ENVIRONMENTS OF DEPOSITION IN THE CARBONIFEROUS LIMESTONE OF SOUTH EAST GOWER

1. ABSTRACT

The area of study on the South East coast of Gower reveals an almost entire sequence of the Carboniferous Limestone Series deposited on a shallow marine carbonate ramp, dipping at 1 ° or less. There are four main environments represented in Gower. 1. Intertidal flats, with subaerially exposed surfaces, including palaeosol and palaeokarstic development. 2. Near shore lagoons, formed by the restriction caused by barrier bar development. 3. Oolitic and bioclastic shoreface sands, forming exposed barrier bars and shoals. 4. Subtidal open shelf environments dominated by biological activity. The deposits were influenced by periodic storm activity, and by tidal and wave currents, with a warm, humid climate, with strong seasonal variations.

Many of the sequences are progradational seaward, with evidence of falls in sea-level, with the tidal flat deposits representing lowest sea-level, and there is also evidence of transgressions, some of these correlating with world sea-level fall events.

2. INTRODUCTION

The Gower peninsula is located on the south west coast of Wales, on the border of the South Wales Coal field, (Figure 1). The area of study on the Gower comprises the coastline from Oxwich to Mumbles, where the geology is composed entirely of Carboniferous Limestone, that has been subject to folding and faulting, with Quaternary material overlying these Upper Palaeozoic features. The structure and basic geology of the Gower can be seen in Figure 2.

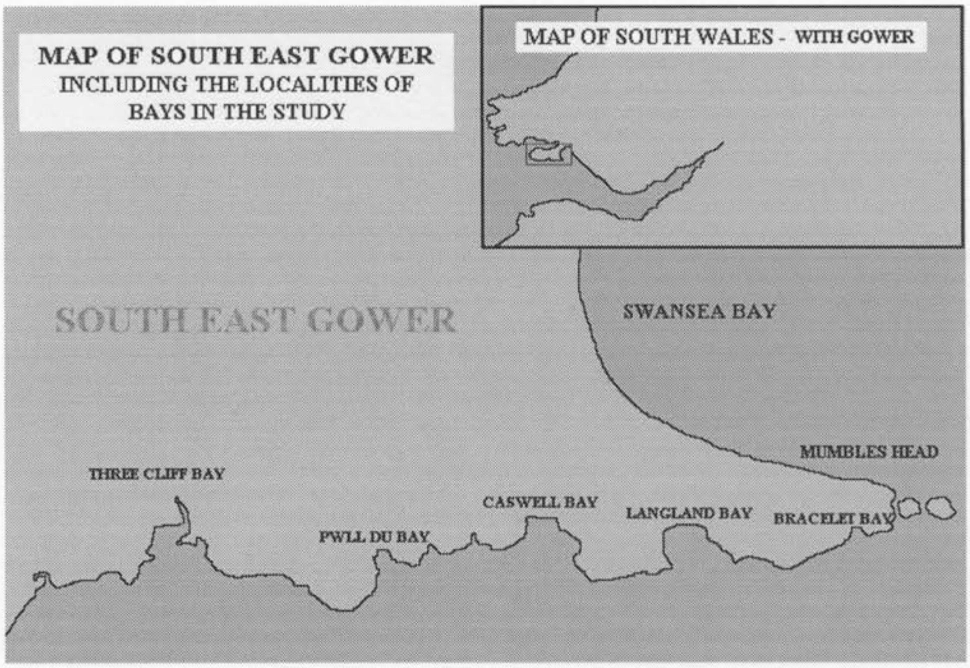


FIGURE ONE:
MAP SHOWING LOCALITY OF GOWER IN SOUTH WALES, AND THE LOCALITIES OF SOME OF THE BAYS STUDIED IN SOUTH EAST GOWER.

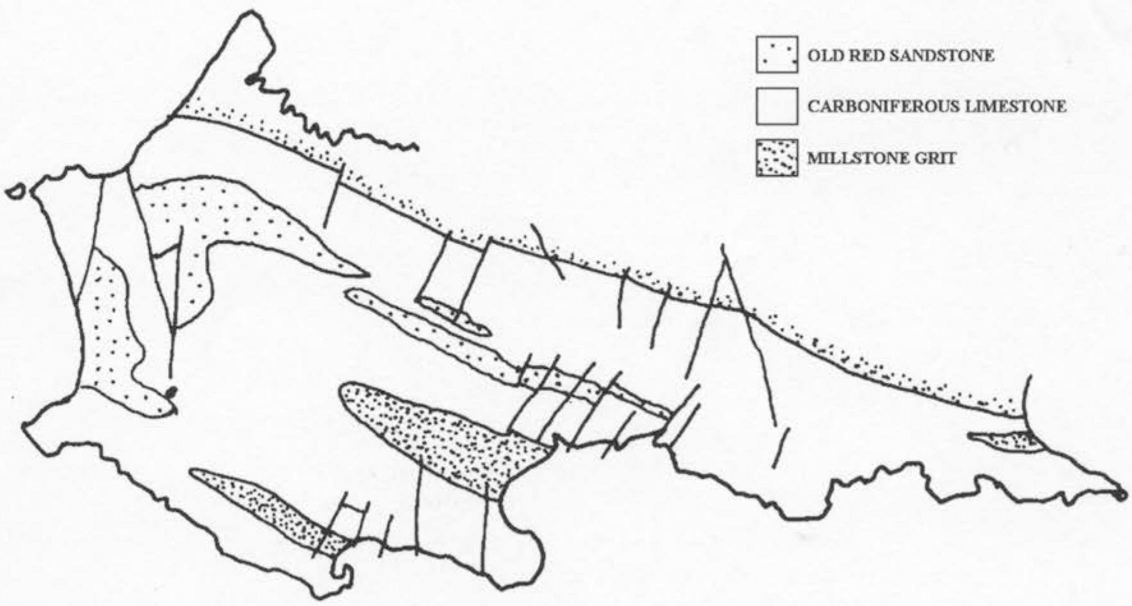


FIGURE TWO: GEOLOGICAL MAP OF THE GOWER, WITH MAJOR GEOLOGICAL BOUNDARIES AND FAULTS.

The beds in Gower directly underlying the Carboniferous Limestone are the Devonian Old Red Sandstone, that were deposited under oxidising non-marine conditions. These merge without a break into the lowermost beds of the chiefly marine Carboniferous Limestone Series. Lying unconformably above the top beds of the Carboniferous Limestone are the beds of the Namurian Millstone Grit, deposited under mainly reducing swampy conditions.

For the purpose of the study the Dinantian Carboniferous limestone has been divided into seven zones that can be recognised lithologically in the field, as almost the entire sequence of the Carboniferous Limestone Series can be seen in the study area. The actual boundaries of these zones can be seen on the field maps made in the course of the study in this area of Gower, these are located as Appendix A. There is a problem in recognising the exact junctions from one zone to the next in these limestones, but there are distinct lithological changes evident that make it possible to differentiate between the zones. Another difficulty with these sequences are the changing names used in the literature, Figure 3 shows the common names used for these rocks in Gower and their correlation with recognised fossil and stratigraphic zones. For the purpose of this study the names of the zones that are most common in the literature are used, (local names used such as Caswell Bay Oolite), although the field maps use the old names, it can be seen from Figure 3, that these are directly transferable.

STAGE	NAMES WITH REFERENCE TO BIOSTRATIGRAPHIC ZONES AND LITHOLOGIES	NAMES WITH REFERENCE TO LOCAL NAMES AND LITHOLOGIES
NAMURIAN MILLSTONE GRIT		
BRIGANTIAN	UPPER LIMESTONE SHALES	OYSTERMOUTH BEDS
	DIBUNOPHYLLUM LIMESTONES	OXWICH HEAD LIMESTONE
ASBIAN		NO DEPOSITION
HOLKERIAN	SEMINULA OOLITE	HUNTS BAY OOLITE
ARUNDIAN	CRINOIDAL LIMESTONES	HIGH TOR LIMESTONE
CHADIAN	MODIOLA PHASE	CASWELL BAY MUDSTONE
	CANINIA OOLITE	CASWELL BAY OOLITE
COURCEYAN	LAMINOSA DOLOMITES	PENMAEN BURROWS LIMESTONE
	LOWER LIMESTONE SHALES	CEFN BRYN SHALES
DEVONIAN OLD RED SANDSTONE		

FIGURE THREE - STRATIGRAPHIC CORRELATION OF ZONES OF THE DINANTIAN OF GOWER.
ADAPTED FROM T.N. GEORGE ET AL, 1976.

The aim of the study is to investigate the sedimentology of the Carboniferous limestone of this area in order to produce models for the deposition of each zone, noting any lateral changes in conditions, for the purpose of providing a model of the sedimentary environments present at that time, especially in relation to sea level changes over the Dinantian period. Each zone is to be described using field observation at appropriate scales and the use of thin sections, also to document sedimentary structure, fossil fauna, petrology and their relationships to determine the probable environments of deposition.

Although much research has been performed on the Carboniferous Limestone Series of the Gower, it should be noted that most of that study has been concentrated on small parts of the sequence, for example R. Riding and V. P. Wright performed facies analysis on one unit, the Caswell Bay Mudstone (Riding & Wright, 1981) and also on an equivalent sequence, the Llanelly Formation (Wright, 1982). One of the most complete accounts of the Dinantian of Gower has been carried out by A.T.S. Ramsay, but this only covers from the Upper Courceyan to the Holkerian stages (Ramsay, 1987). A more generalised study carried out by V.P. Wright concentrates on lateral variations of facies to determine a model for the Dinantian in Gower (Wright, 1986). The study on the South East Gower here is attempting to put together evidence from the whole available sequence, including lateral variations, to provide an overall model for the depositional history of the Dinantian in this area.

3. FACIES AND MICROFACIES DESCRIPTIONS

3.1 CEFN BRYN SHALES

The Cefn Bryn Shales are the lowermost beds of the Carboniferous Limestone and are only seen at one place in the study area, at Three Cliff Bay (Locality 75, Grid Ref: SS53518800, Pages 137-9), with only the upper few metres are exposed. They reveal a variable sequence dominated by dark, thinly bedded, wackestones interbedded with laminated mudstones. Although there is no apparent break in sedimentation between these beds and the Penmaen Burrows Limestone above, the lithological changes here are very apparent.

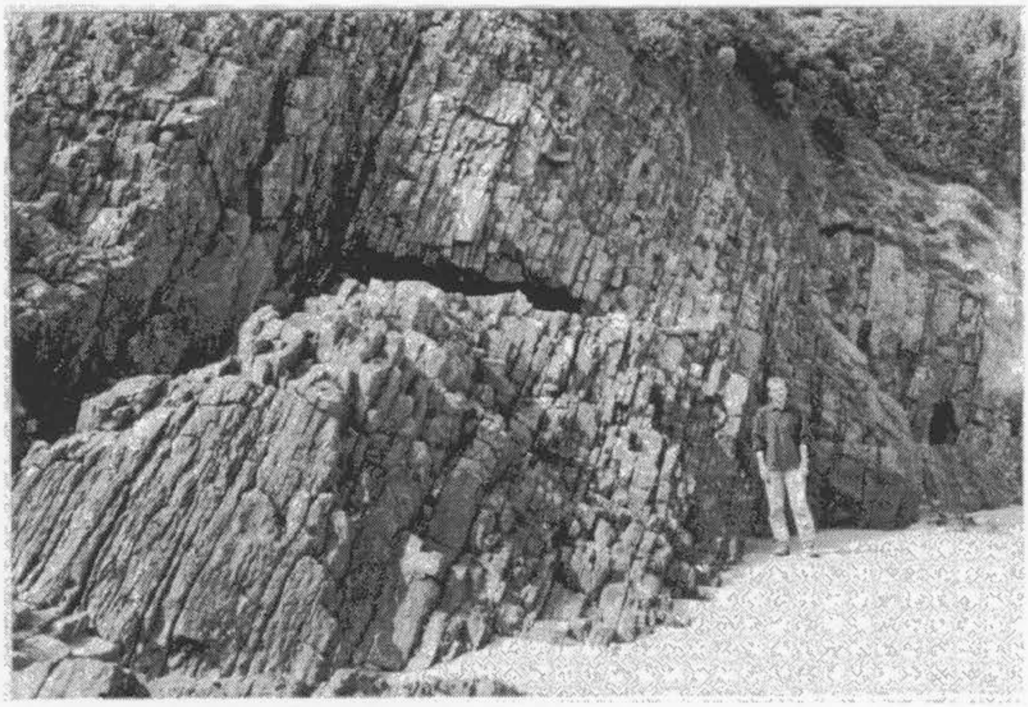
Photograph One: Cefn Bryn Shales, Three Cliff Bay.

The oldest beds of the Carboniferous Limestone at this location, are comprised of a sequence of dark wackestones interbedded both with relatively thick beds of packstone, and also thinly laminated mudstones. These are followed by thinly bedded wackestones interbedded with laminated mudstones. The beds above are medium to coarse grained packstones interbedded with thinly bedded, laminated mudstones. Photograph One, above, illustrates the Cefn Bryn Shales, showing the interbedded wackestones and laminated mudstones.

The topmost beds, underlying the Penmaen Burrows Limestone are comprised of pale grey fossiliferous packstones interbedded with mudstones. These show evidence of horizontal laminations, and small scale undulating laminations. Fossil material is common, with crinoid and brachiopod material, and evidence of bioturbation and burrow formation on many of the bedding surfaces.

3.2 PENMAEN BURROWS LIMESTONE

The eastern most outcrop of the Penmaen Burrows Limestone is seen in Langland Bay, where it has been altered, with evidence of recrystallisation, especially of the fossil material present, preserved by patches of large white crystals. This alteration progressively becomes less towards the west, until at Three Cliff Bay these beds are well preserved, with the structures and details best seen from this locality. Photograph Two below illustrates the beds of the Penmaen Burrows Limestone, with the change from the Cefn Bryn Shales to the right of the picture. The laminated nature of some of the beds can be seen in this photograph.



Photograph Two: Penmaen Burrows Limestone, Three Cliff Bay.

3.2i Caswell Bay

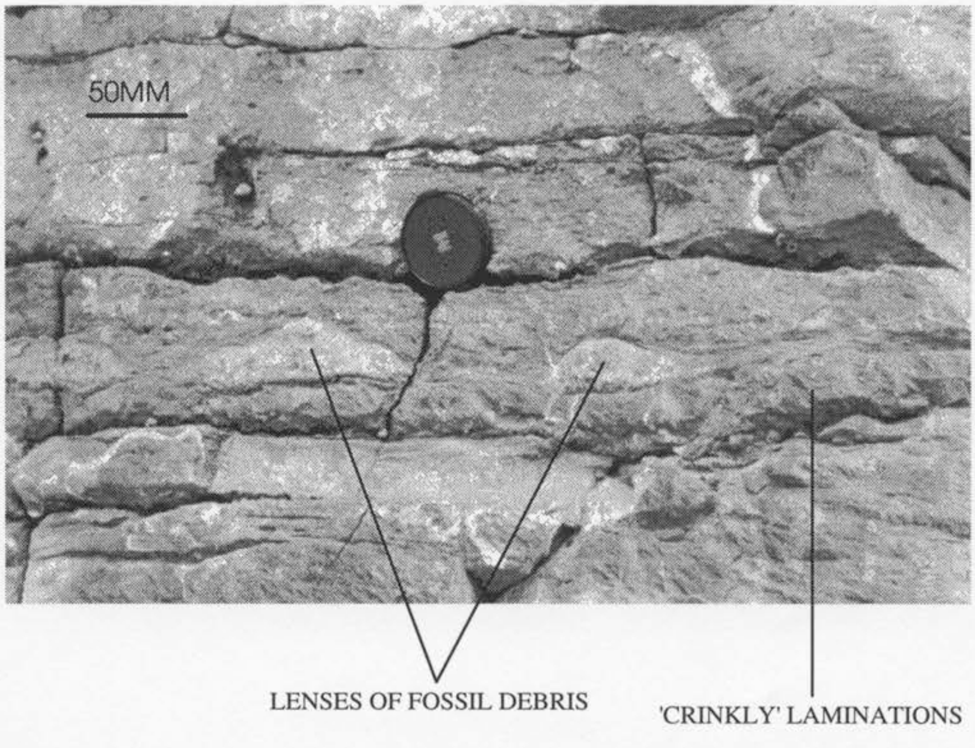
The outcrops of Penmaen Burrows Limestone in Caswell (Localities 41-3 (Pages 74-8, Grid Ref: SS59388740-59548729), 45-6 (Pages 84-6, Grid Ref: SS5935752-5935760) and 48 (Pages 90-1, Grid Ref: SS58968757)) are dominated by dark, thinly bedded wackestones. They are distinctive with their very dark colour and also the lack of fossil material within them. Corals and crinoid fragments are preserved, but much of the fossil material has been obscured by recrystallisation. The lowest beds of this sequence are not seen in Caswell Bay, but the upper junction of the Penmaen Burrows Limestone is seen with a large erosional surface, to be overlain by the Caswell Bay Oolite.

3.2ii Three Cliff Bay

The outcrops of the Penmaen Burrows Limestone are far better preserved and more extensively seen in Three Cliff Bay (Localities 73-5, Pages 132-140, Grid Ref: SS53518800-53958795). Here it is dominated by thinly bedded, dark wackestones, showing many structures, previously obscured by recrystallisation. Photograph Three below shows the Penmaen Burrows Limestone, with the recrystallised appearance of the fossilised material that is present.

Photograph Three: Penmaen Burrows Limestone, Three Cliff Bay.

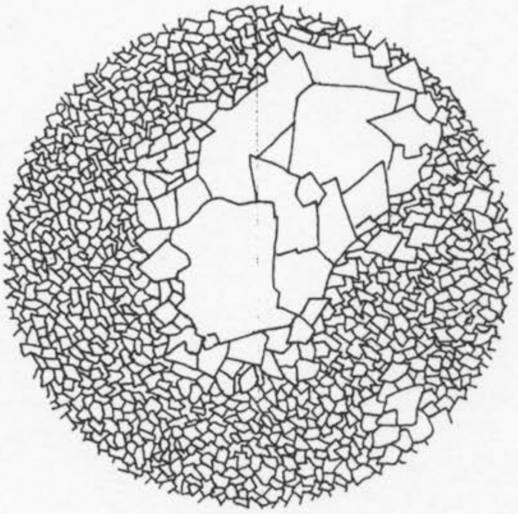
The wackestones show both horizontal laminations and cross bedding, with slumped laminations in some of the beds. There are lenses of coarser material, comprised of fossil debris, with, in some places, thin packstone layers coloured by red or yellow staining. These beds are fossiliferous, containing brachiopod, gastropod and crinoid fragments, with occasional solitary corals. There is also evidence of bioturbation, with many of the bedding plane surfaces covered with burrow formations, both horizontal and vertical. Photograph Four shows an example of the lenses of coarse material developed within some of the beds, and also the 'crinkly' nature of some of the laminations.



Photograph Four: Penmaen Burrows Limestone, Three Cliff Bay.

In Three Cliff Bay the boundary between the Penmaen Burrows Limestone and the Caswell Bay Oolite is exposed as a thick irregular grainstone layer between the two, with an erosional surface on both the top and bottom. The nature of this layer is difficult to determine, although it is clearly a local feature, as it is not seen as Caswell Bay.

3.2iii Penmaen Burrows Microfacies



The thin section seen above is composed entirely of dolomite crystals. This thin section is taken from Langland Bay where the alteration of the beds is greatest. The collection of larger crystals probably represents recrystallisation of fossil material, which in the field can often be seen to be comprised of large white crystals.

FIGURE FOUR: THIN SECTION OF PENMAEN BURROWS LIMESTONE. MAGNIFICATION X 10.

3.3. CASWELL BAY OOLITE

The Caswell Bay Oolite is exposed from Langland Bay to Three Cliff Bay, where it remains consistent in appearance and lithology, being dominated by pale thickly bedded coarse oolitic grainstones.

3.3i Langland Bay

The sequence of Caswell Bay Oolite seen in Langland Bay (Localities 29 (Pages 50-54, Grid Ref: SS61088721) and 32-3 (Pages 56-58, Grid Ref: SS60498718-60728725)) comprises pale, thickly bedded, coarse oolitic grainstones with the oolites collected into bands forming laminations within the beds. These laminations reveal horizontal and cross bedding, the direction of cross bedding often changing within a bed. Fossil material is sparse, but there are common crinoids with brachiopod fragments, and very occasional small corals. The fossil material is of a similar size to the oolites, giving this rock a well sorted appearance. The upper boundary between the Caswell Bay Oolite and the overlying Caswell Bay Mudstone can be seen to be erosional.

3.3ii Caswell Bay

The sequence of Caswell Bay Oolite seen at Caswell Bay is complete with both the upper and lower boundaries (Localities 39 (Pages 72-73, Grid Ref: SS59608712) ,43 (Pages 77-78, Grid Ref: SS59388740) and 46-8 (Pages 85-91, Grid Ref: SS58968757-59358760)). The lower boundary is comprised of a large irregular erosional boundary, with the first bed of oolite deposited directly upon this. It should also be noted that the oolites are finer at the base of the sequence, becoming coarser towards the top.

The sequence seen in Caswell Bay is dominated by thickly bedded, coarse oolitic grainstones with much crinoid debris contained within them. The oolite beds are laminated, the oolites forming horizontal laminations and cross bedding, on small and large scales. There is also evidence of coarsening upwards sequences within the beds, topped by erosional surfaces, before the deposition of the next bed.

These beds are more fossiliferous than the sequence seen at Langland Bay, with the presence of numerous crinoids, with brachiopod fragments, and corals. Photograph five below is to illustrate the cross lamination of many of the beds of Caswell Bay Oolite, showing the changing direction of the laminations, and the concentration of crinoids and coarse debris into bands within the beds.

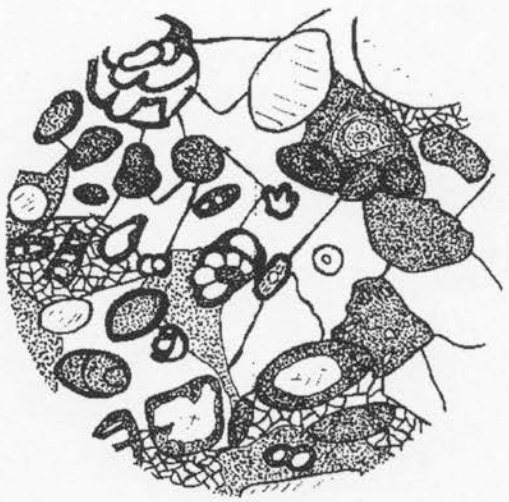
Photograph Five: Caswell Bay Oolite, Caswell Bay.

The uppermost boundary of the Caswell Bay Oolite, separating these beds from the Caswell Bay Mudstone, is clearly erosional, with the Caswell Bay Oolite underneath almost pisolitic in texture.

3.3iii Three Cliff Bay

The sequence of the Caswell Bay Oolite in Three Cliff Bay (Localities 70 (Pages 125-7, Grid Ref: SS53988775), 73 (Pages 132-6, Grid Ref: SS53958795) and 76 (Page 141, Grid Ref: SS53448789)) is massive in appearance with thicker beds and less structure. They are comprised of pale coarse oolitic grainstones, the oolites becoming coarser higher in the sequence. There is a high density of joints formed within them obliterating the structures present. There is also little fossil material, with sparse crinoid fragments.

3.3iv Caswell Bay Oolite Microfacies



The thin section shows the Caswell Bay Oolite at a low magnification to illustrate the nature of the fragments, which include a fossil assemblage with large numbers of foraminfera and crinoids, indicating a restricted fauna. Almost all of the material has the appearance of being micritised to some degree, with an abundance of peloidal grains. The oolitic material present can be seen to be much altered by micritisation, with little 'fresh' material present. Many of the grains have the appearance of being well rounded and also flattened, including rounded intraclasts comprised of bounded and micritised fossil debris. There are numerous patches of fine drusy textured, crystalline calcite, these being interspersed with large calcite crystals with their origin on crinoid fragments.

FIGURE FIVE: THIN SECTION OF CASWELL BAY OOLITE.
MAGNIFICATION X4.

The Thin Section above is a higher magnification of the Caswell Bay Oolite showing principally the nature of the texture of the cement and grains. The material that appeared to be micrite can now be recognised as a very fine drusy texture that has incompletely replaced the grains. This material can be seen to have fractured after the replacement process. The coarser drusy fabric can be now seen as large spar crystals probably as a secondary formed pore cement.

FIGURE SIX: THIN SECTION OF CASWELL BAY OOLITE.
MAGNIFICATION X10.

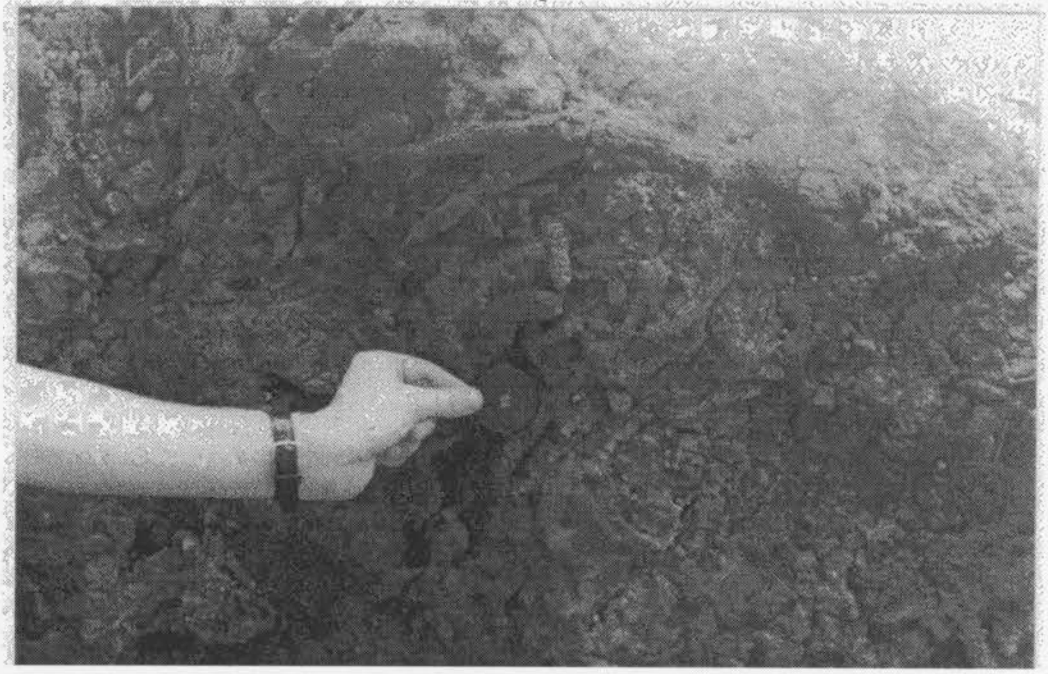
3.4. CASWELL BAY MUDSTONE

The Caswell Bay Mudstone is exposed from Langland Bay to Three Cliff Bay and is dominated by interbedded wackestones and laminated mudstones, which often have characteristic staining.

3.4i Langland Bay

The sequence of the Caswell Bay Mudstone seen in Langland Bay (Localities 29 (Pages 50-54, Grid Ref: SS61088721) and 33 (Pages 56-58, Grid Ref: SS60498718)) is relatively thin compared to that seen at other localities, and has eroded back to reveal the bedding plane surface of the Caswell Bay Oolite and the High Tor Limestone.

The lowest beds of the Caswell Bay Mudstone, are packstone beds interbedded with oolitic wackestones, followed by a pink coloured packstone with crinoid fragments, that are concentrated into bands within the bed. This changes lithology into yellow marly beds interbedded with dark crinoidal wackestones, followed by mudstones interbedded with red stained, and mottled green, laminated marls, with neither showing evidence of fossil material, except for numerous burrow forms preserved on the bedding plane. Photograph six seen below shows the numerous well preserved horizontal and vertical burrows.

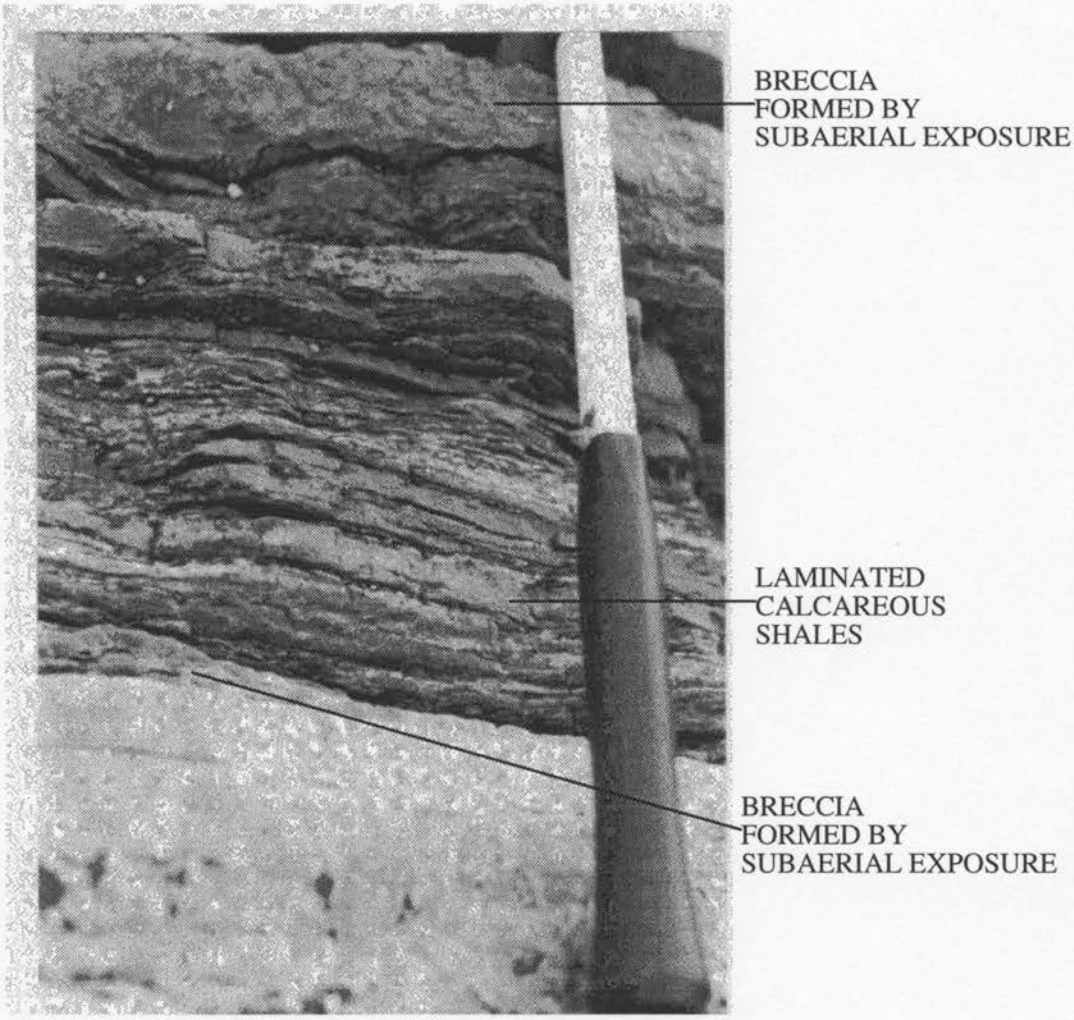


Photograph Six: Burrows on Caswell Bay Mudstone, Langland Bay.

3.4ii Caswell Bay

The Caswell Bay Mudstone is very well preserved in Caswell Bay (Localities 38 (Pages 68-72, Grid Ref: SS59638710), 43-4 (Pages 77-84, Grid Ref: SS59388740), 47 (Pages 86-89, Grid Ref: SS59218762) and 49 (Pages 91-92, Grid Ref: SS58958752)) and provides a thick sequence that dominates the bay. The sequence is once again dominated by interbedded wackestones and mudstones. Photograph seven seen overleaf is a composite photograph to show the great thickness of Caswell Bay Mudstone seen at Caswell Bay.

The lowest bed overlying the Caswell Bay Oolite is a thick bed of breccia, comprised of a pale yellow clay supporting fragments of coarse pale wackestone, exhibiting possible algal growths. Following this is a sequence of unfossiliferous mudstones interbedded with clays and mudstones with platy horizontal laminations. The clays are pale and marly, and often mottled red. These are followed by a thinner breccia, the angular fragments having a pinkish appearance. This is followed by thinly bedded wackestones interbedded with horizontally laminated beds of mudstones, with bands of yellow and red clays, showing evidence of burrow formation, infilled by the clays. There is another thin breccia bed, with a distinct erosional boundary developed on the previous bed. Photograph eight illustrate the breccia beds with laminated mudstones underneath. Higher beds are comprised of laminated wackestones interbedded with laminated mudstones, leading to a pale bed of packstone, followed by an erosional boundary with laminated red clays and mudstones, leading to a short sequence of dark, finely bedded, laminated mudstones.



Photograph Eight: Breccia in Caswell Bay Mudstone, Caswell Bay.

The next sequence of beds are different from of those seen in the Caswell Bay Mudstone at other localities. They are comprised of pale, thickly bedded, oolitic packstones with horizontal laminations and cross bedding, interbedded with thin beds of mudstones. The final bed seen in this sequence is a very coarse oolitic grainstone, almost pisolitic texture, that is also very fossiliferous, showing coarse fragments of crinoids, brachiopods and solitary corals. The junction between the top beds of the Caswell Bay Mudstone and the overlying beds of the High Tor Limestone is erosional, and rather irregular, often cutting more than one bed, so that not all sections reveal the same upper beds.

3.4iii Three Cliff Bay

The Caswell Bay Mudstone in Three Cliff Bay (Localities 70 (Pages 125-7, Grid Ref: SS53988775), 72 (Pages 128-132, Grid Ref: SS53868794) and 77 (Pages 142-3, Grid Ref: SS53398785)) is thinner than that preserved in Caswell Bay, but reveals many of the same features. In Three Cliff Bay the beds show a red or yellow coloration making them rather distinctive in appearance. Photograph nine below shows the 'varved appearance of some of the beds.

Photograph Nine: Caswell Bay Mudstone, Three Cliff Bay.

The lowest bed in Three Cliff Bay follows the Caswell Bay Oolite, over an erosional boundary, with a short sequence of oolitic packstones interbedded with pale thinly laminated mudstones, with an upper erosional surface with the overlying beds comprised of thin wackestones interbedded with laminated mudstones. These are overlain by a number of thin breccia beds, comprising angular fragments of dark mudstone, in a pale clay matrix. These are followed by a sequence of thin oolitic packstones, overlain by wackestones interbedded with laminated mudstone. These are followed by thick beds of pale yellow calcareous clays with a 'varved' appearance, that are occasionally interrupted by thin, black laminated mudstones. There is a further sequence of thin, wackestones interbedded with dark, laminated mudstones, with the topmost beds interbedded with red clay. The High Tor Limestone follows after an erosional boundary.

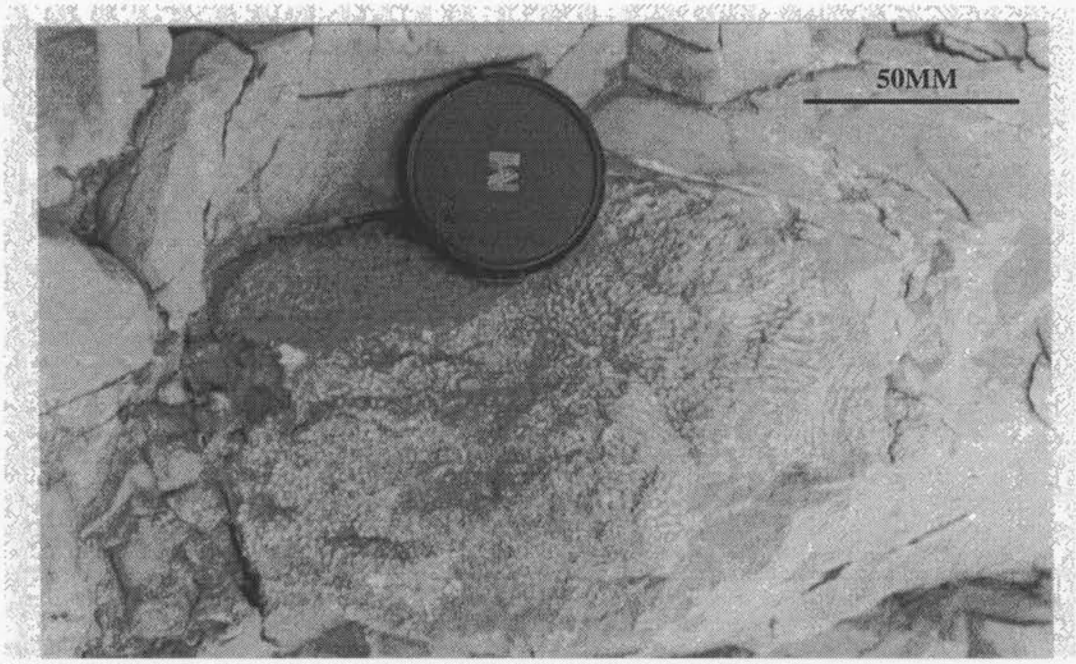
The thin section appearance of a 'varved' mudstone of the Caswell Bay Mudstone is of a very fine grained material, comprised almost wholly of very small, rounded peloids, forming a pelleted mudstone. These are enclosed in a sparry calcite matrix, the apparent concentrations of darker and lighter material, being related to the concentrations of peloids into bands of greater and lesser concentrations.

3.5. HIGH TOR LIMESTONE

The High Tor Limestone lies between the Caswell Bay Mudstone and the Hunts Bay Oolite. It is found from Langland to Three Cliff Bay, and forms the exposure between the bays.

3.5i Langland Bay

The High Tor Limestone of Langland Bay (Localities 35 (Pages 59-60, Grid Ref: SS60508708) and 43 (Pages 77-8, Grid Ref: SS59388740)) follows the Caswell Bay Mudstone with no apparent break, filling burrows that have formed in the Caswell Bay Mudstone. The oldest beds of the High Tor Limestone are dark grey, thinly bedded, highly fossiliferous crinoidal packstones. The fossil material is comprised of 1-2cm sized crinoid fragments, brachiopods and corals. Photograph ten shows a patch of colonial coral from Langland Bay, that are probably examples of *Lithostrotion.* There are numerous examples of gastropod wackestones, with the gastropods having diameters of up to 5cm. As the beds become younger, the fossil material starts to become smaller and less abundant, with the introduction of thin bands of oolites into the beds. At the top of the sequence the beds finally become much thicker and even more oolitic, but there is still abundant fossil material, especially crinoids. The junction between the High Tor Limestone and Hunts Bay Oolite in Langland Bay is marked by a change in lithology to pink mudstones and wackestones, containing crinoid fragments, interbedded with red clays. These are followed by a fine packstone, before the pale oolitic grainstones of the Hunts Bay Oolite.



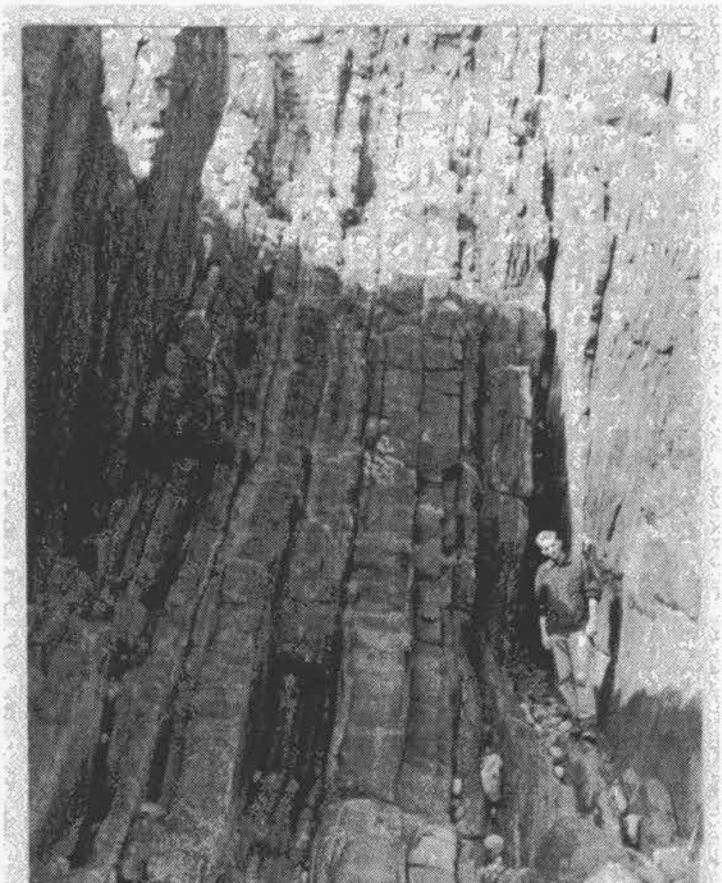
Photograph Ten: Coral Colony, High Tor Limestone, Langland Bay

3.5ii Caswell Bay

The High Tor Limestone of Caswell Bay (Localities 37-38 (Pages 66-72, Grid Ref: SS597286-59638710), 45 (Pages 84-5, Grid Ref: SS59358752) and 50 (Pages 92-3, Grid Ref: SS58928746)) is comprised of thinly bedded crinoidal packstones and wackestones, that are highly fossiliferous at the bottom of the sequence, but becoming more oolitic and thickly bedded towards the top of the sequence. There is a greater variety of fossil material in Caswell Bay, with abundant crinoids, brachiopods, corals and frequent gastropod beds. There is also evidence of algal colonies on some of the beds, with examples of colonial corals of *lithostrotion* variety. In the sequence there are examples of alternations between packstones and wackestones that possibly represent coarsening upwards sequences. The junction between the High Tor Limestone and the overlying Hunts Bay Oolite can be seen to have interbedded wackestones and mudstones developed. These beds are restricted in fossil material, with only occasional crinoid debris present.

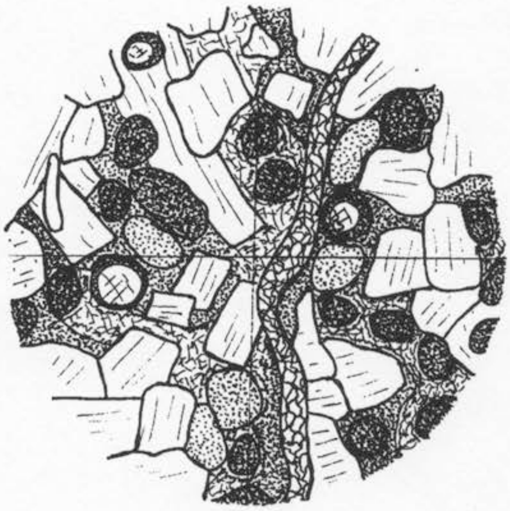
3.5iii Three Cliff Bay

The sequence in Three Cliff Bay (Localities 68-69 Pages 122-5, Grid Ref: SS54268751-54138763), 71 (Page 128, Grid Ref: SS53838775), and 78-79 (Pages 143-6, Grid Ref: SS53328787-53188779)) shows dark, fossiliferous crinoidal packstones and wackestones, that are more thinly bedded at the base of the sequence, with abundant crinoid and coral material present. These become more thickly bedded towards the top of the sequence with the introduction of oolites and the loss of fossil material. These beds are relatively more fine grained than those seen at Caswell or Langland Bay. The junction between the High Tor Limestone and the Hunts Bay Oolite is composed of an erosional surface leading to thinly bedded, wackestones interbedded with laminated mudstones followed by an erosional boundary, with the Hunts Bay Oolite, photograph eleven shows this sequence in Three Cliff Bay.



Photograph Eleven: High Tor Limestone- Mudstone Sequence, Three Cliff Bay.

3.5iv High Tor Limestone Microfacies

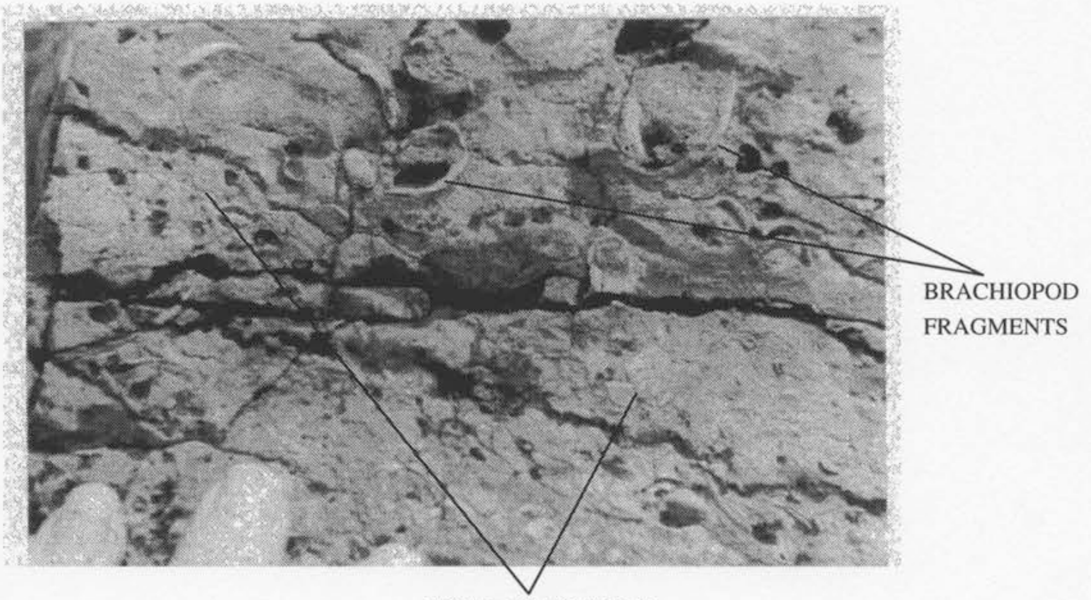


The fossil assemblage of the High Tor Limestone in thin section is comprised of crinoids with occasional brachiopod fragments. The grains have the appearance of being sub-rounded, with an abundance of micrite in the groundmass. There is evidence of micritisation, and a high percentage of the grains are peloids. The cement is comprised of drusy textured calcite filling pore spaces, and also thin veins of drusy textured calcite. Along with the larger fragments of peloids and crinoids are large individual calcite crystals, sometimes associated with crinoid debris. There is very little or no oolitic material present.

FIGURE SEVEN: THIN SECTION OF HIGH TOR LIMESTONE. MAGNIFICATION X4.

3.6 HUNTS BAY OOLITE

Hunts Bay Oolite extends from Bracelet Bay to Three Cliff Bay. Where the contact between the Hunts Bay Oolite and the High Tor Limestone is seen, it is recognised by the sequence of wackestones and laminated mudstones lying between them.



Photograph Twelve: Hunts Bay Oolite, Bracelet Bay.

3.6i Bracelet Bay

The sequence in Bracelet Bay (Localities 6-17, Pages 27-40, Grid Ref: SS63188729-62828700)) is well preserved, although only the top part of the sequence is seen here. The lowest beds seen are coarse oolitic grainstones with laminations, especially medium scale cross bedding features, including herring bone cross bedding, with fossil debris collected into bands. These are followed by very fossiliferous beds, with up to 90% bioclasts. They form a grading up sequence, from oolitic grainstones >> bioclastic grainstones with less oolitic material >> larger fossil material collected into bands >> 90% bioclasts. The fossils include gastropods, numerous solitary corals, fragments of colonial corals, and brachiopods, with the fossils situated in a fine grained matrix. Photograph twelve shows a part of this fossil assemblage from Bracelet Bay.

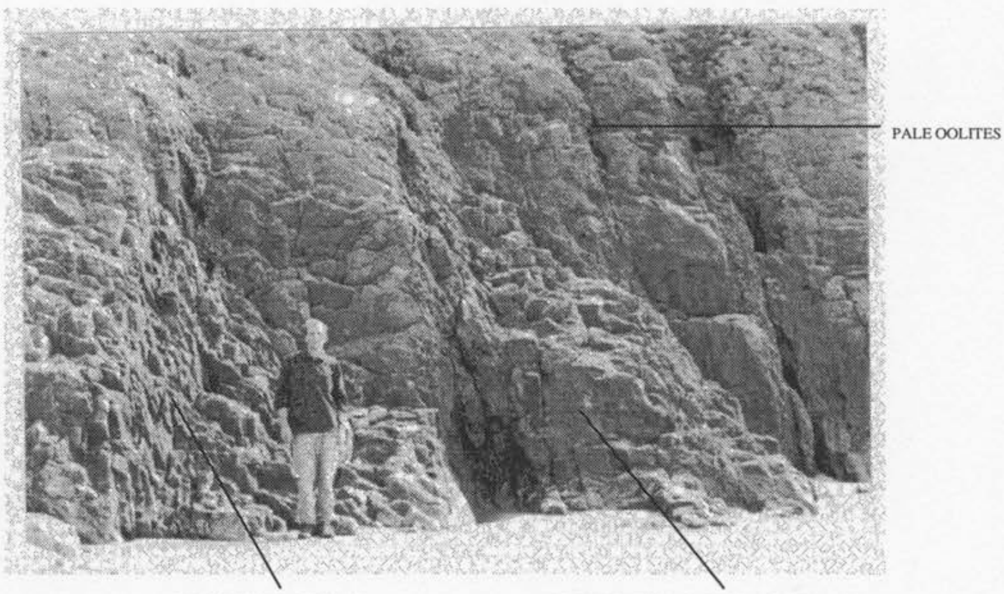
These are followed by fossiliferous oolitic grainstones associated with pale brown packstones, forming breccias with a matrix of packstone and fragments of the oolitic grainstones, derived from the underlying beds. The packstones contain irregular thick laminations, and sometimes gradational boundaries with the grainstone. These are followed by alternating beds of bioclastic grainstone and oolitic grainstone. The fossiliferous beds are coarse grained, containing numerous crinoids, brachiopods and corals. The final beds of the Hunts Bay Oolite in Bracelet Bay are beds of coarse fossiliferous oolitic grainstones, where the oolites and fossil debris form laminated bands. Photograph thirteen shows the thick bedding of the grainstones with laminations, showing cross, and herring bone cross bedding.

Photograph Thirteen: Hunts Bay Oolite, Bracelet Bay.

The junction between the Oxwich Head Limestone and the Hunts Bay Oolite is difficult to determine, however, there is a distinctive pisolitic bed containing little fossil debris that represents the highest bed of the Hunts Bay Oolite, with crinoidal wackestones of the Oxwich Head Limestone above.

3.6ii Pwll Du Bay

The Hunts Bay Oolite in Pwll Du Bay (Localities 54-56 (Pages 100-3, Grid Ref: SS58058716-57768709) and 62 (Pages 112-3, Grid Ref: SS56288683)) is comprised of coarse oolitic grainstones containing rounded shell debris with a well sorted appearance. There are beds and lenses of fine brown packstone showing coarse irregular laminations, forming breccias with the oolitic grainstones as seen in Bracelet Bay. There is evidence of both gradational and sharp boundaries between the grainstones and packstones.



Photograph Fourteen: Hunts Bay Oolite, Three Cliff Bay.

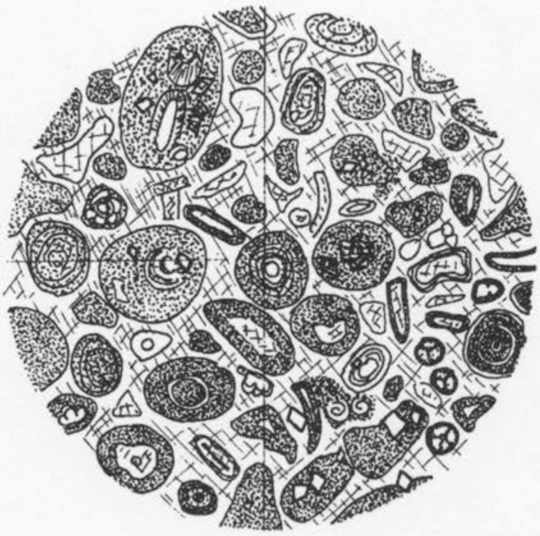
3.6iii Three Cliff Bay

The beds of the Hunts Bay Oolite seen in Three Cliff Bay (Localities 79-84, Pages 144-155, Grid Ref: SS53188779-51318795) begin with very fossiliferous grainstones with crinoid, brachiopod and coral material present, becoming more oolitic and less fossiliferous upwards in the sequence. Higher still in the sequence are the introduction of pale brown packstones, with coarse laminations. These packstones form both beds and lenses with often gradational boundaries. Fragments of laminated oolitic grainstone frequently occur within the packstones. Photograph fourteen shows the nature of some of these packstone beds seen in Three Cliff Bay.

There are thick sequences of beds containing no packstones, and reduced oolitic material, these containing bands of fossiliferous material, in particular large concentrations of brachiopod material. These are preserved very well, with whole beds entirely comprised of brachiopod fragments in a micrite matrix. Photograph fifteen shows a bedding plane surface from Three Cliff Bay to illustrate this concentration of brachiopod material.

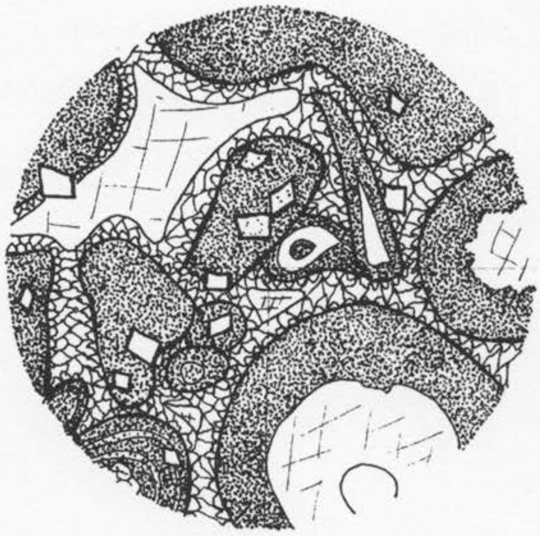
Photograph Fifteen: Brachiopod Material, Hunts Bay Oolite, Three Cliff Bay.

3.6iv Hunts Bay Oolite Microfacies



The thin section shows Hunts Bay Oolite at a low magnification to show the variety of fragments within it. For example, the fossil assemblage of foraminfera, crinoids, brachiopod, coral and also bryozoan fragments. There are numerous peloids, many of which can be seen to be micritised fragments, especially of abundant oolites, whilst most of the other fragments have micritised rims. There are intraclasts comprised of bounded fragments of oolites and fossil debris that have been micritised. Much of the material is clearly rounded, with fragments giving evidence of some working. The cement in this low magnification can be seen to be comprised of a uniform sparry calcite, with a finely grained rim around some of the fragments evident. There is evidence of some small crystal growth of dolomite, growing within the fragments, especially peloids.

FIGURE EIGHT: THIN SECTION OF HUNTS BAY OOLITE.
MAGNIFICATION X 4.

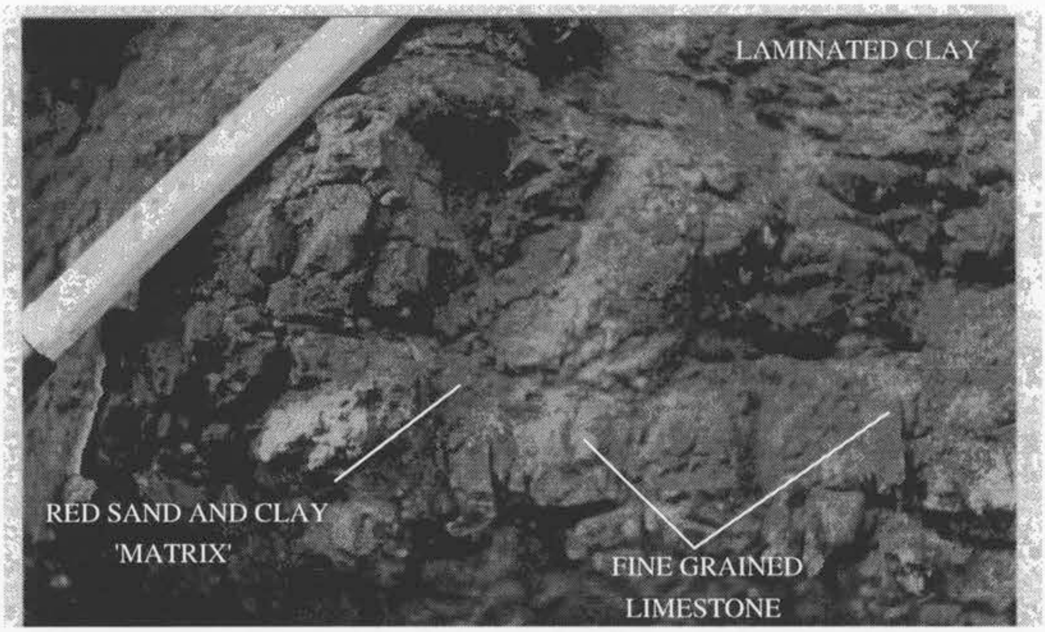


The high magnification section of the Hunts Bay Oolite shows the cement characteristics of this zone. The micrite envelopes can be seen clearly around most of the grains with an isopachous cement developed around the edge of the grains, binding them together. A secondary infill cement can be seen as large crystals developed in pore spaces left after development of the isopachous cement. The oolites show alternating layers of growth and micritisation. The development of rhomboid dolomite crystals within the fragments is also seen clearly.

FIGURE NINE: THIN SECTION OF HUNTS BAY OOLITE.
MAGNIFICATION X 10.

3.7. OXWICH HEAD LIMESTONE and OYSTERMOUTH BEDS

The Oxwich Head Limestone is seen only in two places, Mumbles Head and Pwll Du Bay, the Oystermouth Beds are only seen in one locality, the so-called 'Black Lias' Quarry. The Oystermouth beds represent the topmost beds of the Oxwich Head Limestone, so they are considered together as one zone of the Carboniferous Limestone Series.



Photograph Sixteen: Oxwich Head Limestone, breccia, Mumbles Head.

3.7i Mumbles Head

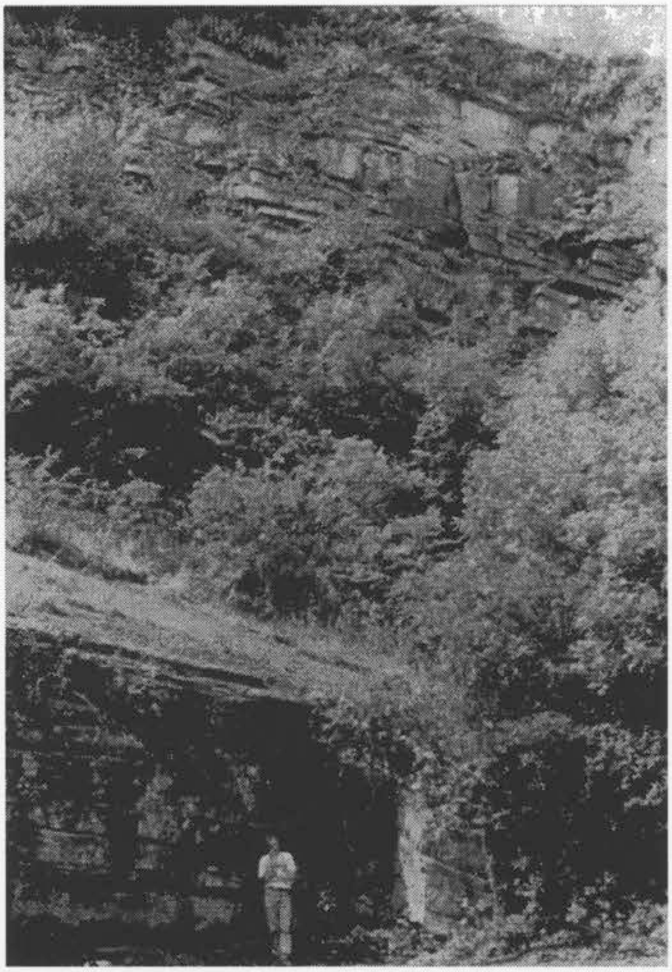
The lowest beds of this zone seen in Mumbles Head (Localities 1(Pages 1-15, Grid Ref: SS62598757-62918742), 8-9 (Pages 29-30, Grid Ref: SS63228716-63298719) and 12 (Page 31, Grid Ref: SS63538714) are represented by a breccia comprised of fine limestone fragments in a matrix of red sand shown in photograph sixteen. Overlying this are dark, unfossiliferous mudstones interbedded with thin clays, mostly coloured red, but often also mottled green. These are overlain by a coarse oolitic and fossiliferous packstone, followed by a dark wackestone with sparse fossil material. Overlying this bed is a thick sequence of so-called 'pseudobreccias', thick beds of fossiliferous packstone that have the appearance of a breccia, due to preferential weathering of softer 'matrix', where fossil material is concentrated within the harder 'fragments'.

The remainder of the beds alternate between dark fossiliferous packstones and paler less fossiliferous wackestones. The fossil material is comprised of numerous crinoids, brachiopods and solitary corals. There is another breccia bed higher in the sequence comprised of angular fragments of mudstones often coated in clays, with a fine sandy matrix.

Photograph Seventeen: 'Pseudobreccia' from Oxwich Head Limestone, Pwll Du Bay.

3.7ii Pwll Du Bay

Much of the sequence seen in Pwll Du Bay (Localities 59-61, Pages 105-112, Grid Ref: SS57458686-57248633) is comprised of thick, very fossiliferous beds of 'pseudobreccia', containing crinoids, solitary corals, brachiopods, foraminiferas and algal growths. Photograph seventeen shows an example of 'pseudobreccia' containing an algal growth, that may be a stromatolite. There are areas of fine pale coloured packstone that merge gradationally with the 'pseudobreccias'. There is a thick bed that contains abundant remains of gastropods that have been extensively affected by recrystallisation. A breccia bed present between two of the 'pseudobreccia' beds, bounded by erosional boundaries on both sides, is comprised of angular fragments of fine grained limestone coated with clays, in a matrix of fine grained sand, the clays exhibiting red and green coloration. The upper beds of the sequence seen here are thinner beds of darker crinoidal wackestones, with a general change in the fossil assemblage to smaller material, only brachiopods, crinoids and small solitary corals are present.



Photograph Eighteen: Oystermouth Beds, Black Lias Quarry.

3.7iii Black Lias Quarry

The beds exposed in the Black Lias Quarry (Locality 2, Page 16, Grid Ref: SS616883) belong to the Oystermouth Beds, the very top of the Carboniferous Limestone series, and are thought to underlie unconformably the Millstone Grit of the Namurian, although the junction is not seen here. The beds are dominated by very dark mudstones and wackestones, containing small infrequent crinoid fragments, with occasional other small fragments of fossil debris. These are interbedded with paler, laminated mudstones, sometimes showing slumped laminations. There are occasionally paler, thicker beds of packstone which contain more abundant fossil material, but in general the Oystermouth Beds have a more restricted fauna, than the lower beds. Photograph eighteen above shows the Oystermouth Beds from the 'Black Lias' Quarry

4. INTERPRETATION

4.1. CEFN BRYN SHALES

The beds of the Cefn Bryn Shales can be seen to display features that would indicate deposition during conditions of a relatively low energy environment, punctuated by periods of storm activity, bringing influxes of rapidly deposited coarser material. Figure nine below shows a diagrammatic log of the sequence of the Cefn Bryn Shales seen in Three Cliff bay.

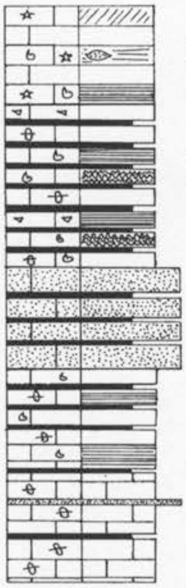


FIGURE NINE: DIAGRAMMATIC LOG OF THE SEQUENCE OF THE CEFN BRYN SHALES SEEN IN THREE CLIFF BAY.

The fossil assemblage here is sparse and very restricted, with abundant evidence of burrow formation and bioturbation, with only crinoid skeletal fragments that have probably been washed in during storm events. The presence of horizontally laminated mudstones indicates slow rates of sedimentation, with little influence of strong tidal or wave currents. Thus indicating the likely conditions of deposition of these beds is below the wave base, on an open offshore shelf. The beds towards the top of the sequence can be seen to show cross bedding, and the input of lenses of bioclastic debris indicating shallowing conditions, and the increasing influence of stronger tidal or wave currents. This environment represents conditions of relatively high sea level at the time of deposition.

4.2. PENMAEN BURROWS LIMESTONE

The beds of the Penmaen Burrow Limestone can be seen to be comprised in the main of laminated fossiliferous beds, with a less restricted fauna and more evidence of current activity than those of the Cefn Bryn Shales. Figure ten below shows a diagrammatic log of the sequence of the Penmaen Burrows Limestone seen in Three Cliff Bay, showing an almost cyclic pattern of limestone deposition followed by influxes of coarser material, probably due to periodic storm events.

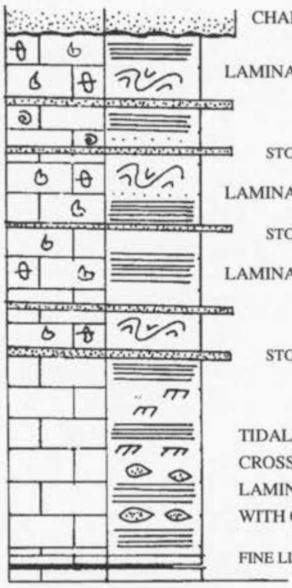


FIGURE TEN: DIAGRAMMATIC LOG OF THE PENMAEN BURROWS LIMESTONE IN THREE CLIFF BAY

The beds show an increased fossil assemblage with corals, gastropods and brachiopods indicating an open shelf environment, while the presence of laminations in the beds, and burrows indicating a relatively slow rate of sedimentation during quiet periods. The beds are topped by an erosional surface, followed by a thick well sorted, but fine grainstone, possibly indicating a channel feature, suggesting a regressive phase with reworking of material, associated with the drop in sea level. The presence of 'crinkly' lamination could be due to the growth of algae, or weak tidal currents. The more diverse fauna present and the possible evidence of wave currents indicate the position of deposition of these to be on an open shelf, near the wave base. This environment represents a relatively high sea level, but shallower conditions than those of the Cefn Bryn Shales.

4.3. CASWELL BAY OOLITE

The beds of the Caswell Bay Oolite seen in Gower clearly indicate the influence of a moderately high energy environment dominated by tidal and wave currents, shown by the rounding and fracturing of grains, with the fossil material being washed in from offshore. Further evidence for the influence of strong currents are the presence of various scales of cross bedding, and erosional surfaces to beds. There is, however, strong evidence for periods of relatively relaxed currents, with the presence of extensively micritised material, numerous peloids, and the presence of intraclasts indicating the probable formations of hardgrounds. This evidence suggests very strongly an environment alternating between high and low energy, perhaps indicating a climate with periodic strong seasonal storm events, such as hurricanes.

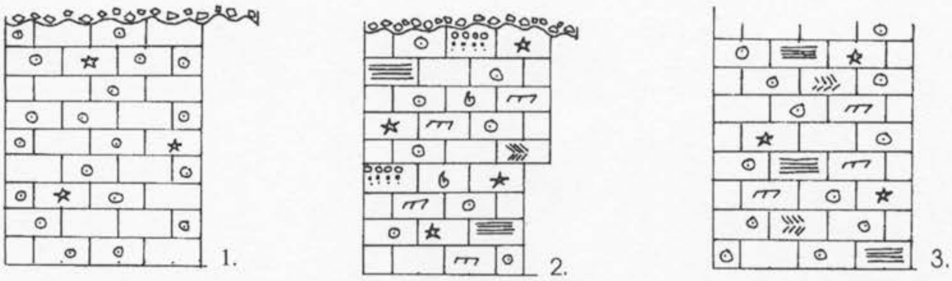


FIGURE ELEVEN: DIAGRAMMATIC LOGS OF THE CASWELL BAY OOLITE
1. THREE CLIFF BAY, 2. CASWELL BAY, 3. LANGLAND BAY

The beds of the Caswell Bay Oolite are coarsening upwards indicating a shallowing in conditions. The environment of deposition is very shallow water, heavily influenced by storm action, and also by tidal and current activity. The storm activity resulted in the rapid deposition of coarse oolitic material and bioclastic debris, with the occurrence of coarsening upwards sequences resulting from rapid deposition. The presence of erosional surfaces, and intraclasts suggests that the currents were enough to tear up the hard ground surfaces that had developed during quiet periods. There is evidence that these oolitic and bioclastic shoals were exposed above the surface at times, shown by the cementing of the grains, with grain replacement and fracturing that are characteristic of meteoric diagenesis, in conditions of $CaCo_3$ rich waters. These beds probably represent shoreface sands, influenced and worked periodically by strong currents, sometimes becoming exposed, for example as barrier bars. This Caswell Bay Oolite in Gower may well represent a transgressive sequence, with the shallowing upwards probably caused by seaward progradation of oolitic shoals and barrier bars.

4.4. CASWELL BAY MUDSTONE

The sequence comprising the Caswell Bay Mudstone represents a very low sea level with the introduction of laminated mudstones and wackestones, with a fine 'crinkly' lamination. The presence of breccias and of this 'crinkly' lamination are an indication of subaerial exposure, with palaokarstic features and evidence of periodic drying out and warping effects of the exposure. The restricted fauna of the limestones and the presence of laminated pelleted mudstones lead to the conclusion that these beds were deposited in a very low energy environment, with the breccias and crinkly laminations a result of the periodic exposure of these, while the bioturbation and burrows in general indicate periods of submergence. These beds represent an intertidal environment with the crinkly laminated beds representing algal growths, and the breccias palaokarstic surfaces. These are both evidence of exposed upper intertidal flats. The bioturbated and burrow preservation are evidence of lower intertidal flats, that are not often exposed, and so much less harsh an environment for animal life. Figure twelve below illustrates the Caswell Bay Oolite.

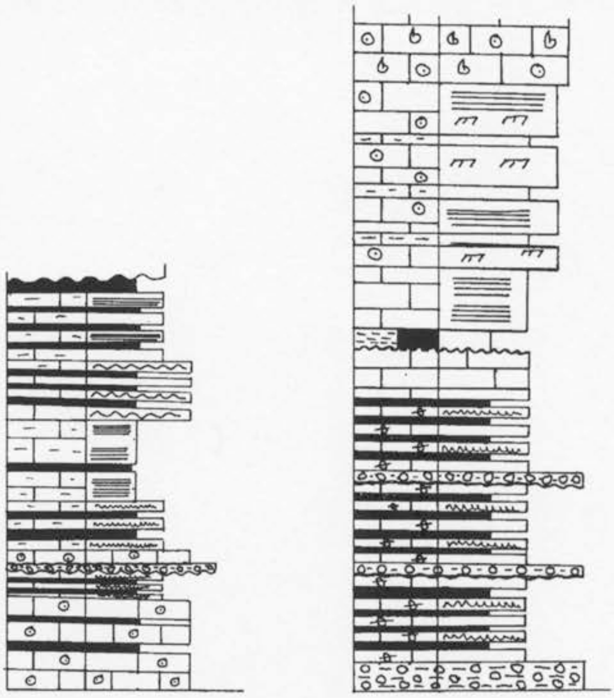


FIGURE TWELVE: DIAGRAMMATIC LOGS OF THE CASWELL BAY MUDSTONE SEQUENCE FROM THREE CLIFF BAY (LEFT) AND CASWELL BAY (RIGHT).

There is lateral variation between the sequence in Caswell Bay and that sequence seen in Three Cliff Bay, with the sequence in Three Cliff Bay showing less evidence of aerial exposure, but rather more evidence of deeper water deposition, with the presence of 'varved sediments'. This indicates the development of a sheltered lagoon, with deposition of laminated pelleted mudstone or clay with periodic influxes of coarser silt or fine sand material from 'overspill' during storm events. In Caswell Bay there is evidence of a transgressive sequence, with conditions apparently deepening with the influx of oolitic material, revelling cross-bedding and large quantities of fossil material. These represent again thick deposits of oolites and bioclastic material of shoreface sands and barrier bar environments.

4.5. High Tor Limestone

The High Tor Limestone is comprised of very fossiliferous beds displaying a rich fauna with crinoids, brachiopods, corals, gastropods and evidence of algal material, illustrating an environment of open circulation giving rise to moderate working of the grains, but the beds are dominated by quiet periods of low energy and sedimentation rate, shown with the high numbers of peloids and micritisation of the grains, with abundant micrite mud.

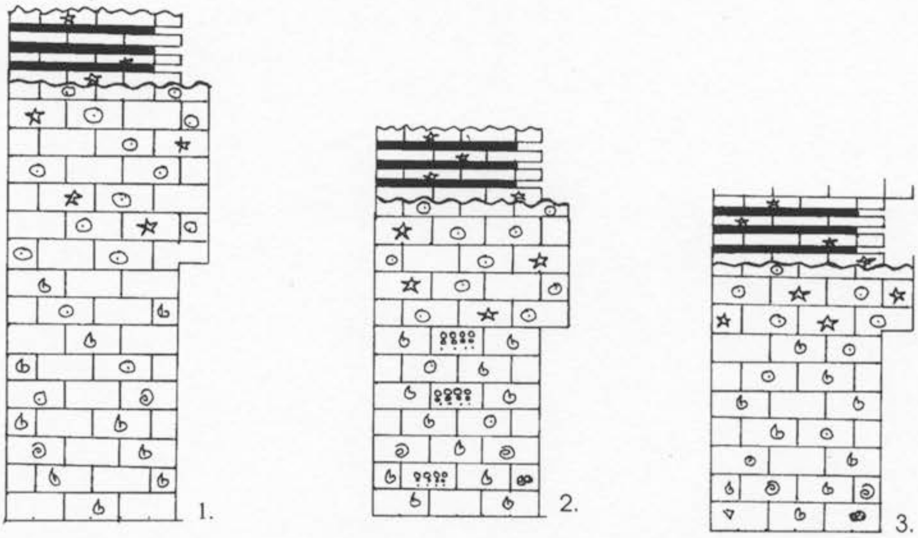


FIGURE THIRTEEN: DIAGRAMMATIC LOGS OF HIGH TOR LIMESTONE
1. THREE CLIFF BAY, 2. CASWELL BAY, 3. LANGLAND BAY

The lowest beds in the sequence are very fossiliferous with an abundance of micrite and bounded with a pore cement, that is marine burial in origin. The sequence becomes more oolitic and less fossiliferous upwards indicating shallowing in conditions, probably due to progradation of material seawards. The presence of interbedded laminated mudstones and wackestones, is very like those seen deposited as the Caswell Bay Mudstone, and represent the same type of environment, intertidal conditions with coarser material, e.g. crinoid debris, being brought in due to storm activity and overspill. The High Tor Limestone represents a thick shallowing upwards sequence, from open shelf, through oolite dominated shoals showing wave and tidal influence, to intertidal deposits in a low energy, restricted environment. These beds show a relative shallowing in conditions upwards, transferring from open-marine conditions through oolitic shoals to tidal flat conditions. This may be due to the progradation of a coastline sea-wards, with little subsidence of any kind to combat the shallowing of conditions.

4.6. HUNTS BAY OOLITE

The Hunts Bay Oolite is comprised of fossiliferous oolitic grainstones, deposited in a high energy environment. The fossil assemblage is dominated by crinoids and foraminiferas, but brachiopods and corals are also abundant in some of the beds. There is a good deal of evidence of reworking, with rounded grains, and much of the fossil material is fragmented. There is also evidence of quiet periods when micritisation of the grains has taken place, seen where micritisation has occurred on alternate layers of oolites. The abundant intraclasts and the formation of an isopachous cement indicate the development of hardgrounds in the shallow waters, that were torn up by strong currents.

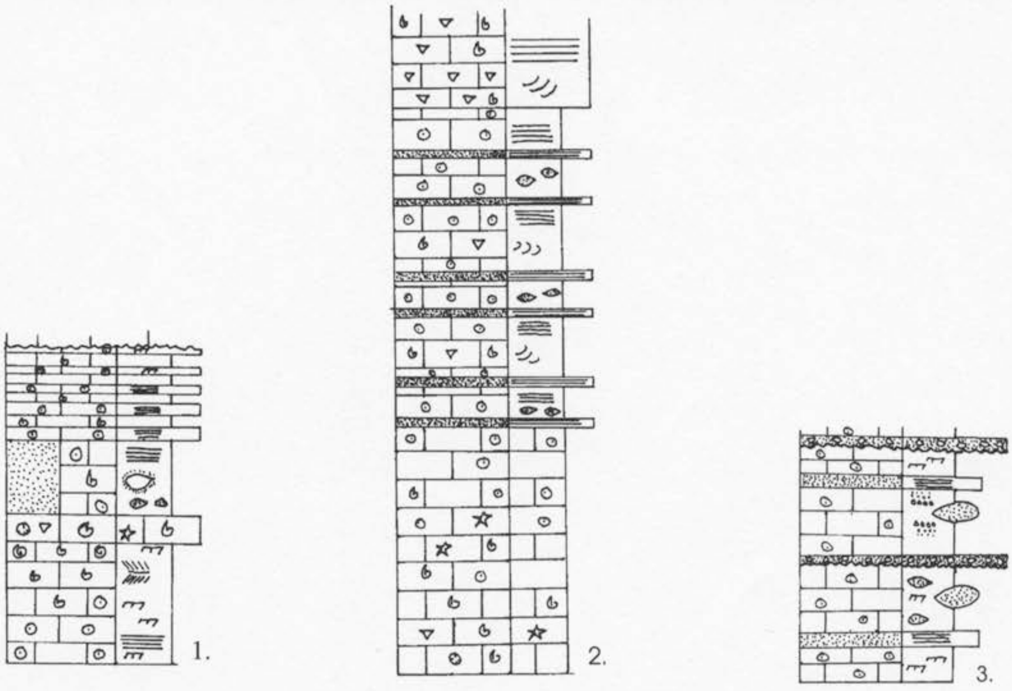


FIGURE FOURTEEN: DIAGRAMMATIC LOG OF HUNTS BAY OOLITE
1. BRACELET BAY, 2. THREE CLIFF BAY, 3. PWLL DU BAY

In the sequence of the Hunts Bay Oolite there is also further evidence of storm events with the appearance of bends and lenses of coarse laminated packstones. These are associated with breccias comprised of angular fragments of coarse oolites in the packstone matrix, indicating hardground formation before these have been ripped up in storm events and rapidly redeposited within the reworked packstones. In places the junctions between these two lithologies are gradational, probably indicating that the sea floor at this time was uncemented and soft, allowing mixing to occur. Another feature of some of the beds of the Hunts Bay Oolite are the presence of coarse concentrations of fossiliferous debris (70% or more) in a micrite matrix. These beds are seen both in Bracelet Bay and in Three Cliff Bay, and are interpreted as beach type deposits, of shell material, perhaps onto barrier islands during high current activity. These beds are associated with features such as herring-bone cross bedding, indicating formation close to wave activity. The beds of the Hunts Bay Oolite therefore represent shoreface bioclastic grainstone deposits, with the formation of barrier bars and islands with beach deposits of bioclastic material. This represents a transgression with a relate deepening of conditions from the beds below.

4.7. OXWICH HEAD LIMESTONE

The beds of the Oxwich Head Limestone have a similar lithology to those beds of the Caswell Bay Mudstone. They are dominated by beds of dark mudstones and wackestones, with sparse fossil material that are frequently interbedded with thin clays, and occasionally breccias of a similar type to those seen in the Caswell Bay Mudstone. These indicate an environment of low energy sediment accumulation, with periods of aerial exposure, and storm activity bringing in influxes of coarser sediment from outside.

The other type of breccias seen in the Oxwich Head Limestone are the so-called 'pseudobreccias'. The pseudobreccia is thought to be formed by preferential dolomitisation of areas around fossil material, indicating an intertidal environment, as it is common for dolomite crusts to form as a result of periodic surface exposure in intertidal carbonates. Evidence from the fauna of these beds indicates evidence of lower tidal flat environments allowing the growth of stromatolites and corals, with brachiopods and gastropods. There are occasional beds containing oolites and fossil debris probably due to washover during storm events. Figure fifteen shows a diagrammatic log of the Oxwich Head Limestone, .

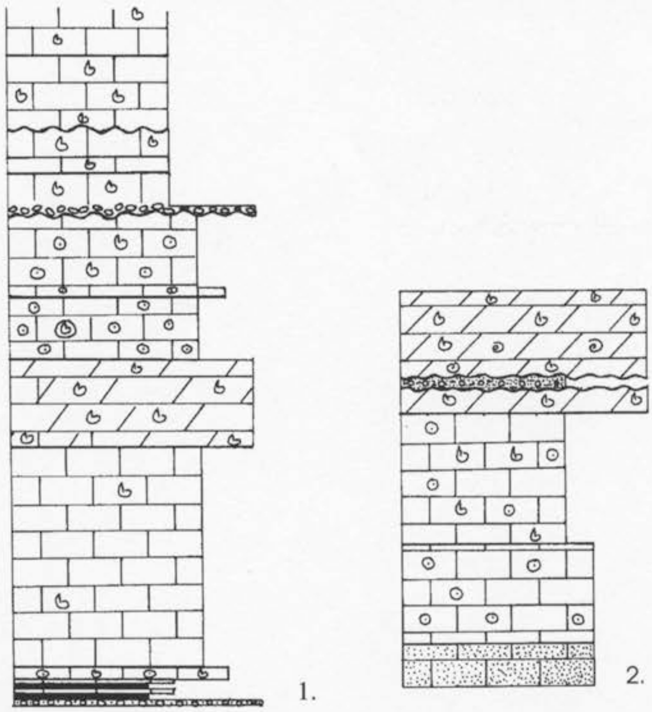


FIGURE SIXTEEN: DIAGRAMMATIC LOG OF THE OXWICH HEAD LIMESTONE
1. MUMBLES HEAD, 2. PWLL DU BAY

Many of the upper beds of the Oxwich Head Limestone show some evidence of possible palaeosols, in the form of thin bands of red and green clays, with a 'dirty' appearance, that are interbedded with unfossiliferous mudstones and breccias. These beds represent a relative shallowing of conditions, probably to sea level fall or once again to the progradation seaward of a coastline.

5. DISCUSSION AND CONCLUSIONS

The beds of the Carboniferous Limestone Series seen in South East Gower are interpreted to have been deposited in four basic environments shown in figure sixteen. These environments are recognised using features of sedimentation and fauna present. The environments recognised correlate with depth of deposition, influence of tidal/wave currents and whether the beds are exposed, or permanently submerged.

DEPOSITIONAL ENVIRONMENTS	EXAMPLES OF SEDIMENT TYPES	EXAMPLES FROM SOUTH EAST GOWER
INTERTIDAL ENVIRONMENT	Pelletal Mudstones, breccias and crinkly laminations formed by microbial mats and subaerial exposure.	CASWELL BAY MUDSTONE OXWICH HEAD LIMESTONE
RESTRICTED LAGOON ENVIRONMENT	Mudstones punctuated by influx of coarser material in washover fans. 'Varved' appearance.	CASWELL BAY MUDSTONE
OOLITE SAND SHOALS Forming Barrier Bars and Barrier Islands	Coarse oolitic sediments with various scales of cross bedding. Beach deposits. Cement formed subaerially, indicating exposure above sea-level.	CASWELL BAY OOLITE HUNTS BAY OOLITE
WAVE INFLUENCED OPEN SHELF	Fine grained bioclastic limestones, especially rich in crinoids and other fossil types. Show evidence of wave influence and storm beds.	PENMAEN BURROWS LIMESTONE HIGH TOR LIMESTONE
STORM INFLUENCED OPEN SHELF	Fine grained limestones and mudstones. Structures obliterated by bioturbation. Coarse material associated with storm events.	CEFN BRYN SHALES

FIGURE SIXTEEN: ENVIRONMENTS OF DEPOSITION ON A SHALLOW MARINE CARBONATE SHELF WITH EXAMPLES SEEN IN SOUTH EAST GOWER.

The first environment of deposition of these beds are intertidal flats, indicated by the presence of pelleted mudstones (that are found on modern intertidal carbonate mud flats). With the presence of 'crinkly' lamination (formed by the trapping of sediment by algal mats, and also periodic drying out of muds), and also the formation of palaeokarstic surfaces, and palaeosols, indicating upper tidal flat conditions. The lower intertidal flats are represented by the highly bioturbated mudstones, with wackestones formed by the overspill of oolites and bioclasts during storm events. The importance of this environment is that it indicates the close proximity of land and coastline, it also indicates very low sea level at time of deposition.

The other depositional environments of Gower indicate progressively deeper water, although the oolitic shoals and shoreface sands also show evidence of subaerial exposure. The deepest conditions are represented by subtidal wackestones and packstones, that are comprised mostly of bioclastic material in a micritc matrix. These were open sea conditions, affected by weak tidal currents, and storm events. These beds were therefore deposited near the wave base, at perhaps a depth of 20-40 metres, which is still quite shallow. There is also deep water with the presence of lagoonal pelleted mudstones with a 'varved' appearance, deposited in a restricted environment affected by strong seasonal variations.

These environments indicate a sequence of facies belts, that follow fairly consistently from east to west, indicating that they are parallel to the palaeo-coastline, lying to the north. There is evidence for this in the palaeocurrents of the herring bone cross bedding in the Hunts Bay Oolite, which indicate the tidal currents were running north to south, giving rise to parallel facies belts as seen in figure seventeen.

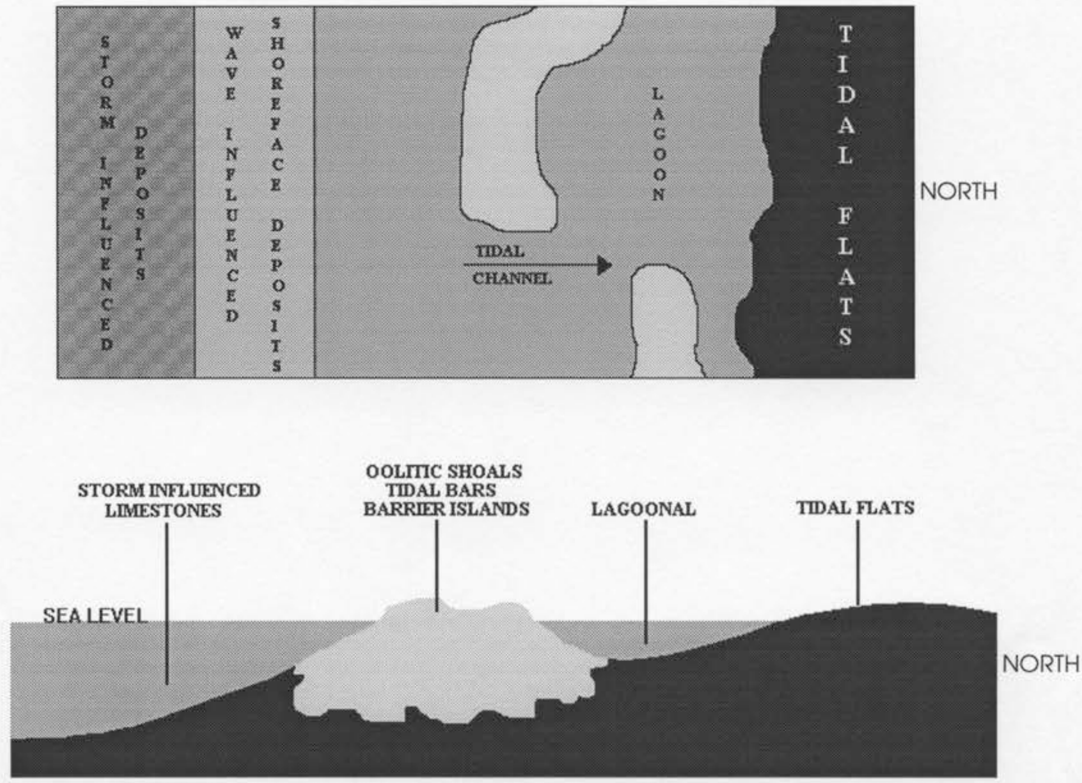


FIGURE SEVENTEEN: MODEL OF DEPOSITION OF THE CARBONIFEROUS LIMESTONE SERIES IN SOUTH EAST GOWER.

The Carboniferous Limestone Series in Gower represents deposits of carbonates on a ramp, dipping at 1 ° or less seaward, also shown in figure seventeen. Evidence for deposition on a ramp rather than a carbonate platform is very strong, with the development of parallel facies belts, no major reef development, and no presence of breccias composed of redeposited limestones, formed by transport down a slope. Evidence suggests that the very low dip of this ramp was also contributory to the tendency of progradational sequences as shallowing occurred upwards due to the deposition over previous sediments. This indicates a relatively stable sea-level for much of the time, with no subsidence of the ramp, causing apparent regressive periods. The intertidal periods as mentioned before representing the lowest sea-level events.

There is evidence of transgressive sequences, formed by sea-level rises, forming the oolitic and bioclastic shoreface sands and barrier bars of the Caswell bay Oolite, and the Hunts Bay Oolite, and also the prograding sequence of the High Tor Limestone. These follow major regressive events, represented by erosional surfaces, and often intertidal sequences. These regressional events correspond to major global sea-level fall.

Other world regressional events in the Dinantian are not so well picked out, although there is some correlation between the regression events and erosional boundaries and facies changes, but not as clearly as those mentioned above.

The climate of the Dinantian in South Wales at this time can be estimated by the nature of the structures present in some of the beds, and also the formation of hardgrounds, and erosional surfaces, with the apparent alternations in conditions. There is a strong storm current influence on these beds indicating conditions of periodic storm activity such as hurricanes. Evidence suggests strong seasonal variations with the formation of 'varved' sediments in lagoon, for example, there may be strong temperature variations as seen in subtropical lagoons. There is no evidence of evaporite deposits in the South East Gower, which would be expected to develop in arid conditions on tidal flats. Together with a lack of 'tepee' structures, and other indicators of a sabkha environment, this indicates the climatic conditions at this time were not arid, but in fact warm, humid conditions.

In conclusion, the Dinantian of South East Gower was deposited on a shallow carbonate ramp, in warm-humid, perhaps sub-tropical conditions. The main influences upon these deposits were storm activity, tidal and wave activity. An important point to mention is that the a modern day example of a shallow carbonate ramp, the epicontinental Persian Gulf, shows a great many of the environments and features seen in the Carboniferous Limestone in Gower. The comparison between these two carbonate ramps has been invaluable as a guide to the likely conditions of deposition during the Dinantian. There are two main differences between the them, however. The first difference is that the Persian Gulf has a small input of aeolian quartz sand, whilst there is no evidence of any input of siliciclastic material in the Gower sequence. Secondly, the Persian Gulf is forming under arid conditions, and therefore shows sabkha environments, but as mentioned before, the Gower does not.

Although the formations of the Dinantian in Gower fit neatly into a standard facies model, further investigation of each zone, individually, and in much greater detail would need to be carried out. Some of the zones of the Dinantian in both Gower and South Wales have been studied in detail, but certainly some of the most interesting have been neglected, in particular the upper zones, from the High Tor Limestone to the Oxwich Head Limestone, which are in some cases better preserved and contain a fuller sequence. Detailed study of these zones would also shed more light onto the environments of deposition of the lower zones, giving a fuller picture than a less detailed study of the whole sequence can provide.

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