth, Tywi and Taf. The M.O.D own about 7Kms of this stretch, from Pembrey Burrows to Tywyn Point. This dune belt is exposed to Atlantic storms and serious erosion of the front line of dunes has been observed in the southern part of the M.O.D. frontage. The M.O.D. also own about 6.5kms from Tywyn Point east into the Gwendraeth Eastuary. This frontage is marshland fronted by saltings and mud and is backed by a 2Km long embankment protecting M.O.D. property from flooding. In the upper part of the Gwendraeth Estuary, Welsh Water are responsible for 2.5Kms of embankments and quays which protect the town of Kidwelly from flooding.

From Kidwelly to Amroth the coast lies within Carmarthen District.

From Kidwelly to St Ishmaels the estuarial marshland is fronted by sand and mud. Here the north bank of the Gwendraeth Estuary is in a natural state (apart from local gabion and boulder protection at the west end of the Holiday Camp at Bryntowny). Near St Ishmaels the land rises along the east shore of the Afon Tywi. The cliffs are fronted by a railway embankment protected by a BR masonry wall. The foreshore along this 1.25Km stretch is of sand and shingle and mud to the north. Further north the railway embankment has little protection except for some groyning of the foreshore. The mud and sand flats along this side of the estuary suffer considerable erosion.

Opposite, on the west bank of the Afon Tywi at Llanstephan there is some 800m of stone faced embankment, with a 200m long masonry sea wall at West End. Fronting this is a wide accreting sandy beach.

From Llanstephan to the east bank of the Taf opposite Laugharne the foreshore is of mud and sand with rock cliffs to the rear. There are no sea defences and there is some local erosion of the cliff face beneath Llanstephan Castle.

Opposite on the west bank of the Taf at Laugharne, about 1Km of river bank is unprotected except for some minor gabion work and dwarf walls stabilising eroding cliffs just north of the village. The 4Km length of estuarial shoreline from Laugharne southeast to Ginst Point is partly owned by M.O.D. and part the responsibility of Welsh Water. Protection of this low lying coastal stretch comprises an old stone faced embankment, fronted by saltings. About half of the

frontage, in the shelter of Ginst Point is however unprotected. At Ginst Point itself, a 1Km long rock faced embankment owned by MOD protects eroding sandy dunes. The protection has not been entirely successful due to sand leaching out from behind and underneath the rock revetment. This may be the result of the lack of a suitable foundation to the revetment, though it has to be said that the sand foreshore in this area is very mobile and subject to large changes in level. This area is open to wave attack and Ginst Spit now extends into the estuary as a result of eastward drift. A refraction study carried out by H.R. showed that there is a concentration of wave energy at this point thus increasing the likelihood of damage.

From Ginst Point westwards, a dune bank protects the "open coast" M.O.D. frontage which stretches about 9Kms to Pendine Village. The hinterland includes the large dune belt known as the Pendine and Laugharne Burrows, which protect low lying marshland to the rear. The dunes are reinforced in places with stone and concrete. There is some dune erosion along most of this frontage. The causes of erosion here may be climatic since public access to the area is rather limited. The nett direction of littoral drift within the north part of Carmarthen Bay is from west to east. Erosion could be connected with a possible reduction of material supply from the west.

Protection over about 500m at Pendine Village (immediately west of the M.O.D. frontage) is the responsibility of the Carmarthen District. This comprises of masonry sea walls and a concrete revetted wall backing the wide sandy beach. West of the village the County Council are responsible for about 250m of masonry wall protecting a minor road.

West from here to the Carmarthen District boundary at Amroth the coastline consists of soft cliffs and is unprotected. The beach is of sand and shingle with some accretion east of Amroth. The width of the intertidal zone reduces in a westward direction. At Amroth a massive pebble ridge backs the sand beach. Remains of a drowned forest can be seen below the low water mark, presumably indicating areas of local erosion also.

The coast from Amroth to St Govan's Head at the western end of Carmarthen Bay lies with South Pembrokeshire District. This includes about 8Kms around Caldy Island which is privately owned and unprotected. Large stretches of the foreshore are leased to the District Council by the Crown Estate Commissioners.

The foreshore at Amroth is sandy and backed by a shingle ridge. Straight, impermeable timber groynes intersect the upper beach and are backed by a concrete and masonry sea wall which, in the centre of the bay, is some 4m above the top of the groynes. The littoral drift is from west to east. In 1977-78 some 8,000 tonnes of imported stone were placed as beach nourishment material, together with about 4,500 tonnes of shingle transferred from the eastern end of the bay.

The coastline west to Wiseman's Bridge is unprotected (a proposal was submitted in 1982 for a concrete stepped sea wall to be built on the shingle ridge at Wiseman's Bridge). This mostly privately owned coastline is fronted by a pebble and rock beach which becomes sand and shingle at the western end. Littoral drift along this foreshore is from west to east. The coast is eroding at the Saundersfoot - Wiseman's Bridge end (and is protected by a sea wall) and

accreting towards Amroth. At Saundersfoot the beach is wide and sandy and enclosed by sandstone promontories. There is a proposal to add to the backshore protection, while at present the harbour arm forms protection locally.

There are no coastal defences south from Saundersfoot to Tenby. This privately owned rocky coastline is separated by sandstone headlands. The foreshore is leased to the District Council by the Crown Estate Commissioners. North Beach, Tenby comprises of a 1Km stretch of sand foreshore which is backed by masonry sea walls and rubble revetments. These and the small harbour are the responsibility of the District Council. The foreshore is leased from the Crown Estate Commissioners. The crumbling limestone cliffs south of Castle Hill, Tenby are protected in part by an abraded masonry wall. These are the responsibility of the District Council.

South of Castle Hill as far as Giltar Point, the coastline is partly in private hands, with some M.O.D. involvement. South Beach a long wide sandy foreshore leased to the District Council by the Crown Estate Commissioners, is backed by sand dunes. The dunes, which are protected at the south end by gabions, are eroding.

West from Giltar Point to Skrinkle Haven, the coastline consists of unprotected high limestone cliffs fronted by a shingle ridge at the high water mark and a sand foreshore (leased to the District Council by the Crown Estate Commissioners). There is some M.O.D. involvement and the wide beach of shingle and sand at Lydstep Haven is privately owned.

Limestone gives way to sandstone as the cliffs run southwest from Skrinkle Haven towards Stackpole Quay.

This cliffed coastline is largely privately owned (again with some M.O.D. involvement). It is interspersed with beaches such as Manobier (sand with a pebble bank), Swanlake (sand) and Fresh water East (sand and shingle). Sand dunes back the bays at Manobier and Freshwater East and the beaches are subject to erosion especially at Freshwater East. The nett west to east littoral drift is low since the beaches are generally thin and separated by rocky promontories.

From Stackpole Quay to St Govan's Head, the coastline comprises high limestone cliffs with occasional sand beaches and small sandy coves. The coastline is privately owned and has no coastal defences.

5.1.6 St Govan's Head to Milford Haven

The southern face of Dyfed's south western peninsula is characterised by high cliffs stacks and caves and narrow beaches. The plateau is dominated by the Army's tank training ground at Castlemartin. Littoral drift is insignificant.

The coast protection from St Govan's Head to the Milford Haven Estuary lies with South Pembrokeshire District. Almost the whole stretch is either privately owned or has National Trust or Ministry of Defence involvement. Some land within the Milford Haven Estuary is leased to industry.

The coastline between St Govan's Head and Linney Head is largely the responsibility of the M.O.D. or is in private ownership. This stretch consists of high limestone cliffs interspersed with small sandy coves. There are no coastal defences.

North of Linney Head are the wide sandy bays of Frainslake South and Freshwater West, the latter subject to erosion. Apart from some gabions which are used to fill in breaches in the dunes there are no coastal defence works. The bay is privately owned with some National Trust involvement.

From Freshwater Bay to Rat Island at the entrance to Milford Haven the cliffed unprotected open coastline is in private ownership.

From Rat Island to Pembroke Ferry the north facing estuarial coastline within Milford Haven is mainly in private ownership with parts leased for industrial use (including the Petro-chemical giants, the C.E.G.B. and the M.O.D.). The dock and harbour walls and quays which are the primary 'coastal defences' are situated in the vicinity of Pembroke Docks. The South Pembrokeshire District Council maintain a short length of concrete sea wall in Pembroke. They also lease stretches of the foreshore from the Crown Estate Commissioners.

5.2 The West Coast.

The west facing coast of Wales, from Milford Haven to the Isle of Anglesey is largely rural although there are several towns mostly situated at the mouths of the estuaries in Cardigan Bay.

5.2.1 Milford Haven to Skomer Island

The south west of Wales lies in Preseli District which extends from Milford Haven west to Skomer Island and then north to Cardigan.

On the north bank of the Daugleddau (within Milford Haven) from Burton Ferry downstream to Neyland, the river bank is unprotected. West from Neyland to

Hazelbeach, there is a mixture of Council owned and private sea walls of masonry, concrete and timber. Foreshore erosion is taking place in this area (upstream of Llanstadwell Church a shingle bank which provides shelter for small boats, is eroding, and future coast protection work is planned). From Hazelbeach west to the outskirts of the town of Milford Haven, there is a mixture of mainly privately owned coastal defences, part of which front an Oil Refinery. Milford Haven has some 6Kms of masonry sea wall and dock and harbour frontage. This is maintained by either the District Council or the Harbour authorities. The defences extend to Gelliwick Bay within which Preseli District Council maintain a 300m long concrete sea wall.

The north shore of Milford Haven stretching west Pickleridge to is unprotected.

Pickleridge has a sand and shingle beach with a muddy foreshore within the strongly indented embayment.

Here the coast is partly protected having a 500m long rock revetment at the head of the embayment. The frontage to the south is also partly protected with a 100m length of masonry sea wall at Dale. This village has a beach of shingle with some sand at low water. The frontage here has been eroding for some time and there is a proposal to extend the defences to protect a minor road.

From Dale Fort around St Anns Head and then north to Skomer Island, the unprotected coastline consists of high cliffs fronted here and there by sandy inlets, the largest of these being Marloes Sands.

Skomer Island at the western extremity of the peninsula is owned by the Nature Conservancy Council.

Other smaller islands off the peninsula are either nature reserves and/or S.S.S.I's. The coastline is strongly indented and there is little drift of beach material.

5.2.2 St Bride's Bay

High red sandstone cliffs dominate the coast north to Littlehaven. There are only a small number of sandy coves such as Musselwick Sands and St Bride's Haven. The foreshore is narrow even at low water and largely free of beach deposits. Littoral drift is insignificant.

The frontage of Littlehaven and Broadhaven is partly protected by coastal defences. At Littlehaven there are about 50m of masonry faced sea wall and a further scheme is proposed here. At Broadhaven, there are 75m of concrete wall at the southern end, 150m of masonry faced concrete wall in the centre and 75m of concrete sea wall at the northern end. The beach fronting these two hamlets is of sand with a shingle and pebble ridge at high water. Proposals are in hand to protect part of the road south of the village.

From here northwards the cliffs are lower and are of the coal series. The sand beach at Newgale is backed by a shingle storm ridge fronting a major road. The only problem here results from the shingle being thrown landwards onto the road during storms. The sand beach which is quite flat and wide faces due west and hence the nett littoral drift is very low.

The rugged cliffs from Newgale Sands to St David's Head have deep inlets with small sand beaches with the exception of Whitesand Bay. Here there is a wide sand beach with some shingle at high tide. Part of the backshore is protected by 100m of rock revetment.

5.2.3 St David's Head to Aberdyfi

The two maritime district councils in the south part of Cardigan Bay are Preseli and Ceredigion. Preseli District extends north to the outskirts of Cardigan, beyond that is Caridigion.

North east from St David's Head to Abereiddy the high rugged coastline is undeveloped. The weathering of cliffs (which contain intrusions of igneous rock) produces little beach material. The rocky foreshore is narrow and the small coves have boulder strewn beaches. Littoral drift is insignificant. At Abereiddy the coastline drops sharply to low lying land. The upper foreshore is of shingle and is backed by a 300m long permeable railway sleeper wall. This 12 year old wall was constructed to halt recession which had been caused by the erosion of the shingle beach. The lower foreshore consists of gray sand sized particles of slate which have been worn down by the action of the sea (slate was exported from local quarries by sea in the past).

Between Abereiddy and Abercastle the high cliffs are fronted in places by sandy inlets. One such inlet is at Porthgain where over 50 years ago the harbour was used for coasters to carry away crushed stone. Now the harbour, owned by Porthgain Village Industries Limited, is a haven for small boats. The slate particles have, over the years, been transported southwards to form the beach at Abereiddy.

The inlet at Abercastle has a small sand, shingle and mud beach and here the District Council maintain a 100m long concrete and masonry sea wall.

From Abercastle northwards, high cliffs of shale give way to harder volcanic rock and this rugged

undeveloped coastline extends to Fishguard Bay. There are a few small inlets with rock and pebble beaches. The many promontories strongly 'compartmentalise' the coastline.

At Fishguard harbour the ferry terminal is owned by Sealink. The coastal stretch, in the shelter of the north breakwater, is some 3Kms long and is protected by masonry walling. The rock mound breakwater protects both the anchorage and the town from north easterly storms.

Along the western corner of the bay a trunk road runs from the harbour to the town of Fishguard. Protection to the road and the low lying hinterland consists of 750m of rock revetment and groynes, maintained by the District Council. The beach at the southern end of the revetment is eroding.

South of the revetment the shale cliffs are unprotected but the hinterland is undeveloped. Lower Town is the old town quarter situated around the inner harbour. It is protected by about 1km of masonry walling.

East of Fishguard Bay the slate cliffs continue with a few small sandy inlets, around Dinas Head to Newport Bay. Landslips at the south east corner of Dinas Head are being stabilised by regrading and gabion protection.

The small inlet of Cwm-yr-Eglwys (which was once a port) has a sand and shingle foreshore backed by a 200m long masonry sea wall built in the 1980's. Further work is planned in the longer term.

Eastwards around Newport Bay the coastline consists again of unprotected shale cliffs which stretch to

Afon Nyfer. The wide sand foreshore at the north side of the river mouth is backed by dunes. At the northern end of Newport Sands, a 100m long rock revetment protects a car park while the backshore is protected by a dune system. North east of Newport Bay the land rises and there are high shale cliffs which continue around Cemaes Head into the Teifi estuary.

On the west bank of the Teifi estuary is a large area of sand accretion known as Poppit Sands, forming the largest beach along this stretch of coastline. Here the broad sand foreshore is backed by sand dunes and there are no coastal defences upstream to the Schedule 4 boundary at Teifon.

The coast protection authority from the Teifi Estuary to Ynyslas is Ceredigion District Council. Responsibility is shared with the Dyfed County Council and with Welsh Water.

From the Schedule 4 boundary on the north bank of the Teifi (opposite Teifon) to near Waun-gelod, the foreshore is mainly mud and there is no protection to the river bank. At Waun-gelod, some 500m of masonry and concrete sea wall protect a road which at this point is very close to the waters edge. Responsibility for coast protection here is shared between the Ceredigion District and the Dyfed County Councils.

Between Waun-gelod and Gwbert there is an area of sand dunes, the Pen yr Ergyd peninsula, which has built out into the estuary. The southern part is a caravan park and the dunes are eroding exposing the shingle at the crest of the foreshore. Protection at the northern end of the peninsula consists of 300m of rock revetment and stabilisation and drainage for the boulder clay coastal slope. The foreshore here is

shingle with muddy sand at low water. Erosion of the backshore has also been taking place just to the south of the rock revetment and there is a proposal to nourish this area and contain it with groynes. The proposal is presently at the consultation stage.

From here northwards the coastline, which is largely undeveloped, is exposed to north westerly storms. Cliffs extend from the mouth of the estuary to New Quay. The foreshore along this stretch consists largely of boulders with some sand near the low water line. The nett drift is in a west to east direction but because of the sparse beach deposits and the indented nature of the coastline, the rate of movement is low. The M.O.D. own Cribach Bay just north of Aberporth. Here there is a steep sand beach backed by unstable shale cliffs. Fluctuations in beach levels and erosion of the cliff face take place here but there are no problems with regard to coastal defence, though military installations on the upper part of the beach are at some risk.

Aberporth is a deeply indented cove a short distance to the south west of Cribach Bay. Here two sand beaches, separated by a small rocky headland are flanked by cliffs. There is some instability in the western cove but this is not posing serious problems since there are no houses at risk in the area. The sea wall here is a minor one and is as much for amenity as it is for coastal defence purposes. The cliffs are overlain by boulder clay and are subject to land slippage and erosion and a concrete retaining wall protects the road at the head of the cove in the eastern bay. There is also some erosion of the boulder clay cliffs to the east of the sea wall and the stream outlet has caused some cliff slippage on the east bank. Part of the bank is protected by a

short length of concrete wall and an area of terminal scour has been filled with riprap.

The coastline continues to be rocky to the east. At the next inlet at Tresaith, the foreshore is wide and sandy. Here too landslip and erosion are a problem. A 50m long concrete sea wall built in the early 1980's has been extended westwards by means of a 100m rock revetment. At low water the beach extends beyond the cove and the sand is continuous to Penbryn where the beach is backed by low sand dunes.

Further northeast at Llangranog a break in the cliffs is created by the valley of the Afon Hawen. At the mouth of the valley a sand beach is bounded by rocky headlands. Coast protection consists of a 100m long patched masonry sea wall which gets overtopped during storms and high tides. Maintenance of the wall is an ongoing commitment.

From Llangranog to Cwmtydu, the coastline again consists of high cliffs fronted by a narrow foreshore and the rate of west to east drift is very low. At Cwmtydu the small shingle beach, flanked by cliffs on either side of the valley, is backed by a 100m long concrete apron and parapet sea wall.

The coastline of high cliffs extends to New Quay. The promontory of New Quay Head to the north of the town provides shelter for its small harbour which is fronted by a sandy beach. Protection comprises an old 150m long masonry quay and some 300m of masonry sea walls. The harbour breakwater has required a good deal of maintenance and appears to have suffered settlement. The end of the breakwater has been extended and is protected with rock armouring. To the north of the breakwater measures have been proposed to stabilise the cliff face as there are houses near the

cliff edge. To the south of the harbour the vertical cliffs are undercut by wave action and the cliff top is also unstable. Works have been proposed to prevent further erosion. These will include stabilisation of the cliff face and toe protection.

In New Quay Bay the soft boulder clay cliffs are attacked at high water. They are fronted by a pebble foreshore over a flat sandy lower beach. The cliffs are subject to considerable slippage and a number of holiday properties are threatened. The headland separating New Quay from Little Quay Bay to the east is particularly susceptible to cliff slippage. Here a small stream exits across the upper shingle foreshore. It is trained on its western bank by means of a short breakwater. A stone revetment to the east protects the cliff toe from erosion. Beyond the revetment two groynes have been constructed to reduce the rate of lowering of beach levels. These defences appear to be in private ownership. The sandy lower foreshore continues east to Little Quay. At Little Quay coast protection consists of about 300m of rock armouring and groynes to protect the toe of the stabilised clay cliffs. Drift in this area is in a west to east direction, except in the vicinity of New Quay where there is an east to west 'counter drift'.

The coastline from Little Quay to Aberayron comprises unprotected boulder clay cliffs fronted by a shingle foreshore with large boulders at the cliff toe. South of Aberayron harbour the shingle beach which is extensively groyned is backed by some 400m of rubble revetment. The accumulation of shingle extends to the seaward end of the harbour arms and there is a significant transfer of material from south to north, in the direction of the nett drift. The harbour is protected by masonry sea walls and immediately to the north is a 100m long crib groyne. Further north

there is a 500m long concrete sea wall. Properties both north and south of the harbour are at risk due to erosion. The seawall north of the entrance has already been undermined. (Emergency works have been implemented in this area recently.) Movement of shingle across the harbour entrance is considerably lower than the "open coast" drift hence the coast to the north is eroding quite rapidly. Long timber groynes extend well to the north of the sea wall in an attempt to reduce the rate of erosion of the shingle ridge.

Between Aberayron to Aberarth unprotected clay cliffs contain pebbles and sand within them and are thus subject to rapid erosion. The mouth of the River Arth is trained and protected by a rock filled crib revetment. The foreshore consists of shingle derived from the cliffs and there is a large shingle bar within the river mouth. The foreshore is groyned and backed by some 300m of rock filled timber breastworks to the south of the river mouth. The cliffs in this area are partly vegetated so it would appear that the rock revetment has partially stabilised the backshore.

North of Aberarth the clay cliffs are also eroding rapidly. The shingle beach continues northwards to Llanrhystud and beyond. From Llanrhystud to Aberystwyth, the coastline is rocky except for a 3km length near Cwm Ceirw where the cliffs are mainly of boulder clay. There are no coastal defences along this whole stretch.

At Aberystwyth the coastline drops to the valley of the River Ystwyth and a shingle ridge runs north some 750m to the old stone pier at the entrance to Aberystwyth harbour. The ridge, which protects the low lying hinterland of the Ystwyth Valley, is subject

to erosion and breaching (the ridge has been formed by drift of shingle, deflecting the river mouth northwards). It would appear that the supply of shingle from the south has dwindled. This, combined with the natural rolling back of the ridge, threatens to form a permanent break and a new outlet to the sea for the Ystwyth. Protection already exists at the southern end (a 150m long concrete wave wall), while at the northern end about 100m of two tiered rock armouring, (held in place by vertical rails) protects the root of the south pier. The rivers Ystwyth and Rheidol both drain through the harbour. An entrance bar indicates that the river/tidal flow is insufficiently strong to prevent material interchange across the harbour mouth. From the harbour northwards coast protection consists of masonry sea walls and some groynes. The urban frontage has two main beaches separated by the headland of Castle Reef. This acts as a major groyne and prevents all but a small amount of material from being transported northwards. The south beach, between the harbour and this headland, has a steep shingle foreshore and is well stocked with pebbles. It is fed with material which bypasses the harbour entrance. The northern beach, which is mainly of pebbles with some sand is flatter and less healthy and was subject to beach replenishment in the early 1980's. Some groynes were also replaced on this frontage at that time. Beach levels at the north end of the frontage have been made up 'artificially' by covering over the upper foreshore with large boulders. Despite these measures the sea wall is occasionally overtopped at this point during heavy storms. Beach pebbles are not stable in front of this highly reflective sea wall and they tend to be transported northwards to the foot of the headland called Constitution Hill. The problem is one of ongoing erosion and there are further proposals to combat this in the longer term. Erosion in this area has been

serious for many decades. For example during a particularly severe storm in 1938 a substantial portion of the northern promenade at Aberystwyth was completely destroyed.

The coastline between Aberystwyth and Clarach consists of unprotected sandstone cliffs. Clarach Bay has a 500m long sand and shingle ridge formed at the mouth of River Clarach. The shingle ridge protects the low lying hinterland from flooding. Coastal defences consist of about 100m of privately owned timber breastwork to the south. To the north a low sheet steel pile and concrete wall protects a building against the sea. There are also some coastal defences presently under construction at the southern end of the bay where a public house is situated close to the shoreline.

From Clarach Bay to Borth the coastline reverts to high clay cliffs which are subject to erosion. The foreshore is generally narrow except for a small sand and shingle beach at Wallog. The south to north drift is low. From the beach at Wallog a natural ridge of shingle, Sarn Cynfelyn, extends seawards for several kilometres beneath the water surface. This is believed to be a glacial feature.

The coastline drops to low lying land at Upper Borth. The village of Borth straddles a shingle spit separating the sea from an area of swampland, the Cors Fochno, to the landward. The flat lower foreshore is of sand while the steep upper beach is of cobbles. Protection to the village and highway consists of timber groynes backed by a rock revetment as well as a timber breastwork (over the village frontage). Littoral drift of shingle is low and in a south to north direction. The lower foreshore is sandy and the spit finishes in an extensive dune system. This spit

has grown northwards across the estuary mouth (the River Dovey) deflecting the river channel towards the north shore. Erosion is taking place at the southern end of the shingle spit at Borth, due to a reduction in the supply of pebbles form the south. In some groyne compartments the shingle has almost disappeared leaving a flat sand foreshore and groynes which now project well above the beach level. As mentioned above this ridge is backed by some 4Kms of timber breastwork and is extensively groyned. The breastwork has been backfilled with beach pebbles though these get washed out in storms. The intention of the brestwork is to reinforce the shingle ridge and protect the lower areas of Borth from flooding. To the north of the breastworks there is a short length of rock protection designed to combat downdrift scour. The groynes continue northward to a point where the dune system is sufficiently wide to be a good buffer against erosion by the sea.

Ynyslas is situated towards the northern end of this spit and to the landward of the dune belt. From here for some 12Kms upstream, Welsh Water have the responsibility for sea defence. Part of the south bank of the estuary is backed by a disused railway embankment but has no coastal defences proper. The estuary bank is fronted by saltings and a large expanse of sand. The intertidal flats, together with the Cors Fochno marsh and the Ynyslas dunes, form the Dyfi National Nature Reserve.

5.2.4 Aberdyfi to Aberdaron

This stretch extends north from the Dovey Estuary to the tip of the Lleyn Peninsula. The coastline from the Dovey to Porthmadoc is within Meirionnydd District. The responsibility for coastal protection is shared with Welsh Water (mostly in estuaries), and

with British Rail at Barmouth and other estuaries where the railway tracks run close to the shore.

From the schedule 4 boundary at Dovey Junction Station downstream to Gogarth Station parts of the low lying land and marsh are given protection against flooding by the earth railway embankment. However the embankment does not always follow the shoreline. Hence the undeveloped land between the line and the river bank can become flooded. Downstream of Gogarth to Aberdyfi responsibility for protection lies in part with the County Council and British Rail. This consists of a rock embankment protecting the railway line and the coast road, both of which hug the north shore of the estuary.

At Aberdyfi at the mouth of the estuary, the coastal defences, which are the responsibility of the District Council, consist of about 650m of masonry sea walls, a jetty and sheet steel piling around the harbour wharves. The sheet steel at the wharves is thought to be in poor condition.

The low lying land north of Aberdyfi to Towyn is the responsibility of Welsh Water. The sand beach and shingle storm ridge are backed by sand dunes. The dunes are subject to erosion and are protected in places at their toe with randomly placed rock.

The holiday resort of Towyn is protected by some 1800m of concrete promenade and seawalls fronted by groynes. Upgrading of the wall is presently in progress. Despite the groyning of the foreshore the beach continues to erode. This part of the coast is aligned to the direction of the predominant south westerly waves and there is only a small nett south to north littoral drift in this area.

From Towyn northwards to the mouth of the River Dysynni there is intermittent rock embankment protection to the railway line. A proposal is also in hand to close a gap in the coastal defences between the Towyn promenade and the railway embankment to the north. The reinforcement is to a spit which has grown northwards as a result of the south to north littoral drift. Water depths at the mouth of the River Dysynni are quite shallow and there is some transfer of beach material across it, principally in a northward direction. There is also some embankment protection on the south bank of the estuary near the excursion limit of ordinary tides. There is a proposal for siting a caravan site south west of Talybont. Protection will include some 500m of timber defences.

Around the north bank of the estuary the District Council and Welsh Water share responsibility for stretches of rock and sand embankment protection.

North of the estuary mouth Tonfanau has a sandy beach scattered with boulders and here another ridge or causeway (the Sarn y Bwlch) of shingle runs seaward from the coast.

The land rises northwards and from Tonfanau to Llwyngrwril the steep cliffs are fronted by a shingle foreshore. At Llwyngwril the foreshore widens to form a promontory of low lying land. Here a sand beach at low tide is backed by a low shingle bank. This bank is subject to erosion and occasional overtopping.

North of Llwyngwril to Friog the steep unstable cliffs run down to the water's edge. Over this frontage (about 2.5Kms) British Rail are responsible for the railway embankment which is cut into the lower part of the cliffs. Rock falls and landslips along this

stretch are common and work is being carried out to alleviate this problem.

From Friog a sand spit (Fairbourne Spit) extends northwards and in its shelter an area of salt marsh and sand dunes has formed. The development of this spit took place after the last period of glaciation and during the subsequent sea level rise. Like many of the other such spits across estuary mouths on the coast of West Wales the spit is suffering from erosion. The problems are probably partly due to the gradual increase in sea level and partly due to a reduction in the littoral supply. Also many settlements are built along the crest of the storm ridges, thus preventing the spits from migrating landwards naturally. Responsibility for protecting Fairbourne Spit belongs to Welsh Water. It has some 3Kms of concrete sea wall, constructed in the early 1980's. However beach levels in front of the wall continue to fall.

The tip of the spit is prone to erosion and is protected by about 400m of rock filled earth embankment. On the south bank of the Mawddach estuary Welsh Water are responsible for the shoreline upstream to Penmaenpool. The whole of this low lying area is now protected by earth embankments, these having been completed in 1981.

From near Penmaenpool downstream to Garth (on the north bank of the estuary) minor earth embankments are fronted by saltings, and protection to this low lying area is the responsibility of either Welsh Water or the County Council (where the road runs close to the water line). Further downstream the road runs very close to the shore and the bank from Garth to Barmouth Harbour is protected by masonry walls, which are the responsibility of the County Council.

Barmouth is situated on a narrow coastal plain north of the estuary mouth. There are extensive sand flats at the mouth of the estuary which are accreting and which help to protect the southern part of the town frontage against wave action. Further protection is given to the harbour area which is within the estuary mouth by a breakwater constructed on a northwest/ southeast alignment on the sand bank called Ynys y Bawd. The sand beach at the southern end of the town is backed by some 900m of concrete sea walls and rock revetment, and this frontage has no serious problems. Further north to Llanaber a stepped concrete sea wall capped by a wave wall protects the coast for a distance of about 3Kms. Erosion and damage to the sea wall apron at the northern end of the frontage has caused concern and a proposal was in hand to renew this in 1982. The foreshore is heavily groyned and the groyne system extends beyond the north end of the sea wall in an attempt to slow down terminal erosion. From Llanaber the railway line runs very close to the crest of the shingle ridge and the seaward face of the railway embankment is protected by rock armouring over a distance of about 1Km.

From Llanaber to the promontory of Shell Island the foreshore consists mainly of sand and there are extensive dunes protecting the low lying hinterland. A large area at the northern end of this coast is the nature reserve of Morfa Dyffryn. This coastline is subject to erosion and the dune system is badly eroded in the vicinity of numerous holiday camps. Some attempt has been made to stabilise the dunes by fencing off the most badly affected areas. The only coastal defences at present consist of some 500m of timber revetment near the south end of the frontage. Possible upgrading of the defences here is under consideration.

Shell Island (or Mochras Island) is formed of boulder clay and overlain by sand dunes. This island has a beach of sand and boulders with a glacially formed causeway of boulders, running out at an angle to the coast. The island is in name only and is now part of the continuous dune foreland which extends to Bar Newydd, enclosing the estuarial saltings of the River Artro.

From Shell Island to Llandanwg, responsibility for the protection of the coastline belongs to Welsh Water and British Rail. The estuary of the River Artro is protected by discontinuous earth embankments. A rock embankment also protects the private harbour on Shell Island on the south side of the estuary. The narrow spit on the north shore of the estuary is badly eroded and the line of dunes is now very thin. The crest of the beach just north of the entrance has a sheet steel piled wall, presumably to stop waves overtopping or breaching this spit. At Llandanwg the line of dunes is also very thin. Erosion in this area is now quite serious with the dune line in danger of breaching. There are short stretches of privately owned coastal defences just north of the church, which give a low degree of protection.

From Llandanwg north to the southern outskirts of Harlech sandy cliffs fronted by a sand and pebble beach, give way to sand dunes. Coast protection north of Llandanwg consists of earth embankments. Responsibility is shared by the District Council and British Rail and there is erosion at the foot of the railway embankment just north of Llandanwg.

Sand dunes extend to Harlech Point, following the northward growth of the spit into the Glaslyn estuary. Much of the hinterland has now been reclaimed. Access points through the dunes at Morfa Harlech are heavily

used and dune erosion and large scale 'blow outs' are evident. The Nature Conservancy Council have carried out a good deal of repair work in the form of sand fencing and localised planting of marram grasses. The area is exposed to Atlantic gales and hence any damage to the dune system is not easily repaired.

The sands of Traeth Bach in the southern part of the estuary are extensive and there appears to be very little in the way of mud deposits. Foreshore rights are leased to the Nature Conservancy Council and the District Council. From Talsarnau to the Afon Dwyryd Toll Bridge on the southern bank of the estuary protection consists of earth embankments and is the responsibility of Welsh Water.

Defences on the north bank of the River Dwyryd (from the Toll Bridge west to Minffordd), are the responsibility of British Rail and consist of earth embankments protecting the railway line.

From Minffordd to Porthmadoc the estuarial shoreline is known as the Penrhyndeudraeth Peninsula and consists of rock cliffs with some sand beaches.

The final kilometre to the District boundary comprises the main road and rail embankment which cross the Glaslyn Estuary to Porthmadoc. Known as 'The Cobb', this rock faced earth embankment is the responsibility of Welsh Water.

The coast protection authority from Porthmadoc to the tip of the Lleyn Peninsula is Dwyfor District Council. Responsibility for the coastal defences along this stretch lies mainly with the District Council with some involvement by Welsh Water, British Rail and private landowners.

Downstream from Porthmadoc to Carreg Samson the north shore of the Glaslyn estuary has a mainly rocky coastline with a sand foreshore and a few inlets. The River Glaslyn runs close to the shoreline along this stretch and hence prevents the build up of any significant sand deposits. Apart from the main stone faced embankment at Porthmadoc itself, which is maintained by Welsh Water, the only coastal defences along this stretch are at Borth y Gest where a 50m long masonry sea wall protects the backshore.

Carreg Samson, just north of Ynys Cyngor, is a large area of sand dunes. The dunes are protected by about 350m of rock revetment, the protection being necessary because of the erosion caused by the River Glaslyn, which has a strong meander at this point. A long, wide sandy beach (Black Rock Sands) stretches north to Craig Ddu. This area is partly the responsibility of the District Council and part Welsh Water although there are in fact no coastal defences. From the headland of Craig Ddu to the outskirts of Criccieth the sandy foreshore is backed by low eroding clay cliffs.

In the embayment east of Criccieth Castle the urban frontage is protected by 100m of rock revetment fronted by groynes built to reduce the rate of 'terminal scour' of the clay cliff. There is then 400m of masonry/concrete sea wall, a 100m length of masonry breakwater and sea wall and finally 75m of stone breastwork. These walls protect clay cliffs. The rocky headland at Criccieth Castle is unprotected. Coast protection along the west beach consists of some 200m of masonry sea wall protecting the road followed by a 250m long concrete sea wall protecting amenity land. The boulder clay cliffs behind the promenade have been dressed back and covered with concrete slabs to prevent weathering. At the top of

cliffs is another promenade. The upper retaining wall has been subject to settlement and a number of the concrete slabs are cracked and joints between other slabs opened out. Erosion/settlement west of the headland is putting some of the properties at risk. The west beach is groyned, but only retains a small amount of shingle and sand.

To the west of the Criccieth, the District Council and Welsh Water share responsibility for about 4Kms of coastline. The thin shingle and boulder beach is backed by low clay cliffs with a low shingle bank further to the west. These cliffs though partly vegetated are clearly eroding and immediately to the east of Criccieth unsuccessful attempts were made to stabilise the beach by means of groynes. These groynes are now largely in disrepair. By comparison with the sand beaches east of Criccieth the foreshore to the west is quite rocky. The only coastal defences consist of a rock revetment about 200m long belonging to Welsh Water. This gives some protection to the spit west of the mouth of the River Dwyfor, this area being liable to flooding. The entrance to the Dwyfor has been deflected eastwards by littoral drift. Judging by the small amount of shingle and sand reaching Criccieth the drift volume is low. This area is fairly well sheltered with the 'wave window' only from the south to southwest. Further westwards the coastline is more open and the drift is somewhat higher.

From the vicinity of Glanllynnau to the River Wen, British Rail protect the main railway line with about 1100m of old masonry and rock sea walls. West of the river Wen, private sea defences of a holiday camp extend for about 2Kms. Beyond the holiday camp the low boulder clay coastline terminates at a rocky head land (Pen y chain). From here there are a series of

sandy bays and rocky headlands enclosing marshland or sand dunes. These bays all indicate a nett west to east littoral drift.

From the rocky headland of Pen y Chain, the first bay comprises sand dunes fronted by a sand and shingle foreshore extending west to Pwllheli. The bay has no coastal defences, the dune system acting as the primary coast protection to the marshy hinterland of Morfa Abererch. This frontage finishes at a rocky foreshore (Carreg yr Imbill) south of the harbour.

The harbour mouth which faces east is flanked by two shingle spits. The form of the spit north of the harbour entrance indicates a local north to south "counter drift" resulting from the sheltering effect of the headland of Carreg y Imbill. The harbour which has a silted up inner harbour area, is protected by masonry, concrete and rock revetments and a privately owned masonry sea wall. The problem of siltation in the harbour, with regards to the development of a marina, was examined by HR in a recent study where it was found that due to the sheltered nature of the harbour area and the low tidal current velocities through the entrance, siltation would continue to take place in the future. It was concluded that although the sea bed was generally free of silt outside the harbour, the eroding boulder clay cliffs of the Lleyn Peninsula (west of the harbour) are a source of suspended silt and mud.

The South Beach of Pwllheli is part of a long sand spit backed by shingle. The spit shelters the harbour from wave action but promotes conditions which lead to siltation. From Carreg y Imbill to the South Beach the spit is backed by sand dunes. It is unprotected except for a short length of sea wall near the rocky outcrop of Carreg y Imbill. Along the South Beach

esplanade, coast protection consists of a 1Km long masonry sea wall almost buried in sand. The beach is accreting and forming sand dunes, presumably because of the healthy west to east littoral drift of sand. The main problems along this frontage is that the dunes are heavily used and are subject to erosion giving wind blown sand onto the esplanade.

West of the esplanade, some 1.2Kms to the golf course, the sand dunes form the primary defence against flooding by the sea. In front of the golf course the dunes are protected by some 400m of rock revetment. Here also dune erosion is due to overuse.

The bay between Pwllheli and Llanbedrog is sub-divided by the rocky promontory of Carreg y Defaid. A 400m length of rock revetment has been constructed by Welsh Water, just east of Carreg y Defaid at the toe of the sand dunes. The dunes here are fronted by a shingle and sand beach and are subject to erosion locally.

From Carreg y Defaid to Abersoch the coastline comprises of sand bays backed by dunes, separated by rocky headlands. The foreshore is wide and composed of sand and shingle. There are no coastal defences along this stretch other than a rubble revetment which protect the dunes fronting a private holiday area north of Abersoch. Where there is no protection the dunes are eroding.

Abersoch faces east and has two beaches separated by a rocky headland. Immediately north of Abersoch, backing the sandy beach, there is a 150m length of masonry and concrete sea wall protecting private properties. The area is well sheltered from wave activity and although the walls are somewhat dilapidated there appears to be no serious problem with regard to coastal defence.

From Abersoch to Marchros a wide sand beach is backed by dunes which form the primary protection to low lying land behind. There appears to be no shortage of sand and the beach huts at the toe of the dunes sometimes become partly buried in sand. However, there is some erosion due to public overuse, especially in the southern half of the bay. Here protection to the dune toe comprises 110m of rock revetment followed by a 900m long concrete sea wall. The sand beach is groyned and there is accretion at the southern end of the beach (as the result of counter drift). The problems in this area, unlike unlike much of the eroding West Wales coastline, appears to be due to man's interference with the natural coastal processes. At Porth Tocyn at the southern extremity of this bay, the coast protection consists of a 50m long concrete sea wall and a 150m long rock revetment.

The final stretch of coastline to Aberdaron Bay is largely undeveloped and consists of clay cliffs and rocky promontories enclosing sandy beaches. There are no coastal defences along this stretch although an extensive rock revetment and cliff slope drainage scheme have been proposed for the western end of Porth Neigwl. Erosion of the boulder clay cliffs is rapid and some properties at the cliff top are at risk both at the eastern end and at the western end of the bay. The sand fraction from the eroding cliffs goes toward maintaining the wide sand beach. The fines are transported seawards by rip currents and may then be transported eastwards in suspension by tidal currents. The bay faces into the direction of the predominant south westerly waves and the nett movement of beach material is low especially as the bay is flanked by major headlands.

In the eastern part of Aberdaron Bay also the clay cliffs are subject to erosion and landslips. There is a short (70m) length of rubble revetment followed by about 300m of rubble revtment held by piled rails to the east of the town. This revetment is presently being upgraded into a sea wall and extended eastwards. The properties at the cliff top are at some risk in this area. Part of the current upgrading involves the stabilisation of the clay cliffs. As at Porth Neigwl the beach is orientated to the direction of the predominant wave attack and although there are lateral movements of beach material there is almost certainly little nett drift. Fines from the eroding clay cliffs are not seen on the beach and must therefore be carried offshore in suspension. The coast is too exposed to Atlantic waves for there to be any possibility of fines being retained for any length of time within the inter tidal zone. The town frontage is protected by a vertical masonry sea wall. To the west of the town the boulder clay cliffs are subject to toe erosion and protection consists of a massive 300m long sloping rock revetment which follows the cliff slope seawards. It is probably intended to act as toe weighting as well as cliff toe protection. Despite the cliff erosion problems there is little evidence of beach erosion at Aberdaron and at times large quantities of windblown sand build up against the sea wall. The beach is of coarse sand and shingle and is quite steep on the upper foreshore.

5.2.5 Aberdaron to Menai Bridge

The north side of the Lleyn peninsula consists of cliffs fronted by a narrow strip of foreshore except in the most strongly indented embayments where there are quite wide sand beaches. At Dinas Dinlle at the northern end of the peninsula the cliffs give way to a spit of shingle backed by sand dunes which extends

into the Menai Strait. The coastline including Anglesey has three coast protection authorities; Dwyfor District Council, and the Borough Councils of Arfon and Ynys Mon.

The Dwyfor District frontage extends from Portmadoc to just north of Aberdesach and defences are almost entirely the responsibility of the District Council. From Aberdaron around the tip of the Lleyn Peninsula to Porth Dinllaen the coastline consists almost entirely of rocky cliffs. There are several long sandy beaches and coves but very few coastal settlements and no coastal defence works.

Porth Dinllaen at the western end of Porth Dinllaen Bay, has a wide sand beach with some shingle on the upper foreshore. The small harbour is sheltered by the rocky headland of Carreg Ddu to the west. The shelter against the predominant waves is so great that there is a counter drift within the bay, the nett movement of beach material being from east to west ie towards the headland. Coast protection in the more exposed eastern part of the bay consists of some 850m of rock revetment a 60m length of sea wall and groynes. The cliffs in this area are of boulder clay and some drainage works have been carried out to stabilise them.

The coast to the east is cliffed with several sandy coves sheltered by headlands. At Porth Nefyn there is a crescent shaped bay with a sand lower foreshore and a shingle upper beach. The harbour is below steep clay cliffs and is protected by a concrete breakwater. To the south and east of the harbour concrete sea walls and a short length of rock revetment protect the cliff toe over a frontage of about 650m. There is some erosion to the north east of the access road due to cliff erosion and some properties could be at risk

as a result. The general direction of the nett littoral drift along this coastline is towards the north east. However due to the shelter of the Penrhyn Nevin headland at the east end of the bay there is a local reversal in drift direction. At Trevor there is another small harbour sheltered by a stone jetty with sea walls and groynes immediately to the west protecting the cliff toe. The car park south of the jetty is fronted by a pebble beach and does not appear to require protection at present. From Trevor to the District boundary near Aberdesach the coastline is mostly of clay cliffs. Here there is a pronounced north easterly drift. The foreshore is a mixture of boulders, pebbles, shingle and sand and is unprotected.

The coast protection authority from Aberdesach to Fort Belan at the entrance to the Menai Straits, is Arfon Borough Council. Of this short stretch of coastline over half is privately owned. From Aberdesach to Dinas Dinlle, the coastline has unprotected eroding boulder clay cliffs, fronted by shingle beaches. From Dinas Dinlle to Morfa Dinlle the eroding shingle beach is protected by a gabion revetment. This consists of a shingle and sand spit which extends northwards into the Menai Straits as a result of north to south littoral drift. The land behind the spit has become naturally reclaimed. The northern end of the spit has widened as a result of landward migrating sand dunes. In recent years the supply of pebbles from the south has dwindled and the shingle ridge is now declining quite rapidly and the hinterland is at risk of flooding. The gabion revetment north of Dinas Dinlle is beginning to break up as a result of falling beach levels. The abrasive action of beach pebbles against the gabion wires is also causing damage to the gabion boxes. The situation is exacerbated by the fact that the road runs along the crest of the shingle ridge and

prevents the ridge from migrating landwards naturally (all shingle ridges which are backed by low lying land tend to migrate land wards as pebbles are thrown over the crest during severe storms). The Borough Council is considering coastal works here.

This shingle spit continues north to Fort Belan and is the only protection along this privately owned, low lying area which is in danger of inundation. The exception is about 200m of rock revetment protecting Fort Belan at the distal end of the spit. West of the spit some 10Kms of shoreline (including Foryd Bay) is generally unprotected except for a few privately owned walls. The upper foreshore is shingle while within Foryd Bay there are extensive areas of salt marsh. The private sea walls are concentrated on the east side of Foryd Bay, an area which is liable to flooding. A further 500m of low lying land to the outskirts of Caernarvon is protected in part by a gabion wall capped with concrete. The wall backs the shingle foreshore which is eroding. The town of Caernarvon has masonry walls over a frontage of 3Kms, these being maintained by the Borough Council. Here also the foreshore is shingle (the Strait hugs the south shore in this area, hence the lack of sand deposits). East of Caernarvon the Strait becomes narrower and here too the narrow foreshore consists of shingle. The stretch from Caernarvon to Port Dinorwic is generally unprotected except for some short lengths of privately owned sea walls.

At Port Dinorwic there is a 200m length of concrete sea wall which was built to protect land reclaimed from the sea. In Dinorwic itself there are about 1000m of privately owned masonry walls which form the harbour and quays. The harbour once exported slate but now provides berths for pleasure craft. From

Dinorwic to Menai Bridge the narrow rocky foreshore is protected by privately owned sea walls.

5.3 The Isle of Anglesey and Conwy Bay

The coast protection authority for the Island is Ynys Mon Borough Council. Responsibility for coastal defence rests almost entirely with the Council except for a small stretch on the south west part of the Island bordering the Straits which is the responsibility of Welsh Water. There are also some private landowners with a coastal frontage. Large areas of sand dunes figure prominently on the south west coastline of Anglesey.

5.3.1 The Menai Bridge to Carmel Head

From the Menai Bridge west to Abermenai Point, the coastline has few coastal defences, although there are short lengths of privately owned sea walls. At Pwl-fanogl some 3Kms west of the bridge, there are eroding clay cliffs, though this does not appear to be putting any properties at risk. Further west much of the land is low lying and liable to flooding. However few measures seem to have been taken to protect this sparsely developed stretch of coast. Newborough Warren at the entrance to the Menai Strait forms the largest area of sand dunes on the west coast of Britain. A relatively narrow sand and shingle spit extends eastwards from the Warren into the Strait terminating at Abermenai Point. To the landward (west) of this spit is a large area of intertidal sands called the Traeth Melynog. At Abermenai Point an old, 700m long rock armoured breakwater was re-constructed about 10 years ago. The breakwater is there to prevent the narrow spit from breaching.

From Abermenai Point north west to Llanddwyn Island and then as far as Maltreath, the low lying shoreline is protected from flooding by sand dunes or salt marsh. The north shore of the Maltraeth estuary is in private ownership. Coast protection is the responsibility of Welsh Water but there are generally few problems in this area.

A hard rocky coastline extends from this estuary north to Aberffraw Bay which has a wide sand beach backed by dunes. North west of here the hard rocks give way to softer, eroding clay cliffs (eg at Porth Cwyfan, 2Kms west of Aberffraw). These are largely unprotected. There is little in the way of littoral drift here, because of the indented nature of the coast.

At Porth Trecastell, some 3Kms north west of Aberffraw, the Council maintain a 20m long masonry retaining wall backing the sandy cove. This wall is being undermined by falling beach levels. There is erosion of the clay cliffs taking place at Porth Nobla. Further north at Cerrig y Defaid there are some privately owned sea walls but these walls seem inadequate as a means of coastal defence. Indeed the primary protection to the low lying land from Porth Trecastell to Rhosneigr are sand dunes.

The village of Rhosneigr has a sandy beach fronted by a rock platform. Protection along this frontage is in private ownership and comprises masonry, concrete and gabion sea walls. The gabion walling is about 250m long and situated at the northern end of the village. The coastline is "soft" but sub divided by headlands and rock platforms and the nett littoral drift is very weak and locally variable in direction.

For the next 21Kms northwards the mainland is sheltered by Holy Island. The very limited littoral

movements are controlled by the tidal currents between Holy Island and the mainland. Here the low lying land is largely the responsibility of Welsh Water and the coast is predominantly of sand dunes or marsh. The only large scale coastal defences are about 500m of gabion mattress revetment protecting M.O.D. property at R.A.F. Valley. The condition of the revetment is not known but this type of coastal defence is liable to rapid wear and has a relatively short design life. There are many creeks and inlets between the mainland and Holy Island, none of which are exposed to serious wave activity. There are no serious coastal defence problems here.

From Silver Bay to Borthwen around the Atlantic shore of Holy Island, there are rocky cliffs. As with most of the coastline of Anglesey, this particular stretch is undeveloped and generally undefended. In Borthwen Bay, the sandy beach is backed by dunes, protected by 250m of gabion wall and some 200m of masonry and concrete sea wall maintained by the Borough Council.

Hard rocky cliffs extend between Borthwen Bay and Treaddur Bay. The east face of Holy Island is strongly indented and although there are a number of sand beaches there is little or no interchange between them and the littoral drift is insignificant.

In Treaddur Bay, a sandy beach is backed by a 500m long concrete capped old masonry sea wall which was last re-constructed in 1980.

From Treaddur Bay around to the headland of North Stack the coastline has high rocky cliffs, a narrow foreshore and little in the way of beach deposits, hence no significant drift.

From North Stack to the Holyhead breakwater the coastline consists of high rocky cliffs and very little in the way of foreshore deposits. The massive breakwater which protects Holyhead harbour from northerly waves is owned by the Harbour Authority. It is built of local stone and concrete and forms the northern arm of the New Harbour. The southern shore of the harbour is maintained by the Borough Council and has a total frontage of about 2Kms of masonry sea wall and is groyned. Some groynes are in a poor condition. South east of the New Harbour is Old Harbour and the Sealink Ferry Terminal. Protection to the harbour frontage comprises of masonry sea walls.

East of the Old Harbour, low clay cliffs are unprotected except for a 500m length of gabion sea walls at Penrhos beach. This was placed about 10 years ago to deter erosion of the clay cliffs at this point.

The coastline from here to Carmel Head on the mainland has little in the way of coastal defences. The only protection is to the Stanley Embankment connecting Holy Island to Anglesey. The coast of Anglesey to Porth Penrhyn Mawr has low clay cliffs or sand dunes. The wide foreshore is sandy but there are also shingle deposits on the upper part of the beach.

From Porth Penhryn Mawr to Porth Tywyn Mawr there are rocky cliffs. The sandy foreshore of Porth Tywyn Mawr is backed by sand dunes and there are no coastal defences.

From Porth Tywyn Mawr to Carmel Head there are again rocky cliffs, with a number of sand and shingle beach es in the embayments. Littoral drift along this frontage is insignificant.

5.3.2 Carmel Head to Puffin Island

From Carmel Head to Cemlyn Bay, the coastline is of hard, cliffs and a rocky foreshore with little in the way of beaches. In Cemlyn Bay a shingle storm ridge impounds a tidal lagoon and on the backshore a 750m long rock revetment has been constructed by the National Trust to protect the land from flooding.

From Cemlyn Bay to Cemaes Bay the coastline continues as hard rocky cliffs and there is no perceptible littoral drift. Within Cemaes Bay there are five separate pocket beaches, three of which are lagely of sand and two of sand and shingle. The coast road at the village of Cemaes is protected by the County Council and comprises some 750m of masonry and concrete sea wall. At the north end of the bay the cliffs are overlain by boulder clay which is eroding without presenting serious problems.

From Cemaes Bay to Amlwch the coast consists of hard, rocky cliffs with again very little in the way of littoral drift. At Amlwch the harbour authority look after some 1500m of masonry sea walls within the port area.

From Amlwch to the north end of Dulas Bay the rocky coastline has no protection other than at Porth Eilean where some 200m of gabion sea wall back a beach of sand and pebbles.

From north of Dulas Bay to south of Lligwy Bay, the coastline comprises of clay cliffs and sand dunes. The eroding cliffs are unprotected and some cliff top properties are at risk at the southern end of Lligwy Bay. Dulas and Lligwy Bays are separated by a small promontory but there is undoubtedly an interchange of material between the two.

Eroding limestone cliffs extend from Lligwy Bay to Moelfre. Some properties on the headland to the east of the town centre are at risk due to cliff instability. The Council maintain short lengths of masonry sea walls at Moelfre.

Eroding limestone cliffs continue to Benllech. At Benllech Sand, the coastline consists of about 1.25Kms of fossilised clay cliffs fronted by sand dunes. The County Council maintain some 300m of masonry wall, protecting the road which runs close to the shore along the town frontage.

The limestone cliffs continue south from Benllech into Red Wharf Bay. The County Council maintain a further 300m of masonry wall protecting a road in the village of the same name on the west shore of the bay. The next 6.5Kms of coastline within Red Wharf Bay is low lying and comprises sand dunes and alluvial deposits. There is a vast expanse of sand within the bay with the intertidal zone some 2Kms wide at low water. Apart from the short length of wall at Red Wharf Bay village, there are no coastal defences in the area.

East of Red Wharf Bay there is a 1km stretch of low clay cliffs which are subject to erosion. From here on to Puffin Island, the cliffs are made up of carboniferous limestone and there are no coastal defences. The inter tidal zone is narrow and rocky and there is no significant littoral drift.

5.3.3 Conwy Bay

Included here is the south coast of Anglesey from Puffin Island to the Menai Bridge. The mainland considered here extends from Menai Bridge to Great Ormes Head where the coast protection authorities are the borough councils of Arfon and Aberconwy.

On the Isle of Anglesey the Ynys Mon Borough Council are the authority for the coastline from Puffin Island to Menai Bridge. Gwynedd County Council maintain some 600m of wall along this frontage where the coast road runs close to the water line at several points.

The coastline from Puffin Island to Beaumaris is largely unprotected. The limestone cliffs adjacent to Puffin Island revert to clay cliffs further west and these are subject to erosion. Lavan Sands dampen wave activity at the shoreline so the area does not have serious problems with regard to coast protection. However, in Lleiniog Bay a gabion mattress protects part of the eroding clay cliffs and other stretches have been fenced off. Near Tre-castell erosion of clay cliffs is putting some properties at risk. Just north of Beaumaris the rate of cliff retreat is substantial but here no properties are at risk. At Beaumaris the Council maintain about a kilometre of the town frontage which is protected by masonry sea walls and a concrete revetment.

Between Beaumaris and Gallows Point the County Council maintain some 600m of masonry sea wall which protect the coast road. The foreshore here is of shingle and alluvium and the frontage is subject to erosion which is probably related to tidal flows within the Strait (since the area is well sheltered from wave action). Gallows Point itself juts out into the inter tidal zone and is protected by gabions. From Gallows Point to the Menai Bridge the hard rocky coastline has no formal coastal defences except for a 200m length of high masonry retaining wall adjacent to the bridge.

On the mainland Arfon Borough Council have responsibility for the coastline from the Menai Bridge east to Llanfairfechan.

East from the Menai Bridge to Bangor there are a number of short stretches of privately owned and maintained sea walls and embankments. The urban frontage at Bangor is maintained by the Borough Council and consists of some 500m of masonry sea wall and about 300m of gabion wall further east. At Port Penrhyn just to the east the harbour authority maintain about 1500m of masonry sea walls. East of Port Penrhyn the shingle upper foreshore is backed by various privately maintained sea walls in varying condition. This frontage is sheltered from wave action by the wide expanse of Lavan Sands. However, on the Borough boundary near Madryn, the low lying land is liable to flooding. Sea walls and revetments protect this frontage.

From Madryn the Aberconwy Borough Council are the coast protection authority and their jurisdiction extends to Great Ormes Head and beyond.

East of the Borough boundary to Llanfairfechan the coastline is in private ownership. At the west end defences comprise a rock armoured earth embankment, followed by a masonry sea walls fronted by timber groynes.

The urban frontage of Llanfairfechan is maintained by the Borough Council. The concrete sea wall fronts the promenade and the shingle foreshore is groyned. The lower foreshore consists of very wide sand flats which reduce wave energy to such a degree that there is no pronounced littoral drift of shingle on the upper part of the beach. However, beach lowering is taking place in this area and the concrete wall at the east end of the frontage has rock armouring at its toe. East of Llanfairfechan, British Rail maintain about 1.5Kms of masonry sea wall beyond which a limestone headland juts out into the bay. East of the headland the

British Rail sea wall continues for a further 200m to the outskirts of Penmaenmawr. Construction of a new trunk road (the A55 Coast Road) is currently taking place. Because of the high cliffs immediately behind the village, the A55 (North Wales Coast Road) is being routed across the upper part of the foreshore and a new promenade is to be rebuilt some 30m seaward of the existing one. The upper foreshore is presently stable and consists of cobbles. Littoral frift along this frontage is low due to the small 'wave approach window'. The nett direction of drift is in a west to east direction. Once the road has been built the promenade will be reconstructed and a 'renourished' cobble beach placed in front of it. As part of the A55 reconstruction scheme Hydraulics Research have carried out a number of studies. Some of these studies were in connection with the design of the seaward embankment which will consist of concrete armour units and also in connection with beach replenishment in front of the proposed promenade (see Bibliography). Because of the embayed nature of the coast and the low rate of littoral drift the problems of maintaining a beach seaward of its present position are not expected to be serious.

Between Penmaenmawr and Dwygyfylchi, British Rail maintain about 850m of masonry sea wall followed by some 150m of timber revetment fronted by groynes. This section is also fronted by a shingle foreshore overlying a flat sand lower foreshore.

The privately owned frontage at Dwygyflchi has no coastal defences and consists of a clay bank backing a shingle beach. This is subject to erosion and properties are liable to be at risk. Beyond Dwygyflchi, British Rail maintain a 450m long masonry sea wall extending almost to Penmaen-bach Point. This wall is fronted by groynes on a sand and shingle

foreshore. The A55 coast road will run to the seaward of these defences and the heavily armoured seaward face of the road embankment will forego the need for any further coastal defence works along this frontage. Beyond the rocky headland of Penmaen-bach Point the coastline changes to the low lying estuarial valley of the Conwy. Conwy Morfa has a large sand and shingle spit with salt marsh area which has become reclaimed from the sea and is now covered by sand dunes. The coastline of Conwy Morfa is undefended except for some low cost measures designed to prevent dune erosion, including brushwood fencing and marram grass. The new A55 North Wales Coast Road will run across Conwy Morfa on an embankment and will extend partly across the Conwy over reclaimed land. It will then cross the estuary in an immersed tube tunnel and will then run on an embankment built on reclaimed land on the east shore of the Conwy (to the north and south of Llandudno Junction). From there it will take an inland route eastwards to Colwyn Bay. The Conwy crossing is Britain's largest single road contract and many hydraulic and numerical model studies have been carried out by Hydraulics Research to assess the feasibility of sinking the submerged tube into place and assessing the impact of the reclamation on the estuarial regime. Other ancillary studies have included both field investigations and desk studies (see Bibliography for a selected list of reports).

The west bank of the estuary in the vicinity of the A55 crossing, about 900m long, has no artificial defences and comprises mudflats and saltings. There will be no coastal defence problems in the foreseeable future, however, as the reclaimed land will be protected to a high standard. The Conwy frontage upstream of the crossing, including the harbour area, is protected by masonry sea walls.

There are no coastal defence works along west shore of the Conwy upstream to the schedule 4 boundary at the Tal-y-Cafn Bridge.

Along the east bank of the Conwy estuary from Tal-y-Cafn bridge north to Deganwy there are few coastal defence works except for the railway embankment and some fragmentary private defences. (The frontage in the vicinity of Llandudno Junction will be protected by the A55 road embankment.) The eroding low clay cliff coastline at Deganwy is fronted by a storm beach of sand and shingle. Coast protection here comprises some 400m of concrete sea wall backed by a promenade. A gap of about 100m is followed by 600m of permeable, rock filled timber revetment to the north. Constructed in 1980, the revetment protects low clay cliffs which are covered by embryo dunes. From Deganwy to Llandudno West Shore, sand dunes are the only protection. Some erosion is taking place along this frontage but it is not serious as it affects no properties (the foreshore is backed by golf links). A large rock breakwater has been proposed, which would be sited just north of the timber revetment. Another large breakwater is proposed further northward and it is proposed to nourish the frontage in between with imported beach material. At Llandudno West Shore the urban coastline is protected by 750m of stepped concrete revetment fronted by groynes. This area has a long history of damage and remedial works have been taking place for a number of years. Reconstruction to the revetment and groyne system took place in 1980 but the sea wall in this area is still in a rather poor condition. The foreshore here is wide and of sand and shingle.

North of Llandudno west shore, the Borough Council maintain a 500m long section of masonry sea wall supporting the road around to the Great Orme. This

wall too, is in rather poor condition. It is intended to construct the northern of the two massive breakwaters (mentioned above) in this area. It is intended that this scheme should give added protection to the wall.

The Great Orme headland is unprotected. The Head is a major divide with regard to littoral movement and changes in the Conwy Estuary can be considered as independent of beach change taking place on the Llandudno north shore and vice versa.

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FIGURES

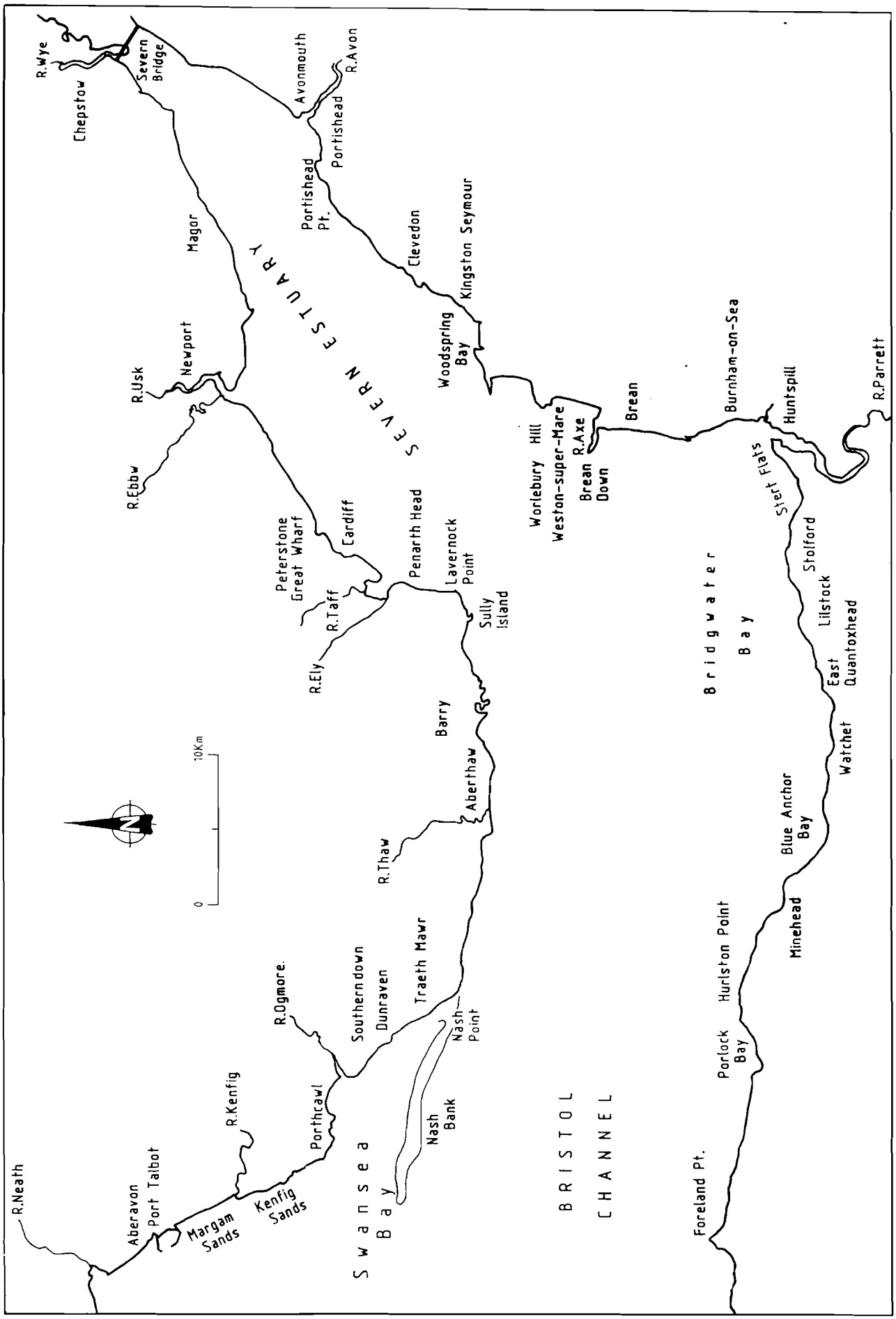

Fig 1 The Wye to Port Talbot

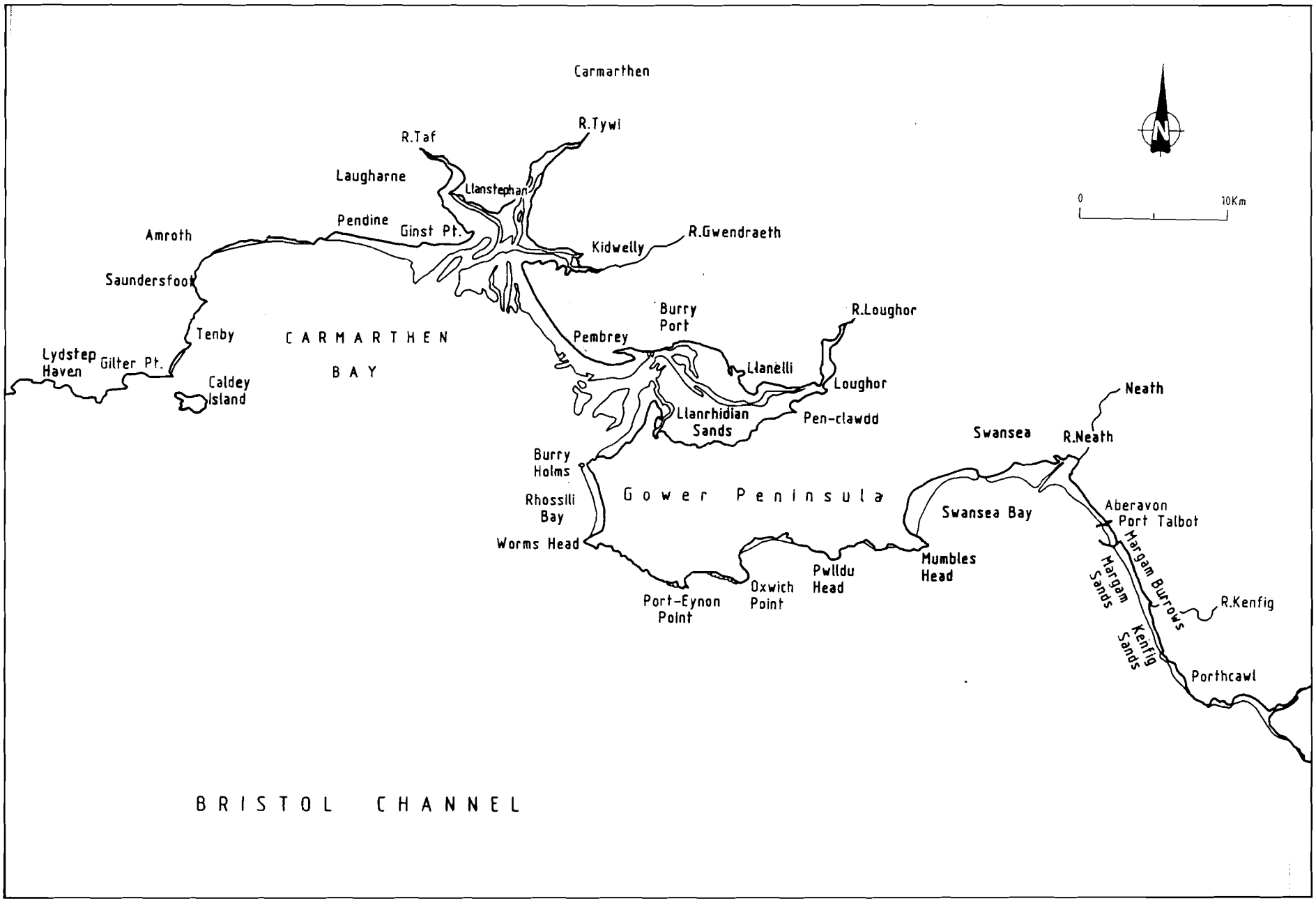

Fig 2 Port Talbot to Caldey Island

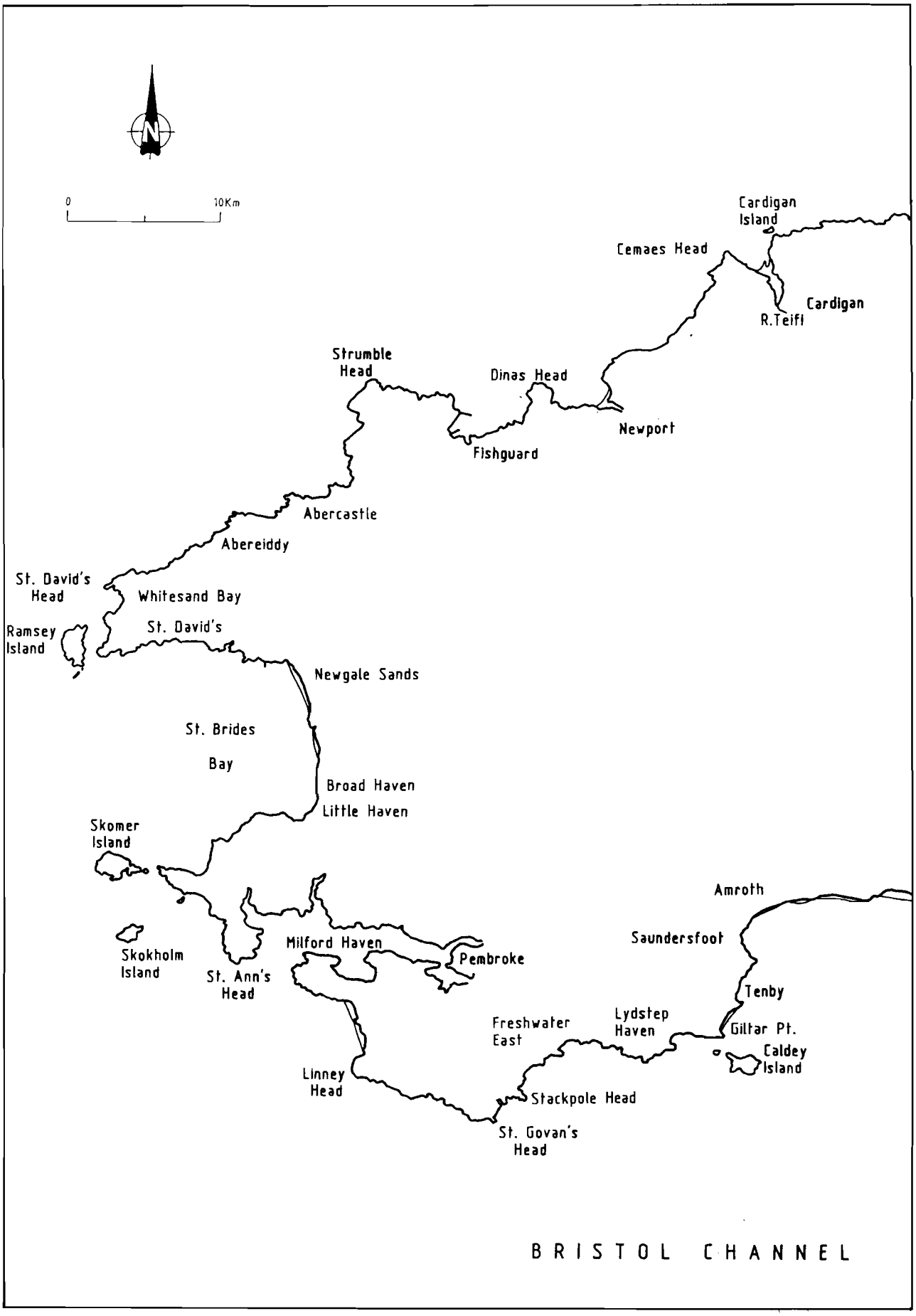

Fig 3 Caldey Island to Cardigan Island

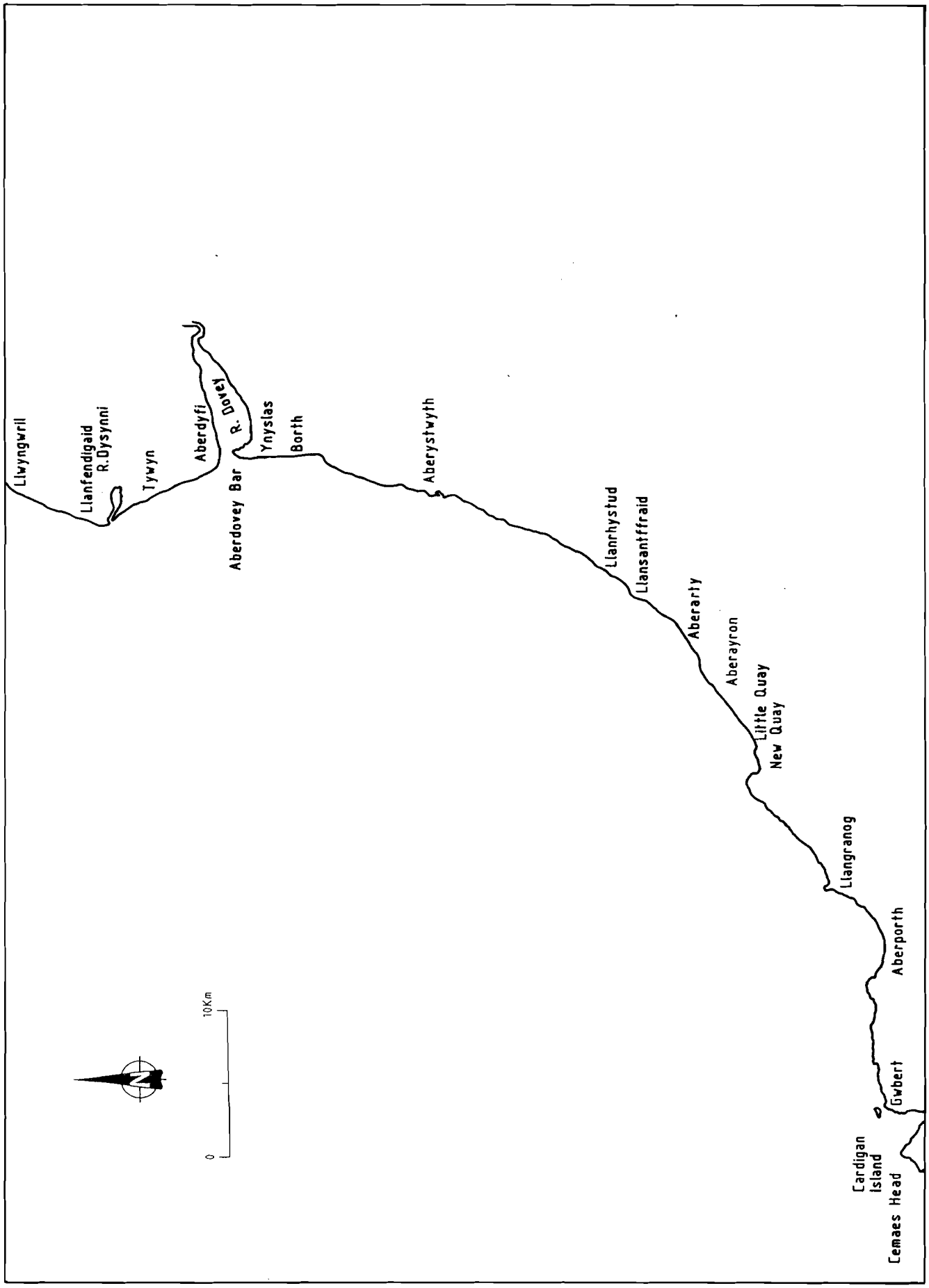

Fig 4 Cardigan Island to Llwyngwril

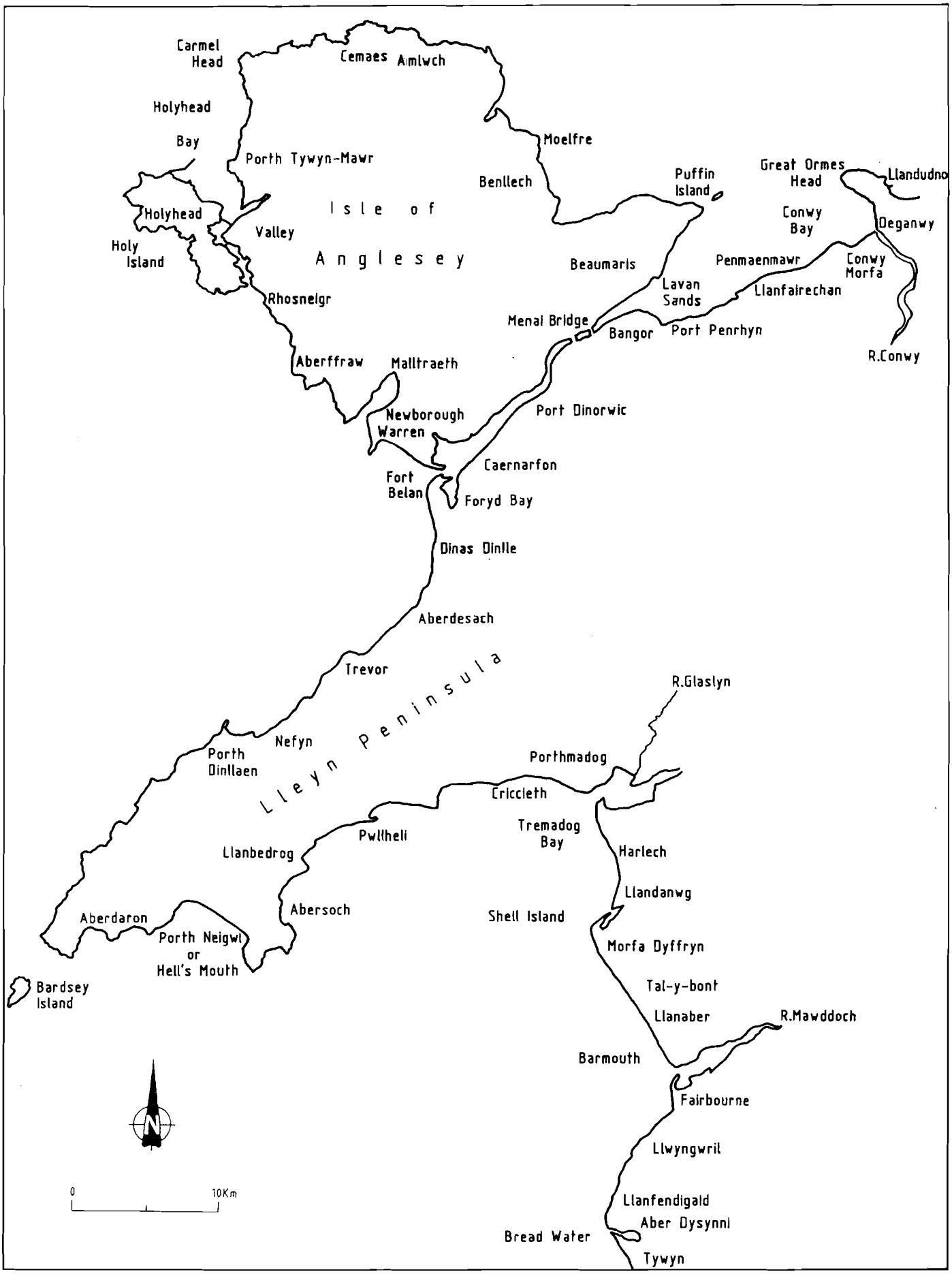

Fig 5 Llwyngwril to Great Orme's Head