THE SEDIMENTOLOGY OF THE HOLKERIAN
ROCKS OF SOUTH WALES

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1868-1915
DECLARATION

This is to certify that the work submitted for the degree of Doctor of Philosophy, under the title of "The Sedimentology of the Holkerian rocks of South Wales" is the result of original work.

All authors and works consulted are fully acknowledged. No part of this thesis has been accepted in substance for any other degree and is not currently being submitted in candidature for any other degree.

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ABSTRACT

In this thesis the Holkerian age rocks of South Wales are reviewed in four main areas: Pembrokeshire, Gower, the North Crop and the Vale of Glamorgan. This is the first basinwide study of a Dinantian stage in the U.K.

The sedimentology of the Holkerian rocks is interpreted using a scheme of fourteen lithofacies and four lithofacies associations. The latter include Open Shelf, Oolitic Barrier, Marginal Back Barrier and Back Barrier Lagoon associations.

The Open Shelf association represents the deposits of a muddy outer shelf area, which was prone to storm redeposition of bioclastic sands. The Oolitic Barrier association represents a broad shallow area characterised by active ooid shoals at its seaward edges and elsewhere by the deposition of oolitic aggregate grains under conditions of early cementation and low rates of sedimentation. The Marginal Back Barrier association represents the areas immediately shoreward of the Oolitic Barrier. The lithofacies association is heterolithic and represents the deposits of micritic tidal flats within a background sediment of subtidal peloid sands. The tidal flats were channelised and oncoids were formed in the mouths of these channels. The tidal flats were also rimmed by low energy beaches.

The Back Barrier Lagoon association represents an area marginal to the Holkerian shoreline. This was characterised by a mosaic of environments including a widespread subtidal peloid sand, micritic tidal flats, ooid shoals, reworked quartz sands, carbonate bank/flood tidal delta developments and complex intertidal shorelines.

The evolution of the carbonate shelf is described using the terminology of Read (1985). The South Wales Shelf developed through Holkerian times from a ramp with sheet sands, to a ramp with oolitic shoal barrier and back barrier lagoon complex, to an accretionary rimmed shelf by the end of the Holkerian.

Controls on this evolution are split into structural and sedimentological controls. The main structural controls on shelf morphology were uplift on the Usk Axis in the east, flexure on a broadly east/west shelf hinge (now the Cefn Bryn Thrust, Gower) to accommodate high rates of sedimentation and uplift on the Ritec Fault in Pembrokeshire. The main sedimentological control was the progradation of the oolitic shoal barrier complex. This created the tripartite division of the South Wales Shelf into Outer Shelf, Oolitic Barrier and Back Barrier areas.
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CHAPTER 1.

INTRODUCTION AND HISTORY OF RESEARCH
1.1 AREA OF STUDY

This study was limited to Holkerian age rocks of the South Wales shelf sequence. These outcrop on the peripheries of the South Wales and Pembrokeshire Coalfields (Fig. 1.1). The area covered extends approximately 150 km (E-W) and 40 km (N-S).

The Holkerian outcrop can be divided into four main areas, namely; The Vale of Glamorgan, Gower, Pembrokeshire and the North Crop of the South Wales Coalfield (Fig. 1.1). In this thesis each area is described individually, although all four areas are interpreted together to elucidate the Holkerian sedimentology of the South Wales shelf. Further details on the location of sections named in the text are given within each relevant chapter.

The majority of the fieldwork was confined to the four main areas. However some consideration was given to the adjacent areas in the South West Province (Southern Ireland, South Wales, Bristol and the Mendips (Fig. 1.2). This was so that the South Wales work could be put into a regional context.

1.2 AIMS OF RESEARCH

The main aims of this research are:

1. To elucidate the distribution of the various Holkerian lithofacies throughout the South Wales shelf sequence and to revise the existing lithostratigraphical nomenclature. As an adjunct to the latter, a reconnaissance of the rocks of the adjoining stages has been undertaken so that the local Holkerian and Asbian basal boundaries could be analysed in the light of the Late Arundian to Early Asbian event stratigraphy (see Ramsbottom 1973 and George et al 1976).

2. To interpret environments of deposition for each lithofacies and to assess controls on their distribution,
FIG. 1.2 OUTCROP OF CARBONIFEROUS LIMESTONE FACIES IN THE SOUTH WEST PROVINCE.
relating them to each other, in a dynamic model.

3. To put the sedimentology of the South Wales Holkerian shelf sequence into the context of the South West Province and establish the roles of (a) local syn-sedimentary tectonism

(b) allocyclic sedimentary processes

in controlling the evolution of the Holkerian sequences of the South Wales Shelf.

1.3 HISTORY OF RESEARCH AND LITERATURE REVIEW

1.3.1 The Nineteenth Century

Early nineteenth century work on the geology of South Wales refers to the occurrence and stratigraphical position of the Carboniferous or "Mountain" Limestone (Martin 1806, Buckland and Conybeare 1824, De la Beche 1829, Conybeare 1832 and Murchison 1836). Subdivisions of the Carboniferous Limestone were not made. However in the first memoir of the newly-instituted Geological Survey of Great Britain, De la Beche (1846) recognised the presence of the Lower and Upper Limestone Shales, that occur at the base and top of the Carboniferous Limestone respectively. Later on in the century, general comparisons were made between the Carboniferous Limestone of North and South Wales (Morton 1881) and equivalent age rocks, The Culm, in North Devon (Hicks 1891).

At the turn of the century, the Survey's "New Series" one inch to one mile maps and accompanying memoirs were being produced in South Wales. The memoirs described the Carboniferous Limestone in terms of the "Main Limestone" bracketed by the Lower and Upper Limestone Shales (Strahan 1899, Strahan and Gibson 1900, Strahan and Cantrill 1902, 1904, 1912; and Strahan et al 1904).
1.3.2 **Vaughanian Zonation**

A major breakthrough in Dinantian stratigraphy was made by Vaughan, with his biostratigraphic zonation of the Avon gorge section (Vaughan 1905) based on coral and brachiopod genera. The possibilities of extending correlation with this new tool were soon realised. Vaughan's main *Seminula* Zone (S₂) – broadly synonymous with the Holkerian, was recognised in South Wales by a number of workers: Gubbin (1905) in Southwest Gower; Delepine (1910) in the Bridgend area; Dixon and Vaughan (1911) in the Gower; Dixey and Sibly (1918) in the Vale of Glamorgan; Trueman (1924), Trueman and George (1924) also in the Gower; George (1927), Robertson and George (1929) on the North Crop; George (1933) in the west of the Vale of Glamorgan; and George (1940) in the Gower.

The Survey memoirs published after Vaughan's 1905 paper also included the new zonal scheme (Strahan 1907a, Strahan 1907b), Strahan 1909, Strahan et al. 1909, Strahan et al. 1914, Cantrill et al. 1916 and Dixon 1921). Thus the S₂ zone was recognised over most of South Wales.

However, Vaughan's zonal scheme was accompanied by a haphazard lithostratigraphy. Prominent lithologies in the Bristol District were given a zonal notation by Vaughan and were subsequently used by the later workers in the rest of the South West Province. However many stratigraphic units remained unnamed. It was not until the post-war mapping of the Monmouth/Chepstow and Bristol/Mendip areas by Kellaway and Welch (1955) that a strict lithostratigraphic approach was taken in describing the Dinantian of the South West Province. This approach was first applied in the South Wales area by Stephens (1973).

Not all of the S₂ zone (*sensu* Vaughan 1905) is included in
the Holkerian as defined by George et al (1976). The base of the Holkerian is taken, locally in the Avon Gorge, at the base of the Seminula Oolite (George et al 1976). Vaughan's S2 definition includes some of the bioclastic and algal limestones below the oolite which are identified as being of Arundian age by George et al (1976). Thus George et al state that the Holkerian stage "approximates" to the former S2 zone.

1.3.3 Eustacy - The Holkerian Defined

Vaughan's zonal scheme had many imperfections, partly because the macrofauna used was facies controlled and partly because of non-sequences in the Avon Gorge section on which Vaughan's original work was done. Ramsbottom pointed this latter fact out, whilst only obliquely referring to the former and summarised the previous literature on the detailed imperfections (Ramsbottom 1970 P. 146). Three years later, (Ramsbottom 1973) he introduced an entirely new synthesis of Dinantian stratigraphy.

A series of transgressions and regressions forming six major cycles was recognised. The upper two major cycles comprised a number of minor cycles. The regression at the end of each cycle could culminate in a period of non-deposition, thus creating the non-sequences evident in the Avon Gorge. The cycles were attributed to eustatic sea level changes and it was suggested that they might be recognised world-wide.

Ramsbottom (1973) proposed to replace the Vaughanian system of zonation with a chronostratigraphy based on his cycles. Each major cycle could form a stage, which would be formally named and stratotyped. This was done by George et al (1976) and the results published in a Geological Society Special Report. The Holkerian (along with five other stages) was defined and correlated
Introduction and History of Research throughout Great Britain.

The stage stratotypes were defined lithologically. However, some boundaries were based on odd lithological changes e.g. the base of the Arundian was placed at a dolomite/limestone transition (Simpson, in press). The sedimentology of some of the stratotypes is also considered to deserve more rigorous analysis in some places (see Chapter II, Section 4). Furthermore, the stratotypes locally do not contain the stage fauna as defined in George et al (1976) for some considerable distance above the base (Clayton and Sevastopulo 1981).

Even though these problems with the stratotypes existed, Ramsbottom continued to champion his ideas on eustatic cycles with three subsequent papers (Ramsbottom 1977, 1979 and 1981).

1.3.4 Sedimentology

The earliest sedimentological work on the Holkerian rocks of South Wales was Dixon's and Vaughan's (1911) paper on the Gower Peninsula. Dixon described several facies throughout the Dinantian sequence. He recognised four "lagoon phases" one of which was at the top of the S2 zone. In this he identified certain lithologies, "calcite mudstones, intraclasts, pisolites, oolites, intermixed with standard limestones" and a restricted fauna and flora, which he suggested characterised shallow water deposition. Dixon used these "lagoon phases" to recognise a series of shallowing upwards cycles and linked them with "earth movements".

Dixon continued his pioneering sedimentological work with the publication of a Survey memoir on the area around Pembroke and Tenby (Dixon 1921). In this he again identified a lagoon phase at the top of the S2 zone, as well as providing written logs of the various S2 zone sections. Another phase, the
"zaphrentid phase" was also identified and interpreted as the deposits of a "..muddy sea." This phase dominated the zones below the S2 zone in the southernmost part of the area and "tails off gradually" in the S2 zone itself.

These two papers by Dixon influenced much of the future sedimentological work both on the Holkerian and the rest of the Dinantian sequence of South Wales. However by this time Vaughan had died and Dixon's interest in publication on the Dinantian of South Wales waned with the death of his "ever-helping" friend and mentor.

George extended Dixon's early sedimentological work to the North Crop exposures. In the first of two papers, he identified shaly partings and made some comment on sedimentological processes within the S2 zone, in "wedge bedded oolitic limestones...the beds bear evidence of penecontemporaneous erosion" (George1927). He also mentioned sandy beds at the base of the sequence in the east of the area. In a second paper (Robertson and George 1929) a coral band was identified at various heights above the base of the sequence. This was taken to represent varying degrees of topographical relief on the "intra-Avonian unconformity". A quartz conglomerate was also found at the base of the Holkerian at Careg Yr Ogof.

George then turned his attention to the Dinantian sequence in the Vale of Glamorgan (George 1933). In this paper, the S2 zone was mapped out and details of the various exposures given. Following Dixon's lead, he recognised a lagoonal facies in the upper portion of the S2 zone with "much evidence of rapid current action and contemporaneous brecciation". He also identified a "standard limestone" facies. This he interpreted to be
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"...generally deeper water..." with "only occasional development of contemporaneous brecciation and acute current bedding."

In a broader work (George 1958), mention is made again of the sandy beds in the east of the North Crop. It is suggested that they are linked with fluvial input to the adjacent Forest of Dean area, represented by the Drybrook Sandstone. George also commented on the lithologies present in the S₂ zone of the North Crop and interpreted their depositional environment "...they represent conditions of "banks" and algal flat sedimentation that persisted for a relatively long time."

In Pembrokeshire, the oolitic S₂ zone sequences were described and interpreted by Sullivan (1966). These were recognised to have "migrated southwards in Seminulan times". Sullivan also interpreted interbedding of oolitic and bioclastic sediments as evidence of pulsatory migration.

Ramsbottom, in a rather general paper on Carboniferous palaeogeographies (Ramsbottom 1970) included the Holkerian sediments of South Wales in a palaeogeographic map of "zone five". He referred to a large area of oolite deposition, which he suggested "indicates another slight advance of the sea", but made no other sedimentological observations on this zone.

George, in another broad paper (George 1972) referred to the "Seminulan Cycle" and described it as "the most varied of Avonian rock suites". However he gave some lithological detail of the "Concretionary Beds" at the top of the S₂ zone in South Wales. In the same year the depositional history of some parts of the Visean (including the Holkerian) in Bristol and the Gower were compared by MacQuown and Bloxham (1972). The sedimentological content of this paper was hampered by its limited geographical scope. However the oolitic sequence, now included in the
Holkerian, was interpreted as a prograding ooid shoal.

During the early eighties, Wright has made several contributions to Dinantian (including Holkerian) sedimentology in South Wales. In an early paper (Wright 1980) he suggested a climatic change from hot arid to hot humid between the Arundian and Upper Carboniferous (bracketing the Holkerian) based on palaeosol evidence. In a field guide to the North Crop around Abergavenny (Wright, Raven and Burchette 1981) he gave a brief description of the Dowlais Limestone (Holkerian). He noted various "...shallow subtidal, intertidal and subaerial deposits" and interpreted the sequence as a "fluctuating quiet water shelf lagoon, oolite shoal, intertidal to swamp (seat earth) setting." However he also noted that "there has not been any detailed work on this unit."

One year later (Wright 1982a), he published evidence of omission surfaces within the Dowlais Limestone. This was based on concentrations of exhumed burrow fills on bedding planes. These, he interpreted as being concentrated during storms.

A conference in 1984 entitled "European Dinantian Environments" provided several general reviews of Dinantian sedimentology in South Wales. Junghans et al (1984) described the sediments of South West Gower. They interpreted the "upward increase in oolite" through the Holkerian sequence as suggesting "progressive shoaling". Ramsay (1984) described the Courceyan to Holkerian part of the Dinantian sequence throughout the Gower. He compared the sedimentary processes which controlled the deposition of the Holkerian Hunt's Bay Oolite with those operating at present in the Bahamas.

The most recent contribution to Dinantian sedimentology in
South Wales (Wright 1986) proposes an overall carbonate ramp style of deposition on the South Wales shelf from the Courceyan through to the Holkerian. The evidence for this comes from pre-Holkerian sediments, but the conclusion includes the Holkerian within the overall model.

1.3.5 Structural Controls

The literature on the origin of underlying structures, both Caledonian and Variscan, which affected Dinantian sedimentation and contributed to the present outcrop pattern and structure of the resultant Dinantian rocks is numerous. No attempt is made here to give a complete review of it. Reviews of Variscan structure and tectonic environment in the area adjacent to South Wales include; Floyd 1972, Reading 1973, Matthews 1977, Gardiner and Sheridan 1981, Isaac et al 1982, Shackleton et al 1982, and Kellaway and Hancock 1983.

Similar information on the South Wales area includes structural details on the East Crop of the South Wales Coalfield (Moore 1948, Blundell 1952). Two recent papers give a more up to date synthesis of the structure of Pembrokeshire (Hancock et al 1983) and the structure of the South Wales Coalfield (Owen and Weaver 1983). In the former, processes of thin skin tectonics (intracrustal decollement and thrusting) are invoked to explain the outcrop structure of Pembrokeshire.

Synsedimentary Dinantian tectonics in South Wales are quite well documented. However most studies interpret the effects as not affecting Holkerian age sediments e.g. "the Usk Anticline had insignificant effects during the deposition of the Seminula zone" (George 1954a). Also "The Seminulan transgression marked the onset of uniform marine conditions over a large area of the shelf." (Sullivan 1966). In the same paper (Fig. 5, page 231)
Sullivan indicated no facies change in the Holkerian sediments across the Ritec fault in Pembrokeshire.

Even so, facies changes in Holkerian age rocks adjacent to the Usk Anticline are noted in two papers (George 1956 and George 1958). Owen summarised these and other effects of Dinantian synsedimentary tectonics (Owen 1964 and Owen 1970). Sullivan summarised pre-Holkerian synsedimentary tectonics in Pembrokeshire (Sullivan 1965).

Several general papers have been written in an attempt to produce an overall model of Dinantian basin development, including the South Wales area; (Bott and Johnson 1967, Leeder 1976, George 1978a, Dewey 1982, Leeder 1982). These appeal to an overall tensional tectonic regime related to southerly directed subducting slab pull forces, to explain differential subsidence within the U.K. during the Dinantian.

1.3.6 Regional Reviews

Regional review papers can provide a background for the study of the depositional history of Holkerian age rocks. Useful reviews of South Wales geology are found in Pringle and George (1937), Pringle and George (1948), Jones (1956) and George (1970a, 1974).

1.5 **PRESENTATION OF RESULTS**

In accordance with the regulations and requirements for the degree of Doctor of Philosophy at U.C.W. Aberystwyth the methods and results of the research are embodied in this thesis. Chapter II gives a description of the framework of the research in order that the reader is not lost in a plethora of detailed lithostratigraphic nomenclature. The sedimentology is then approached by a breakdown of major lithofacies associations within each geographical area studied (Fig. 1.1). The lithofacies associations are then explained in greater detail for each area. A concluding chapter then analyses the facies sequences and incorporates them into models of sedimentation.

Wherever necessary, diagrams, tables, photographs and summary logs are incorporated and referred to in the text. Graphic logs of the major logged sections are presented on a 1:200 scale in four separate enclosures. Point count data is presented in tables arranged by lithofacies and lithofacies associations (Appendix One).

Within the text, the point count data is presented as tetrahedral stereoplots, which can be viewed in 3-D if a suitable stereoscope is used. Two plots are used, one to illustrate lithofacies and one to illustrate ooid type. The former plots the following variables at the tetrahedral apices: peloids/intraclasts (IP or PEL) micrite matrix (MICRITE) bioclasts (BIO) and ooids (OOIDS). The latter plots various ooid types at the tetrahedral apices: thoroughly micritised ooids (HOMOG) ooids with concentric/radial cortical textures (CONC/RAD) ooids with radial cortical textures (RAD) and oolitic aggregate grains (COMP). For clarity, in most cases only one representative example is plotted.
CHAPTER 2.

FRAMEWORK OF RESEARCH

LITHOSTRATIGRAPHY AND LITHOFACIES
2.1 Lithostratigraphic Nomenclature and Correlation

2.1.1 Introduction

The establishment of strictly lithological nomenclature within the Carboniferous Limestone of the Forest of Dean, Bristol and The Mendips areas by the Survey (Kellaway and Welch, 1955) led to a partial adoption of this scheme in the rest of South Wales (Stephens, 1973 and Junghans, 1974). George et al (1976) added to this, extending correlations of rock units throughout the South West Province and the British Isles. However, many names used to define the same rock unit, even in adjacent geographical areas, were still different. During the re-survey of the Bridgend and Cardiff sheets by the British Geological Survey (Wilson et al in press, Waters and Lawrence, in press) lithostratigraphic nomenclature was rationalised using a system where priority was given to first named rock units. Where no name existed new names were defined e.g.: Stormy Limestone (Davies, 1982).

This study has modified and extended the lithostratigraphic nomenclature of the recent B.G.S. work in the Vale of Glamorgan, combined with that of the Geological Society's 1976 Report (George et al, 1976) to the rest of South Wales. New names have been defined and in some cases existing terminology has been redefined.

In South Wales six formations encompass the Holkerian Stage. Within the Vale of Glamorgan two of these formations (the Stormy Limestone and the Cornelly Oolite Formations) constitute a formal unit, the Hunt's Bay Group (Wilson et al in press and Waters and Lawrence in press). In the eastern parts of the Vale of Glamorgan these two formations are not recognised due to a facies change and Holkerian age rocks are included within the Hunt's Bay Group.
(undivided). In the Gower the Hunt's Bay Group is equivalent to the Hunt's Bay Oolite Formation sensu Stephens (1973).

The Holkerian South Wales Shelf was fringed by an oolitic barrier sequence (broadly defined by the Cornelly Oolite Formation). This created a protected back barrier lagoonal sequence (the Dowlais Limestone and Stormy Limestone Formations) and passed offshore into a dominantly bioclastic limestone sequence (the Stackpole Limestone Formation) and interbedded limestone/shale sequences (the Overton Cliff Formation and the Wash Member of the Pen-Y-Holt Limestone).

The six formations and their various subdivisions which encompass the Holkerian are described below and their distribution summarised in Fig. 2.1. Place names used may be located by reference to the location maps found at the beginning of each area chapter (Figs. 3.1, 4.1, 5.1, 6.1).

The overlying Asbian age rocks and the underlying Arundian and older age rocks are also briefly described

2.1.2 Lithostratigraphy

2.1.2.1 Holkerian Age Rocks

Wash Member (Pen-Y-Holt Limestone) - New Name

Name: After a prominent bedding plane exposure called The Wash (SR 919943) approximately 200m west of the Green Bridge of Wales (SR 925943) in the south of the Bosherton Outcrop area (Fig. 3.1).

Type Section: From the top of a metre thick dolomite at The Wash to the overlying bioclastic limestones of the Stackpole Limestone Formation at the Green Bridge of Wales.

Thickness: Approximately 37m at the type locality (difficult to measure due to vertical cliff exposure) 54m at Stackpole Quay and 21m at Lydstep Point (SS 093975).
FIG. 21 LITHOSTRATIGRAPHIC NOMENCLATURE OF HOLKERIAN AGE ROCKS AND THEIR UNDERLYING / OVERLYING ROCK UNITS.

- SEE TEXT FOR LITHOLOGICAL DESCRIPTIONS.

VERTICAL SCALE - 1:2000
Lithology: The member is characterised by thin bedded, bioclastic limestones and nodular cherts interbedded with thin shales. Gastropods and *Caninophyllum archieci* are common.

Boundaries: At the type locality the junction with the underlying Pen-Y-Holt Limestone (Arundian - George *et al* 1976) is marked by a metre thick dolomite. There is also a change from the thicker shale interbeds of the interbedded limestone/shale lithologies of the Pen-Y-Holt Limestone to the thinner shale interbeds of the Wash Member. This transition is well exposed at Sixth Point, Stackpole Quay (Figs.3.3 and 3.4). At Lydstep Point, the Member overlies the thick bedded peloidal, bioclastic limestones of the High Tor Limestone (Arundian - George *et al* 1976). Throughout its outcrop area the Member is overlain by the bioclastic lithologies of the Stackpole Limestone Formation.

Distribution: The Member has only been recognised south of Lydstep Point in Pembrokeshire.

Age: The Member has been assigned an Holkerian age on foraminiferal evidence. This is based on the identification of *Draffania biloba* from beds below the arch of the Green Bridge of Wales.

**Overton Cliff Formation** (Redefined)

Name: After a feature called Overton Cliff (SS 458848) on the Southwest coast of Gower where the formation is well exposed. Elevated to formation status from member status (of the High Tor Limestone) as defined by Junghans (1974).

Thickness: The formation decreases in thickness northwards from 35m at Thurba Head (SS 423869) to 2m at Burry Holm (SS 926404).

Lithology: The formation consists of bioclastic limestones and shales interbedded on a dm to m scale.

Boundaries: The formation is overlain by the predominantly
bioclastic lithologies of the basal parts of the Red Chamber Member (Cornelly Oolite Formation). It is underlain by the peloidal and bioclastic lithologies of the High Tor Limestone.

Distribution: The formation is found only within Western Gower between Thurba Head, Overton Cliff and Burry Holm.

Depositional Environment: The formation represents the muddy shelf conditions, with storm introduced limestone beds, which prevailed on the outermost open shelf areas of the Holkerian South Wales Shelf.

Age: The identification of a diagnostic Holkerian coral fauna, including the cerioid Lithostrotion araneum in the first limestone bed of the formation (Simpson 1986) has been supported, in this study, by the identification of other characteristic Holkerian macrofauna including Davidsonina carbonaria.

**Stackpole Limestone Formation (Redefined)**

Name: Derived from Stackpole Quay, Pembrokeshire (SR 919943) where the formation is well exposed. The current definition of the formation is more specific than that of George et al (1976) which incorporated all Holkerian age rocks in Pembrokeshire within the formation.

Thickness: The formation generally thins northwards from approximately 240m in the southernmost areas of the Bosherton Outcrop to 22m at Stackpole Quay and 3m at Lydstep Point (SS 093975). At Tenby South Sands (SN 135002) the formation increases in thickness to 10m.

Lithology: The formation is dominated by bioclastic limestones with textures ranging from wackestone to grainstone. Crinoid fragments are a common component grain type.

Boundaries: The formation overlies the interbedded peloidal
bioclastic limestone and shale lithologies of the Wash Member (Holkerian) of the underlying Pen-Y-Holt Limestone. At Tenby South Sands the formation overlies the oolitic, peloidal and bioclastic lithologies characteristic of the upper parts of the High Tor Limestone Formation at that locality. The formation is overlain by the oolitic lithologies of the Cornelly Oolite Formation (Holkerian, Wilson et al in press).

Distribution: The formation is only recognised in those outcrops which are south of the Ritec Fault in Pembrokeshire.

Depositional Environment: The formation represents the bioclastic sands which formed on the open shelf areas of the Holkerian South Wales Shelf. These were seaward of the developing Holkerian oolitic shoal barrier system.

**Cornelly Oolite Formation**

Name: After Cornelly Quarry (SS 835800) in the Vale of Glamorgan where the formation was first described (Wilson et al in press).

Thickness: The formation has a variable thickness ranging from a maximum of 211m at Hunt's Bay (SS 562868) in Gower to less than 15m in the south of the Bosherton Outcrop area (Gun Cliff SR 989943) in Pembrokeshire.

Lithology: The formation is dominated by oolitic lithologies which are generally characterised by the occurrence of oolitic aggregate grains. There are also subordinate amounts of bioclastic and peloidal lithologies. These have wackestone, packstone and grainstone textures and are interbedded with the oolitic lithologies on a variety of scales (cm to m).

Boundaries: In all parts of the study area where it outcrops, the Cornelly Oolite Formation is overlain by the Stormy Limestone Formation. This junction is marked by the base of the first micrite of the overlying formation. The Cornelly Oolite Formation
Lithostratigraphy and Lithofacies

is underlain by rock units which are dominated by bioclastic limestone lithologies. These are either Holkerian in age (Stackpole Limestone Formation) or Arundian in age (High Tor Limestone). The exception to this is in Southwest Gower where the formation overlies the interbedded limestone/shale lithologies of the Overton Cliff Formation.

Distribution: The formation is found in all parts of the study area except for the North Crop and the areas north of the Ritec Fault in Pembrokeshire. In the eastern parts of the Vale of Glamorgan the formation is not formally recognised due to a facies change, but similar lithologies are included within the Hunt’s Bay Group (undivided).

Depositional Environment: The formation represents a variety of environments associated with the development of ooid shoals and consequently an oolitic barrier system on the South Wales Shelf.

Subdivisions: Within Gower, the excellent exposures of the formation permit some localised subdivisions based on variations in the ratios of oolitic with bioclastic and/or peloidal lithologies. These subdivisions are termed the Red Chamber Member (Redefined), The Deep Slade Member (New Name) and the Pwll Du Member (New Name). These subdivisions are not recognised outside of Gower. In the Central and Eastern Vale of Glamorgan two members are recognised which are included within the Hunt’s Bay Group. Of these only the Argoed Limestone Member is Holkerian in age (Waters and Lawrence in press). In Pembrokeshire the formation is undivided.

Red Chamber Member (Redefined)

Name: After a cave of the same name (SS 426666) on the Southwest Gower coast where the member is well exposed. Modified from the
bioclastic limestone description of Junghans (1974) to include thinly (dm to m) interbedded oolitic beds within bioclastic lithologies.

Type Section: At Red Chamber, from the top of the interbedded limestones and shales of the Overton Cliff Formation to the base of the thicker bedded oolitic lithologies of the Pwll Du Member.

Thickness: The member is thickest (140m) at its type locality in Southwest Gower. It becomes progressively thinner northeastwards and is 93m thick at Three Cliffs Bay (SS 532878) and 28m thick at Hunt's Bay.

Lithology: The member is dominated by bioclastic lithologies interbedded with oolitic lithologies. The oolitic interbeds range in thickness from dm to m scale.

Boundaries: The base of the member is defined either by the transition to the thicker bedded oolitic lithologies of the Deep Slade Member (Cornelly Oolite Formation) or to the limestone/shale interbeds of the Overton Cliff Formation. The upper boundary is marked by the transition to the thicker bedded oolitic lithologies of the overlying Pwll Du Member (Cornelly Oolite Formation).

Distribution: The member is only recognised in South Gower.

Deep Slade Member: (New Name)

Name: From the valley which leads down to Hunt's Bay where the member is well exposed.

Type Section: On the western side of Hunt's Bay (SS 562868) from the top of the peloidal and bioclastic limestones of the High Tor Limestone to the overlying bioclastic limestones with interbedded oolitic lithologies of the Red Chamber Member.

Thickness: 72m at the type section, thinning to 63m at Three Cliffs Bay.
Lithology: The member is dominated by oolitic lithologies characterised by oolitic aggregate grains. The oolitic lithologies are generally massive but are, in places, pseudobedded.

Boundaries: The member is sharply underlain by the bioclastic and peloidal limestones of the High Tor Limestone. The transition to the overlying Red Chamber Member (Cornelly Oolite Formation) is marked by the change to bioclastic limestones with interbedded oolitic lithologies.

Distribution: The member is only recognised at Three Cliffs Bay and Hunt's Bay.

Pwll Du Member (New Name)

Name: After the headland of the same name situated on the eastern side of Hunt's Bay (SS 570863) where the member is well exposed.

Type Section: Below the cliffs which form the headland of Pwll Du, Gower (SS 570863). From the top of the bioclastic limestones with interbedded oolitic lithologies (Red Chamber Member) to the first micrite of the Stormy Limestone Formation.

Thickness: The member is thickest at Hunt's Bay (105m) and thins to 54m at Three Cliffs Bay and 57m in Southwest Gower.

Lithology: The member is dominated by oolitic lithologies characterised by oolitic aggregate grains. However there are minor amounts of interbedded peloidal, simple ooid and bioclastic lithologies.

Boundaries: The base of the member is defined by the transition to the interbedded bioclastic and oolitic lithologies characteristic of the underlying Red Chamber Member. The top of the member is sharply defined at the base of the first micrite of the overlying Stormy Limestone Formation.
Lithostratigraphy and Lithofacies

Distribution: The member is recognised throughout the sections studied on the South Gower coast.

**Argoed Limestone Member** *(New Name)*

Name: After Argoed Isha Quarry (SS 995791) in the Vale of Glamorgan where the member is exposed.

Type Section: In Argoed Isha Quarry, from the top of the oolitic lithologies representing the Cefnyrhendy Oolite Member (Arundian - Waters and Lawrence in press) to the overlying oolitic lithologies equivalent to the Cornelly Oolite Formation (Hunt's Bay Group).

Thickness: The member is approximately 12m thick in the eastern Vale of Glamorgan.

Lithology: The member comprises thin bedded, dolomitised bioclastic limestones.

Boundaries: The member is overlain by the dominantly oolitic lithologies which are equivalent to the Cornelly Oolite Formation (Hunt's Bay Group - undivided). The junction with the underlying massive, partly cross bedded oolitic limestones of the Cefnyrhendy Oolite Member is sharp and is marked by a palaeokarst overlain by a thin palaeosol (Waters and Lawrence in press).

Distribution: The member is only found in the Eastern and Central areas of the Vale of Glamorgan (Figs. 6.1 and 6.2).

**Stormy Limestone Formation**

Name: After a group of quarries near Stormy Down (SS 828802) in the Western Vale of Glamorgan (Fig. 6.1) where the formation is well exposed (Davies 1982).

Thickness: The formation generally decreases in thickness from north to south over its outcrop area. In the Western Vale of Glamorgan (Lock's Lane Borehole - SS 881777, Fig. 6.1) it is 60m thick. In Gower, the formation decreases in thickness from 45m at...
Hunt's Bay to 38m at Three Cliffs Bay to 29m in Southwest Gower. In Pembrokeshire, the formation is in excess of 100m thick at Tenby South Sands and thins progressively southwards from 52m at Lydstep Point to a feather edge in the Bosherston Outcrop area.

Lithology: The formation is an heterolith, but the lithologies can be grouped into two broad lithofacies (Pel-Bio Limestone and Micritic and Cryptalgal Lithofacies). The former is characterised by limestones containing variable amounts of peloids, bioclasts and ooids exhibiting a range of textures from wackestone to grainstone. The latter is comprised of various micritic and peloidal lithologies, both of which contain cryptalgal structures. The peloidal lithologies may contain oncoids and/or intraclasts and have textures ranging from wackestone to grainstone. Carbonaceous shales are also recorded, but are rare.

Boundaries: Throughout the outcrop area, the formation is overlain by a number of rock units of Asbian age. The junction is always conformable, and marked by palaeokarst development. In Pembrokeshire the overlying rock unit is the Crickmail Limestone and in the Gower and the Vale of Glamorgan it is the Oxwich Head Limestone (George et al. 1976). In Gower and Pembrokeshire the junction is marked by a sharp facies change to coarse oolitic and bioclastic lithologies. In the Vale of Glamorgan the overlying rock unit is a calcareous sandstone (the Pant Mawr Sandstone, Davies 1982) which is the basal member of the Oxwich Head Limestone. The base of the Stormy Limestone Formation is defined at the base of the first micrite lithology above the oolitic, bioclastic and peloidal lithologies characteristic of the Cornelly Oolite Formation. Laterally, to the north, the formation grades into lithologies characteristic of the Dowlais Limestone.
Formation. However this transition is not well exposed within the study area.

Distribution: The formation is found throughout the study area except on the North Crop and areas to the north of the Ritec Fault in Pembrokeshire. In the Eastern Vale of Glamorgan it is not recognised, but similar lithologies are found within the Hunt's Bay Group (undivided), Fig.6.2.

Depositional Environment: The formation represents a variety of marginal back barrier environments formed immediately adjacent to the rearwards edge of the developing oolitic shoal barrier sequence on the Holkerian South Wales Shelf.

**Dowlais Limestone Formation**

Name: The name is derived from the group of quarries immediately north of Merthyr Tydfil (Fig.5.1) George et al 1976.

Thickness: Averages approximately 90m over most of the North Crop, but thins to a feather edge near Haverfordwest (SM 960148) and is eroded to less than 60m by Namurian overstep in the east.

Lithology: The formation is heterolithic, but consists mainly of dark peloidal and bioclastic limestones. There are also minor amounts of carbonaceous shales, simple ooid lithologies, micrites, cryptalgal lithologies, peloidal lithologies, sandy limestones and oolitic aggregate/intraclast lithologies. These various lithologies are grouped into a seven-fold lithofacies scheme (Fig.2.2).

Boundaries: Four rock units overlie the formation (Fig.2.1). These are, from east to west, the overstepping Millstone Grit (Namurian) the Penderyn Oolite, the Greenhall Limestone and the Pendine Oolite, which are all conformable and Asbian in age (George et al 1976). The lower boundary of the formation is also coincident with four rock units. From east to west these are the
Gilwern Clay Member of the Llanelly Formation (Arundian - Wright, Raven and Burchette 1981) the Lower Limestone Shales (Courceyan - George et al 1976) the Pendine Conglomerate (Chadian - George et al 1976) and Silurian slates (Strahan et al 1914). All the underlying and overlying boundaries mentioned are marked by erosion surfaces and/or palaeokarsts.

Distribution: The formation is found all along the North Crop and in outcrops north of the Ritec Fault near Carew (SN 047037) in Pembrokeshire Fig.3.1.

Depositional Environments: The formation represents a range of back barrier and marginal back barrier environments where predominantly fine grained peloidal and bioclastic lagoonal sediments were deposited.

Subdivisions: Across most of the North Crop, the formation is split into three distinct lithological units. These are given member status and are termed the Penwyllt Member, the Cyl Yr Ychen Member and the Ponsticill Member.

Penwyllt Member (New Name)

Name: From Penwyllt Quarry (SN 857162) where the member is best exposed (Fig.5.1).

Type Section: Penwyllt Quarry, from the top of the buff fawn weathering limestone unit of the Lower Limestone Shales to the first carbonaceous shales interbedded with thicker bedded peloidal bioclastic lagoonal limestones of the overlying Cyl Yr Ychen Member.

Thickness: 44m in the type section, 40m at Pendine (SN 232077) 32m at Cyl Yr Ychen Quarry (SN 615165) and 37m at Twynau Gwynion Quarry (SO 108063).

Lithology: The member consists mainly of dark, peloidal
bioclastic lithologies interspersed with lighter oolitic aggregate and simple ooid lithologies which are overlain by micrites and cryptalgal lithologies. To the east of Careg-Yr-Ogof (SN 771216) the member contains thin quartzitic sandy limestones near its base.

Boundaries: The lowermost boundary of the member coincides with that of the Dowlais Limestone Formation and is described above. The member is overlain by the thicker bedded peloidal bioclastic lithologies interbedded with carbonaceous shales characteristic of the Cyl Yr Ychen Member. The junction is gradational.

Distribution: The member has been recognised only between Twynau Gwynion Quarry in the east and Pendine in the west of the North Crop (Fig.5.1).

**Cyl Yr Ychen Member** (New Name)

**Name:** Taken from the type locality at Cyl Yr Ychen Quarry (SN 615165).

**Type Section:** At Cyl Yr Ychen Quarry, from 32m above the Lower Limestone Shales (buff silicified limestone - Courceyan, George et al 1976) to 25m below the palaeokarst with grey clay which marks the base of the Greenhall Limestone (coarse oolitic, bioclastic lithologies - Asbian, George et al 1976).

**Thickness:** The member ranges in thickness from 18m at the type section to 16m at Penwyllt Quarry, 22m at Twynau Gwynion Quarry to only 3m at Pendine.

**Lithology:** The member is characterised by thick (metre) bedded, fine grained, carbonaceous, peloidal, bioclastic limestones interbedded with cm to dm thick carbonaceous shales.

**Boundaries:** The lowermost boundary of the member has been described in the section on the Penwyllt Member. The uppermost boundary is gradational and is recognised by the change to
lighter grey (less carbonaceous) and coarser intraclast, peloidal, bioclastic limestones with micrites and cryptalgal fabrics characteristic of the Ponsticill Member.

Distribution: The distribution of this member is the same as for the Penwyllt Member described above.

Ponsticill Member (New Name)

Name: After the village of the same name (SO 056112) to the west of Twynau Gwynion Quarries (SO 064108) where the type section is located.

Type Section: Twynau Gwynion Quarries, from the top of the thick carbonaceous peloidal limestones interbedded with shales (Cyl Yr Ychen Member) located 41m below the palaeokarst which marks the junction of the Dowlais Limestone Formation (and the Pontsticill Member) with the coarse oolitic and bioclastic lithologies characteristic of the Penderyn Oolite (Asbian - George et al 1976).

Thickness: The member is 41m thick at the type section and varies from 25m thick at Cyl Yr Ychen Quarry to 36m at Penwyllt Quarry and 46m at Pendine.

Lithology: The member is dominated by peloidal, bioclastic lithologies with micritic intraclasts and minor amounts of Composita coquinas with oncoids.

Boundaries: The junction of the member with the underlying lithologies characteristic of the Cyl Yr Ychen Member has been described above. Similarly, the upper limits of the member define those of the Dowlais Limestone Formation and have been described within the section on that lithological unit.

Distribution: The distribution of the member is the same as that described for the other two members of the Dowlais Limestone
Lithostratigraphy and Lithofacies 27

Formation.

2.1.2.1 Asbian Age Rocks

Only brief lithological descriptions are given of the following rock units.

Crickmail Limestone: (Pembrokeshire) Thick bedded, coarse oolitic and bioclastic limestones.

Oxwich Head Limestone: (Gower and the Vale of Glamorgan) Coarse oolitic and bioclastic limestones.

Pant Mawr Sandstone Member: (Oxwich Head Limestone - Vale of Glamorgan) Fine to medium grained calcareous sandstone.

Penderyn Oolite: (Eastern North Crop) Coarse oolitic and bioclastic limestones.

Greenhall Limestone: (Cyl Yr Ychen Quarry) Light grey, coarse peloidal, bioclastic and minor oolitic lithologies.

Pendine Oolite: (Pendine and Western North Crop) Coarse oolitic and bioclastic limestones.

2.1.2.3 Arundian Age Rocks

The following are only brief lithological descriptions.

Pen-Y-Holt Limestone: (Excluding the Wash Member - Pembrokeshire) Interbedded bioclastic limestones and shales with thicker shales than the Wash Member.

High Tor Limestone: (Pembrokeshire, Gower and the Vale of Glamorgan) Thickly bedded peloidal and bioclastic limestones. Locally oolitic in Pembrokeshire and the Vale of Glamorgan.

Cefnyrhendy Oolite Member: (High Tor Limestone - Vale of Glamorgan) Massive, partly cross bedded oolitic limestones.

Gilwern Clay Member: (Llanelly Formation - Eastern North Crop) Red and green clays overlain by seatearth with coal development.
2.1.2.4 **Pre-Arundian Age Rocks**

These rock units underlie the Dowlais Limestone Formation and demonstrate the transgressive nature of that formation. They are confined to the North Crop and are described briefly below.

**Lower Limestone Shales:** (Courceyan – Burchette 1977, Cyl Yr Ychen Quarry and Penwyllt Quarry) Dark carbonaceous shales overlain by buff/fawn weathering neomorphosed limestones with pale grey shale and nodules (caliche development).

**Pendine Conglomerate:** (Chadian – George et al 1976, Pendine) Micritic, peloidal and bioclastic limestones with yellow clays, karstic horizons and associated pedogenic features.

### 2.2 Lithofacies Schemes

An important step in elucidating the gross sedimentology of the Holkerian sequences has been the identification of lithofacies in the logged sections.

A scheme of fourteen lithofacies has been set up to describe characteristic lithologies, or groups of lithologies. These have been grouped into four lithofacies associations. The associations are used to interpret the lithofacies in terms of gross depositional environments which existed on the Holkerian South Wales Shelf. The structure of the scheme is summarised in fig.2.2. The characteristic lithofacies and lithologies which make up each lithofacies association are described below. Their distribution both in vertical section and in three dimensions is then discussed in the following section.

#### 2.2.1 Descriptions

**2.2.1.1 Lithofacies Association A: Open Shelf**

This association represents those parts of the Holkerian carbonate shelf which were seawards of a mid-shelf oolitic barrier system. The association is comprised of three
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<td>3. Bioclastic Limestone plus Oolite</td>
<td>- Limestone</td>
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<td>- Oolitic Limestone</td>
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<td>17. Simple Ooid</td>
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<tr>
<td></td>
<td>18. Simple Ooid</td>
<td>- Bioclastic</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Autochthonous</th>
<th>Calcite Mudstones (Micrites and variations thereof)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>e.g. vuggy cryptalgal laminates</td>
</tr>
<tr>
<td></td>
<td>bioclastic grainstone laminae</td>
</tr>
<tr>
<td></td>
<td>bioturbated Chondrites</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Allochthonous</th>
<th>Anastamosing Stylolites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gradational Bases and Sharp Tops</td>
</tr>
<tr>
<td></td>
<td>Overlying Irregular/Encrusted Surfaces</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Similar lithological variations as for lithofacies 8. (see above)</th>
<th>- Sandy Pel-Bio Limestones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Sandy Micritic and Cryptagal Limestones</td>
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</tbody>
</table>
lithofacies. These are termed the Limestone/Shale lithofacies, the Bioclastic Limestone Lithofacies and the Bioclastic Limestone plus Oolite Lithofacies.

**Limestone/Shale Lithofacies**

This lithofacies is interpreted to represent the most offshore areas of the Holkerian shelf. It is composed of two lithologies (limestone and shale) which are interbedded.

Typically the limestones are 75cm to 100cm thick with thinner intervening shales. The limestones are peloidal, bioclastic limestones. They generally have sharp bases and gradational tops. They also contain lags of coarse bioclastic material, commonly crinoid columnals, small horn corals, large caniniiid corals and gastropods.

The interbedded shales contain a similar, but distinct fauna which is interpreted to have been autochthonous. Most shales are laterally continuous on an outcrop scale (100's of metres) but some shales fade laterally, on a decameter scale, into wispy, anastomosis pressure solution seams. Both limestone and shale lithologies are characteristically bioturbated by *Zoophycos* and *Thalassinoides*.

**Bioclastic Limestone Lithofacies**

This lithofacies comprises one basic lithology with only minor variations in allochems, grain size and texture. True bedding is rarely observed whilst pseudobedding (bounded by pressure solution seams) is common. Both true beds and pseudobeds occur on a dm to m scale.

In general, there is a lack of sedimentary structures observed in this lithofacies and this is attributed to a high degree of bioturbation. Where sedimentary structures are
preserved they are usually characterised by coarse lags with arcuate bases, which are scour and fill type structures. In finer grained beds, parallel lamination is recorded. Hummocky cross stratification is rare, but where observed, is associated with sequences characteristic of waning flow.

Average grain size ranges from very fine to granule-grade, with textures ranging from wackestone to grainstone. The highest proportion of bioclasts is represented by echinoderm fragments (Appendix One, Table 1.1). In thin section these are seen to be dominantly crinoid columnals which range up to 40mm in diameter (fig.4.8). Brachiopod, trilobite and dasycladacean algal fragments account for most of the other bioclasts.

Another characteristic feature of the lithofacies is the occurrence of cherts. These are found both in nodule and "bedded" forms.

**Bioclastic Limestone plus Oolite Lithofacies**

This lithofacies is interpreted to represent the part of the open shelf area which was adjacent to a mid-shelf oolitic barrier.

The lithofacies is comprised of two lithologies: bioclastic limestone and oolitic limestone. These are interbedded from a metre scale down to the scale of a few grains.

The bioclastic limestone lithology is similar to the lithology recorded in the bioclastic limestone lithofacies section. There is some variation on this theme though, including a general increase in peloid content (Appendix One, Table 1.2) and in some samples there is also an increase in numbers of *Koninckopora* fragments. These are represented by higher point count values for algae (Appendix One, Table 1.2).

The oolitic limestone lithology is characterised by oolitic
aggregate grains and concentric ooids. The former are recorded as composite ooids on point count data (Appendix One, Table 1.2). The oolitic limestones have sharp, locally erosive bases and gradational tops. They exhibit a variety of sedimentary structures interpreted to have been formed by unidirectional (trough cross stratification, current ripples) and bidirectional (hummock cross stratification, wave ripple lamination) current action.

2.2.1.2 Lithofacies Association B: Oolitic Barrier

This association represents the oolitic sediments which accumulated initially within mid-shelf areas, but which prograded seawards during the evolution of the Holkerian shelf. These sediments created a hydrodynamic barrier to onshore directed currents.

The association is comprised of three lithofacies. These are the Oolitic Aggregate Lithofacies, the Simple Ooid Lithofacies and the Oolitic Rudstone and Floatstone lithofacies.

**Oolitic Aggregate Lithofacies**

The most characteristic feature of this lithofacies is the predominance of oolitic aggregate grains. (Specimens HB 24, 26 and 29, Appendix One, Table 1.3). These are well rounded, occasionally botryoidal grain made up of individual ooids commonly cemented together with micrite (fig.4.25).

Although ooids dominate the lithofacies, peloids are also common. Bioclasts are represented by echinoderm fragments (mainly crinoid columnals), brachiopods, molluscs (mainly gastropods) and various algae (Appendix One, Table 1.3). Grain sizes vary from medium grained sand to granule grade and textures are dominated by grainstones (i.e. low micrite point count
Lithostratigraphy and Lithofacies 32

values, Appendix One, Table 1.3).

The lithofacies is thick bedded and, in places, pseudobedded. Sedimentary structures are rare, but varied, with recorded examples of trough cross bedding, ripple cross lamination bidirectional current structures and low angle planar lamination.

**Simple Ooid Lithofacies**

This lithofacies is characterised by the large number of single, well rounded ooids. These usually have a concentric/radial cortical texture (e.g., Specimens HB 37, 48 and 50. Appendix One, Table 1.3). Bioclasts are comparatively rare and are mainly accounted for by echinoderm grains and foraminifera. Most of the remaining grains are peloids.

The lithofacies is well sorted and grain sizes vary from fine to medium sand grade. Textures are dominated by grainstones (Appendix One, Table 1.3).

Sedimentary structures are rare, with trough cross bedding occasionally recorded. The lithofacies commonly forms beds 1m to 2m thick with sharp tops and gradational bases overlying oolitic aggregate facies.

**Oolitic Rudstone and Floatstone Lithofacies**

This lithofacies is characterised by oolitic and peloidal intraclasts greater than 2mm in diameter. The intraclasts are well rounded and have micritised edges. Most intraclasts have a flattened, discoidal shape and these mainly form floatstone textures. More rarely, the intraclasts are irregularly shaped and these usually form rudstone textures.

The lithofacies is intimately interbedded with the Oolite Aggregate Lithofacies and the Simple Ooid Lithofacies. It is rarely more than 2m thick and has an average thickness of a few centimetres.
2.2.1.3 Lithofacies Association C: Marginal Back Barrier

This association represents the sediments which accumulated in the areas immediately adjacent to the shoreward side of the oolitic barrier sequences.

The association is comprised of two lithofacies, these are the Pel-Bio Limestone lithofacies and the Micritic and Cryptalgal Lithofacies.

Pel-Bio Limestone Lithofacies

This lithofacies is dominated by peloids and bioclasts although ooids may account for a significant proportion of grains in some specimens (e.g. P.E. 21, Appendix One, Table 1.4.1).

Three end-member lithologies, within a gradational series, are identified, oolitic peloidal limestone, bioclastic peloidal limestone and peloidal limestone. Grain sizes vary from very fine sand grade to coarse sand grade. Textures from wackestone to packstone with all gradations between.

Generally the finer grained lithologies are wackestone or packstones and contain greater amounts of algal fragments than their coarser counterparts. The lithofacies is usually thick bedded, or pseudobedded, but is also intimately interbedded on a decimeter scale with lithologies characteristic of the Micritic and Cryptalgal Lithofacies.

Micritic and Cryptalgal Lithofacies

This lithofacies comprises a number of lithologies which are characterised either by an abundance of micrite matrix, micritic allochems, or by the occurrence of cryptalgal structure (Appendix One, Table 1.4.2). The various lithologies are described below.

Micrites are rarely more than a few centimetres thick. They exhibit a wide variety of characteristic features. These include
Lithostratigraphy and Lithofacies

Vugs which can be irregular, tubular or laminoid, cryptalgal laminates, mm to cm thick bioclastic grainstone laminae and Chondrites - type bioturbation.

Oncolitic lithologies have peloidal packstone or grainstone textures. The oncoloids commonly form basal lags to dm scale fining upwards sequences.

Micritic intraclast lithologies have peloidal grainstone textures. The intraclasts usually form the tops to dm scale coarsening upwards sequences.

Silt grade peloidal lithologies are dominated by micritic matrix and allochems. They contain mm thick, laterally discontinuous grainstone laminae. This lithology grades into a pure micrite lithology.

A rare feature of the lithofacies is the thin (cm thick) carbonaceous shale lithology. This contains micritic intraclasts and bioclasts (especially Lithostroton coralites).

The lithofacies is usually thin bedded (dm scale) which contrasts with the other, thicker bedded lithofacies (Pel-Bio Limestone) of the Marginal Back Barrier Lithofacies Association.

2.2.1.4 Lithofacies Association D: Back Barrier Lagoon

This association is interpreted to represent those sediments which accumulated in the areas between the shoreline and the marginal back barrier areas. It is the most lithologically complex of the four lithofacies associations and comprises six lithofacies: Dark Pel-Bio Limestone lithofacies
Carbonaceous Shale lithofacies
Simple Ooid lithofacies
Micritic and Cryptalgal lithofacies
Sandy Limestone lithofacies
Oolitic Aggregate lithofacies
The last two lithofacies consist of allochems which are considered to have an origin external to the Back-Barrier Lagoon and are summarised as allochthonous. All the other lithofacies are comprised of allochems with an intra-lagoon origin. These are termed autochthonous.

**Dark, Pel-Bio Limestone Lithofacies**

This lithofacies is dominated by peloids and bioclasts. Most samples contain more bioclasts than peloids (Appendix One, Table 1.5.1). Bioclasts are dominated by brachiopods, molluscs, algae and foraminifera, echinoderms are rare.

The lithofacies is comprised of two lithologies (peloidal and bioclastic limestones) which are end members within a gradational series. These lithologies have variable amounts of opaque carbonaceous and pyritic material within allochems and the matrix. This affects the hue of the limestone and accounts for the dark appearance of some lithologies in the field.

Grain sizes vary from very fine sand grade to medium sand grade. Textures range from wackestone to grainstone with all gradations inbetween. The lithofacies is bedded on a dm/m scale and sedimentary structures are rare. These are confined to occasional lags of bioclastic material.

**Carbonaceous Shale Lithofacies**

Three main types of carbonaceous shaly parting make up the lithofacies, namely the anastomosing stylolites, the shales with gradational bases and sharp tops and the shales which overlie irregular and/or encrusted surfaces.

The anastomosing stylolites are thin (mm to cm) pressure solution seams which grade in intensity into the surrounding Dark Pel-Bio Limestone lithofacies. These shaley partings do not
contain primary sedimentary features e.g: fauna, bioturbation or rhizoliths.

The shales with gradational bases and sharp tops are cm/dm thick units which are generally laterally continuous on an outcrop scale. The shales are composed of fine sand graded bioclasts within a neomorphosed micrite matrix which contains opaque carbon and pyrite. Occasionally, the shales contain lags of coarser coral and brachiopod debris. In rare cases, rhizoliths have been recorded at the base of the shales.

The shales which overlie irregular and/or encrusted surfaces have a similar texture to the shales with gradational bases and sharp tops. However, they sharply overlie irregular surfaces which exhibit a trough and mound topography. These surfaces sometimes erode tidal flat deposits. The underlying surfaces are occasionally encrusted by corals, Chaebetes, or by complex cryptalgal structures.

**Simple Ooid Lithofacies**

This lithofacies is dominated by ooids and peloids, within grainstone textures (Appendix One, Table 1.5.2). The ooids have mainly concentric/radial, or concentric cortical textures, are well sorted and range in size from fine to medium sand grade. Oolitic aggregate grains and bioclasts are rare.

The lithofacies generally occurs in beds less than a metre thick, which have gradational contacts with surrounding lithofacies.

**Micritic and Cryptalgal Lithofacies**

This lithofacies is equivalent to the same lithofacies described within the Marginal Back Barrier Lithofacies Association. It contains the same range of basic lithologies and lithological variations with the exception of the thin
carbonaceous shale lithology.

**Sandy Limestone Lithofacies**

This lithofacies is characterised by the occurrence of quartz sand grains. These are associated with two calcareous lithologies; sandy pel-bio limestones and sandy micritic and cryptalgal limestones.

The sandy pel-bio limestones contain angular to sub-rounded fine sand to pebble grade quartz grains. These occur with peloids, ooids and bioclasts (e.g. Specimens 2101, 2124, Appendix One, Table 1.5.4). The smaller quartz grains sometimes form the nuclei for ooids. These lithologies form normally graded beds on a dm/m scale. These are trough cross bedded with vertical set scales of 10cm to 30cm.

The sandy micritic and cryptalgal limestones contain silt to medium sand grade quartz grains. Cryptalgal structures vary from oncoids to micritic cryptalgal laminates. The latter contain thin (mm) laminae of quartz grains, ooids peloids and bioclasts.

**Oolitic Aggregate/Intraclast lithofacies**

This is a dominantly oolitic lithofacies containing oolitic and micritic intraclasts. Peloids and bioclasts account for the rest of the grains (Appendix One, Table 1.5.5). The most characteristic allochem is the oolitic aggregate grain. These grains together with small horn corals, rare crinoid ossicles and thick shelled gastropods and brachiopods are reminiscent of the Oolitic Barrier Lithofacies Association.

The lithofacies forms sharp based units 1m to 3m thick, which are trough cross bedded. These commonly have a basal lag of abraded bioclasts as described above.
2.2.2 **Distribution of Lithofacies**

Figures 2.3 and 2.5 show the general distribution of Holkerian lithofacies associations and selected lithofacies in South Wales (see Fig. 2.4 for key). Fig 2.3 illustrates the relationship of the lithofacies schemes to the lithostratigraphy outlined earlier in this chapter. Fig 2.5 is an attempt to palinspastically reconstruct the three-dimensional distribution of the Holkerian lithofacies.

The diagrams highlight several important features of the distribution of the various lithofacies associations and lithofacies. The most prominent feature is the progradational nature of the Oolitic Barrier Lithofacies Association which is especially well demonstrated by the Pembrokeshire section in Fig. 2.5.

Immediately behind the Oolitic Barrier Lithofacies Association, lie the two lithofacies which make up the Marginal Back Barrier Lithofacies Association. The widespread distribution of the Pel-Bio Limestone Lithofacies contrasts with the thinner and more patchy developments of the Micritic and Cryptalgal Lithofacies.

Northwards of these lithofacies associations, the sequences are dominated by the Back Barrier Lithofacies Association. The distribution of individual lithofacies within this association is, in general, too complex to illustrate on diagrams of this scale. However, the confinement of the sandy limestone lithofacies to the lowermost parts of the sequence in the northeastern areas of the North Crop is marked. The other feature of interest is the complex interfingering of the Marginal Back Barrier Lithofacies Association with the Back Barrier Lagoon Lithofacies Association. This indicates the gradational nature
FIG. 23 GENERAL DISTRIBUTION OF LITHOFACIES ASSOCIATIONS AND SELECTED LITHOFACIES RELATIVE TO LITHOSTRATIGRAPHY. FOR FULL LITHOSTRATIGRAPHIC NOMENCLATURE, REFER TO FIG. 2.1. FOR KEY TO LITHOFACIES ORNAMENTS, REFER TO FIG. 2.4
FIG. 2.4 KEY TO LITHOFACIES ASSOCIATION AND LITHOFACIES ORNAMENTS USED IN FIGS. 2.3 AND 2.5.

Limestone/Shale Lithofacies

Bioclastic Limestone Lithofacies

Bioclastic Limestone plus Oolite Lithofacies

Oolitic Barrier Lithofacies Association

Pel-Bio Limestone Lithofacies

Micritic and Cryptalgal Lithofacies

Back Barrier Lagoon Lithofacies Association

(Sandy Limestone Lithofacies— inset)

Dolomitised sequence in the eastern Vale of Glamorgan.
of the boundary between these two associations.

Southwards of the Oolitic Barrier Lithofacies Association the lithofacies which make up the Open Shelf Lithofacies Association are found. The parts of the Open Shelf Lithofacies Association which are adjacent to the Oolitic Barrier Lithofacies Association are usually occupied by the Bioclastic Limestone plus Oolite lithofacies. Most of the Open Shelf Lithofacies Association is characterised by the bioclastic limestone lithofacies with the limestone/shale lithofacies confined to the lowermost parts of the sequence in this southernmost outcrops.

The relationship of the lithofacies schemes to lithostratigraphy illustrates the hybrid lithological nature of several lithostratigraphic units, especially the Cornelly Oolite Formation and the Stormy Limestone Formation. This reflects the problems of imposing an artificial classification and nomenclature on gradational sequences representing several environments and facies. An obvious example of this is the appearance of thin sequences of the Pel-Bio Limestone Lithofacies (Marginal Back Barrier Lithofacies Association) within the dominantly Oolitic Barrier Lithofacies Association sequences of the top of the Cornelly Oolite Formation at Lydstep Point, Three Cliffs Bay, and Bosherton (Fig. 2-3).

The identification of lithofacies and their distribution demonstrates that the Holkerian sequences in South Wales represent the deposits of a southerly deepening shelf with a midshelf oolitic barrier. This barrier divided the shelf into three areas; an Open Shelf area, an Oolitic Barrier area and a Back Barrier area. This basic sedimentological framework for the Holkerian sequences of South Wales is expanded on in the following chapters.
FIG. 2-5 FENCE DIAGRAM SHOWING GENERAL DISTRIBUTION OF HOLKERIAN LITHOFACIES ASSOCIATIONS AND OF SELECTED LITHOFACIES IN SOUTH WALES (See Fig. 24 for key).
CHAPTER 3.

PEMBROKESHIRE
FIG. 3.1 DINANTIAN OUTCROP IN SOUTHERN PEMBROKESHIRE
Table 3.1 Summary Lithostratigraphic Descriptions – Pembrokeshire

<table>
<thead>
<tr>
<th>Chronostrat.</th>
<th>Lithostrat.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbian</td>
<td>Crickmail Limestone</td>
<td>= Thick bedded, coarse oolitic and bioclastic limestones</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Dowlais Limestone Formation</td>
<td>= Heterolithocomprising dark pel-bio limestones, carbonaceous shale, simple ooid, micritic/cryptalgal and oolitic aggregate/micritic intraclast lithofacies</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Stormy Limestone Formation</td>
<td>= Heterolithocomprising pel-bio limestone and micritic/cryptalgal lithofacies</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Cornelly Oolite Formation</td>
<td>= Oolitic sequence characterised by oolitic aggregate grains with thin intercalations of bioclastic and peloidal limestones</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Stackpole Limestone Formation</td>
<td>= Fine to coarse grained thin to medium bedded crinoidal bioclastic limestones</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Pen-Y-Holt Limestone</td>
<td>= Wash Member: Thin bedded, shaly peloidal bioclastic limestones (gastropod rich) with nodular cherts interbedded with shales.</td>
</tr>
<tr>
<td>Arundian</td>
<td>Pen-Y-Holt Limestone</td>
<td>= Interbedded bioclastic limestones and thicker shales.</td>
</tr>
<tr>
<td>Arundian</td>
<td>High Tor Limestone</td>
<td>= Thick bedded peloidal and bioclastic limestones with minor oolitic lithologies.</td>
</tr>
</tbody>
</table>
3.1. INTRODUCTION

Pembrokeshire (see Fig. 3.1) provides a section from some of the deepest water Holkerian carbonate facies in Britain, through to some of the most nearshore facies. The Ritee Fault also appears to have been active earlier in the Dinantian (Sullivan 1965 and 1966) and has affected Holkerian sedimentation as well.

The Holkerian outcrop pattern in this area splits into four main sections due to Variscan macrofolds. The Bosherton outcrop, in southernmost Pembrokeshire, is dominated by the most offshore Holkerian lithofacies (Open Shelf Lithofacies Association in the Stackpole Limestone Formation and the Wash Member of the Pen-Y-Holt Limestone, Table 3.1). These are well exposed in coastal sections, although in places the cliffs are vertical and inaccessible.

Further north, the Pembroke Syncline contains outcrops of Holkerian age rocks which are dominated by shallower water facies. (Dominantly Oolitic Barrier and Marginal Back Barrier Lithofacies Associations, represented by the Cornelly Oolite Formation and the Stormy Limestone Formation, respectively). These include Caldey Island and Lydstep Point on the southern limb and Giltar on the northern limb. In the eastern part of the syncline, the Holkerian outcrops are strongly folded and sheared.

The Tenby Anticline lies adjacent to and south of the Ritee Fault. The South Sands outcrop provides a good section through Arundian and Holkerian rocks, although the top of the Holkerian section is not exposed. The Holkerian section is dominated by the Marginal Back Barrier Lithofacies Association characteristic of the Stormy Limestone Formation.

The Holkerian outcrops to the north of the Ritee Fault are mainly confined to quarry exposures. Unfortunately, many of these
have been silted up by alluvium, filled in or have become badly overgrown. However some clues to the sedimentology of these exposures can be gleaned from the last published work of the Geological Survey on this area (Dixon 1921 and Strahan et al 1914). One working quarry (Kiln Quarry SN 048043) north of Carew, provides a good section through the Holkerian and is represented by the Dowlais Limestone Formation characterised by the Back Barrier Lagoon Lithofacies Association.

The attenuated Holkerian sequences north of the Pembrokeshire Coalfield are not described in this chapter. Due to their affinities (lithological and otherwise) with other North Crop sections further east, they are described with them in Chapter 5.

3.2 LITHOFACIES ASSOCIATION A: Open Shelf

3.2.1 Limestone/Shale Lithofacies

Holkerian Limestone/Shale Lithofacies are represented, in the Bosherton Outcrop and in the Lydstep Syncline, at Lydstep Point (SS 093975), by the Wash Member (Holkerian) of the largely Arundian Pen Y Holt Limestone. These deposits represent a long period of sedimentation, spanning the Arundian and Early Holkerian, when a dominantly shaly open shelf area was occasionally prone to storm introduced carbonate-rich material. Dixon (1921) referred to this as the "Zaphrentid Phase" due to its characteristic facies controlled fauna of small zaphrentid corals. The Lithofacies is described below, first from localities in the Bosherton Outcrop and then from the Lydstep Syncline.

3.2.1.1 Green Bridge of Wales and Stackpole Quay

At the Green Bridge of Wales (SR 925943) the upper limit of the limestone/shale lithofacies has been picked out by erosion
(see Fig.3.2). The more friable argillaceous bands have been washed away leaving the limestones without support. Thus the limestones have fallen away leaving a natural arch at the point where limestones predominate over shales.

Fig.3.2 Gradational change from the Wash Member (Limestone Shale Lithofacies) at the base of the stack, to the Stackpole Limestone Formation (Bioclastic Limestone Lithofacies) at the top of the arch. Holkerian microfauna recovered from point on arch marked (H). The Green Bridge of Wales (SR 925943).

Below this point lie approximately 150m of limestone/shale alternations before a prominent 6m thick argillaceous mudstone is reached at Cabin Door (SR 898953) within the Pen Y Holt Limestone. This argillaceous mudstone horizon marks an event which is easily recognisable over the whole of the Bosherton outcrop. The intervening limestone/shale alternations were split into three groups by Dixon (1921) on lithological and faunal criteria. He termed these groups 7, 8 (Pen Y Holt Limestone) and 9 (the Wash Member). Groups 7 and 9 are very similar lithologically, with thin limestone/shale couplets, whereas group
8 has noticeably thicker shales. Dixon put the Vaughanian \( C_2/S_1 \) boundary halfway through group 8 on the faunal criterion that \textit{Lithostrotion martini} becomes abundant in the upper half of that group. He also placed the \( S_1/S_2 \) boundary at the group 9/ group 10 transition i.e. at the base of the arch of the Green Bridge of Wales. Since Holkerian foraminifera have been recovered from limestones within group 9, the Arundian/Holkerian boundary is placed at the boundary between group 8 (Pen Y Holt Limestone) and group 9 (the Wash Member) within this sequence.

The 6m thick argillaceous mudstone at Church Door (Pen Y Holt Limestone) is Arundian on faunal criteria (Simpson, 1986). It would also seem to correlate with shoaling/deepening events seen in the mid-Arundian of Gower and elsewhere in South Wales (Spalton, 1982 and Simpson, 1985). Thus it does not represent an Arundian/Holkerian boundary event.

Lack of microfaunal evidence at the Stackpole Quay outcrop (SR 995953) makes the identification of the Arundian/Holkerian boundary difficult. Due to structural complications such as thrusting and strike-slip movement on faults (see Fig.3.3) the thicknesses' of Dixon's (1921) groups are difficult to assess. In general, they are thinner than at the Green Bridge of Wales outcrop. Fig.3.4 shows the transition from the Pen Y Holt Limestone (group 8) to the Wash Member (group 9) at Sixth Point (Fig.3.3) and from the Wash Member to the Stackpole Limestone Formation (group 10) at Seventh Point. These lithostratigraphic junctions are gradational and a sharp lithological change, or event, is not seen below this until the 6m argillaceous mudstone at Fourth Point. This, as discussed above, is Arundian in age, on faunal evidence. Thus the Arundian/Holkerian boundary does not seem to be marked by a sharp lithological change in this area.
FIG. 3.3 MAP OF STACKPOLE QUAY AREA
(After Dixon 1921 and Hancock et al. 1983)
Fig. 3.4 The Wash Member at Stackpole Quay (Limestone/Shale Lithofacies). To the right of the photo, the thicker bedded unit which forms the prominent ridge on the skyline (and Sixth Point) is the topmost part of the underlying Pen-Y-Holt Limestone. To the extreme left of the photo, the Stackpole Limestone Formation forms Seventh Point. This marks the lithological change from the Limestone/Shale Lithofacies of the Wash Member to the Bioclastic Limestone Lithofacies of the Stackpole Limestone Formation. Stackpole Quay (SR 995953).

Within the Bosherton Outcrop the limestone lithologies of the Limestone/Shale Lithofacies are, texturally, wackestones or packstones. A high proportion of the allochems (approximately 60%) are echinoderm fragments; spines and crinoid ossicles are common elements. Brachiopod, trilobite and gastropod fragments make up the rest of the bioclastic material. There is a noticeable lack of green algae, but red algae are present. Archaeodiscids dominate a foraminiferal assemblage which includes some tetraxids and a single specimen of *Draffania biloba* has been recorded from just beneath the arch of the Green Bridge of Wales. The shaly lithologies have a similar allochem content to the limestone lithologies, but contain more argillaceous material and
are commonly dolomitised.

(ii) Lydstep Point

At the south eastern edge of Lydstep Point (SS 093975) there is a 15m to 20m sequence of thin bedded Limestone/Shale Lithofacies, which represent the Wash Member. The Limestone/Shale Lithofacies weathers out as an easily traceable saddle which runs along strike on the cliff tops (see Fig.3.5).

Fig.3.5 Thin bedded limestones and shales of the Wash Member (Limestone/Shale Lithofacies). This forms an easily traceable saddle between the more resistant Bioclastic Limestone Lithofacies of the underlying High Tor Limestone (Arundian) on the left of the photo, and the overlying Stackpole Limestone Formation on the right of the photo. Lydstep Point (SS 093975).

Below this is the High Tor Limestone (Arundian) a 20m to 25m thick-beded peletal bioclastic limestone. Above it are the bioclastic and oolitic limestones of the Stackpole Limestone Formation and the Cornelly Oolite Formation respectively. These contain an Holkerian macrofauna (*Composita ficoides*, *Davidsonina carbonaria* and others).

The Limestone/Shale Lithofacies of the Wash Member at
Lydstep Point differs slightly from the same lithofacies in the Wash Member of the Bosherton Outcrop. The argillaceous lithologies at Lydstep Point are not so well developed as in the Bosherton sequences. The limestone lithologies at Lydstep Point, in thin section, differ from those in the Bosherton Outcrop in that the Lydstep Point limestone lithologies contain more micritised grains, less micrite in their matrix and also contain Koninckopora. However they do have a very similar bioclastic content of echinoderm fragments (mainly crinoid ossicles), brachiopod, trilobite and gastropod debris. On this, thin section evidence, the limestone lithologies at Lydstep Point are interpreted to represent a similar sediment, but deposited and reworked in shallower, more agitated, conditions than the limestones lithologies in the Bosherton Outcrop Limestone/Shale Lithofacies sequences.

3.2.2 Bioclastic Limestone Lithofacies

3.2.2.1 Description

This lithofacies is widespread in the Holkerian sections south of the Ritec Fault, as it dominates the Stackpole Limestone Formation.

The lithofacies is bedded on a 50cm to 1m scale. However, much of what seems to be bedding is, on closer observation, pseudo-bedding (Simpson 1984 and 1985). Most of the prominent surfaces that stand out at outcrop are defined by pressure dissolution seams. These show little, or no, lithological change across their boundaries. In some cases events are seen between prominent pressure solution seams. These events usually consist of lags of coarser, crinoidal material in a background sediment of fine grained (average grain size less than 1mm), peloidal,
crinoidal bioclastic packstones. These lags are the remnants of a more poorly sorted sediment which has been subject to winnowing by bottom currents.

In the lower parts of the Stackpole Limestone Formation in the Bosherton outcrop, the lithofacies shows less evidence of winnowing current action than in the upper parts of the Stackpole Limestone Formation in the same area. The limestones are still crinoidal bioclastics, but are texturally wackestones rather than packstones. Some of the fauna shows less evidence of fragmentation. Crinoid stems are often preserved almost whole, with many ossicles still attached to each other (Fig. 3.6).

![Fig. 3.6 Crinoid stem with several ossicles attached (bioclastic limestone lithology). The tissues that held the ossicles together may have taken some time to decay, but the length of the stem is taken as evidence that it was not subject to much reworking after death. Stackpole Limestone Formation, Flimston Peninsula (SR 935943).](image)

Similarly these stems are often associated with many parts of the crinoid calyx. These crinoid remains are essentially autochthonous and have not been subject to much current action...
after death.

In thin section, the lithofacies is characterised by a high percentage of crinoidal debris (Appendix One, Table 1.1). Other bioclasts include; brachiopods, trilobites and rare gasteropods. In some thin sections most of the allochems have become heavily micritised. Texturally, wackestones and packstones dominate, although most of the micrite has been neomorphosed to a sparry matrix.

Nodular and lenticular chert is common (Fig.3.7). Lenses of chert are parallel or sub-parallel to bedding, whilst some chert nodules appear to mimic burrow morphology. The controls on chert formation and replacement of fauna are discussed further in Section 4.2.2.1.

Fig.3.7 Nodular and lenticular chert in bioclastic limestone lithology (Limestone/Shale Lithofacies). Wash Member, Stackpole Quay, 5m.
3.2.2.2 Interpretation

Sedimentary structures indicate that bottom currents were occasionally active during the deposition of the Bioclastic Limestone Lithofacies. However, the presence of micritic matrix, in thin sections, indicates that these currents were not persistently strong enough to winnow away the micrite. Alternatively, the currents may have been persistent, but if large numbers of crinoids were bottom dwelling, then they would have absorbed the hydrodynamic energy of bottom currents. In these crinoid thickets, micrite would have accumulated around the bases of the crinoids, thus creating a deposit with a paucity of grainstone textures and only rare preservation of sedimentary structures.

3.2.3 Bioclastic Limestone Plus Oolite Lithofacies

3.2.3.1 Introduction

This lithofacies is characteristic of the Cornelly Oolite Formation throughout Pembrokeshire. However, in the most southerly parts of the Bosherton Outcrop e.g. Gun Cliff (SR 989942) the Lithofacies is poorly developed within the Cornelly Oolite Formation. The best development of the Lithofacies is within the Cornelly Oolite Formation at Stackpole Quay. However, much of this sequence has been cut out by a large strike fault (Fig.3.3).

The Gower sequences provide a much better section through the parts of the South Wales Shelf where the Lithofacies is well developed. Consequently the Lithofacies is described in more detail in the Gower Chapter (Section 4.2.3). However the Pembrokeshire developments of the Lithofacies are described below.
3.2.3.2 Description

Sharp based intercalations, of oolitic sediment, 5cm to 50cm in thickness, with gradational tops occur within fine grained, crinoid dominated, bioclastic packstones and grainstones. The oolitic intercalations occur rhythmically on a 20cm to metre scale. They contain a fauna of crinoid ossicles, brachiopods and corals. These are often recorded in positions of hydrodynamic instability and the oolitic sediment is also poorly sorted (Fig.3.8). The bases of the intercalations sometimes exhibit cuspate scour, although tool marks or prod marks have not been recorded.
Fig. 3.8 Poorly sorted oolitic intercalation (light grey) overlain by bioclastic limestone lithology (dark grey). Oolitic intercalation contains scattered crinoid ossicles and small horn corals. Bioclastic Limestone Plus Oolite Lithofacies, Cornelly Oolite Formation, Stackpole Quay, 65m.

Sedimentary structures consist of symmetrical and asymmetrical ripple lamination cosets. The component sets of these decrease in scale up section. Significantly, low angle hummocky stratification has been recorded at the base of sequences which culminate in these ripple lamination cosets. Bioturbation is commonly represented by vertical, approximately 1cm diameter, tubes (Monocraterion or Skolithos) which redistribute the ooids throughout the surrounding bioclastic limestone lithologies.

Many of the oolitic allochems are oolitic aggregate grains. Large (greater than 2mm) botryoidal intraclasts are a dominant feature of the oolitic lithologies of this Lithofacies. Micritised fragments of Koninckopora, aligned on the foreset laminae of ripple cross lamination, are also common.

3.2.3.3 Summary

The poorly sorted, sharp based erosive nature of the oolitic intercalations suggest that they represent a sudden influx of sediment into fine grained, relatively well sorted, crinoid dominated bioclastic sediment. The predominance of intraclasts and micritised allochems implies that the ooids were not generated in situ, but were transported from elsewhere.

The transport of these sediments involved a waning flow mechanism. This assertion combined with the evidence of sharp bases, rhythmic sedimentation and presence of hummocky stratification sequences suggests that the origin of the oolitic intercalations is related to major storm events. Thus the Bioclastic Limestone Plus Oolite Lithofacies was deposited within
storm wave base (Dott 1983).

The overall distribution of the facies was related to the development of the oolitic shoal barrier which sourced the ooids. During the earliest and latest periods of oolitic shoal barrier development the redistribution of ooids was inhibited. Early in the Holkerian the ooid shoals and associated areas of oolitic aggregate grain deposition were not well established. Thus there was a paucity of source ooids for redeposition. During progradation, as the shoals became well established and the area of Oolitic Aggregate Lithofacies deposition expanded, the source of oolitic aggregate allochems for storm redistribution was much greater. As regression reached its peak and the bathymetry of the South Wales Shelf became shallower and the shelf slope less pronounced, deposition of the Marginal Back Barrier Lithofacies Association dominated. Thus the source areas of ooids were mostly covered, restricting the amount of oolitic sediment available for redistribution.

3.3 LITHOFACIES ASSOCIATION B: Oolitic Barrier

3.3.1 Introduction - Distribution of Oolite Bodies

In Pembrokeshire the lithofacies which make up this Lithofacies Association are found within the Cornelly Oolite Formation. The general distribution of the Oolitic Barrier Lithofacies Association is shown in Fig.2.5.

The geometry of the main bodies of Holkerian oolitic sediment in Pembrokeshire, is further illustrated by an isopach map (Fig.3.9). The major feature of which is the concentration of the thickest oolitic developments in the northern part of the Bosherton Outcrop.
FIG. 3.9 ISOPACH MAP FOR HOLKERRIAN OOLITIC SEQUENCES IN PEMBROKESHIRE
-ALL ISOPACHS SOUTH OF THE RITEC FAULT REFER TO THE CORNELLY OOLITE FMTN.

- Decrease in Thickness of "Light Oolite"; i.e., Oolitic Aggregate/Intraclast lithofacies in the Dowlais Limestone Formation

- Quarry localities in Dowlais Limestone Formation north of the Ritec Fault

- West Williamston
- Kiln Quarry
- Pinchester Quarry
- Coachylands Quarry

- Scale: 0 km, 5 km, 10 km
The oolitic sequences south of the Ritec Fault show a gradual increase in thickness to the south. However there is a rapid thinning at the edge of the main oolitic sediment body south of Stackpole Quay.

The data from the eastern part of the Pembroke Syncline is poor due to structural problems and the fact that the Angle Syncline contains no Dinantian above the Courceyan. Thus it is not possible to extend the isopachs into this area.

This distribution reflects the progradational nature of the oolitic shoal barrier system and the topographic control of the Ritec Fault on the siting of initial ooid shoal formation. In the rest of this section, each component lithofacies of the Oolitic Barrier Lithofacies Association is described and discussed separately.

3.3.1.1 Oolitic Aggregate Lithofacies

Within this lithofacies the most characteristic and prolific allochem is the oolitic aggregate grain. Beds containing these grains account for approximately 80% of the Cornelly Oolite Formation south of the Ritec Fault.

These beds are massive and appear to be "bedded" on a 2m to 3m scale. However much of this is pseudobedding (see Section 3.2.2 for discussion). Internally the facies is thoroughly bioturbated, mainly by a Thalassinoides-type burrow system. Where bioturbation is less intense, sedimentary structures are occasionally observed. Trough cross bedding, with sets on a 5cm to 25cm vertical scale, is the most common type of sedimentary structure. In places, metre scale dune cross bedding is preserved. Units containing this style of cross bedding often have sharp erosive bases with lags of oolitic intraclasts (Oolitic Rudstone and Floatstone Lithofacies). These lags are
sometimes followed, in sequence, by trough cross bedding, with decreasing thickness of cosets up section. Similar sequences in the Hunt's Bay Oolite Formation, in the Gower, have been interpreted as tidally reworked sand waves (Ramsay 1984).

Sequences, 2m to 3m thick, of low angle, planar lamination also occur, if rarely (Fig.3.10). These have been found in close association with micritic lithologies (Micritic and Cryptalgal Lithofacies) and represent beach, or longshore bar environments.

Fig.3.10 Low angle planar lamination associated with small scale trough cross bedding. Interpreted to be foreshore deposits of beach sequence developed in Oolitic Aggregate Lithofacies, Cornelly Oolite Formation, Tenby South Sands, 129m.

Sedimentary structures, in general, are not well preserved. The massive weathering of the facies at outcrop reflects the homogenous nature of the sediment. In thin section, the oolitic aggregate grains are often greater than 2mm in diameter and are heavily micritised (Fig.3.11). The accompanying tetrahedral plots of point count data (Fig.3.12) show a typical example of this
Lithofacies from Stackpole Quay. The plots emphasise the high percentage of intraclasts and ooids and the common occurrence of micritised oolitic aggregate grains (recorded under compound and homogenous ooids).

Fig.3.11 Oolitic aggregate grains (Oolitic Aggregate Lithofacies) showing botryoidal outlines and ghosts of component ooids. The latter are surrounded by micrite which is interpreted as an original cement. Field of view is 4.5mm. Photomicrograph - Thin Section 203. Cornelly Oolite Formation, Stackpole Quay, 181m.

In outline, the oolitic aggregate grains have many, rounded protuberances and internally they consist of well rounded grains. Micritisation often precludes identification of these, but many have the size and shape of simple ooids seen in other parts of the Cornelly Oolite Formation. Less regular, micritised, component grains are also found, as well as foraminifera, algal/brachiopod/crinoidal debris and other bioclastic fragments.

In some cases, the ghosts of early, isopachous, fringing cements are preserved as microspar surrounding the component grains within the oolitic aggregate grains. The rest of the pore
Pembrokeshire 60

FIG. 3.12 POINT COUNT DATA STEREOPLOT
OOLITIC AGGREGATE LITHOFACIES
SPEC. 203

A: LITHOFACIES

B: OO OID TYPE
space is invariably filled in by micrite. This may have originally been a sparry cement which has since become micritised. However there are cases where an early fringing cement is seen followed by pore occluding micrite, which suggests that the micrites were primary. Dravis (1979) documents rapid lithification of modern oolitic sediment by micritic cements on Eleuthera Bank, in the Bahamas. These are primary, high magnesium, calcitic muds. In some examples, Dravis describes chasmolithic and endolithic algal filaments which have initially bound the grains together. Similar occurrences of this have also been recorded in Bahamanian grapestone facies (Winland and Mathews, 1974). There is no evidence for algal filaments within the interstices of the oolitic aggregate grains of the Holkerian Oolitic Aggregate Lithofacies. However, the evidence for primary micritic cements within those grains is unequivocal.

Thus the Oolitic Aggregate Lithofacies represents a widespread, stabilised, sediment composed of early cemented grains. This would have resembled a modern day Bahamanian grapestone facies. The ubiquity of early cementation is underlined by the occurrence of multiple generation oolitic intraclasts, which are described within the Oolitic Rudstone and Floatstone Lithofacies section.

3.3.1.2 Simple Ooid Lithofacies

This Lithofacies is rare within the Cornelly Oolite Formation of Pembrokeshire. Single ooids are the dominant allochem, accounting for up to 60% of a thin section point count (Appendix One, Table 1.3). These often exhibit a concentric/radial cortical texture and are not heavily micritised. Oolitic Aggregate grains are conspicuous by their almost total absence. Other allochems include small (diameter
less than 200 microns) peloids and a few foraminifera. Brachiopods and crinoid fragments are the major bioclastic components, but they make up less than 10% of the sediment.

Sedimentary structures are rare in this Lithofacies. The beds, which are only 1m to 2m thick, often have erosive, sharp bases. The lack of heavy micritisation in the simple ooids is in sharp contrast to the oolitic aggregate grains of the Oolitic Aggregate Lithofacies. Considering the reliable evidence for rapid and early cementation in the other oolitic lithofacies of the Oolitic Barrier Lithofacies Association, it is also unusual not to find it within this Lithofacies. These facts suggest that the simple ooids were buried too rapidly to be cemented up on the sea floor, or become prone to micritisation. The high rates of sedimentation required for this imply that these ooids may represent the, areally restricted, zones of active, Holkerian oolitic sand.

The Lithofacies is better exposed within the Cornelly Oolite Formation of Gower and is described in more detail in Section 4.3.1.3.

3.3.1.3 Oolitic Floatstone and Rudstone Lithofacies

Early cementation was an important process in the Holkerian oolitic environment. The widespread distribution of the Oolitic Aggregate Lithofacies was a result of this. Further evidence for the importance of early cementation comes from the Oolitic Rudstone and Floatstone Lithofacies.

The occurrence of oolitic intraclasts within the Cornelly Oolite Formation has already been mentioned in Section 3.3.2.1. Well rounded intraclasts commonly form sparse lags with floatstone textures at the bases of Oolitic Aggregate Lithofacies
sequences. In these lags the intraclasts are less than 5cm in diameter and 'float' within a matrix of oolitic aggregate grains.

Another type of intraclast accumulation forms a rudstone lithology. In these cases the intraclasts are larger than in the floatstone lithologies (commonly up to 10cm in diameter) more angular and occur as conglomeratic lags (see Fig.3.13).

Fig.3.13 Angular intraclasts, up to 7cm in diameter, occur in a rudstone texture as lags within oolitic aggregate lithology (Oolitic Rudstone and Floatstone Lithofacies). Cornelly Oolite Formation, Stackpole Quay, 243.5m.

These angular intraclasts frequently have micritised edges. In some cases, they also have a thin, 1mm to 2mm, oncolitic, algal veneer developed on part, or all of their surface. This veneer may contain several peloidal and micritic laminations, each of which may have a micritised surface. Encrusters e.g. Chaetetes, may colonise the surface either of the oncolitic veneer or of the uncoated intraclast (see Fig.3.14). Although the conditions for an encrusting mode of life would favour borers as well, no evidence for borings has been found on these
Angular intraclasts in a rudstone texture have thin (1mm to 2mm) oncolitic veneers. One intraclast is encrusted by Chaetetes. This intraclast accumulation has created an hardground environment. Vertical scale of polished slab is 18cm. Oolitic Rudstone and Floatstone Lithofacies, Cornelly Oolite Formation, Cliff Top west of Mowingword (SR 991944).

The origins of both types of oolitic intraclast are probably due to the breakup of cemented crusts. This breakup, in modern examples, has been attributed to storms (Dravis 1979) and to the growth of large scale (100's of metres) polygonal fracture systems within cemented crust on the sea floor (Shinn 1969).

The intraclasts of the rudstone accumulations reflect a complex history. After their initial genesis from fractured
crusts, they then could be subject to transport and micritisation. Their oncolitic veneers suggest periods of algal growth on their surfaces interspersed with periods of low energy movement. The intraclasts have then accumulated in some way to create a hardground environment of their own. Their encrustation reflects their subsequent stability and prevailing low rates of sedimentation.

On initial examination, the oncolitic veneer appears to be similar to the coniatolitic crusts deposited in some supratidal environments e.g. the Trucial Coast of the Persian Gulf (Purser and Loreau 1973). However the absence of any dripstone micromorphology and the presence of distinct layers of trapped sediment in the oncolitic veneer, suggest an algal origin. Thus the environments through which the rudstone intraclasts passed, though undoubtedly marine, were probably at some time very shallow subtidal to allow the formation of oncolitic veneers.

The intraclasts of the floatstone accumulations appear to have had a less complex history. After exhumation from a crust, they then experienced a period, or periods of movement and abrasion which produced their well rounded shape. During this time they were susceptible to micritisation by endolithic algae before being incorporated within a dominantly oolitic aggregate grain, or simple ooid sediment.

Thus the two types of intraclast accumulation reflect different environments of deposition, although they may have had an initially common genesis. The floatstone accumulations are more typical of the active, simple ooid, or oolitic aggregate grain environments. The rudstone accumulations in contrast, may represent several environments. In the simplest case they appear
to represent an accumulation of intraclasts in areas of low sedimentation rate. However in the cases where the intraclasts have an oncolitic veneer, they represent a more specialised shallow subtidal environment. In particular this type of intraclast has been found near the top of the Cornelly Oolite Formation in the cliffs west of Mowingword (SR 991944). Here the Cornelly Oolite Formation has its thinnest development and occupies its highest stratigraphic position in Pembrokeshire. It represents depositional environments at the progradational limits of the Holkerian oolitic sequence. These are unusual and probably represent a hybrid of oolitic barrier and marginal back barrier processes.

3.3.1.4 Summary

The Cornelly Oolite Formation, represents an east-west trending, prograding ooid shoal/barrier complex. This was situated in the central area of the Holkerian shelf. Fig.3.9 shows that the shoal had its thickest development in the southern part of the central shelf area. The progradational nature of the shoal/barrier is demonstrated in Fig.2.5. However, the temporal variation of thickness is seen in Fig.3.15 which shows that the shoal/barrier complex had a threefold evolution.

The first phase in the evolution of the shoal/barrier was controlled by two factors. One was a change in rate of initial sea level rise, the other was the effect of an inherited late Arundian shelf topography. Fig.3.15 part 1, highlights the sequence of events from the late Arundian to the early Holkerian. In the late Arundian there was a broad upwarp in the shelf profile related to movement on the Ritec Fault at depth. This created a land surface to the north of Tenby (Sullivan 1965, 1966). There was a small oolitic shoal development at Tenby.
FIG. 3.15 EVOLUTION OF ARUNDIAN TO END-HOLKERIAN OOLITIC SEQUENCES IN PEMBROKESHIRE

Part 1. Late Arundian to Early Holkerian

A: LATE ARUNDIAN

B: VERY EARLY HOLKERIAN, ONSET OF SEA LEVEL RISE

C: EARLY HOLKERIAN
FIG. 3.15 EVOLUTION OF ARUNDIAN TO END-HOLKERIAN OOLITIC SEQUENCES IN PEMBROKESHIRE

Part 2. Mid-Holkerian

Part 3. Late-Holkerian to End-Holkerian

A: LATE HOLKERIAN

B: END-HOLKERIAN

DROP IN SEA LEVEL - TERRESTRIAL DEPOSITION ESTABLISHED OVER THE PEMBROKESHIRE SHELF
before the shelf profile dropped off southwards. Further offshore Bioclastic Limestone Lithofacies sediments interfingered with Limestone/Shale Lithofacies sediments.

The onset of Holkerian sea level rise was initially rapid. This drowned the late Arundian shelf topography and shut off the oolitic development at Tenby. Bioclastic Limestone Lithofacies sedimentation became widespread and the Limestone/Shale Lithofacies encroached up the shelf. Shortly after this the rate of sea level rise decreased and sediment accumulation rates caught up (sedimentary regression). The upwarp which was established in the Arundian was not completely smothered by the earliest Holkerian sediments. Thus where it impinged on the correct water depths, the conditions for ooid production could once again be satisfied and Holkerian oolitic deposition was established.

The second phase in the evolution of the shoal/barrier complex was the subsequent, widespread development of the Oolitic Aggregate Lithofacies. This was sourced from the active ooid shoals at the seaward edge of the shoal system (see Fig.3.15 part 2). Thus a shoal/barrier complex was now established and in the protected marginal back barrier areas e.g. Tenby, there was deposition of the sediments characteristic of the Marginal Back Barrier Lithofacies Association. Progradation then occurred rapidly as sedimentation rates equalled rates of sea level rise and oolitic deposition occurred over a wide area. The effect of shelf topography became less marked as sedimentation overwhelmed it.

The third phase of evolution (see Fig.3.15 part 3) was the rapid development of the Marginal Back Barrier Lithofacies Association sequences in response to progradation. This shut down
the large areas of oolitic deposition and by the latest Holkerian, the shoal/barrier sequence was restricted to areas represented by the Bosherton Outcrop. The establishment of very shallow subtidal to intertidal environments was reflected in an interfingering of Pel-Bio Limestone and Micritic and Cryptalgal Lithofacies. This style of deposition was eventually shut off by a major drop of sea level and establishment of terrestrial deposition at the end of the Holkerian.

The cartoons in Fig.3.15 only show the scenario of ooid shoal/barrier development in two dimensions over a north-south section. The western extent of the Cornelly Oolite Formation is unknown due to outcrop restrictions. However, evidence from the Back Barrier Lagoon Lithofacies Association in Pembrokeshire and the western parts of the North Crop suggests that the shoal/barrier sequence thins westwards.

Within the shoal/barrier sequence two main types of environment have been identified. One consisted of active oolitic sands. It contained both simple ooids and oolitic aggregate grains and was areally restricted. The other consisted of oolitic sands which were cemented or stabilised (possibly by algal mats, Gebelein 1967) and which covered a much wider area.

The existence of these two types of environment is supported by the textural evidence detailed in Sections 3.3.1.1, 3.3.1.2 and 3.3.1.3. The floatstone textures fit in with the, areally restricted, active oolitic sand environment. Some of the rudstone textures fit in with the, inactive, cemented or stabilised oolitic sand environments.

Apart from the dominance of grainstone textures the Oolitic Aggregate Lithofacies has many other similar features to modern
Bahamanian grapestone facies (Winland and Mathews, 1974). Thus the mid-Holkerian ooid shoal/barrier complex is considered to have covered an area of fairly uniform depth similar to the Bahamanian platform sequences. Therefore, taken in isolation, the Holkerian mid-shelf area may appear to have been part of a platform (sensu Tucker 1985 - see Section 7.3.3.2 for discussion), but put into the context of its adjacent Lithofacies it represents only part of an evolving ramp sequence.

3.4 **LITHOFACIES ASSOCIATION C: Marginal Back Barrier Lithofacies**

3.4.1 **Introduction**

The broad shallow complex area of oolitic depositional environments described in Section 3.3 provided a mid-shelf barrier to the higher energy conditions that prevailed offshore. This created a marginal back barrier area characterised by a facies mosaic of shallow subtidal to supratidal depositional environments. The deposits formed in these environments created the Marginal Back Barrier Lithofacies Association. Although initially part of a topographic feature (Fig.3.15) the wide areal extent of the oolitic shoal complex became an equally important factor in creating a barrier to high energy conditions.

In Pembrokeshire the Marginal Back Barrier Lithofacies Association occurs within the Stormy Limestone Formation and in places interfingers with the oolitic developments of the Cornelly Oolite Formation below them (Fig.3.16). The Marginal Back Barrier Lithofacies Association consists of two lithofacies which are described briefly below and in more detail in the following Sections.
Fig. 3.16 DISTRIBUTION OF MARGINAL BACK BARRIER SEQUENCES IN HOLKERIAN LITHOSERATIGRAPHY OF PEMBROKESHIRE. See Also Enclosure 1.
The most common lithofacies is the Pel-Bio Limestone Lithofacies. This interfingers with the oolitic lithofacies of the Oolitic Barrier Lithofacies Association and with the other lithofacies of the Marginal Back Barrier Lithofacies Association. The Pel-Bio Limestone Lithofacies is interpreted to have been formed by a general background sediment. This exhibited variations in its constituent grains depending on its distribution within the marginal back barrier areas.

The other lithofacies characteristic of the Marginal Back Barrier Lithofacies Association is the Micritic and Cryptalgal Lithofacies. This lithofacies is interpreted to represent ponded and channelised tidal flat environments which formed immediately adjacent to the rear edge of the prograding shoal barrier complex.

3.4.2 Pel-Bio Limestone Lithofacies

3.4.2.1 Description

In the field, on weathered surfaces, the Pel-Bio Limestone Lithofacies generally appears lighter coloured, more massive and less thin bedded than the Micritic and Cryptalgal Lithofacies. The lighter colour is due to the presence of heavily micritised allochems.

In thin section the lithofacies is dominated by micritised grains (peloids) which vary in size and origin. Fig.3.17 shows a typical fine grained (less than 200 microns) peloidal neomorphosed packstone. From their outlines some of the peloids may originally have been bioclasts. Others are well rounded micritic grains and were probably faecal pellets. Small foraminifera and calcispheres make up the rest of the sediment.
Fig. 3.17 Peloids (micritised grains and faecal pellets) and bioclasts are the dominant components of the Pel-Bio Limestone Lithofacies. Field of view is 4.5mm. Photomicrograph - Thin Section 116. Cornelly Oolite Formation, Lydstep Point, 122m.

Fig. 3.18 Coarser development of the Pel-Bio Limestone Lithofacies than shown in Fig. 3.17. Algal components are more common e.g. Koninckopora fragment at bottom left of photo, as are small ooids. This reflects the variable sediment input into the
subtidal peloid sands of the marginal back barrier environment. Field of view is 4.5mm. Photomicrograph - Thin Section 565. Tenby South Sands, 143m.

Fig.3.18 shows a coarser example of the Pel-Bio Limestone Lithofacies. The micritised Koninckopora fragment is approximately 2mm long. There is a subordinate population of fine grained peloids as in Fig.3.17. However there are also some small ooids and some crinoidal debris with associated syntaxial overgrowths. These variations in allochem content are shown within Fig.3.19.

Faunally the lithofacies is dominated by scattered brachiopods, mainly Productus corrugatus-hemisphericus, Linoproductus and Composita. The latter occasionally being preserved with both valves intact in coquinas (see Fig.3.20). The parts of the lithofacies which interfinger with the oolitic lithofacies of the Oolitic Barrier Lithofacies Association frequently contain lags of small (less than 2mm) crinoid ossicles.

Sedimentary structures are generally rare, although in places where the lithofacies becomes more oolitic, ripple cross lamination (individual sets up to 10cm in vertical scale) and lags of coarser material are recorded. The homogeneity of the lithofacies in any one sequence, the scattered nature of the fauna and the rare preservation of sedimentary structures suggests thorough bioturbation.
FIG. 3.19 POINT COUNT DATA STEREOPLOT
PEL-BIO LIMESTONE LITHOFACIES
- ALL DATA, PEMBROKESHIRE

A: TENBY

B: LYDSTEP
3.4.2.2 Distribution

The distribution of this lithofacies is shown in Fig. 3.21 and is marked by the lightly stippled areas. This shows the development of the lithofacies on different parts of the shelf. It also shows that, in places, the lithofacies interfingers with the Oolitic Barrier Lithofacies Association as well as with the rest of the Marginal Back Barrier Lithofacies Association. The lithofacies occurs within both the Cornelly Oolite Formation and the Stormy Limestone Formation.

At Lydstep Point, the lithofacies forms an approximately 15m thick unit at the top of the Cornelly Oolite Formation. This unit separates the underlying oolitic lithofacies of the Oolitic Barrier Lithofacies Association from the overlying Micritic and Cryptalgal Lithofacies. The latter forming the base of the Stormy Limestone Formation. Above this point another approximately 15m...
FIG. 3.21 DISTRIBUTION OF MARGINAL BACK BARRIER LITHOFACIES ASSOCIATION IN PEMBROKESHIRE

Key:
- **PELIDAL**
- **PEL-BIO**
- **PEL-OF**
- **PEL-BIO LIMESTONE LITHOFACIES**
- **MICRITE**
- **VUGGY MICRITE**
- **MICRITE INTRAFLASTS**
- **MICRITIC-CRYPTALGAL FEATURES**
- **MARGINAL BACK BARRIER LITHOFACIES ASSOCIATION**
- **OLITIC RUDISTONE**
- **FLOATSTONE LITHOFACIES**
- **OLITIC AGGREGATE LITHOFACIES**
- **OLITIC BARRIER LITHOFACIES ASSOCIATION**

STACKPOLE QUAY

LYDSTEP POINT

TENBY SOUTH SANDS
thick unit of the Pel-Bio Limestone Lithofacies forms the base to a fining upwards sequence which culminates in a Micritic and Cryptalgal Lithofacies top. This is in turn followed by approximately 25m of, dominantly fine grained, thin bedded lithologies representing the Micritic and Cryptalgal Lithofacies (Fig.3.22).

![Fig.3.22 Thick bedded Pel-Bio Limestone Lithofacies (on left of photo.) overlain by the thinner bedded Micritic and Cryptalgal Lithofacies (on right of photo.) Together the two lithofacies form the Marginal Back Barrier Lithofacies Association. The junction between the two lithofacies in this photo. marks the junction between the Cornelly Oolite Formation and the Stormy Limestone Formation. The sequence youngs to the right. Lydstep Point, approximately 125m to 135m.](image)
At Tenby, the Pel-Bio Limestone Lithofacies does not occur within the Cornelly Oolite Formation. However, within the Stormy Limestone Formation the Micritic and Cryptalgal Lithofacies does not become so dominant up section as it does at Lydstep Point. Instead the Pel-Bio Limestone Lithofacies becomes well developed and contains characteristic fining up sequences. These fining up sequences occasionally culminate in the deposition of lithologies characteristic of the Micritic and Cryptalgal Lithofacies. However they are more frequently truncated by coarser developments of the Pel-Bio Limestone Lithofacies.

Another feature of the Pel-Bio Limestone Lithofacies developments in this area is the input of scattered ooids. At the base of the Stormy Limestone Formation this input creates isolated coarsening upwards sequences (on a 3m to 4m scale) within the larger scale (5m to 15m) fining upwards motif of the Pel-Bio Limestone Lithofacies. The more usual distribution of ooid input higher up the Stormy Limestone Formation is at the bases of peloidal packstone/grainstone fining upwards sequences.

At Stackpole Quay, the Pel-Bio Limestone Lithofacies occurs within the upper 60m of the Cornelly Oolite Formation. Vertical cliff exposures make access and interpretation of this part of the sequence very difficult. However higher up in the Cornelly Oolite Formation the characteristic fining upwards sequences of the Pel-Bio Limestone Formation are alternately enhanced or modified by oolitic input. Some sequences have coarse oolitic bases and finer peloidal packstone/grainstone tops, others have finer peloidal packstone/grainstone bases and coarser oolitic tops.

At Gun Cliff the Pel-Bio Limestone Lithofacies occurs within the top 20m of the Cornelly Oolite Formation in much the same way
as at Stackpole Quay. However, at Gun Cliff there is a more intimate interbedding of lithologies characteristic of both the Oolitic Barrier and Marginal Back Barrier Lithofacies Associations. There are also unusual lithologies at this locality such as large oolitic intraclasts with oncolitic rinds and the occurrence of two prominent bands of Daviesiella llangollensis in life position (see Fig.3.23). At the top of the Cornelly Oolite Formation a 30cm micrite with rhizolith marks the Stormy Limestone Formation. This is succeeded by a marked facies change to coarse oolitic grainstones with metre scale trough cross bedding characteristic of the Crickmail Limestone (Asbian).
Fig.3.23 Pel-Bio Limestone Lithofacies developed at the top of the Cornelly Oolite Formation. A band of extremely thick shelled *Daviesiella llangollensis* in life position is seen at the level of the notebook. The Stormy Limestone Formation is represented by a 20cm fenestral micrite (Micritic and Cryptalgal Lithofacies) marked SLF. This is followed by the massive oolitic lithologies of the Crickmail Limestone. The Marginal Back Barrier Lithofacies Association runs from the top of the 1m dolomite (by red camera case, bottom right) to the top of the Stormy Limestone Formation, a thickness of approximately 12m. Gun Cliff (SR 988943)

3.4.2.3 Summary

The variable lithofacies transitions and allochem content of the Pel-Bio Limestone Lithofacies suggests that it was present in a variety of depositional environments. These existed in the areas immediately adjacent to the rear of the oolitic shoal/barrier complex and the lithofacies probably represents a general background sediment in this area.

In the shelf areas around Tenby, where progradation of the shoal/barrier complex occurred relatively early on in the Holkerian, the lithofacies is well developed. Here it represents the shallow subtidal environment which was still occasionally prone to oolitic input i.e. washovers forming oolitic bases to fining upwards sequences. In places aggradation would result in the establishment of tidal flat environments.

In the shelf areas around Lydstep Point where the Marginal Back Barrier Lithofacies Association has the thickest developments of the Micritic and Cryptalgal Lithofacies in Pembrokeshire, the Pel-Bio Lithofacies still occurs but is subordinate to the deposits of tidal flats. In these areas the lithofacies acts as a replacement to the migrating oolitic environments before tidal flat sedimentation starts. The fining upwards sequences reflecting aggradation.

In the shelf areas around Stackpole Quay, at the progradational limits of the ooid/shoal barrier complex, the
lithofacies interfingers with the Oolitic Barrier Lithofacies Association. This represents the breakdown of the shoal/barrier complex and reflects the establishment of deposition within a more uniformly shallow, subtidal area (rimmed shelf - see Section 7.3.3.2 for discussion). Occasionally this would feature tidal flat deposition e.g. Gun Cliff, but not developed to the same extent as the stratigraphically longer lived tidal flat sequences seen on the Lydstep Point part of the shelf.

It is interesting to note the effect of these variable environments on the fauna used for biostratigraphy. Strank (1981) described several variations in foraminiferal diversity between the Holkerian sequences in Pembrokeshire and those of the Askrigg Block and Derbyshire. Within the Stormy Limestone Formation of Tenby South Sands, she described a foraminiferal assemblage which was both unusual and diverse compared with those elsewhere. This she ascribed to a "specialised environment" for the South Sands sediments. The sedimentological evidence presented here supports that view.

This "specialised environment" was found, by Strank, to contain *Koskino bigerina* sp. This foraminifera had previously only been found in the early Asbian of the Askrigg Block and the late Asbian of Belgium. It is possible therefore that since this biostratigraphically used, "Asbian" foraminifera was found in an unusual Holkerian facies, it may have been strongly facies controlled.

3.4.3 Micritic and Cryptagal Lithofacies

3.4.3.1 Introduction

This lithofacies contains a variety of lithologies which are considered to have been deposited on, or around micritic and peloidal tidal flats. As part of the Marginal Back Barrier
Lithofacies Association the lithofacies is found exclusively within the Stormy Limestone Formation.

3.4.3.2 Description and Interpretation

The lithofacies contains a wide range of component lithologies. The most common of these is the "porcellanous" micrite. This is a fine grained isotropic lithology, dominated by mud grade calcium carbonate, or micrite. Although very dark, these weather to form an almost white surface (Fig.3.24). The lithology is interpreted to represent intertidal to supratidal mud accumulated on tidal flats in the most protected parts of the back-barrier area.

Fig.3.24 "Porcellanous" micrite lithology (Micritic and Cryptalgal Lithofacies) exhibiting various lithological variations. Sharp based bioclastic grainstone laminae (below lens cap) Chondrites bioturbation (to left of lens cap) and small (mm size) tubular fenestrae (top right of photo.) Lydstep Point, 176.5m.

The basic micrite lithology has several modifications. In places it contains sharp based, thin (1cm to 5cm) grainstone
laminae of poorly sorted bioclastic debris (Fig. 3.24). These are interpreted as high energy washover deposits. Bioclastic material from areas adjacent to the tidal flats could be distributed over them during high level storm tides (Shinn 1983a). In some cases upper intertidal or supratidal parts of the micritic flats would have been emergent for some time. Mudcracking and flaking would have occurred. Evidence for this is found in micritic mudflake intraclasts included in some of the washover laminae.

Further evidence for longer periods of emergence is reflected in the nature of some of the vugs in the micrites. Vugs, or "birdseyes" in micrites should not be regarded as evidence for exposure as similar textures are found in Recent subtidal sediments (Shinn 1983b). However in some micrites, found in the peritidal facies, vertical, or subvertical, mm width tubes are seen. In thin section these have been found to be root moulds, or root casts (sensu Klappa, 1980). Fig. 3.25 shows an example of a root cast with a geopetal infill. Other spar filled, but irregular, mm size cavities are also seen. These were probably the result of gas escape as there is no evidence for evaporite mineral growth either in vug morphology or in thin section. It would appear that the micrites cemented before deep burial to preserve these vuggy textures (Shinn and Robbin 1983) although evidence for early cements in PPL, XPL and CL examination of thin sections has not been found.

The micrites are occasionally bioturbated by a Chondrites type system of branching tubes (1mm to 3mm in diameter). These are infilled with a ?faecal pellet, or coarser bioclastic infill as they penetrate the graded bioclastic laminae described above (Fig. 3.24).
Fig. 3.25 Neomorphosed geopetal sediment and sparry calcite filled root cast type of rhizolith developed within micrite (Micritic and Cryptalgal Lithofacies). Evidence for subaerial exposure at Gun Cliff (SR 988943).

Another common lithology of the Micritic and Cryptalgal Lithofacies is a fine grained, silt grade, peloidal packstone or wackestone. This frequently grades into the micrite lithology. It also contains coarser grainstone laminae with lateral discontinuities. Similar textures have been compared by Shinn (1983a) to supratidal levee deposits on a chanelled tidal flat. However these deposits may also have been formed on the supratidal backside areas of low lying beach ridges.

Various algal textures are also preserved within the lithofacies. Cryptalgal laminations (*sensu* Aitken 1967) are occasionally found in micritic sequences. They are characterised by crinkled lamination of trapped peloidal and micritic sediment with associated micro-unconformities (Fig. 3.26). By analogy with Recent algal mats (Logan et al 1974) they were probably formed in the intertidal zone. Due to their variable texture the exact
position of growth within this zone can not be deduced with any accuracy.

Fig.3.26 Cryptalgal lamination (Micritic and Cryptalgal Lithofacies) forms the base of the Stormy Limestone Formation at Tenby South Sands. It also represents the intertidal deposits formed in the backshore environment which now overlies the beach sequence shown in Fig.3.10. Tenby South Sands, 132m.

Another cryptalgal lithology within the lithofacies is an oncolitic coquinoid lithology. These form sharp based sequences (10cm to 50cm thick). The oncoids often have an algal coat of micritic tubes e.g. Ortonella or Girvanella. In some cases they consist of a dense micrite with discontinuous vuggy laminae. These algal coatings frequently enclose a specimen of Composita with both valves intact (Fig.3.27). Other nuclei include fragments of corals and brachiopods as well as intraclasts. The growth of the algal coats must have been initially rapid to preserve whole specimens of Composita before fragmentation of the valves. It is possible that algal growth was so rapid as to overwhelm the living specimens of Composita.
Logan et al. (1974) suggested that oncolites form in agitated lower intertidal conditions. However Halley (1975) suggests that oncolite formation may extend into the shallow subtidal. Evidence from other areas in South Wales (Chapter IV) implies that these oncolitic coquinoid lithologies form basal lags in tidal channels. Lateral pinch-outs of channel edges are not observed in the Pembrokeshire exposures. However the tidal channel lag interpretation could explain their distribution in vertical section. Channelised tidal flats are well documented for Recent examples (Shinn et al. 1969).

The final lithology characteristic of the Micritic and Cryptalgal Lithofacies is dominated by a fine grained, dark brown weathering carbonaceous shale. This is found variably capping algally laminated horizons or within the silt grade peloidal lithology. It commonly contains a fauna of fragmented
Lithostrotrion and brachiopods (Fig.3.28). It is suggested that these shales represent tidal channel overbank deposits. The provenance of their insoluble content is not known, but may be derived from soils, or wind blown detritus. The origin of the marine fauna is probably related to washover deposits as corals are unlikely to be able to exist in such an environment.

Fig.3.28 Dark brown weathering shale with a lag of fasiculate Lithostrotrion corallites at its base. This lithology is found within the Micritic and Cryptalgal Lithofacies of the Marginal Back Barrier Lithofacies Association. It shows some similarities to the Carbonaceous Shale Lithofacies of the Back Barrier Lagoon Lithofacies Association and is interpreted as an overbank deposit to tidal channels/inlets. Stormy Limestone Formation, Eel Point, Caldey Island (SS131972)

3.4.3.3 Distribution of Lithofacies and Component Lithologies

The distribution of the Micritic and Cryptalgal Lithofacies has already been partly described in relation to the Pel-Bio Limestone Lithofacies and is shown in Fig.3.21. The two lithofacies are obviously related in that they combine to form fining upwards sequences on a 2m to 10m scale. Peloidal
packstones and grainstones (Pel-Bio Limestone Lithofacies) are capped by lithologies of the Micritic and Cryptalgal Lithofacies.

This fining upwards motif is not the only grain size variation sequence observed in the Marginal Back Barrier Lithofacies Association. Where the Pel-Bio Limestone Lithofacies becomes strongly oolitic the Micritic and Cryptalgal Lithofacies may cap coarsening upwards sequences (Fig. 3.21 Tenby South Sands). However these variations in style of grain size sequence only reflects the variety of depositional environments in which the Pel-Bio Limestone Lithofacies predominated. The fact that the Pel-Bio Limestone Lithofacies sequences are commonly overlain by the Micritic and Cryptalgal Lithofacies indicates that as the shallow subtidal environments prograded, or aggraded they subsequently formed the sites for the establishment of tidal flat environments.

The thickness of the Micritic and Cryptalgal Lithofacies in the Marginal Back Barrier Lithofacies Association sequences varies considerably (Fig. 3.21). At the Bosherton Outcrop the Lithofacies is represented by only a few thin micrites at the top of the Marginal Back Barrier Lithofacies Association sequence. In contrast, at Lydstep the Lithofacies is thickly developed, whilst at Tenby the dominant Pel-Bio Limestone Lithofacies is interspersed with many thin developments of the Micritic and Cryptalgal Lithofacies.

The lithological components within these different thickness developments of the Micritic and Cryptalgal Lithofacies varies too. At the Bosherton Outcrop the Lithofacies consists only of one or two, thin (less than 10cm) vuggy micrites with rhizolith. At Lydstep a greater variety of lithologies are found as well as fining upwards sequences on a scale of 10cm to 2m. These often
have a base of the oncolitic coquinoid lithology. This is followed by very fine grained (silt grade) peloidal wackestone with coarser, grainstone laminations finally culminating in micrites, with various modifications e.g. vugs, bioturbation and cryptagal lamination. These sequences are interpreted as the deposits of migrating tidal channels. Oncolitic channel lags are overlain by intertidal and supratidal sediments as the channels migrate laterally.

Thin carbonaceous shales also become more common between Lydstep and Tenby. However, at Tenby South Sands the component lithologies of the Micritic and Cryptagal Lithofacies exhibit less variety than at Lydstep. The oncolitic coquinoid lithologies are rare, whereas micrites, cryptagal laminations and shales become more common.

3.4.3.4 Summary

The variations within the Micritic and Cryptagal Lithofacies of thickness and of component lithologies reflects the development of a complex mosaic of environments within the marginal back barrier area. In some of the central parts of the shelf e.g. Lydstep, discreet areas at the rear edge of the shoal/barrier complex became dominated by tidal flat deposition. The broad, shallow central area of the shoal/barrier protected the rear edge from the higher energy conditions prevailing further offshore. Thus tidal flats, with well developed channel systems developed where shallow subtidal peloidal sands (of the Pel-Bio Limestone Lithofacies) prograded, or aggraded to intertidal levels. These tidal flats dominated deposition in the more protected areas, but where overwhelmed by the prograding, or aggrading shallow subtidal peloidal sands in higher energy areas
as relative sea level rose.

Further up the shelf e.g. at Tenby the marginal back barrier area was set up in the Early Holkerian. The oolitic shoal/barrier complex was not so well developed as in the Mid to Late Holkerian. Thus there was initially less protection from higher energy conditions. Tidal flat deposition was initiated, but was not so well developed as in the central portions of the shelf. Instead the back barrier area was dominated by shallow subtidal sands (Pel-Bio Limestone Lithofacies).

By the Mid to Late Holkerian the shoal/barrier complex had prograded to the south and was forming an effective barrier which allowed the formation of the, long lived, tidal flat environments within the central parts of the shelf. The areas further up the shelf were still dominated by peloidal sands. However a general increase of micritic intraclasts up section within the Pel-Bio Lithofacies at Tenby reflects the wide areal extent of supratidal micrites within the rimmed shelf area developed during the Late Holkerian. In the areas of the shelf now represented by the Bosherton Outcrop, the rimmed shelf was characterised by a mixture of Oolitic Barrier and Marginal Back Barrier environments. Aggradation, or progradation of peloidal and oolitic sands resulted in the establishment of tidal flat areas dominated by intertidal to supratidal deposition.

The overall situation shows many similarities to the Recent shoal barrier complex and protected back-barrier lagoon areas of the Central Trucial Coast in the Persian Gulf (Purser and Evans, 1973). There, an ooid shoal barrier complex; the Great Pearl Bank Barrier, forms a wide, flat platform. Behind this is a deeper, protected lagoonal area; the Khor Al Bazm Lagoon, with a variety of peloidal sediments. On the protected lagoonal sides of the
barrier, carbonate muds and pellet sands are deposited.

3.5 **LITHOFACIES ASSOCIATION D: Back Barrier Lagoon**

3.5.1 Introduction

North of the Ritec Fault the Holkerian age rocks undergo a marked facies change and are entirely represented by the Dowlais Limestone Formation. A variety of lithofacies characteristic of the Back Barrier Lagoon Lithofacies Association are found within the Formation.

The Dowlais Limestone Formation is dominated by the Dark Pel-Bio Limestone Lithofacies. However in the upper parts of the Formation the lithofacies becomes dominated by lighter grey (less carbonaceous) peloidal and bioclastic lithologies. There are also several sequences of the Oolitic Aggregate/Intraclast Lithofacies which becomes less common westwards.

The Dowlais Limestone Formation is exposed in a series of quarries (Fig.3.29). Although the quarries around the West Williamston area were well exposed during the last survey by the B.G.S. (Strahan et al 1914) they have now become silted up by alluvium and overgrown. The quarries east of Carew have suffered a similar fate. Only Kiln Quarry has remained a working quarry and has been extended so that most of the Dowlais Limestone Formation is exposed. The basal 30m and the top 5m of the Formation are not seen in the quarry.

The following descriptions and interpretations have mainly been based on the Kiln Quarry section, with additional information culled from the Haverfordwest memoir (Strahan et al 1914) and the unpublished notebooks and field slips of two of the original survey workers; E.E.L. Dixon and A. Strahan. Access to the latter was given to the author by the kind permission of the B.G.S.
The Dowlais Limestone Formation in this area is described and interpreted below in terms of the component lithofacies of the Back Barrier Lithofacies Association.

3.5.1 Lithofacies Descriptions and Interpretations

3.5.2.1 Dark Pel-Bio Limestone Lithofacies

In Kiln Quarry the Lithofacies is characterised by carbonaceous, fine grained, peloidal wackestones, packstones and grainstones, which are bedded on a dm/m scale (Fig.3.30). However in the upper parts of the Dowlais Limestone Formation in Kiln Quarry the lithofacies becomes less carbonaceous and frequently contains planar foresets (dm scale).

Sedimentary structures in the darker lithologies are rare, but when preserved are best seen on weathered surfaces. Fig.3.31 shows a peloidal grainstone sequence near the base of the Kiln Quarry section. Large scale, planar foresets with aligned Composita and productid fragments are followed by trough cross beds on a 10cm to 20 cm scale. These are, in turn, truncated by large scale, low angle planar cross beds with fragments of Composita and small vertical burrows.

This sequence is interpreted to represent a fluctuating shoreface (Inden and Moore 1983). The two low angle planar cross bedded sequences are interpreted to represent the swash zone which retreated and then prograded leaving the intervening small scale trough cross bedded unit. This represents the lower shoreface deposits which were reworked by tidal, or longshore currents.

The Dark Pel-Bio Limestone Lithofacies is interpreted to represent the background peloidal, bioclastic sandy and muddy sediments which formed in the back barrier lagoon area. These were reworked by wave and tidal currents. The occurrence of the
FIG. 330 LOG AND INTERPRETATION OF KILN QUARRY

DESCRIPTION

- Scale Planar Foresets in Pel GST
- Oolitic Aggregate/Intraclast Lithofacies with Micritic Intraclast Base
  - Light Grey Pel PKST
- Fines Up

- Scale Planar, Low Angle Cross Bedding in Pel GSTs
  - Light Oolite
  - Dark Carbonaceous Pel PKST/GSTS

- Light Oolite with Scale Trough Cross Bedding
  - L.L.H Complex
  - Light Oolite
  - Dark Carbonaceous Pel PKST/GSTS with Shales

- Light Oolite
  - Breciated Tops to Micrites
- Lithostroction Patch

- Very Carbonaceous Peloidal Lithology
- Micritic + PELITAL Lithofacies
- Micritic + Cryptalgal Lithofacies
- Micritic Intraclast

INTERPRETATION

- Oolitic Washovers
  - Development of Ramped Shelf Profile Results in Widespread Shallow Subtidal Peloidal Sand Environment

- Foreshore Deposits
  - Oolitic Washover
  - Background Peloidal Muds - Sands - Back Barrier Lagoon

- Background Peloidal Muds - Back Barrier Lagoon Sediments

- Simple Ooid Shoals
  - Oolitic Aggregate/Intraclast Lithofacies
  - Micritic Tidal Flats
  - Isolated Ooid Shoals
  - Background Back Barrier Lagoon Sediments

Key:

- Micrite
- Very Carbonaceous Peloidal Lithology
- Micritic + Cryptalgal Lithofacies
- Peloidal/Bioclastic Lithofacies
- Dark Pel-Bio Limestone Lithofacies
- Less Carbonaceous Peloidal Lithology
- Oolitic Aggregate/Intraclast Lithofacies

INCREASING TEXTURAL MATURITY
5 m to Top of Section (Crickhowel Limestone)
Fig.3.31 Low angle planar lamination and trough cross bedding developed in less carbonaceous peloidal lithology of the Dark Pel-Bio Limestone Lithofacies. These structures are interpreted to represent foreshore and shoreface environments of a beach sequence. Dowlais Limestone Formation, Kiln Quarry, 3m to 4m.

less carbonaceous lithologies in the upper parts of the Dowlais Limestone Formation is a result of the establishment of the rimmed shelf area in the Late Holkerian. This resulted in the gradual breakdown of the division between Oolitic Barrier and Back Barrier Lagoon environments.

3.5.3.2 Carbonaceous Shale Lithofacies

This lithofacies is poorly developed within the Dowlais Limestone Formation of this area. Carbonaceous shales with gradational bases and sharp tops are developed above lithologies characteristic of the Dark Pel-Bio Limestone Lithofacies (Fig.3.32). In some cases the shales are overlain by lithologies characteristic of the Micritic and Cryptagal Lithofacies.

The carbonaceous shales represent periods of relatively low sedimentation rate within the background peloidal, bioclastic
sediment. Their association with cryptagalaminates and other intertidal deposits suggests that they were deposited in very shallow to emergent conditions.

Fig.3.32 Carbonaceous shales (Carbonaceous Shale Lithofacies) developed around carbonaceous peloidal lithologies (Dark Pel-Bio Limestone Lithofacies). These lithofacies are interpreted as the restricted environments of the back barrier lagoon. Dowlais Limestone Formation, Kiln Quarry, 2m.

3.5.2.3 Micritic and Cryptagal Lithofacies

In Kiln Quarry this lithofacies is dominated by micritic and cryptagal lithologies. These overlie a variety of other lithofacies including the Dark Pel-Bio Limestone Lithofacies, the Simple Ooid Lithofacies and the Oolitic Aggregate/Intraclast Lithofacies.

The component lithologies of the Micritic and Cryptagal Lithofacies frequently show features associated with emergence e.g. mudcracking. Fig.3.33 shows an example of a thrombolitic, cryptagal mottled micrite. This has become mudcracked and the interstices filled in with the overlying peloidal
wackestone/packstone. In other places micritic, cryptagalaminates are well developed.

The Micritic and Cryptagal Lithofacies in Kiln Quarry represents the deposits of micritic tidal flats. These developed when the other back barrier lagoon sediments either aggraded, or prograded into the intertidal zone. Environments which were prone to this were prograding localised ooid shoals (Simple Ooid Lithofacies) aggrading oolitic washover deposits (Oolitic Aggregate/Intraclast Lithofacies) and aggrading peloidal, bioclastic sands (Pel-Bio Limestone Lithofacies).

3.5.2.4 Simple Ooid Lithofacies

In Kiln Quarry this lithofacies only occurs in the lower half of the exposed section of Dowlais Limestone Formation.
Elsewhere in the area, the Simple Ooid Lithofacies was identified by Strahan et al. (1914) using the descriptive field term "dark oolite".

The Simple Ooid Lithofacies forms sequences which are generally less than a meter thick. Their contacts with underlying lithologies are gradational. In thin section the lithofacies is dominated by single ooids in a micritic grainstone texture (Fig. 3.34). The ooids invariably have concentric/radial cortical textures (Fig. 3.35) which are brown and pseudo-pleiochroic. This combined with concentrations of opaque minerals (?pyrite) gives the lithofacies its characteristic dark hue in the field.

Fig. 3.34 Single, simple ooids within a neomorphosed micritic grainstone (Simple Ooid Lithofacies, Back Barrier Lagoon Lithofacies Association). The ooids have an overall concentric/radial cortical texture, within a twofold division. This includes a sparry inner area and an irregular outer micritic area, which is interpreted to be the result of agitated accretion followed by lower energy accretion. Compare with Simple Ooid Lithofacies Fig 5.19. Field of view is 4.5mm. Photomicrograph - Thin Section 2006, Dowlais Limestone Formation, Kiln Quarry 10m.
FIG. 3.35 POINT COUNT DATA STEREOPLOT
SIMPLE OOID LITHOFACIES KILN QUARRY
SPEC. 2006

A: LITHOFACIES

B: OOID TYPE
The Simple Ooid Lithofacies is interpreted to represent oolitic tidal bars developed at the western end of the back barrier lagoon. Similar features have been recorded in the Khor al Bazm Lagoon on the Trucial Coast, Persian Gulf (Loreau and Purser 1973). The distribution of the lithofacies is related to the less protected nature of the western end of the back barrier lagoon (see Section 5.2.3.2 for discussion).

3.5.2.5 Oolitic Aggregate/Intraclast Lithofacies

In Kiln Quarry the Oolitic Aggregate/Intraclast Lithofacies forms sequences 1m to 5m thick (Fig.3.30). Strahan et al (1914) identified the lithofacies, in a similar way as they did for the Simple Ooid Lithofacies, by referring to it as "light oolite". Its distribution was described as increasing southeastwards from West Williamston (SN 035058). This qualitative assessment has been confirmed by the author, although two of the important data points, Pincheston Quarry (SN 064031) and Coachlands Quarry (SN 073028) Fig.3.29, have since either been filled in, or have become badly overgrown.

The Oolitic Aggregate/Intraclast Lithofacies sequences always have sharp, erosive bases. Where the lithofacies overlies micritic lithologies of the Micritic and Cryptalgal Lithofacies it contains ripped up pebble grade intraclasts of the underlying micrites (Fig.3.36). The basal parts of the lithofacies frequently exhibit meter scale cosets of trough cross bedding.

The most common allochem is the oolitic aggregate grain. These are often heavily micritised which gives the lithofacies its characteristic light grey colour in the field. Bioclasts account for much of the rest of the component allochems. Faunally the lithofacies is distinct from the interbedded lithologies of the other lithofacies. Crinoidal debris, small conical corals,
rare large caniniid-type corals and thick shelled productids are the dominant elements. Of these, only the productids are found in the other lithofacies.

Fig.3.36 Ripped up intraclast of underlying cryptalgally laminated micrite is included within a coarse oolitic aggregate, bioclastic lag at the base of an Oolitic Aggregate/Intraclast Lithofacies sequence. This is interpreted as an oolitic washover deposit developed within the back barrier lagoon. Vertical scale of polished slab is 6cm. Dark area at top right of slab is an artefact introduced during slab manufacture. Dowlais Limestone Formation, Kiln Quarry, 72m.

The lithofacies is overlain by a variety of lithofacies. The most common transitions are to the Dark Pel-Bio Limestone Lithofacies, but transitions to the Simple Ooid Lithofacies and the Micritic and Cryptalgal Lithofacies are also recorded.

From the above evidence and by comparison with other exposures of the lithofacies in the Dowlais Limestone Formation of the North Crop, the lithofacies is interpreted to represent storm induced washovers from the oolitic barrier into the back barrier lagoon (see Section 5.3.2.3 for discussion). The decrease
in total thickness of the lithofacies away from the Ritec Fault (and the thick developments of Oolitic Barrier Lithofacies Association to the south of that structure) supports this interpretation.

3.5.3 Summary

The sequences from the areas north of the Ritec Fault represent a back barrier lagoon partially isolated from the marginal back barrier area. This isolation, reflected in the sharp facies change, was partly due to a topographic surface expression of the Ritec Fault at depth and partly due to the increased distance from the rear edge of the oolitic shoal/barrier complex.

The isolation was not complete as the back barrier lagoon was prone to storm induced oolitic washovers sourced from the oolitic shoal/barrier complex. Also the predominance of the less carbonaceous lithologies of the Dark Pel-Bio Limestone Lithofacies with evidence of relatively high energies of deposition in the upper parts of the Dowlais Limestone Formation suggests that the isolation of the back barrier lagoon had diminished by the Late Holkerian. This was related to the establishment of the rimmed shelf profile by that time.

The back barrier lagoon was characterised by a widespread peloidal, bioclastic sand with oolitic tidal bars. These occasionally prograded, or aggraded into the intertidal zone to form micritic tidal flats. This is a similar interpretation as that reached for the rest of the Dowlais Limestone Formation described from the North Crop (Chapter V). The main difference is the increase in the amounts of Oolitic Aggregate Lithofacies Association in the Pembrokeshire Dowlais Limestone Formation. This is related to its proximity to the Oolitic Barrier
Lithofacies Association deposits south of the Ritec Fault.

3.6 SUMMARY OF LITHOFACIES SCHEMES

The Holkerian sections of Pembrokeshire, record the development of a transgressive/regressive carbonate shelf sequence.

Early Holkerian sedimentation was affected by an inherited shelf topography. This was dominated by a southerly sloping carbonate shelf with a slight break in slope in the upper shelf area (Tenby). During the Arundian this represented the transition from shallow marine to terrestrial deposition and was a surface expression of movement on the Ritec Fault at depth.

Initially the transgression was rapid, flooding the end-Arundian shelf topography. The main Arundian lithofacies of Pel-Bio limestones and limestone/shale advanced up the shelf. The topography of the break in shelf slope at Tenby was significant enough to isolate the areas to the north from this initial lithofacies advance. In these areas a discreet set of shallow, restricted lithofacies (the Back Barrier Lagoon Lithofacies Association) was initiated.

Very soon after this, the rate of transgression slowed down. The shelf topography subsequently controlled the initiation and siting of oolitic shoal development. The shoals grew rapidly and large volumes of oolitic sediment were deposited. This initiated a shoal/barrier complex. The Holkerian shelf was now split into four sections, represented in the geological record by the four main lithofacies associations described in Chapter III.

Once initiated, this fourfold division became self perpetuating. Continued high rates of sedimentation on the southern edges of the shoal/barrier complex led to its
Pembrokeshire progradation. This created a protected marginal back barrier area with a mosaic of tidal flats in a background of shallow subtidal peloidal sands. The areas to the north of the initial shelf break were still isolated by the inherited shelf topography and formed a back barrier lagoon. However as this topography diminished due to sediment burial the back barrier lagoon remained isolated because of the developing oolitic shoal/barrier complex.

The areas of relatively passive sedimentation to the south of the shoal/barrier complex were gradually overwhelmed by its seaward progradation. Thus the main control on sedimentation on the shelf was the progradation of the shoal/barrier complex.

Although initially preserving and enhancing the fourfold division of the shelf, the development of the shoal/barrier complex and the infilling behind it ultimately destroyed it. As the complex prograded it created back barrier areas with a more uniform topography than the initially southerly sloping shelf profile (ramp). This allowed large areas of the tidal flat / peloid sand mosaic to develop. These environments gradually replaced the oolitic sequences and by the end of the Holkerian dominated most parts of the shelf forming a rimmed shelf profile.

At the edge of this area of more uniform topography, ooid shoal activity was much reduced and produced less oolitic sediment. Further offshore crinoid dominated bioclastic sand deposition continued. At the end of the Holkerian the whole system of marine deposition was shut down by a dramatic drop in sea level.

The relatively steady increase of depth of deposition away from the land within the Pembrokeshire shelf facies suggests that the Holkerian shelf profile was initially a ramp (Ahr, 1973 and Read, 1985). The lack of continuous reef trends and deeper water
breccias supports this interpretation.

The evolution of the Pembrokeshire ramp broadly follows a scheme outlined by Read (1985), from a ramp with a fringing bank (Late Arundian) to a ramp with a barrier ooid shoal complex (Mid to Late Holkerian) to a rimmed shelf (Latest Holkerian). However the various stages in this evolutionary sequence differ from the idealised models in the details of the facies sequences. The most obvious variation being the development of a marginal back barrier area on the rear edge of the Holkerian prograding shoal/barrier complex.

The overall tectonic setting of the ramp and the models for sedimentary, eustatic and/or tectonic controls on ramp evolution are considered in Chapter VII.

3.7 TENBY SOUTH SANDS - THE ARUNDIAN/HOLKERIAN TRANSITION

At Tenby South Sands, the cliff exposures provide a section through the southern limb of the Tenby Anticline (Figs.3.37 and 3.38). Late Courceyan age rocks are exposed in the core of the anticline (at the extreme right of the photo) and the sequence runs through almost to the top of the Holkerian. The position of the Arundian/Holkerian boundary has not previously been identified with certainty and thus the section is described from above the Chadian/Arundian boundary which is taken at the Gully Oolite/Caswell Bay Mudstone (C.B.M.) junction (George et al 1976).
FIG. 3.37  CLIFF SECTION, TENBY
SOUTH SANDS

LITHOSTRATIGRAPHY
STORMY LIMESTONE FORMATION  CORNELLY OOLITE THIN  STAGNOLE BECH THIN  HIGH TOP LIMESTONE  C.B.M.  CANINIA OOLITE

CHRONOSTRATIGRAPHY
HOLKERIAN ——— ARUNDIAN ——— CHADIAN

C.B.M. = CASWELL BAY MUDSTONE
In the section above the C.B.M. two discreet oolitic sequences occur, one at the top of the High Tor Limestone and the other forming the Cornelly Oolite Formation (see Fig. 3.39). The lower of the two sequences (High Tor Limestone) is approximately 75m above the base of the C.B.M. and is approximately 15m thick. It is underlain by slightly dolomitised crinoid dominated bioclastic limestones. The oolitic content is restricted to oolitic aggregate grains and the sequence contains mainly grainstone textures (Fig. 3.40 and Fig. 3.41).

The second oolitic sequence (Cornelly Oolite Formation) occurs approximately 10m above the first, with an intervening unit of Pel-Bio Limestone Lithofacies (Stackpole Limestone Formation). This unit is finer grained and thinner bedded at its base. The Cornelly Oolite Formation is 50m thick and contains a variety of Oolitic Barrier Lithofacies, although the Oolitic
FIG. 3.9 INTERPRETIVE SOUTH SANDS

INTERPRETATION

FIRST MICRITE OF MARGINAL BACK BARRIER SEQUENCE
LOW ANGLE PLANAR LAMINATION

LITHOSTRATIFICATION PATCH REEF

THIN BEDDED AND FINE GRAINED HORIZON
GOLITIC INTRACLASTS

COLONISED CRINOID DOMINATED BIOCLASTIC LIMESTONE

LIMESTONE/SHALE SEQUENCE
MICRITE PLUS RHIZOLITH
GASTEROPOD LIMESTONES

BACK BARRIER SEQUENCE
SEE FIG 3.8 FOR MORE DETAIL

GENERAL MIX OF SUBTIDAL/SUPRATIDAL SEDIMENTS CHARACTERISTIC OF BACK BARRIER AREA

TIDAL FLATS
SHOREFACE SEQUENCE
BEACH BERM TO TIDAL FLATS
OOID SHOAL/BARRIER COMPLEX
OOGIDS DRIFT IN
START OF SEDIMENTARY REGRESSION

TOTAL DEEPENING EVENT/MAJOR MESSOTHRIX BOUNDARY
SHALLOWING-PROXIMITY TO ARUNDIAN OOID SHOAL

START OF REGRESSION

DEEPENING
SHALLOWING AND EMERGENCE WITHIN ARUNDIAN EVENT TRACEABLE OVER MUCH OF SOUTH WALES

FOR KEY SEE FIG 3.16

CHRONOSTRATIGRAPHY

VAUGHANIAN ZONATION

LITHOSTRATIGRAPHY

STORMY LIMESTONE FORMATION

CORNELLY OOLITE FORMATION

STACKPOLE LIMESTONE FORMATION

HIGH TOR LIMESTONE

CASWELL BAY MUDDSTONE
Aggregate/Intraclast Lithofacies dominates. At the top of the Cornelly Oolite Formation there is a 3m thick unit of low angle planar lamination. This is succeeded by an abrupt facies change to a Cryptagalaminite micrite lithology (Stormy Limestone Formation) and other lithologies and lithofacies characteristic of the Marginal Back Barrier Lithofacies Association. The low angle laminated unit is interpreted as part of a shoreface sequence (Section 3.3.2.1 and Fig.3.10).

Fig.3.40 Oolitic aggregate grain in Oolitic Aggregate Lithofacies of Upper High Tor Limestone (Arundian). Arundian archaeodiscid foraminifera forms the nucleus for one component ooid of the oolitic aggregate grain. Field of view is 1.5mm. Photomicrograph - Thin Section 486, Tenby South Sands, 42.5m.

The latest published work on the South Sands section (Dixon 1921) used the Vaughanian zonation scheme. Dixon placed the C2/S1 subzone boundary at a group of "soft, thin bedded dolomitic rocks with shaley partings". These are approximately 20m above the top of the Caswell Bay Mudstone within the High Tor Limestone (Figs.3.37 and 3.39). He placed the S1/S2 subzone boundary at the
FIG. 3.41 POINT COUNT DATA STEREOPLOT
UPPER ARUNDIAN OOLITHIC SEQUENCE, TENBY
(HIGH TOR LIMESTONE)

A: LITHOFACIES

B: OOID TYPE
base of the Cornelly Oolite Formation. This he described as a transition "into thick bedded oolite" (Fig.3.42)

Fig.3.42 Thin bedded unit of Bioclastic Limestone Lithofacies (Stackpole Limestone Formation) marked SLF, is underlain and overlain by thicker bedded Oolitic Aggregate Lithofacies of the Upper High Tor Limestone, marked HLF (to the right of the photo) and the Cornelly Oolite Formation, marked COF (to the left of the photo). The junction between the High Tor Limestone Formation and the Stackpole Limestone Formation marks the Arundian/Holkerian transition. Imperial Hotel steps, Tenby South Sands.

However this facies change would have affected the coral and brachiopod faunas on which Vaughan's zonation scheme was based. It is no surprise therefore that the macrofaunal change occurs at this point. The identification of the stage boundary on the criteria of event stratigraphy may give a more valid result than the facies controlled macrofaunal biostratigraphy.

Above the undoubted Chadian/Arundian stage boundary there are only two possible mesothen boundaries at which may approximate to the Holkerian/Arundian stage boundary. The first is at the limestone/shale sequence 20m above the top of the Caswell Bay Mudstone within the High Tor Limestone (Figs.3.37 and
3.39). This is preceded by a micrite lithology with rhizoliths, above gastropod rich limestones. Similar sequences have been recorded in the Gower and have been discussed in Section 3.2.1.1 and are undoubtably intra Arundian events.

The second candidate is the transition from the oolitic sequence at the top of the High Tor Limestone to the thin bedded lithologies of the Pel-Bio Limestone Lithofacies (basal Stackpole Limestone Formation). This would represent a Late Arundian, shoaling oolitic development followed by an Early Holkerian deepening. This would have shut off oolitic sedimentation and established a background sediment of crinoid dominated bioclastic sands. However sedimentary regression would soon have caught up with sea level rise and the Holkerian oolitic sequence was then established. This scenario of events implies that the oolitic top of the High Tor Limestone would fit in well with a mesothem boundary approximating to the Arundian/Holkerian stage boundary.

The oolitic intraclast from the lower oolitic sequence shown in Fig.3.40 contains an ooid with a foraminifera for a nucleus. This is a primitive Arundian form of archaeodiscid, but on its own is not totally conclusive evidence for an Arundian age for these rocks as it may have been reworked. Unfortunately the only micropalaeontological biostratigraphic work on this section (Strank, 1981) was more concerned with the Stormy Limestone Formation and did not consider the High Tor Limestone/Stackpole Limestone Formation junction in detail. Thus unless further micropalaeontological biostratigraphic work proves otherwise, the Holkerian/Arundian boundary is taken at the top of the oolitic High Tor Limestone.
3.8 **THE HOLKERIAN ASBIAN BOUNDARY**

3.8.1 **Introduction**

Throughout Pembrokeshire the end of Holkerian deposition was marked by a period of subaerial exposure. The resulting exposure horizon contains a variety of diagenetic facies developments ranging from karst to caliche.

The style and intensity of these developments can vary rapidly, both vertically and laterally. This is partly due to the variable effects of subaerial pedogenesis and partly due to subsequent modification by erosion. All the subaerial deposits are followed by transgressive, oolitic and bioclastic Asbian lithologies. However they are deposited on a variety of host limestones. This, combined with position on the shelf, controls the type of deposit formed.

3.8.2 **Boundary Locations**

3.8.2.1 **Pembroke Syncline**

On this part of the Pembrokeshire shelf sequence the Asbian/Holkerian boundary is marked by a well developed caliche profile. At Lydstep Point the profile is approximately 50cm thick (Fig.3.43). At the top there is a thin, less than 5cm, reddened, platy laminated zone. This grades downwards into a chalky nodular zone, approximately 40cm thick, which itself grades into the underlying host peloidal wackestone.
Fig. 3.43 Caliche profile developed at the top of the Stormy Limestone Formation at Lydstep Point. Host limestone (Micritic and Cryptalgal Lithofacies) is seen at the far right of the photo. The overlying Crickmair Limestone is seen at the far left of the photo. Lydstep Point.

At Valleyfield Top (SR 109983), there is a similar profile developed (Fig. 3.44). The chalky nodular horizon is slightly thicker (approximately 60cm) and grades up into a platy laminar horizon. The lower parts of this horizon contain mm to cm sized glaebules, composed of microspar to pseudospar. These "float" in a red stained micritic matrix and have associated circum-granular cracking. Further up this horizon laminae are defined by coarser, 100 micron size, patches of microspar and pseudospar alternating with finer grained haematised material.
Above this a 5cm to 20cm, ochreous, poorly sorted conglomerate with clay matrix is developed. This contains clasts of the underlying chalky nodular and reddened platy laminar horizons. Yellow clay clasts are also found and overall clast size varies from 0.5cm to 2cm. In parts the conglomerate has a bedded appearance.

Fig.3.44 Caliche profile developed at the top of the Stormy Limestone Formation at Valleyfield Top. Pale limestone by hammerhead is chalky nodular zone developed in Micritic and Cryptalgal Lithofacies. This is overlain by a red conglomerate with a clay matrix and finally by the massive bioclastic lithologies of the Crickmail Limestone. Valleyfield Top (SS 109983).

At the north east end of St. Margaret's Island (SS 123973) a reddened nodular horizon is developed. This is approximately 30cm thick and overlies a mamillated palaeokarstic surface.

These caliche profiles are similar to caliche profiles developed in the western Mediterranean and Texas described by Esteban and Klappa (1983). Many of the features described above are characteristic of subaerial exposure, especially the caliche
glaebules and associated circum-granular cracking at Valleyfield Top. Fig. 3.45, is taken from a thin section from the top of the chalky nodular horizon at Valleyfield Top. A laminated micritic crust coats the internal surfaces of bioclasts with the rest of the pore space occluded by blocky calcite. This is similar to laminated subaerial crusts described by Multer and Hofmeister (1968) from the Florida Keys, but may also represent a type of tufa. The implications of this are that the texture is vadose in origin, but not necessarily subaerial (Esteban, 1976).

Fig. 3.45 Laminated micritic crust (M) coats the insides of bioclasts with the rest of the pore space filled by sparry calcite. The micritic crust is a vadose deposit formed subaerially. Taken from chalky caliche horizon shown in Fig. 3.44. Field of view is 4.5mm. Photomicrograph - Thin Section 328. Valleyfield Top (SS 109983).

The inclusion of clasts from the underlying horizons in the poorly sorted conglomerate exposed at Valleyfield Top, implies reworking of the profile. The bedded nature of this deposit may be subaqueous in origin and possibly fluvial.
appears to have been a certain amount of tectonic modification (Fig.3.44) and the bedding features may be an artefact.

The development of karst facies underlying the nodular development at St. Margaret's Island implies a period of carbonate dissolution before caliche development. This variation from the karst absent profiles of Lydstep and Valleyfield Top is not unusual. It possible for karst and caliche development to coexist in adjacent areas (Esteban and Klappa, 1983). Alternatively there may have been karst development at Lydstep and Valleyfield Top, but it has subsequently been subsumed within the caliche profile.

3.8.2.2 Bosherton Outcrop

Within the Bosherton Outcrop, the Holkerian/Asbian boundary shows a greater variation than at the exposures in the Pembroke Syncline.

At Stackpole Quay, well developed caliche or karst profiles are not preserved. However there is evidence for a faunal break. Approximately 4m of peloidal, bioclastic packstones with an Holkerian macrofauna, are followed by 1m of thin bedded, slightly dolomitised, fine grained wackestone (see Fig.3.46). This is, in turn, followed by massively bedded bioclastic limestones with an Asbian coral fauna (Dibunophyllum). There is no evidence for karst development, but there is some evidence for caliche. Rhizoliths (Klappa 1980a) are preserved within the Holkerian peloidal, bioclastic packstones. Fig.3.47 shows root casts (approximately 1mm in diameter) with laminated micritic tubes enclosing a sparry infill. This implies a period of subaerial exposure for the peloidal bioclastics. If a more complete karst or caliche profile was developed it was subsequently removed.
Fig.3.46 Junction between the Cornelly Oolite Formation and the Crickmail Limestone at Stackpole Quay. The massive limestones at the right of the photo, (Cornelly Oolite Formation) are formed of Pel-Bio Limestone Lithofacies which contain rhizoliths. The thin bedded unit (Crickmail Limestone) is formed of slightly dolomitised wackestones and packstones. It is interpreted to represent a deeper water facies developed in response to a major transgressive event. It is overlain by coarser bioclastic limestones characteristic of most of the Crickmail Limestone. Sequence youngs to the left. Stackpole Quay (SR 995953).
Fig. 3.47 Root cast types of rhizoliths (R) developed in Pel-Bio Limestone Lithofacies. Rhizoliths have micritic halos of altered host sediment and sparry calcite infills. Evidence for subaerial exposure at the top of the Cornelly Oolite Formation at Stackpole Quay (see also Fig. 3.46). Field of view is 4.5 mm.

In the cliffs immediately to the west of St. Govan's Chapel (SR 966928) massive Holkerian, bioclastic limestones (Pel-Bio Limestone Lithofacies) are succeeded by Asbian limestones which have a characteristic stepped topography (Fig. 3.48). The junction between these two sequences is marked by the development of thin karst and caliche profiles. The karstic surface is characterised by rounded smooth pinacles, less than 15 cm tall, and intervening, flat floored troughs (Fig. 3.49). This is similar to kamenitza karst development (Esteban and Klappa, 1983).
Fig. 3.48 The junction between the Stackpole Limestone Formation and the Crickmail Limestone (PK) is marked by the change in cliff topography from massive bioclastic limestones to the stepped topography characteristic of the Crickmail Limestone pseudobreccias. Cliffs to the west of St. Govan's Chapel (SR 966928).

Fig. 3.49 Palaeokarst developed in Bioclastic Limestone Lithofacies on the top of the Stackpole Limestone Formation at the location marked PK in Fig. 3.48.
The caliche profile is represented by a red/orange, nodular clay. This contains microspar glaebules with circum-granular cracking, the cracks being infilled with a red clay. This profile therefore contains evidence of subaerial exposure. Furthermore, discreet anticlinal structures are developed within this caliche profile (Fig.3.50). It is possible that these may have been tectonically produced. However they possess many features diagnostic of caliche pseudo anticlines as documented by Assereto and Kendall (1977). This in itself is not certain evidence for subaerial exposure, but combined with the glaebules and associated circum-granular cracking lends further weight to the interpretation. A tectonic origin appears unlikely as the overlying limestones show no evidence of accommodation structures.

Fig.3.50 Orange/Red nodular clay with development of caliche pseudoanticline. This is formed above the palaeokarst shown in Fig.3.49. The antiformal feature is primary in origin as the overlying bioclastic limestone lithology of the Crickmail Limestone onlaps onto it.

At Gun Cliff (SR 991944) the Holkerian/Asbian boundary shows
a marked facies change from mixed peloidal/ooidal limestones to coarse oolitic grainstones with an intervening, thin, intertidal micrite development (see Section 3.4.2.1). Although no karst facies is recorded, evidence for a caliche facies is seen as rhizoliths within the micrite. Fig.3.25 features a typical root cast with a laminated micritic tube and associated geopetal infill. There is also a 500 micron halo of altered host sediment around the root cast. Similar features have been documented by Spalton (1982) within Chadian and Arundian terrestrial sediments of South Wales.

3.8.2.3 Tenby and Areas North of the Ritec Fault

At Tenby South Sands the Holkerian/Asbian boundary is not preserved. It has been faulted and eroded away.

In the areas north of the Ritec Fault, the boundary is only exposed by New Park Quarry (Fig.3.29). This quarry is now heavily overgrown and the rocks covered with moss and lichen. However during the last survey of the area by the B.G.S. it was a working quarry. E.E.L. Dixon records (unpublished field notebooks) a lithological transition from fine grained, dark oolites of the *Seminula* zone to the thick bedded and coarse grained oolites of the *Dibunophyllum* zone. The transition was marked by a thin grey, buff shale. A similar style of subaerial exposure horizon has been recorded for other sections along the North Crop. The grey shale would appear to have been part of a caliche facies development. The grey colour is related to concentration of the relatively insoluble carbonaceous content of the host limestones by a variety of pedogenic processes.

3.8.3 Summary

The widespread evidence for subaerial exposure at the end of Holkerian deposition implies a period of regression. The controls
on this may be related to structural uplift, or to a eustatic drop in sea level coincident with this major mesothem boundary (Ramsbottom 1973). This is discussed in more detail in Chapter VII.

The drop in sea level seems to have been abrupt, with no evidence of gradual facies change. In some areas e.g. at St. Govan's Chapel, crinoid dominated bioclastic limestone lithologies (Open Shelf Lithofacies Association) are interpreted to have been deposited in some of the deepest water settings of the South Wales Shelf. These are followed immediately by a subaerial exposure horizon. Whatever the overall mechanism for creating such widespread subaerial exposure was, it had to be capable of rapidly reducing at least 10m to 20m of sea level.

The thinner developments of both caliche and karst facies within the Bosherton Outcrop may be explained by the erosive nature of the overlying Asbian sediments. Alternatively their distance from the thicker terrestrial deposits further north may suggest a palaeoenvironmental control.

Similarly the thick caliche facies development of the Pembroke Syncline reflect a more mature profile, which probably subsumed any underlying palaeokarstic development.

The caliche facies above the Dowlais Limestone Formation is unique in Pembrokeshire, but has affinities with similar horizons on the North Crop. Here the host lithology had most control on caliche development, releasing insoluble carbonaceous material on dissolution. Thus a grey, carbonaceous caliche profile was produced.
CHAPTER 4.

GOWER
FIG. 4.1 OUTCROP OF HOLKERIAN AGE ROCKS IN GOWER SHOWING MAJOR STRUCTURAL FEATURES

Key:

- HOLKERIAN AGE ROCKS
- STORMY LIMESTONE FORMATION
- CORNELLY OOLITE FORMATION
- OVERTON CLIFF FORMATION

0km 5km
### Table 4.1 Summary Lithostratigraphic Description - Gower

<table>
<thead>
<tr>
<th>Chronostrat.</th>
<th>Lithostrat.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbian</td>
<td>Oxwich Head Limestone = Coarse oolitic and bioclastic limestones</td>
<td></td>
</tr>
<tr>
<td>Holkerian</td>
<td>Stormy Limestone = Heterolith comprising pel-bio limestone and micritic/cryptalgal lithofacies</td>
<td></td>
</tr>
<tr>
<td>Holkerian</td>
<td>Cornelly Oolite Formation = Pwll Du Member: Dominantly oolitic limestones with intercalations of bioclastic and peloidal limestones</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dominantly oolitic sequence with intercalations of bioclastic and peloidal limestones</td>
<td></td>
</tr>
<tr>
<td>Holkerian</td>
<td>Overton Cliff Formation = Bioclastic limestones with shales interbedded on a dm to m scale</td>
<td></td>
</tr>
<tr>
<td>Arundian</td>
<td>High Tor Limestone = Thickly bedded peloidal, bioclastic limestones</td>
<td></td>
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</table>
4.1 **INTRODUCTION**

The Holkerian age rocks which outcrop in the Gower Peninsula are represented by three formations, the Overton Cliff Formation, the Cornelly Oolite Formation and the Stormy Limestone Formation (Table 4.1). The Overton Cliff Formation only occurs in Southwest and West Gower at the base of the Holkerian sequence (Figs. 4.1 and 2.1). The Cornelly Oolite and Stormy Limestone Formations make up the bulk of the Holkerian rocks and are found in all the sections included in this study (Fig. 4.1).

The deepest water facies exposed in Gower are found in Southwest Gower. In this area, the Overton Cliff Formation and the lower half of the Cornelly Oolite Formation (Red Chamber Member) contain lithofacies characteristic of the Open Shelf Lithofacies Association. These are overlain by lithofacies of the Oolitic Barrier Lithofacies Association (Pwll Du Member – Cornelly Oolite Formation) and of the Marginal Back Barrier Lithofacies Association (Stormy Limestone Formation).

In Central South Gower (Fig. 4.1) the Holkerian sections are dominated by the Cornelly Oolite Formation. This is, in turn, dominated by lithofacies characteristic of the Oolitic Barrier Lithofacies Association. However, there are also minor amounts of lithofacies referable to the Open Shelf and Marginal Back Barrier Lithofacies Associations. In this area the Stormy Limestone is more thickly developed than in Southwest Gower and is comprised of lithofacies characteristic of the Marginal Back Barrier Lithofacies Association.

In Eastern Gower faulting has made identification of the Holkerian sequences difficult. However lithologies characteristic of the Cornelly Oolite Formation have been recognised and represent Oolitic Barrier and Marginal Back Barrier Lithofacies
Associations. At Mumbles Head (Fig. 4.1) the Stormy Limestone is formed totally of the Marginal Back Barrier Lithofacies Association.

In North Gower the Holkerian sections are generally not well exposed. At Burry Holm (Fig. 4.1) the topmost parts of the Stormy Limestone Formation (Marginal Back Barrier Lithofacies) are not exposed, but the Cornelly Oolite and Overton Cliff Formations are found. These are dominated by the Open Shelf Lithofacies Association, although the upper parts of the Cornelly Oolite Formation contain lithofacies of the Oolitic Barrier and Marginal Back Barrier Lithofacies Associations.

Overall the development of the shelf sequences in Gower is similar to that described from Pembrokeshire. However, more varied exposures of the Open Shelf, Oolitic Barrier and Marginal Back Barrier Lithofacies Associations have enabled a more refined interpretation of these environments to be made. In contrast to Pembrokeshire there are no exposures of the Back Barrier Lagoon Lithofacies Association.

The Holkerian shelf sequences are described below using the lithofacies schemes outlined in Chapter II.

4.2 LITHOFACIES ASSOCIATION A: Open Shelf

4.2.1 Limestones/Shale Lithofacies

This lithofacies is found, in Gower, only within the Overton Cliff Formation. It represents the muddy shelf conditions which existed in the most offshore parts of the South Wales Shelf. The lithofacies is described below, first from the Southwest Gower area and then from Burry Holm in North Gower.

4.2.1.1 Southwest Gower

In this area the lithofacies is described mainly from the
exposures of the Overton Cliff Formation at Thurba Head (SS 423869) with some additional evidence from the more limited exposures at Overton Cliff (SS458848).

The Overton Cliff Formation consists of peloidal, bioclastic wackestone and packstone lithologies interbedded on a dm/m scale with calcareous shales (Fig. 4.2). It is developed at the base of the Holkerian sequence in Southwest Gower.

The shale interbeds contain features e.g. bioturbation which imply that they are primary. However there has also been a certain amount of diagenetic modification. In some cases the shales have been enhanced by pressure solution creating sharp interfaces with the bounding bioclastic limestones. In the most extreme examples, shales fade laterally into pressure solution seams which in turn fade into massive bioclastic limestone (Fig. 4.3). At these extreme boundaries the shales and pressure solution seams may anastamose.

Though the shales are affected by diagenetic effects, inherited inhomogeneities e.g. insoluble content in the sediment pile probably affected the siting of the pressure solution effects (Logan and Seminiuk 1985). Therefore the shales do reflect original sedimentary features and are interpreted as such.

The limestones are packstones and wackestones which are dominated by fine to coarse grained bioclastic material with sharp based, graded lags. These lags contain fragmented accumulations of fauna e.g. thin shelled productids, gastropods, corals and crinoid debris. In places the sharp bases of the lags overlie bioturbated sediment.
FIG. 4.2 LOG OF THE OVERTON CLIFF FORMATION
AT THURBA HEAD

- RED CHAMBER MEMBER (KORNELLY DOLomite FORMATION)
- FINE GRAINED, SHALy DOLomite WITH SHARP
  BASED "EVENT" DEPOSITS - SUBSEQUENTLY BIOTURBATED

THICK SHALES AND THIN BIOCLASTIC LIMESTONES

BIOCLASTIC PACKAGE WITH SEVEN MAJOR PRESSURE
SOLUTION SEAMS FADE LATERALLY INTO SHALES ZOOPHYTIDS ON SOME PARTINGS, ALTHOUGH SHALE ALMOST NON-EXISTANT

THIN SHALES AND COARSER BIOCLASTIC LIMESTONES
STYLOLITES PASSING LATERALLY INTO SHALES

BIOCLASTIC LIMESTONES WITH COARSER CRINOIDAL LAGS
SOLITARY CORALS, PRODUCTIDS AND CANINIDS,
NO GASTEROPODS AND NO SHALES - ONLY
PRESSURE SOLUTION SEAMS

THIN LIMESTONES WITH GRADED LAGS OF
BIOCLASTIC MATERIAL INTERBEDDED WITH
THIN SHALES

COARSER LAGS IN BIOCLASTIC LIMESTONE + BELLEROPHONTIDS
GASTEROPODS
THIN LIMESTONES AND SHALES

BIOCLASTIC LIMESTONE + BRACHIOPODS, SOLITARY CORALS AND
SOLITARY CORALS, PRODUCTIDS AND CANINIDS
THIN LIMESTONES AND SHALES

COARSE BIOCLASTIC LIMESTONE AND GASTEROPODS
ANASTOMOSING THIN LIMESTONES AND SHALES

VERY FINE GRAINED, DARK BIOCLASTIC LIMESTONE
AND CANINID-TYPE CORALS

FINE GRAINED BIOCLASTICS AND CANINID-TYPE CORALS
THICK SHALE WITH AUTOCHTHONOUS FAUNA + ZOOPHYTIDS
PELOIDAL BIOCLASTICS AND CRINOIDAL LAGS

MASSIVE COARSE BIOCLASTIC LIMESTONE
CANINIDS AND TURITELLID-TYPE GASTEROPODS
THIN SHALES

CRINOID LITHOSTRATUM

Key:

- SHALE LITHOLOGY
- PRESSURE SOLUTION SEAMS/STYLOLITES
- GASTEROPODS
- CORALS
- ZOOPHYTIDS
- CANINIDS-TYPE BIOTURBATION

- INCREASING TEXTURAL MATURITY
Fig. 4.3 Limestones with shales (Limestone/Shale Lithofacies). Limestones have sharp bases and gradational tops. At the level of the ruler, shales pass laterally into pressure solution seams which in turn pass into massive bioclastic limestone. Overton Cliff Formation, Thurba Head, 10m.

Although the limestone/shale boundaries have been affected by diagenesis, detailed observation gives some clues to the types of transition that occur. In most cases the shales appear to have gradational bases with the tops of the limestones. These are frequently bioturbated with Zoophycos, the lobes of which have diameters of up to 30cm. In contrast, the tops of the shales in all cases are sharply truncated by the overlying limestones.

The shales contain many of the same faunal elements as the limestones. They contain a characteristic fauna of phillipsid trilobites, Davidsonina carbonaria, Cleiothyridina, bryozoa and crinoid calyces. Delicate structures such as crinoid calyces have been preserved almost in situ (Fig. 4.4).
Fig. 4.4 Shale, within Limestone/Shale Lithofacies, contains a variety of fauna including a caninioid coral, brachiopod and crinoid fragments. The crinoid debris consists of ossicles and calyx plates. This rare concentration of calyx plates suggests that after death, the crinoid disintegrated in situ without hydrodynamic reworking. Evidence for the low energy environment represented by the shales. Overton Cliff Formation, Thurba Head, 14m.

Most shales are less than 50cm thick (average 10cm). However at the top of the Overton Cliff Formation (Fig. 4.2) a 1.5m shaly, fine grained dolomite is preserved (Fig. 4.5). This contains sharp based, graded sequences similar to those described above for the bioclastic limestone lithology but much finer grained and lacking their associated fauna. The tops of these graded horizons are bioturbated with downward branching mm sized tubes and Zoophycos (Fig. 4.6).
Fig. 4.5 Fine grained dolomitised shale lithology (Limestone/Shale Lithofacies). This example has been stained with Alizarin Red S using the techniques described by Dickson 1965. Small patches of undolomitised host shale (HL) are stained pink, but the majority of the lithology consists of unstained dolomite. A single high magnesium calcite crinoid ossicle (C) has also escaped dolomitisation. Field of view is 4.5mm. Photomicrograph - Thin Section 2054. Overton Cliff Formation, Thurba Head, 31m.

Fig. 4.6 Sharp based "event" beds preserved in fine grained
dolomite lithology - Limestone/Shale Lithofacies (Fig. 4.5). Top of underlying "event" bed is bioturbated with Chondrites and Zoophycos. Base of overlying "event" bed is sharp and the bed is normally graded. Overton Cliff Formation, Thurba Head, 31m.

4.2.1.2 Burry Holm

The Overton Cliff Formation is represented at Burry Holm by approximately 4m of thin limestones with shaly interbeds (Fig. 4.7). These succeed the coarse crinoidal, peloidal bioclastic limestone lithologies characteristic of the High Tor Limestone Formation (Arundian - George et al 1976).

Fig. 4.7 4m of Limestone/Shale Lithofacies represents the Overton Cliff Formation at Burry Holm, which overlies the High Tor Limestone (Arundian) seen at the base of the photo. Burry Holm (SS 403926).

The lithofacies exhibits similar features to those described from the Overton Cliff Formation at Thurba Head. The bioclastic limestone lithologies have sharp bases which grade up into bioturbated tops. In places, they also contain lags of coarser, mainly crinoidal material.

The shales contain a more or less in situ fauna of large
spiriferids, caniniid - type corals, small horn corals and crinoid debris. They are bioturbated by Zoophycos and in places contain a network of very fine (less than 1mm diameter) micritic tubes with a sparry infill. Rare bifurcations suggest that they are part of a burrow system. The concentration of these tubes on certain horizons, their uniform size and lack of associated altered sediment halos precludes them being rhizoliths.

4.2.1.3 Interpretation and Summary

The sharp based limestone lithologies are interpreted to have been muddy and sandy carbonate sediments which were introduced into a predominantly muddy outer shelf area by storm processes (e.g. tempestites, Einsele (1982) and Seilacher 1982). Reworking by periodic current action created sequences consisting of winnowed lags.

The preservation of delicate faunal structures in the shale lithologies implies that hydrodynamic conditions on the muddy outer shelf were quiet compared to areas of the shelf represented by the bioclastic limestone lithofacies. The variable thickness of the bioclastic limestone lithologies in the limestone/shale lithofacies may represent proximality trends to the adjacent areas of bioclastic sediment deposition (Aigner and Reineck 1982). Alternatively the thickness variations may be related to variations in the intensity and duration of storm events, in itself related to larger scale (global) climatic changes (Schwarzacher and Fischer 1982).

The proximality explanation is more likely as it would explain the occurrence of both the coarse bioclastic interbeds and the fine grained event beds with sharp bases and bioturbated tops found in the fine grained unit at the top of the Overton Cliff Formation at Thurba Head (Figs.4.2 and 4.6)
4.2.2 Bioclastic Limestone Lithofacies

The Lithofacies is particularly well developed within the Red Chamber Member of the Cornelly Oolite Formation. In Southwest Gower the basal 25m of the Red Chamber Member above the Overton Cliff Formation is dominated by the Lithofacies. Similarly the basal few meters of the Red Chamber Member at Three Cliffs Bay and at Hunt's Bay (Central South Gower) are also characterised by developments of the Lithofacies.

The Lithofacies was deposited as crinoid dominated sands and muds on the outer parts of the Holkerian shelf. The thinner developments of the Lithofacies in Gower compared with Pembrokeshire suggests that the Gower section represents a shallower part of the Holkerian shelf.

4.2.2.1 Description

The crinoid dominated bioclastic limestone lithologies which make up the Lithofacies vary in texture from wackestone to grainstone with packstone textures being the most common. In thin section (Fig.4.8) crinoid columnals (up to 5mm) are a common element in a finer grained background of micrite and peloidal material (Fig.4.9). Rare fragments of trilobites are also preserved as are productids, rare Syringopora and zaphrentid corals.

A common phenomenon in the facies is the replacement of limestone by silica. On a macroscopic scale this either takes the form of discreet nodules, or laterally continuous lenses of chert which can be followed for tens of meters. The nodules are generally less than 25cm in diameter and are frequently concentrically banded (Fig.4.10). This banding on unweathered surfaces is characterised by light and dark colour variations. Vertically elongate nodules pseudomorph burrow systems.
Fig. 4.8 Bioclastic Limestone Lithofacies, showing predominance of bioclasts in packstone texture. Large crinoid ossicle contains neomorphosed geopetal sediment. Crinoid debris is common, but other bioclasts such as trilobites and brachiopods are also found. Field of view is 4.5 mm. Photomicrograph - Thin Section 10, Port Eynon.

Fig. 4.9 POINT COUNT DATA STEREOPLOT Bioclastic Limestone Lithofacies SPEC. 10

LITHOFACIES
Fig. 4.10 Concentrically banded chert nodules in Bioclastic Limestone Lithofacies. The vertical elongate nodule, by the lens cap, appears to pseudomorph a burrow system. Red Chamber Member, Port Eynon.

The laterally continuous lenses of chert are usually less than 30cm thick and can appear to be "bedded". However in places they cut across bedding and are eventually, laterally discontinuous (Fig. 4.11).

In thin section the most common replacement of a packstone host texture is microcrystalline quartz (sensu Folk and Weaver, 1952). Areas of sparry calcite in grainstone host textures are embayed by small small quartz crystals. In Fig. 4.12, these textures are developed as well as a pseudo-drusy quartz mosaic. This is replacing an original sparry calcite fill evidenced by relic inclusions in the quartz crystals and along their interstices. The fact that the calcite shell of the surrounding small brachiopod is not replaced is unusual, but may be related to its original mineralogy and/or grain size considerations.
4.11 "Bedded" cherts in Bioclastic Limestone Lithofacies exhibit lateral discontinuities and cut across true bedding, Red Chamber Member, Port Eynon, 15m.

4.2.2.2 Sedimentary Structures

As with the Pembrokeshire examples, the Bioclastic Limestone Lithofacies in Gower contains lags of coarser crinoidal debris. In general the Gower developments are finer grained than their Pembrokeshire counterparts. However, in places lenticular structures contain a fill of very coarse crinoidal debris (Fig. 4.13). The latter have erosive bases, are poorly sorted and are up to 10m long, but only about 10cm thick. They are found truncating bioturbated surfaces and are overlain by wave ripple cross lamination decreasing in scale up section (Fig. 4.14).
Fig. 4.12 Chert replacing Bioclastic Limestone Lithofacies. Neomorphosed packstone host texture is replaced by microcrystalline quartz. Initial sparry calcite fill of small brachiopod is replaced by pseudo-drusy quartz mosaic. Field of view is 1.5mm. Photomicrograph - Thin Section 4, Red Chamber Member, Port Eynon.

Fig. 4.13 Sharp based coarse crinoidal lags in Bioclastic Limestone Lithofacies. Interpreted as thick basal lag of hummocky
stratification sequence. Red Chamber Member, Port Eynon.

Fig. 4.14 Small scale ripple lamination, decreases in scale up section. Interpreted as part of a waning flow hummocky cross stratification sequence. Bioclastic Limestone Lithofacies, Red Chamber Member, Three Cliffs Bay.

In other parts of the sequence low angle (less than 15 degrees) truncations of laminae are recorded. These are part of a hummocky structure with synformal swales and antiformal hummocks and with a wavelength of 2m to 5m (Fig.4.15). This example truncates parallel laminations below and grades into a structureless ?bioturbated fine grained top.

These two types of structures are interpreted as variations of an idealised hummocky stratification sequence (Dott and Bourgeois, 1982). The first case, with the coarse crinoidal scoured base, would correspond to a sequence with a thickened basal lag with a thin, or missing flat/hummocky laminae sequence. In the second case, the hummocky zone is well developed, as is the flat laminae zone, but the cross laminae zone is missing, presumably obliterated by bioturbation.
Fig. 4.15 Low angle (less than 15 degrees) truncations of laminae (above ruler) forming swale and hummock structures. Interpreted as well developed hummocky zone of hummocky cross stratification. Bioclastic Limestone Lithofacies. Red Chamber Member, Three Cliffs Bay.

Fig. 4.16 Fine grained lithology of Bioclastic Limestone Lithofacies, bioturbated by Skolithos/Monocraterion - type trace. Red Chamber Member, Three Cliffs Bay.
These variations are better seen in the Bioclastic Limestone plus Oolite Lithofacies described in the next Section, as the ooids highlight the structures. Both Lithofacies are characterised by bioturbation of flat laminae by a Monocraterion - Skolithos type trace (Fig. 4.16). It would appear, therefore, that the Bioclastic Limestone Lithofacies in Gower was deposited within storm wave base in a similar way to the equivalent Lithofacies in Pembrokeshire.

4.2.3 Bioclastic Limestone Plus Oolite Lithofacies

The main developments of the Lithofacies are within the Red Chamber Member of the Cornelly Oolite Formation. The Pwll Du and Deep Slade Members both contain thin (less than 5m) intercalations of the Lithofacies, but these are subordinate to the dominant Oolitic Aggregate Grain/Intraclast Lithofacies characteristic of those members.

As in Pembrokeshire, the Lithofacies appears to be temporally and spatially related to the development of the oolitic shoal/barrier complex. Of the three main mid-shelf sequences in Gower, it is best developed in the outer mid-shelf areas (Port Eynon and Three Cliffs Bay). The central mid-shelf areas (Hunt's Bay) are dominated by the thick oolitic sequences of the Deep Slade and Pwll Du Members.

Thus over the section of the South Wales Shelf represented by Gower, the Bioclastic Limestone plus Oolite Lithofacies was best developed during the Mid Holkerian and was rare, or absent before, or after that time.

4.2.3.1 Description

The Lithofacies is characterised by thin (dm/m scale) laterally continuous, interbeds of oolitic packstone and grainstone lithologies within fine grained bioclastic packstone
FIG. 4.17 POINT COUNT DATA STEREOPLOT
BIOCLASTIC LIMESTONE PLUS OOLITE
SPEC. 9,3-8 LITHOFACIES

A: LITHOFACIES

MICRITE

OOIDS

B: OOID TYPE

CONC/RAD

HOMOG

RAD

COMP
and grainstone lithologies.

The component ooids of the oolitic lithologies are mainly oolitic aggregate grains which are often heavily micritised. Simple unmicritised ooids are rare. This is reflected in the point count data (Fig. 4.17B) as a typical example of the Lithofacies plots almost equidistant between homogenous (micritised) and compound (oolitic aggregate grain) apices of the ooid type tetrahedra. Where the ooids are preserved in a packstone texture, the intersticial micrite has been neomorphosed to a cloudy spar with relict areas of micrite. Fig. 4.18, shows an example of this, with a cross cutting fracture filled with a clear, late calcite cement. This contrasts with and emphasises the cloudy nature of the neomorphic spar.

Fig. 4.18 Oolitic aggregate allochems "floating in a neomorphosed packstone/wackestone texture. Cross cutting fracture filled with "late" spar highlights the cloudy nature of the neomorphic spar. Bioclastic Limestone Plus Oolite Lithofacies. Field of view is 4.5mm, Red Chamber Member, Port Eynon.

On a larger scale, the oolitic lithologies often have sharp
bases which frequently coincide with pressure solution seams, or stylolites. Thus their pre-compaction thicknesses may have been greater. The preserved thicknesses vary from less than 3cm up to a metre or more, but are commonly 10cm to 15cm thick.

The oolitic lithologies have gradational tops with the overlying, frequently ripple laminated, or parallel laminated fine grained bioclastic lithologies. The latter contain crinoidal fragments and peloidal material and are similar to the finer grained bioclastic lithologies of the Bioclastic Limestone Lithofacies.

Repetition of the oolitic lithologies occurs on a variety of scales. Most commonly, 10cm to 15cm thick beds repeat every 20cm to 40cm. However in some places where the Lithofacies begins to grade into the Bioclastic Limestone Lithofacies, the oolitic lithologies may be separated by 2m or more of fine grained bioclastic lithologies.

In general, the fauna is similar to that found in the Bioclastic Limestone Lithofacies, but is sparser. Crinoid fragments are the most common element followed by thick shelled bellerophontid gastropods and rare small horn corals. Productids are notable by their absence throughout most of the Lithofacies.

4.2.3.2 Sedimentary Structures

The oolitic lithologies which overlie the finer grained, bioturbated, or parallel laminated bioclastic lithologies have sharp, erosive bases. The oolitic lithologies often form the bases to hummooky cross stratified sequences and contain wave ripple lamination. More rarely they contain unidirectional current structures.

In places, the bases of the thinner oolitic beds are cuspsate (Fig.4.19). This is an expression of the infilled basal scours
of festoon cross bedding. More commonly the bases of the thicker oolitic beds are planar as opposed to these scour and fill structures. The planar bases are occasionally accompanied by a lag of fragmented fauna e.g. bellerophontid gastropods and crinoid debris. They are interpreted to be higher energy (storm redistributed) deposits than the thinner cuspate based wisps which indicate unidirectional currents (fair weather reworking). The variation in thickness of the oolitic beds is related to proximality of the source areas of ooids (Aignar and Reineck, 1982).

Fig. 4.19 Sharp, cuspate bases to oolitic intercalations in bioclastic limestone (Bioclastic Limestone Plus Oolite Lithofacies). These represent the bases of trough cross beds. Red Chamber Member, Three Cliffs Bay.

Above these variable bases the oolitic lithologies almost invariably contain low angle, second order truncation surfaces. These sometimes exhibit hummocks and swales and are interpreted to be part of a hummocky stratification sequence (Dott and
The thickness of these sequences varies from less than 2cm up to several tens of cm. This hummocky sequence may then be followed by planar lamination, or wave ripple cross lamination developed in fine grained bioclastic lithologies (Fig. 4.20). The whole sequence records a period of suddenly increased energy followed by a period of waning flow conditions and/or reworking. The occurrence of hummocky stratification sequences suggests that the oolitic lithologies in the Bioclastic Limestone plus Oolite Lithofacies were largely generated by storm redeposition of ooids from the source ooid shoal/barrier complex.
Subsequent to initial deposition, fair weather bottom currents (oscillatory and unidirectional) reworked the allochthonous oolitic sediment which contained the hummocky cross stratification structures. During this time, wave and/or current ripple lamination was produced. This, together with thorough bioturbation accounts for the oolitic lithologies which contain a reduced, or non-existent hummocky layer.

This evidence fits in with the environment of deposition postulated for the adjacent Bioclastic Limestone Lithofacies. Both Lithofacies are influenced by storm redeposition of sediments interspersed with fair weather reworking and bioturbation. The Bioclastic Limestone Plus Oolite Lithofacies was deposited in the parts of the South Wales Shelf which were adjacent to the developing ooid shoal/barrier complex. This provided the oolitic sediments which now emphasise the variety of sedimentary structures found in the Lithofacies. The variable thickness of the storm generated oolitic lithologies reflects both the intensity of the storms which generated them and their proximity to the source areas.

4.2.4 Summary

The distribution of the three component Lithofacies of the Open Shelf Lithofacies Association in Gower is summarised in Fig.2.5.

The Limestone/Shale Lithofacies Association represents the muddy outer shelf areas of the South Wales Shelf which were prone to the influx of storm redistributed bioclastic sediment. The shale lithologies represent periods of lower sedimentation rate than the interbedded bioclastic limestone lithologies. Thus,
overall the Lithofacies represents a period of reduced sedimentation rate on the South Wales Shelf. The main control on rates of deposition was a deepening event coeval with the base of the Holkerian Stage. On the shallower parts of the Holkerian shelf the deepening was not sufficient to shut down the higher rates of carbonate deposition.

As sedimentation rates caught up with rates of transgression a facies change occurred. On the shallower parts of the shelf this change was initiated more rapidly than on the deeper parts where muddy shelf deposition lasted longer. The type of facies transition was geographically controlled. In the upper mid-shelf areas, represented by the South Central Gower sections, oolitic sediments (Oolitic Barrier Lithofacies Association) were deposited. However on the outer mid-shelf areas, the shoaling effect was more gradual due to the greater water depths. The muddy shelf areas were gradually overwhelmed by crinoid dominated bioclastic sands and silts (Bioclastic Limestone Lithofacies) which were deposited within storm wave base.

As the oolitic shoal/barrier became established it covered a wider area and had greater source potential for redistribution of its component grains. Thus by the mid-Holkerian the areas offshore from the shoal/barrier complex were intermittently covered by thin storm redeposited oolitic material. The crinoid dominated bioclastic sands and silts became interbedded with layers of oolitic sediment (Bioclastic Limestone Plus Oolite Lithofacies).

The oolitic shoal/barrier complex continued to prograde southwards covering all the parts of the South Wales Shelf represented by the Gower sections with deposits characteristic of the Oolitic Barrier Lithofacies Association. These are described
in the following section.

4.3 LITHOFACIES ASSOCIATION B: Oolitic Barrier

In Gower this Lithofacies Association is found only within the Cornelly Oolite Formation (Figs. 4.21, 4.22 and 4.23). The component Lithofacies and their distributions are described and interpreted below.

4.3.1 General Distribution of Ooid Bodies

The Cornelly Oolite Formation of Gower is split into three members, the Red Chamber Member, the Deep Slade Member and the Pwll Du Member (Figs. 4.21, 4.22 and 4.23).

The Red Chamber Member has already been discussed in detail in Section 4.2.3. It represents an area of crinoid dominated bioclastic sand and silt deposition offshore from the main oolitic shoal/barrier complex, which received intermittent input of storm redeposited oolitic sediments. The main oolitic shoal/barrier complex is represented by the Deep Slade and Pwll Du Members.

The relative thicknesses of the three members, over South Central Gower and Southwest Gower, are shown as an isopach map (Fig. 4.24). Two important features of this are the limited southerly extent of the Deep Slade Member and the widespread distribution of the Pwll Du Member. This suggests that the shoal/barrier complex in Gower experienced a twofold pulsed progradation (Fig. 2.5).
FIG. 4.21 LOG AND LITHOSTRATIGRAPHY OF THE SOUTHWEST GOWER SECTIONS
- Illustrating distribution of selected lithofacies and lithofacies associations.
(See also Enclosure 2)
FIG. 4.22 LOG AND LITHOSTRATIGRAPHY OF THE THREE CLIFFS BAY SECTION
- Illustrating distribution of selected lithofacies and lithofacies associations
(See also Enclosure 2)

Key: See Fig. 4.21 for key
FIG. 4.23 LOG AND LITHOSTRATIGRAPHY OF THE HUNT'S BAY SECTION

- Illustrating the distribution of selected lithofacies and facies associations.

(See also Enclosure 2)

Key: Refer to Fig. 4.21 for key to lithofacies and lithofacies association ornamenets
FIG. 4.24 ISOPACH MAP OF MEMBERS WITHIN THE CORNELLY OOLITE FORMATION, GOWER.

- (See Fig. 4.1 for locality names)
4.3.2 Oolitic Aggregate Lithofacies

The Deep Slade and Pwll Du Members are dominated by this Lithofacies (Enclosure 2.) which comprises thick bedded, or pseudobedded packstone and grainstone lithologies. These are often massive and contain little evidence for sedimentary structures.

The dominant component allochem is the oolitic aggregate grain. These are well rounded, occasionally botryoidal and average 1mm to 2mm in diameter (Fig.4.25). Although most of the oolitic aggregate grains are heavily micritised, the outlines of several constituent grains can often be distinguished. In most cases, these are ooids with either concentric laminae, or concentric/radial cortices. The grains within the compound ooids appear to be cemented together by a micritic matrix. The significance of this has already been discussed in Section 3.3.1.1.

Fig.4.25 Oolitic Aggregate Lithofacies. Oolitic aggregate grains have botryoidal outlines and micritic cements between component
oooids. Isopachous fringing cements predate drusy calcite fill of grainstone texture. Field of view is 4.5mm. Deep Slade Member, Hunt's Bay.

The Lithofacies contains a low percentage of bioclasts and has a variable content of other allochems. These appear to be related to the amount of micrite in the matrix (Fig.4.26). Grainstone textures are more common than packstone textures, only 12% of point counted samples of the facies contain more than 20% micrite in their matrices (Appendix One, Table 1.3). Within the grainstone textures some samples also contain single, simple ooids (less than 0.5mm in diameter). Where packstone textures dominate (see Fig.4.27) the compound ooid grains are in a matrix of finer (less than 0.5mm) grains and micrite. These grains are partially micritised bioclastic fragments, peloids, algal debris and foraminifera. These two examples are end members in a gradational sequence which reflects the variation of environments in which this widespread Lithofacies was deposited.

The Lithofacies shows many similarities to the grapestone lithofacies described from the Bahamas Bank by Purdy (1963(a) and 1963(b). Where the Lithofacies was adjacent to active ooid shoals, it would contain a greater proportion of single, simple ooids. In most areas the Lithofacies was probably cemented, or stabilised by subtidal mats, as in Recent Bahamanian examples (Bathurst 1967(b), Neumann et al 1970 and Scoffin 1970). This and the associated low rates of sedimentation (Winland and Mathews 1974) would account for the abundance of grainstone textures.

In other areas, where rates of micrite production were high and winnowing current energy low, packstone textures would dominate. These areas would occur in the protected central parts of the shoal/barrier complex.
PAGE NUMBERING AS ORIGINAL
Fig. 4.27 Oolitic aggregate grain incorporated within packstone intraclast (left side of photo.) which is itself in an oolitic aggregate sediment. Oolitic floatstone lithology of Oolitic Rudstone and Floatstone Lithofacies. Cross Polars, Field of view is 4.5mm. Pwll Du Member, Hunt's Bay.

The general absence of preserved sedimentary structures is probably related to sediment stabilisation due to formation of algal mats and cementation inhibiting the generation of ripple marks (Gebelein 1970). Thorough bioturbation would remove traces of any structures formed anyhow. In general, where sedimentary structures are preserved, the Lithofacies has a finer grained development with more single ooids.

Where trough cross bedding is developed in the Lithofacies it is developed on a variety of scales. In some places, sequences (approximately 5m thick) occur, with thickness of trough cosets decreasing upwards. At the base of these, meter scale asymptotic foresets are sometimes developed (see Fig. 4.28). More commonly only smaller scale trough cross bedding is preserved, a feature characteristic of most of the Lithofacies (see Fig. 4.29).
FIG. 4.26  POINT COUNT DATA STEREOPLOT
OOLITIC AGGREGATE LITHOFACIES - GOWER
SPECS. HB 24 + HB 41

-See Appendix One, Table 1.3

A: LITHOFACIES

B: OOID TYPE
Fig. 4.28 Asymptotic toesets of metre scale megaripple cross bedding. Developed in Oolitic Aggregate Lithofacies at base of large scale (5m) sequence recording lower energies of deposition up section. Red Chamber Member, Hunt's Bay.

Fig. 4.29 Trough cross bedding preserved in Oolitic Aggregate
Lithofacies. Pwll Du Member, Hunt's Bay.

In rare cases, hummocky stratification sequences are preserved. Fig. 4.30 shows an example of one of these sequences with a basal unit of antiformal hummocks and synformal swales with an approximately 50cm wavelength. This is succeeded by small scale wave ripple cross lamination and finally by structureless bioturbated Oolitic Aggregate Lithofacies.

Fig. 4.30 Hummocky cross stratification sequence developed in Oolitic Aggregate Lithofacies. Hummocky unit with low angle truncations of laminae is seen in middle left of photo. This is followed by wave ripple lamination and finally, bioturbated sediment at the top of the photo. Red Chamber Member at Three Cliffs Bay.

The overall interpretation of these structures is complex. There is much literature on Recent sand bodies of the Bahamas (Hine 1977, Hine and Neumann 1979, etc. see Halley et al 1983 for a review). There is comparatively little on other Recent carbonate environments e.g. barrier developments on ramps, which may be more analogous to the Holkerian shoal/barrier sequences described above.
It is tempting to select any number of the many documented Recent sand body morphologies and attempt to fit ancient features to these models. However, the main characteristics of Recent sand bodies which are used to classify them, e.g., geometry and orientation (Ball 1967), require detailed palaeocurrent data to support any interpretation of ancient examples. There is not sufficient data of this type, due to lack of structures, to make these detailed interpretations. Thus, rather than identify specific sand body morphologies (e.g., Ramsay 1984) in areas where there is insufficient palaeocurrent data to define them, some basic inferences about the hydrodynamic conditions on the shoal/barrier are made.

Assuming that bioturbation does not preferentially affect particular lithologies within the Lithofacies, the dominance of preserved sedimentary structures in the finer grained grainstone lithologies of the Oolitic Aggregate Lithofacies implies that these were more mobile than their coarser equivalents. Assuming that the active ooid shoals were in the areas of highest energy (the offshore margin of the shoal/barrier complex) the finer grainstone lithologies of the Lithofacies would represent the areas adjacent to, but behind them. Similarly, the coarser grainstone and packstone lithologies of the Lithofacies would represent areas further away, towards the interior and rear edge of the shoal/barrier complex. The paucity of structures in the coarser grainstone and packstone facies fits in with the petrographic evidence for early cementation, inferred stabilisation by algal mats and low rates of sedimentation.

By analogy with the Bahamanian examples, a variety of sand body morphologies were probably formed within the finer grained
The lithologies of the Lithofacies. These could have included marine sand belts, or tidal sand belts. Since the distinction between these is based mainly on their geometry relative to a bank margin, the lack of relevant palaeocurrent data precludes specific identification.

The presence of metre scale trough cross bedding in some beds could suggest an aeolian origin for them. This would be in keeping with Recent examples of aeolian ridges in carbonate sand environments. However a lack of evidence for dripstone cements, or rhizoliths in thin section does not support this interpretation. If they are marine in origin, then they probably represent the deposits of migrating megaripples.

The occurrence of low angle parallel lamination, overlying trough cross bedded units with large (greater than 1cm diameter) intraclasts are interpreted as shoreface to foreshore beach deposits (see Section 3.3.1.1 for discussion).

Overall, the movement of oolitic aggregate sand would have been controlled by the amount of stabilisation either by cementation, or by algal mats. However where the oolitic aggregate sand was not so well stabilised, fair weather currents, tides etc. could transport oolitic sediment away from the source ooid shoals. The influence of storm redeposition on the parts of the shelf offshore from the shoal/barrier complex has already been documented. However hummocky stratification sequences are rare in the Oolitic Aggregate Lithofacies. This does not reflect the distribution of storms on the Holkerian shelf, but rather the stability of the oolitic aggregate sand and its resistance to reworking.
4.3.3 Oolitic Rudstone and Floatstone Lithofacies

Intraclasts larger than pebble grade are a common component within the Oolitic Barrier Lithofacies Association in Gower. They form floatstone or rudstone textures, but the latter are rare. In general the intraclasts are well rounded, but their outlines range from sub-spherical to irregular.

Fig. 4.31 shows an intraclast floatstone texture with a bioturbated, fine grained oolitic aggregate grainstone matrix. The most obvious intraclast is a cross bedded ooid grainstone with finer bioclastic laminae in the center of the photo. There are several other, smaller intraclasts (Fig. 4.32) but they are more difficult to distinguish from the background sediment as they have a similar composition to it. Truncation of grains and micritised edges identify their boundaries.

The floatstone and rudstone accumulations of intraclasts reflects the importance of early cementation, reworking and redeposition in the shoal/barrier environment. Although hardgrounds with associated mineralisation and boring have not been recorded, intraclasts do have micritised edges probably formed by endolithic algae. Furthermore, isopachous fringing cements indicate cementation in a marine phreatic environment.

The ubiquity and morphology of the smaller rounded intraclasts within the Oolitic Barrier Lithofacies Association suggest that they have been subject to much reworking and abrasion. It is difficult to pinpoint a particular source for these intraclasts. As discussed in Section 3.3.1.3 fractured sea floor crusts could be one source. The flattened, or discoid nature of many intraclasts lends weight to this theory. Rarely, intraclasts are highly irregular in outline, with overhangs and cavities developed (Fig. 4.33). These features are subrounded and...
Fig. 4.31 OOLITIC INTRACLASTS FORM A FLOATSTONE TEXTURE WITHIN OOLITIC LITHOLOGY (OOLITIC RUDSTONE AND FLOATSTONE LITHOFACES). INTRACLASTS ARE WELL ROUNDED SEE FIG. 4.32 (OPPOSITE) FOR CLAST IDENTIFICATION.

Fig. 4.32 Detail of Specimen 39, Pwll Du Member Hunts Bay 111m Showing Position of intraclasts of Fig 4.32.
not angular, which precludes a fracture origin for them.

Fig. 4.33 Floatstone texture accumulation of intraclasts. Many of which are highly irregular in outline. Note intraclast at top left of photo. with pronounced overhang. Intraclasts are in oolitic aggregate lithology, Oolitic Rudstone and Floatstone Lithofacies.

In one particular outcrop, near the base of the Pwll Du Member at Hunt's Bay, there is a sequence containing these unusual intraclasts. At the base of the sequence there are ooid grainstones and fine grained bioclastic packstones interbedded on a cm scale. These show evidence for scouring on their bases. They are followed by approximately three meters of a trough cross bedded, fine grained oolitic aggregate grain grainstone lithology. It is this lithology that contains rudstone and floatstone accumulations of pebble and cobble grade intraclasts, some of which are highly irregular in outline (Fig. 4.33). Above this lithology is a well sorted, fine grained, oolitic aggregate grain grainstone with large planar foresets dipping gently towards the southwest.
This sequence is interpreted to represent a beach sequence. The lowermost thinly interbedded muddy and sandy lithologies represent the offshore deposits. These are overlain by the trough cross bedded foreshore deposits which are, in turn, truncated by planar foresets representing shoreface deposits. The association of the irregular shaped intraclasts with the trough cross bedded foreshore deposits suggests that they may have had a beachrock origin. Their external morphology supports this interpretation with an irregular outline reflecting the microtopography formed on the in situ beachrock by mechanical erosion/undercutting and chemical solution (Donaldson and Ricketts, 1979). Subsequently the beachrock was broken up by high energy storm events, reworked and redeposited in the foreshore zone of the beach sequence.

There may be other beach sequences in the Oolitic Barrier Lithofacies Association, but unless well developed, they are difficult to recognise from other high energy structures in the Lithofacies Association. However the presence of irregular intraclasts combined with a sequence of trough cross bedding and low angle laminations is characteristic of beach deposits (Inden and Moore, 1983). Further evidence for exposure, or the supratidal deposits of a backshore zone are not preserved in the example described above. This may be due to subsequent reworking in the high energy oolitic barrier environment. Indeed, the preservation of any part of a beach sequence is probably only due to localised high rates of sedimentation and cementation.

4.3.4 Simple Ooid Lithofacies

Although the Oolitic Aggregate Lithofacies dominates the Oolitic Barrier Lithofacies Association, there are rare examples of beds where single, simple ooids are the most common allochem. These beds are never more than 2m thick and contain very well
sorted, fine grained oolitic sediment. They are included within the Simple Ooid Lithofacies.

Fig. 4.34 shows an example of this Lithofacies. The ooids have an average diameter of 200 microns to 500 microns. They form around a variety of nuclei, foraminifera and peloids being most common. The cortices of the ooids are well developed (average 150 microns thick) and are mainly concentric/radial. However in a few cases, radial or homogenous (cryptocrystalline) ooids have been recorded in point counts (Fig. 4.35B, Appendix One Table 1.3). The outer laminae are well developed and have not been micritised by endoliths.

Fig. 4.34 Simple Ooid Lithofacies (Oolitic Barrier Lithofacies Association). Note the predominance of single, simple ooids with concentric/radial cortical textures. Field of view is 4.5mm. Photomicrograph - Thin Section 37, Pwll Du Member, Hunt's Bay.

Other grains include foraminifera, peloids and rare bioclasts. Bioclastic fragments account for less than 10% of point counted samples (Fig. 4.35A, Appendix One, Table 1.3). These
FIG 4.35 POINT COUNT DATA STEREOPLOT
SIMPLE OOID LITHOFACIES
SPECS. HB38, HB48 + HB50
- See Appendix One, Table 1.3

A: LITHOFACIES

B: OOID TYPE
non-oolitic grains have the same average diameters as the ooids, reflecting the very well sorted nature of the facies. Micrite content is low (less than 2%, Appendix One, Table 1.3) and the grainstone textures are formed by drusy calcite cements with no evidence for early isopachous fringes.

Sedimentary structures are rare. The beds are generally massive with gradational bases and sharp tops. They overlie coarser lithologies of the Oolitic Aggregate Lithofacies and are frequently overlain by oolitic intraclasts in a floatstone texture (Oolitic Rudstone and Floatstone Lithofacies). Occasional trough cross bedding is recorded, from rare, small scale, less than 10cm thick cosets, up to more common 50cm thick cosets.

The Lithofacies is interpreted to be a deposit of active oolitic sand, equivalent to the oolite facies of Purdy (1963, b). The low percentage of bioclasts and the lack of Oolitic aggregate grains distinguishes it from the Oolitic Aggregate Lithofacies.

The lack of micritisation, the subrounded to rounded morphology and size range of the ooids compares well with Recent Bahamanian areas of active oolitic sand. These are areas where conditions for ooid formation are optimum. The lack of micritisation implies that the ooids were in an agitated environment preventing the activity of endoliths and subsequent micritisation (Dravis, 1979).

Similarly the lack of isopachous fringing cements suggests that these active ooid sands avoided the widespread early cementation so characteristic of the shoal/barrier environment. To do this, the ooids would have to be buried rapidly after formation.

In Recent active ooid shoals, daily wind and tidal generated
currents create ripple marks which result in ripple cross lamination on a scale of 10cm. High energy events move larger ripples, resulting in ripple cosets on an average scale of 60cm (Ball, 1967). The rare preservation of the smaller trough cross beds implies that the Simple Ooid Lithofacies was subject to fair weather currents which created the agitated conditions suitable for ooid formation. However the rare high energy events which formed the larger, 50cm trough cross beds, buried the active ooid sands preventing early cementation and crust formation from taking place.

Burial of uncemented oolitic sand was uncommon since most active sand would have been subject to early cementation, evidenced by the widespread Oolitic Aggregate Lithofacies. Only rarely would the active oolitic sediment be preserved by burial, reflected in the paucity of the Simple Ooid Lithofacies in the Oolitic Barrier Lithofacies Association.

4.3.5 Summary

The Oolitic Barrier Lithofacies Association in Gower is dominated by the Oolitic Aggregate Lithofacies. This represents the large areas of stabilised "grapestone"-like sediments which formed on the Holkerian shoal/barrier complex.

The source areas of active oolitic sand were confined to the offshore edges of the shoal/barrier and were areally restricted. This was a result of the hydrodynamic conditions on the shoal/barrier and the rapid early cementation of the oolitic sediment. In some Recent Bahamanian examples of active ooid shoals e.g. Lily Bank (Ball, 1967) underlying topography does not control initial sites of ooid formation. Instead the position of relict, shelf edge morphology i.e. re-entrants, concentrates
tidal and wave current flow. This in turn creates a localised agitated environment for ooid formation.

In South Central Gower, there is no evidence for an inherited Late Arundian shelf topography related to structure as described from the Pembrokeshire sequences (Chapter III). Thus the siting of ooid shoals in the part of the Holkerian shelf represented by the South Central Gower sections was related to the position of re-entrants on the offshore edge of the shoal/barrier complex. These re-entrants were sedimentary in origin and formed by local variations in progradation and aggradation of the oolitic sediments. The fact that they existed and probably migrated during the evolution of the complex is reflected in the small scale variations in thickness of the interbedded oolitic and bioclastic lithologies in the Bioclastic Limestone Plus Oolite Lithofacies. As the "ragged" barrier edge migrated laterally the proximity of the source areas of ooids to the adjacent areas of dominantly bioclastic sand deposition would vary. Thus when oolitic sediment was redistributed by storms this variation in proximity would be reflected in the variation in thickness of the oolitic tempestites.

The separation of the Deep Slade and Pwll Du Members by the Red Chamber Member probably represents migration of a larger scale re-entrant. A eustatic sea level control on shoal/barrier progradation to produce this feature is considered unlikely as a similar effect is not recorded at the same stratigraphic level elsewhere in the Holkerian shelf sequences. A structural control involving rapid sediment buildup followed by a shut down of ooid production and isostatic subsidence c.f. delta switching is also rejected. This is due to a lack of evidence for development of regressive facies at the top of the Deep Slade
Member e.g. Subaerial exposure features, or surfaces with features characteristic of low rates of sedimentation - thorough bioturbation etc. Furthermore the transition between the Deep Slade and Red Chamber Members is a gradational one.

4.4 LITHOFACIES ASSOCIATION C: Marginal Back Barrier

Lithologies characteristic of this Lithofacies Association are found within the Stormy Limestone Formation and the upper parts of the Pwll Du Member (Cornelly Oolite Formation) Fig. 4.36.

The two Lithofacies which make up the Lithofacies Association (Pel-Bio Limestone and Micritic and Cryptalgal Lithofacies) and their various component lithologies are described and interpreted below.

4.4.1 Pel-Bio Limestone Lithofacies

The Pel-Bio Limestone Lithofacies is interpreted to represent a widespread subtidal peloidal sand developed within the Marginal Back Barrier area. Its characteristic lithologies and sequences are described in the following section.

4.4.1.1 Description

The Lithologies which make up the Lithofacies exhibit a variety of allochem types, grain sizes and textures. However, the most common grain type in all lithologies is the peloid (micritised grain).

The spectrum of the component grains in a representative collection of these lithologies is summarised in Fig. 4.37. In general, there is a lack of bioclastic material (average less than 25% in point counted samples, Appendix One, Table 1.4.1) and most examples contain a high percentage of peloids and intraclasts (average 60% of point counted samples).
FIG. 4.36 DISTRIBUTION OF MARGINAL BACK BARRIER LITHOFACIES AND LITHOLOGIES IN THE STORMY LIMESTONE AND PWLL DU MEMBER

(CORNELLY OOLITE FORMATION)
Fig. 4.38 Fine grained (average grain size less than 200 microns) peloidal packstone lithology of the Pel-Bio Limestone Lithofacies. Most allochems are peloids, or algal debris. Field of view is 4.5mm. Photomicrograph - Thin Section 53, Stormy Limestone Formation, Hunt's Bay.
The finer grained lithologies (average grain size less than 200 microns) are mostly packstones, or wackestones (Fig. 4.38). The allochems are mainly irregular well rounded peloids with many foraminifera, algal fragments especially *Ortonella* and *Girvanella*, calcispheres and rare small bioclasts.

The coarser grained lithologies (average grain size ranges from 300 microns to 1mm) have packstone, or grainstone textures. This is illustrated by the lower point count values for micrite e.g. specimens 56 and 62(i) Fig. 4.37 and Appendix One, Table 1.4.1. Common allochems are subrounded peloids, compound and single ooids, algae especially *Koninckopora* fragments, foraminifera especially *Dainella holkeriana* and rare crinoid and brachiopod debris.

In outcrop, the Lithofacies is often massive and appears to be unbedded. However trough cross bedding is preserved at the base of some sequences (Fig. 3.36). In general though, there is a lack of preserved sedimentary structures. This combined with a scattered fauna suggests that the Lithofacies may be thoroughly bioturbated.

The Lithofacies contains some characteristic faunal and floral elements. Productids especially *Productus corrugatus-hemisphericus* and thin shelled *Linoproductus* are common. *Composita* is also common and often forms monospecific coquinas. In the coarser grained, grainstone lithologies crinoid fragments and rare small solitary conical corals e.g. *Aulophyllum* are recorded. *Chaetetes* is often recorded encrusting intraclasts, or other fauna (Fig. 4.39). Algal debris is also common especially *Koninckopora* either whole, or as fragments plus cm sized spheres of *Ortonella* and *Girvanella*. Thick shelled bellerophontids are recorded in the coarser grainstone lithologies whilst thinner
shelled high spired gastropods are occasionally found in the finer grained lithologies.

Fig. 4.39 A fragment of brachiopod shell encrusted by Chaetetes which is a common faunal component of the Marginal Back Barrier Lithofacies Association. Pwll Du Member, Three Cliffs Bay.

4.4.1.2 Distribution

The distribution of the Lithofacies within the Stormy Limestone Formation and the upper parts of the Pwll Du Member is shown as the lightly stippled areas in Fig. 4.36.

In most cases, the Lithofacies forms the bases of sequences which fine up to the thin bedded, fine grained peloidal, micritic and oncolitic lithologies characteristic of the Micritic and Cryptalgal Lithofacies. In places the finer grained tops of these sequences are truncated by the coarser grained lithologies of the Pel-Bio Limestone Lithofacies.

At Port Eynon, the Lithofacies dominates the Marginal Back Barrier Lithofacies Association with a series of fining upwards sequences. Some of these have very well sorted, slightly oolitic
bases with small scale, less than 10cm thick cosets of trough cross bedding.

At Three Cliffs Bay, the topmost 20m of the Pwll Du Member is composed of partially oolitic lithologies of the Lithofacies. The next 20m of the overlying Stormy Limestone Formation is dominated by the Micritic and Cryptalgal Lithofacies. This sequence is then sharply and erosively truncated by the Pel-Bio Limestone Lithofacies which exhibits the typical fining upwards sequences characteristic of most of the Lithofacies. However this sequence is interrupted by an approximately 8m thick intercalation of laterally impersistent oncoid lags (Micritic and Cryptalgal Lithofacies), 5m above its base.

At Pwll Du Head, the Lithofacies abruptly overlies the massive oolitic sequences of the upper Pwll Du Member (Cornelly Oolite Formation) and interfingers with fine grained lithologies of the Micritic and Cryptalgal Lithofacies over the next 15m. A sharp, erosive junction with an underlying 1.75m thick peritidal micrite marks the return of the characteristic fining upwards sequences. However, almost immediately there is a change to thinner fining upwards sequences with thick (50cm to 1m) oncoid intraclast lags characteristic of the Micritic and Cryptalgal Lithofacies.

4.4.1.3 Interpretation

The Lithofacies is interpreted to represent a widespread peloid sand situated in the marginal back barrier areas. Its variable allochem content reflects the influence of the variety of environments which developed adjacent to it.

The fining upwards sequences are interpreted to be the result of localised aggradation. Coarser bases with associated
trough cross bedding imply the presence of mobile sand bodies. The geometry of these bodies is not known, but the small scale of trough cross bedding suggests relatively low energy current action compared with the oolitic barrier sequences.

The coarser grainstone lithologies with ooids reflects that part of the Lithofacies which was adjacent to the oolitic developments of the shoal/barrier. Consequently these lithologies are found at the top of the Pwll Du Member interfingering with oolitic lithologies of the Oolitic Barrier Lithofacies Association. However these lithologies are also seen above the sequence dominated by the Micritic and Cryptalgal Lithofacies at Three Cliffs Bay (Fig. 4.36). This implies that after localised tidal flat aggradation, the oolitic peloid sand facies migrated over this area.

The finer grained packstone developments of the Lithofacies grade into some of the finer grained lithologies of the Micritic and Cryptalgal Lithofacies. The increase in percentage of micritic matrix and decrease in grain size reflects the "quieter" hydrodynamic environment. The source of many of the smaller peloids is probably faecal pellets. However a significant proportion of the peloids may have had an origin as abraded micritic intraclasts, algal debris and more rarely bioclasts. The high incidence of micritisation implies a shallow subtidal environment with a low degree of agitation.

4.4.2 Micritic and Cryptalgal Lithofacies

This heterolithic lithofacies is found only in the Stormy Limestone Formation. The range of component lithologies is similar over most of study area where it is exposed. However, certain lithological sequences are particularly well developed in the Gower. These have enabled more refined interpretations to be
made about some of the marginal back barrier environments.

The various component lithologies of the Lithofacies are briefly described below. Specific lithological sequences are then described and interpreted. The distribution of the Lithofacies within the Stormy Limestone Formation is shown in Fig. 4.36 and Enclosure 2.

4.4.2.1 Description of Component Lithologies

The most characteristic component lithology of the Micritic and Cryptalgal Lithofacies is the "porcellanous" micrite. Modifications of the basic micrite lithology include thin (cm) bioclastic grainstone laminae repeated on a 5cm to 20cm scale, mudcracks, birdseyes (some rhizocreations), Chondrites/Spirorbis - type bioturbation and cryptalgal lamination.

These lithologies grade into slightly coarser, silt grade peloidal packstone, or wackestone lithologies. These have coarser grainstone laminae with lateral discontinuities similar to the examples described from Pembrokeshire.

Brown weathering carbonaceous shales are extremely rare in South Central and Southwest Gower and in all cases overlie micrite lithologies. There is one example at Pwll Du Head, where a shaly intraclast veneer overlies a micrite with thrombolitic algal mounds (Fig. 4.40). This bears a striking resemblance to the mound topography found underlying the Carbonaceous Shale Lithofacies (Back Barrier Lagoon Lithofacies - Dowlais Limestone Formation) on the North Crop (see Section 5.2.2.2) and may reflect a hint of the back-barrier lagoon environments further to the north.
Fig. 4.40 Shaly intraclast veneer overlies micrite with cryptagal mounds formed of thrombolitic texture (by hammer). Stormy Limestone Formation, Hunt's Bay. (Compare with similar feature in the Carbonaceous Shale Lithofacies (Back Barrier Lagoon Lithofacies Association) at Twynau Gwynion Quarry on the North Crop - Fig. 5.16).

The development of oncolitic coquinas in peloidal packstone and grainstone lithologies is much more characteristic of the Marginal Back Barrier Lithofacies Association in Gower than in Pembrokeshire. Their prolific development was recognised in the earliest sedimentological work on Gower when they were termed the "concretionary beds" (Dixon and Vaughan 1911). The oncolitic coquinas often form the basal lags to small scale (5cm to 50cm thick) fining upwards sequences. These are described and interpreted in more detail in Section 4.4.2.2 below.

Another lithology which was poorly represented in the Marginal Back Barrier Lithofacies Association of Pembrokeshire, but which is well developed in Gower is the intraclast, peloidal grainstone. This lithology is intimately associated with the peloidal packstones and grainstones with oncolitic coquinas. The
lithology commonly occurs as thin (10cm to 20cm) coarsening upwards sequences. These developments are described and interpreted in more detail within the next section.

4.4.2.2 Interpretation

The various micritic lithologies contain features indicative of shallow subtidal to intertidal and supratidal conditions. They were probably deposited on micritic tidal flats. The silt grade peloidal packstone and wackestone lithologies with discontinuous grainstone laminae are interpreted to represent supratidal levee deposits of tidal flat channels (Shinn 1983a)

By analogy with the Carbonaceous Shale Lithofacies of the Back Barrier Lagoon Lithofacies Association, and due to their association with micritic lithologies, the brown weathering carbonaceous shales are interpreted to represent tidal channel overbank deposits.

The oncolitic coquinas in peloidal packstone and grainstone lithologies are interpreted to be formed as basal lags and channel fills in tidal inlets/channels. This interpretation is considered in more detail below.

The intraclast peloidal grainstone lithologies which form the tops to coarsening upwards sequences are interpreted as the thin foreshore units of low energy beach sequences. This interpretation is also discussed in more detail below.

Low Energy Beach Sequences

Small scale (less than 1m, average 20cm) coarsening upwards sequences are recorded from the Marginal Back Barrier Lithofacies Association of Three Cliffs Bay and Pwll Du Head. They are particularly prevalent at the latter locality.
The coarsening upwards sequences have basal parts comprising peloidal packstones or wackestones. These have a paucity of trough cross bedding and where sedimentary structures are developed, they are very small scale (cm scale ripple cross lamination). In places these basal lithologies are strongly bioturbated.

The peloidal basal lithologies grade up into the coarser grainstone tops of the sequences (Fig. 4.41). These consist mainly of granule to pebble grade intraclasts although small oncoids, Chaetetes, gasteropods and Composita fragments are common. These grainstone tops are usually less than 30cm thick and average 10cm. The intraclasts are either micritic, or are composed of fine grained ooid, peloid grainstone. The micritic intraclasts are usually smaller (less than 4mm) and are rounded to well rounded. The morphology of the ooid, peloid grainstone intraclasts ranges from well rounded oblate shapes to prolate discs, or chips. Typical width/height ratios of the chips average 20:1. Their edges are often heavily micritised, sometimes asymmetrically. Their undersides sometimes have pendant cements developed within shelter porosity.

Many intraclasts and Composita fragments are coated with an algal veneer, or are enourusted by Chaetetes. The algal coats are usually asymmetrically developed, putting them into the SS-I, or SS-R types of oncolite described by Logan et al (1964) although some rare SS-C types are recorded.

Where the peloidal packstone bases grade into the coarser tops, the sediment is strongly bimodal. Coarser intraclasts, shell fragments and coated grains are surrounded by a finer grained (less than 500 microns, average 200 microns) peloid/ooid background sediment. However, further up the sequences the
sediment becomes well rounded and well sorted with a clean grainstone texture developed. These layers contain small tabular to spherical keystone vugs.

Fig. 4.41 Intraclasts and oncoids in a peloidal background sediment form a coarsening upwards sequence which has a grainstone texture at its top. This is interpreted as a low energy beach sequence. Scale at side of slab is in cm. Micritic and Cryptalgal Lithofacies, Stormy Limestone Formation, Hunt’s Bay.

The overall coarsening upwards sequence is interpreted to be part of a low energy regressive beach sequence (see Fig. 4.42). The coarser grainstone tops represent a thin foreshore unit. The coarser intraclast, coated grain, shell fragment debris being concentrated by low energy wave swash. This would be strong enough to produce the well rounded, well sorted grainstone textures found in the top of the sequences. The keystone vugs described above probably represent voids immediately above the swash zone left by air escaping from intergranular pores during flood tidal action (Inden and Moore, 1983). In common with
1. Idealized Low Energy Regressive Beach Sequence. (Hinde + Moore 1983)
   - Low energy tidal flat
   - Thin foreshore unit
   - Vugs + dripstone cements
   - Munsell cements
   - Monospecific coquinas
   - **Composita** common
   - Absence of trough cross bedding implies lack of effective longshore currents.

2. Idealized Tidal Inlet/Channel Sequence. (Shinn, 1983b)
   - Intertidal/supratidal deposits
   - Supratidal levee deposits
   - Combined pond - intertidal sediment
   - Channel lag/fill, mainly **Composita** - oncoids
   - Rare intraclasts
   - Trough cross beds
   - Sequence sharply overlies a variety of facies

3. Stacked Low Energy Beach Sequences
   - c.f. Spec. 63, Pwll Du Head 22m
   - Stacked thin foreshore units dominated by intraclasts

5. Combined Sequence: Low Energy Beach Followed by Tidal Inlet/Channel (Common)

4. Stacked Tidal Inlet/Channel Sequences
   - c.f. Spec. 2119, Pwll Du Head 41m
   - Oncolitic channel lags, fill vary from 3cm to 30cm

6. Combined Sequence Tidal Inlet/Channel Followed by Low Energy Beach (Rare)
Recent low energy beaches e.g. Florida Bay there is a low diversity of abraded shell fragments with almost monospecific coquinas of *Composita*, or bellerophonid gastropods developed.

The fine grained peloidal wackestone, or packstone bases represent low energy shallow offshore, or poorly developed shoreface sequences. The presence of rare small scale ripple cross lamination is evidence for weak longshore currents, whilst strong bioturbation has reworked most of the sediment.

In an idealised regressive low energy beach sequence compiled from a number of examples in the Marginal Back Barrier Lithofacies Association (Fig.4.42i) the thin foreshore units would be overlain by low energy tidal flat, supratidal, or terrigenous deposits. However in most of the examples found at Pwll Du Head this complete sequence is not recorded. Instead, repeated coarsening upwards sequences, on a 10cm to 20cm scale are observed (see Fig.4.42iii and Fig.4.43). These are interpreted to be the result of competition between two processes, one being transgression and the other being beach sequence accumulation. Rates of transgression appear to be continous and slower than rates of beach sequence accumulation. Thus there is an effective sea level control on continous foreshore sequence development which creates the observed stacked low energy beach sequences.

Occasionally these coarsening upwards intraclast, coated grain sequences are abruptly overlain by an oncolitic coquinoi lithology. This then fines up to a peloidal packstone. These transitions are interpreted to be the result of tidal channel reworking of a beach sequence. Tidal channel/inlet deposits are discussed in the next section and the significance of the combined sequences is interpreted in Section 4.3.
Fig. 4.43 View of cliff face (notebook at bottom left for scale) at Pwll Du Head showing a number of coarsening upwards sequences as described in Figs. 4.41 and 4.42. The darker bands represent finer grained peloidal sediment which forms the bases to the coarsening upwards sequences. The lighter bands represent the coarse intraclast and oncoid rich upper parts of the sequences. Stacked low energy beach sequences, "Concretionary Beds" of Dixon and Vaughan 1911. Micritic and Cryptalgal Lithofacies, Stormy Limestone Formation, Hunt's Bay.

Tidal Inlet/Channel Fills - Oncoid and Oncolite Formation

Fining upwards sequences with oncolitic bases are observed in most sections containing Marginal Back Barrier Lithofacies Association described from Pembrokeshire. They are particularly well developed in Gower at Three Cliffs Bay and Pwll Du Head. These exposures exhibit several features which suggest that the fining upwards sequences are the deposits of tidal channels, or inlets.

An idealised fining upwards sequence can be compiled from a number of examples observed in the Marginal Back Barrier Lithofacies Association (Fig. 4.42ii). Typically these have sharp, erosive bases which are overlain by oncolitic coquinas in a
peloidal packstone, or grainstone matrix. These basal lags exhibit a crude grading and vary in thickness from 10cm to 60cm. Occasionally they may be trough cross bedded. The coquinas are dominated by fragments and whole specimens of Composita, although bellerophontid and turritellid type gastropods are also found. Intraclasts are rare, but Chaetetes is common, especially encrusting shell fragments. Almost all these components have an algal veneer, or coating. These consist mainly of Ortonella/Girvanella micritic tubes, but encrusting Chaetetes are found within the coats. Most of these coated grains conform to SS-I, or SS_R oncoid types, SS-C types are comparatively rare.

These oncolitic coquinas are invariably followed by a peloidal packstone, or wackestone sequence. The peloids are of a similar grain size to those found in the oncolitic coquinas (less than 500 microns, average 200 microns). The main difference is that many of the peloids in the oncolitic coquinas have a thin micritic coat which identifies them as pseudoolids. Sedimentary structures in the peloidal packstones and wackestones are rare and the sediment is often bioturbated.

The next transition in the sequence is variable. In some cases, the peloidal packstones and wackestones fine up to micritic lithologies. These contain a variety of structures indicative of intertidal to supratidal deposition; cryptalgal laminates, mudcracks and vugs (root tubules, or root casts). However this transition may be complicated by an intervening fine grained (silt grade) peloidal sediment with discontinuous laminae of grainstone material. This layer may vary from 5cm to 30cm in thickness.

Overall, the whole fining upwards sequence varies from 20cm
to greater than 1m. This is typical for tidal, channel deposits recorded from the channeled belt of Andros Island tidal flats, Great Bahamas Bank (Shinn et al. 1969). The bimodal, peloidal packstone/oncolitic coquinas are interpreted to be part of a channel lag/fill deposit. The rare trough cross bedding is probably the result of migration of sand bodies near the mouths of the tidal channels, or inlets (Jindrich 1969). The fining upwards sequences reflect the migration of the tidal channels, with the underlying channel lag/fill sediment being overlain by pond and intertidal sediment represented by the peloidal packstones and wackestones. These, in turn may then be overlain by supratidal channel levee sediments or by the various intertidal, or supratidal micritic deposits.

At Pwll Du Head, the complete tidal channel sequence is only rarely developed. A much more common development is the repetition of sequences with oncolitic coquinas fining up to peloidal packstones and wackestones on a scale of 5cm to 50cm (Fig. 4.42iv and Fig. 4.44). In these cases, lateral migration of channels and subsequent development of the complete tidal channel sequence is hindered by constantly rising sea level. If sea level and sediment supply were constant then the whole intertidal zone would be reworked many times and complete sequences would be more likely to be developed (Shinn 1983).

The stacked tidal channel/inlet sequences are a response to renewed episodes of tidal channel fill. In some places the intervening pond and intertidal peloidal packstones and wackestones are poorly developed resulting in thick oncolitic coquinoid deposits being formed. At Three Cliffs Bay (Fig. 4.36, 46m to 56m) these stacked oncolitic channel lag sequences are well developed. These appear to fill a long lived channel feature
as the channel edges mimic underlying coquinas (Fig. 4.45). These channel edges lend further weight to the interpretation of the fining upwards sequences as tidal channel/inlet deposits.

The source of the oncoids is considered to be the same for both the low energy beach sequences and the tidal channel/inlet sequences. This is due to their similar composition i.e. a dominance of SS-I and SS-R types over SS-C types. The SS-I types show many similarities to Recent algal "biscuits" (Ginsburg, 1960). They have a strong asymmetry of laminae and in some cases projections, or "roots" on their undersides (see Figs. 4.44 and 4.41).
Fig. 4.45 Thick oncolitic coquinas form the basal lags for channel fill sediments. The edge of one of these channels is shown in this photo. This channel edge feature was long lived, as the underlying coquinas mimic the wedging out structure of the overlying oncolitic channel fill lag. Micritic and Cryptalgal Lithofacies, Stormy Limestone Formation, Three Cliffs Bay.

Growth of the algal coats appears to have been rapid as several specimens of coated *Composita* are preserved whole. Movement of the oncoids would have been intermittent to allow the formation of the SS-R types. Encrustation by *Chaetetes* implies that there were hiatuses during growth of the coats and that they would then be subject to early cementation.

In studies on Recent oncoids, or algal "biscuits", their distribution is related to the presence of moderate, continuous currents away from wave surge and to low rates of sediment accumulation (Gebelein 1969). It would appear that the marginal back barrier environment, immediately to the rear of the ooid shoal/barrier complex, was ideal for oncoid formation. The wide shallow area of the shoal/barrier would have reduced wave surge and bottom currents by bottom friction. However tidal currents
and the reduced bottom currents would be just strong enough to have net current movement. Similarly there is abundant evidence for low rates of sedimentation in the compound ooid facies (see Section 3.3.1.1 for discussion). Coincidently, reduced wave surge also accounts for the reduced development of beach shoreface sequences due to weak longshore currents and thus explain the occurrence of low energy beach sequences.

Although stacked channel/inlet sequences are common, they are not the only combination of tidal channel sequences that can occur. Combined sequences are recorded where fining upwards, tidal channel/inlet sequences are followed by coarsening upwards, low energy beach sequences (Fig. 4.42vi). However these are rare in comparison to the occurrence of combined sequences where low energy beach sequences are followed by tidal channel/inlet sequences (Fig. 4.42v). This is related to the palaeogeographic setting of these environments, where low energy beaches are situated barrierwards of the channelised/ponded areas (Section 4.3). During progradation of the entire marginal back barrier tidal flat complex, the tidal channel/pond sequences would subsequently overlie and rework the low energy beach sequences.

4.3 Summary

The environments in which the Marginal Back Barrier Lithofacies were deposited can be split into two main groups; the subtidal environment (Pel-Bio Limestone Lithofacies) and the intertidal to supratidal environment (Micritic and Cryptalgal Lithofacies). The two groups were not rigidly separated geographically. Thus in vertical section there are a wide variety of facies transitions.

Fig. 4.46 summarises the inferred distribution of facies and
FIG. 4.46 INTERPRETATION OF FACIES DISTRIBUTION FOR THE MARGINAL BACK BARRIER SEQUENCES OF GOWER

ENVIRONMENT INTERPRETATIONS (CAPITALISED)

FACIES TYPES (Lowercase Letters)

KEY:

Vertically Layered Barren Limestones Association

Subtidal Environments

- Peloidal Sands - Pel-Bio Limestone Lithofacies
- Barrier Complex Channel
- Bar
- Boulders
- Flood tidal Delta Sand Bodies
- Zones of Oncoid Formation + Reworking

Intertidal to Supratidal Environments - Muriatic and Cryptobedded Lithofacies

- Low energy Beaches - Intraclast / Oncoid Coarsening Upwards Sequences
- Pond
- Supratidal Levee
- Tidal Channels / Dikes

Arrows in barrier complex channel show dominance of transport to rear of barrier (tide / wave / storm) over transport barrierwards (tide)

Vertical scale greatly exaggerated

Approx. 1 km
environments in the back-barrier area. The subtidal environment is dominated by the peloidal muds and sands represented by the Pel-Bio Limestone Lithofacies. These interfinger with the facies characteristic of the shoal/barrier sequences to the south (Oolitic Barrier Lithofacies Association) and grade into the more protected back-barrier lagoon areas to the north. Therefore they contain the broad spectrum of allochem types described in Section 4.4.1.1.

Within this broad marginal back barrier area of peloid sands there was also a mosaic of very shallow subtidal to intertidal and emergent tidal flat environments. These tidal flats were fringed by low energy beaches and dominated by subtidal to intertidal ponds and tidal channels, or inlets. These were probably submerged for most of the time and should really be included under the subtidal environments heading in Fig. 4.46. However due to their close association with the intertidal to supratidal deposits of the tidal flats they are included under that heading.

The lack of evaporite deposits and the predominance of tidal channel, or inlet deposits suggests that these tidal flats were not arid, but humid (Shinn et al. 1969, Ginsburg and Hardie 1975 and Shinn 1983a). At the edges of the channels and in the areas to the rear of the low energy beaches, supratidal levee sediments were deposited. The laterally discontinous grainstone laminae in these reflect rare inundation by spring, or storm tides. Migration of the channels produced the characteristic fining upwards sequences described in Section 4.4.2.2. These interfingered with the coarsening upwards sequences produced by the low energy beaches.

The predominance of combined sequences, where low energy
beach deposits are reworked by tidal channel deposits implies that the dominant control on patterns of sedimentation was progradation of the entire tidal flat area. Most low energy beaches would be situated on the barrierward edges of the tidal flats and thus would be overlain and reworked by the tidal channels during progradation. The rare occurrence of complete regressive tidal channel, or low energy beach sequences (see Fig. 4.42, i and ii) implies that there was a constantly rising sea level.

The sources of the oncoids found in the tidal channel and low energy beach sequences were shallow subtidal areas close to the tidal channels, but open to constant, moderate currents. Thus they would have been concentrated on the barrierwards edges of the tidal flats, but were also prevalent at the rearwards edges near the openings of the rare barrier complex channels (Section 4.7).

The conditions necessary for oncoid formation closely mirror those required for the deposition of the low energy beach sequences. These are, constant moderate currents away from wave surge and low rates of sedimentation. These conditions were created by the wide, shallow areas of the shoal/barrier complex itself.

Vertical sequences produced by tidal flat progradation commonly show an overall fining upwards motif developed on a 10m to 30m scale. Interruptions of these sequences by coarser sediment input is related to the migration of openings, or channels through the barrier complex. These barrier complex channels were the main conduits for wave and tidal currents and storm surge from the offshore barrier areas to the back-barrier
areas. They were responsible for the development of high energy facies containing a mixture of marginal back barrier peloid sands with shoal/barrier oolitic aggregate and bioclastic sediment. In places abandonment facies of the tidal flat environments were developed e.g. micrites with rhizolith, capping complete tidal channel sequences, or bioturbated surfaces (Fig.4.36, Pwll Du Head, 45m). These were overlain by transgressive higher energy facies related to migration of the barrier complex channels.

Overall the back-barrier areas were characterised by a mosaic of tidal flat environments in a shallow subtidal peloid sand. Processes on the tidal flats including tidal channel migration and beach sequence aggradation produced the small scale (20cm to 2m) sequences seen in vertical section. Evolution of the tidal flat areas and migration of barrier complex channels created facies changes on a larger scale (5m to 25m). Progradation of the entire shoal/barrier complex resulted in the even larger scale sequences, where the marginal back barrier sequences overlie those of the shoal/barrier complex.

4.5 SUMMARY OF LITHOFACIES SCHEMES - PALAEOGEOGRAPHIC EVOLUTION

Immediately prior to the Holkerian, the Arundian shelf in Gower was covered by a widespread crinoidal sheet sand (the High Tor Limestone). This did not become emergent during the Arundian/Holkerian transition.

The start of Holkerian deposition coincided with a rapid rise in sea level. The response of sedimentation to this was controlled by the slope of the existing ramp morphology of the shelf (Fig.4.47,A). In the more onshore areas of the Gower part of the South Wales Shelf, initiation of active ooid shoals was controlled by broad re-entrants. These concentrated wave and tidal current flow creating a localised agitated environment
FIG. 4.47 EVOLUTION OF HOLKERIAN PALAEOGEOGRAPHIES IN GOWER.

A. Early Holkerian

Early Holkerian (Arundian) component stratigraphy of Hunt's Bay oolite formation controlled by lateral migration of shoal barrier complex's ragged offshore margin.

B. Mid Holkerian

Mid Holkerian (compoloy Nr SrPaolphy) of Hunt's Day core formation controlled by lateral migration of shoal barrier complex's ragged offshore margin.

C. Late Holkerian

Late Holkerian (rack-barrier complex) established - progrades over shoal/barrier complex.

Key:
- Oolitic barrier lithofacies association
- Bioclastic lime + oolite lithofacies
- Open shelf lithofacies association
suitable for ooid formation. Rapid early cementation and redistribution resulted in the widespread development of the Oolitic Aggregate Lithofacies. Further offshore, the initial high rates of transgression outstripped rates of sedimentation. This resulted in the reduced rates of deposition which created the Limestone/Shale Lithofacies of the Overton Cliff Formation.

By the Mid-Holkerian the ooid shoal/barrier complex had become established. The three dimensional morphology of these oolitic sequences implies that, overall, the complex was prograding. The internal stratigraphy was controlled by lateral migration of the offshore edge of the barrier complex. This occurred on two scales (Fig.4.47,B). On a smaller scale, the ragged edge of the barrier complex resulted in meter scale intercalations of fine grained bioclastics within the oolitic sequences. On a larger scale, broad re-entrants resulted in Decameter scale intercalations of two adjacent Lithofacies; the Bioclastic Limestone Plus Oolite and the Oolitic Aggregate Lithofacies.

Once the ooid shoal/barrier complex was prograding, it provided sheltered areas to its rear where a variety of subtidal, intertidal and supratidal facies were developed. These marginal back barrier sequences were deposited above those of the shoal/barrier complex as the complex prograded. Thus the marginal back barrier environments became widespread in Gower. During the Late Holkerian, shoal/barrier progradation continued southwards and a rimmed shelf profile was established. This resulted in a palaeogeography where a mosaic of subtidal/intertidal and supratidal flats occurred within a widespread subtidal peloid sand. All of the Gower sequences became dominated by the Marginal Back Barrier Lithofacies.
4.6 TRANS - BARRIER COMPLEX CHANNELS

At Mumbles Head (SS 631873) Fig.4.48, an approximately 50m wide channel feature, with a variety of channel fill episodes, cuts down into peloidal, oolitic packstone and grainstone lithologies (Marginal Back Barrier Lithofacies Association - Stormy Limestone Formation).

The channel sequence occurs 20m below the top of the Stormy Limestone Formation (Fig.4.48). It is overlain by lithologies characteristic of the Micritic and Cryptalgal Lithofacies Association.

The underlying peloidal, oolitic packstone and grainstone lithologies (Pel-Bio Limestone Lithofacies - Bed 1, Fig.4.48) contain large scale planar foresets. At the eastern end of the channel a gastropod, Composita, productid coquina (Bed 2) overlies Bed 1. These underlying beds were subsequently eroded and the channel feature initiated. Bed 2 appears to have been more resilient than Bed 1 and forms a channel edge. The channel was then infilled by the first beds of the channel sequence (Beds 3 and 4).

These are peloidal, bioclastic packstone and grainstone lithologies (Pel-Bio Limestone Lithofacies) which were deposited synchronously. Evidence for this is seen in their overlapping edges (see left hand side of Photo. in Fig.4.48). They also contain large, boulder size, intraclasts of Oolitic Aggregate Lithofacies and of the underlying peloidal, oolitic packstone and grainstone lithologies. These are interpreted to be undercut, lithified channel edges which have subsequently been incorporated into the channel fill. The presence of the Oolitic Aggregate Lithofacies intraclasts lends weight to the interpretation that these channels cut across the shoal/barrier complex.
Fig 4.48 TRANS-BARRIER COMPLEX CHANNEL SEQUENCE AT MUMBLES HEAD
(SS. 63058728)

SEE TEXT FOR DESCRIPTION
OF NUMBERED BEDS

LOCATION MAP

Photo. DETAIL OF CHANNEL FILL (SEE ABOVE LINE DRAWING).

BOULDER SIZE OOLITIC INTRACLASTS IN OVERLAPPING BEDS 3 & 4

STORMY LIMESTONE FORMATION

MUMBLES HEAD

OXWICH HEAD

LIMESTONE (ASBIAN)

CORNELLY OOLITE FORMATION

HOLKERIAN

CHANNEL SEQUENCE
After this initial channel scour and infill, a thin (50cm) layer of fine grained, well sorted peloidal packstones and grainstones was deposited (Bed 5). Then a second major erosive event occurred, cutting down through Beds 3, 4 and 5. This was infilled by coarse ooidal, peloidal grainstones with large tabular foresets (Bed 6). These are interpreted to be the result of bar migration across the channel after the second erosive episode.

By this time the channel was less of a marked feature and although Bed 8 cuts down on Beds 7, 5 and 6 the depth of erosion is less than 50cm. Both Beds 7 and 8 are fine grained, well sorted peloidal, ooidal packstones and grainstones. After deposition of Bed 8, the channel feature was abandoned, or had migrated. There is a sharp facies change to a thin (less than 20cm) micrite (Micritic and Cryptalgal Lithofacies).

The channel sequence at Mumbles Head is unique within the study area. Its large scale and its smaller width to depth ratio (average 20:1) contrasts with the tidal inlet/channel deposits (see Section 4.4.3 for description). The occurrence of oolitic aggregate grain intraclasts suggests that it probably traversed the shoal/barrier complex.

These trans shoal/barrier complex channels would have provided a pathway for storm surge currents to cut across the oolitic barrier into the marginal back barrier and back barrier lagoon areas. This would have introduced oolitic barrier sediment into the back barrier lagoon as washover lobes. Subsequently, during fair weather the channels would have acted as conduits for tidal currents. Thus the initial washover sediments could then be reworked.
The Oolitic Aggregate/Intraclast Lithofacies (Back Barrier Lagoon Lithofacies - Dowlais Limestone Formation) has been interpreted to represent these oolitic washovers (Section 5.3.2). A number of lithological sequences have also been documented and interpreted to represent a variety of reworking environments developed on the oolitic washovers.

The presence of these trans barrier complex channels would also have had an effect on sediment supply and hydrodynamic energy conditions in the marginal back barrier areas. Migration of the barrier complex channels could account for sudden environmental changes in the marginal back barrier areas.

At Three Cliffs Bay (Fig. 4.36, 45m) there is an example of a sharp change in depositional environment. A micritic lithology (Micritic and Cryptalgal Lithofacies) is erosively overlain by coarse peloidal packstone and grainstone lithologies (Pel-Bio Limestone Lithofacies) Fig. 4.49.
Limestone Lithofacies. Scoured overhang with lag of coarse bioclastic material implies transgression and high energy erosion of tidal flat micrite, related to migration of trans barrier complex channel. Stormy Limestone Formation, Three Cliffs Bay.

Similarly changes to higher energy conditions reflected in sharp grain size changes are documented within the Pel-Bio Limestone Lithofacies (Fig. 4.50)

Fig. 4.50 Sharp contact between a fine grained peloidal lithology and a coarser grained, ooidal and bioclastic peloidal lithology, both of the Pel-Bio Limestone Lithofacies. This illustrates the wide variety of grain types and sizes within this lithofacies. The sharp junction represents a change to higher energy conditions related to migration of a trans barrier complex channel. Pwll Du Member, Hunt's Bay.

Alternatively a decrease in sedimentation rate may be related to migration of a barrier complex channel away from a given area. This might explain depositional hiatus' marked by heavily bioturbated horizons (Fig. 4.51).

Similar features to the Holkerian trans barrier complex channels exist in the central parts of the Great Pearl Bank Barrier, Trucial Coast (Purser and Evans 1973). These allow barrier sands, both ooidal and skeletal, to to be swept across
the barrier by wave and tidal currents into the back-barrier areas.

Fig 5.51 Fine grained peloidal lithology of the Pel-Bio Limestone Lithofacies (light grey) is bioturbated by a Thallasinoides burrow system. This is infilled by an overlying coarser bioclastic peloidal lithology (dark grey) of the Pel-Bio Limestone Lithofacies. The burrowed horizon represents an hiatus in deposition followed by a change to a higher energy depositional environment. This is related to trans barrier complex channel migration. Stormy Limestone Formation, Hunt's Bay

4.6 THE END OF HOLKERIAN DEPOSITION - THE HOLKERIAN/ASBIAN BOUNDARY

Throughout Gower the end of Holkerian marine sedimentation was marked by a widespread, subaerial exposure horizon and associated terrestrial deposition. This is represented in most areas by a karst facies although caliche facies is also represented.

At Port Eynon, the coastal exposures containing the top of the Holkerian section are buried by Recent beach sand. However, further inland there are some quarry exposures of the same
horizon approximately 200m WSW of the Youth Hostel (SS 467847). Here a prominent bedding plane overlies nodular caliche facies developed in a host lithology of peloidal packstone. The nodules consist of microspar and contain rhizoliths. There is no evidence for karst development. It may have existed, but was probably subsumed by caliche development.

At Three Cliffs Bay, approximately 15m north of the southern tip of Great Tor (SS 530876) a palaeokarstic surface is developed in peloidal packstones and grainstones with some crinoid debris. Steep sided troughs, average 5cm in diameter and 20cm deep contain a platy caliche facies development at their bases. This consists of a thin (less than 1cm) laminated red shale with rhizoliths. The karst topography is subsequently infilled with a coarse ooid grainstone (Fig. 4.52). This lithology accounts for the first two meters of the overlying Asbian sequence and is trough cross bedded.

Fig. 4.52 Palaeokarstic surface developed on top of the Stormy
Limestone Formation at Three Cliffs Bay. Troughs are lined with caliche facies deposits and infilled with the pale grey oolitic sediments of the overlying Oxwich Head Limestone.

At Pwll Du Head, the top of the Holkerian sequence is marked by a palaeokarst development on the coast near Graves End (SS 572863). This can be followed along strike into the cliffs of Pwll Du Head. This palaeokarst has a rounded irregular surface and is developed on fine grained peloidal packstones and grainstones (Fig. 4.53). It is overlain by 4m of coarser crinoidal bioclastics before the first Asbian subaerial exposure horizon is recorded. There is some evidence for caliche facies development in the underlying peloidal packstones and grainstones. Patches of microspar, or pseudospar contain rhizoliths which is preserved by partially haematised pyrite.

Fig. 4.53 Palaeokarstic surface developed on top of the Stormy Limestone Formation at Hunt's Bay. Mamilated trough and mound topography is seen in foreground and in cross section by the hammer head.

In contrast to the subaerial exposure horizons on the equivalent parts of the Holkerian shelf in Pembrokeshire, there
is a minimal development of caliche facies in Gower. This is probably due to erosion by marine reworking. In all examples in Gower, the end-Holkerian terrestrial deposits are followed by high energy marine bioclastic, or oolitic facies.

The abrupt nature of the transition from marine deposition to terrestrial deposition is similar to that recorded in Pembrokeshire. This implies that there was a drop in relative sea level which affected both these parts of the South Wales shelf at the end of the Holkerian. This feature is widespread throughout England and Wales (George et al 1976) and may be coincident with a mesothem boundary (Ramsbottom 1973). Its significance is discussed further in Chapter VII.
CHAPTER 5.
THE NORTH CROP
FIG. 5.1  DINANTIAN OUTCROP AND HOLKERIAN SECTIONS ALONG THE NORTH CROP
Table 5.1 **Summary Lithostratigraphic Description - The North Crop**

<table>
<thead>
<tr>
<th>Chronostrat.</th>
<th>Lithostrat.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Namurian</td>
<td>Millstone Grit</td>
<td>= Quartz sands, silts and conglomerates with occasional clasts of Dowlais Limestone Formation at base.</td>
</tr>
<tr>
<td>Asbian</td>
<td>Penderyn Oolite</td>
<td>= Coarse oolitic and bioclastic limestones.</td>
</tr>
<tr>
<td>Asbian</td>
<td>Greenhall Limestone</td>
<td>= Light grey, coarse peloidal and bioclastic limestones with minor oolitic limestones.</td>
</tr>
<tr>
<td>Asbian</td>
<td>Pendine Oolite</td>
<td>= Coarse oolitic and bioclastic limestones.</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Dowlais Limestone</td>
<td>= Pontsticill Member: Micritic Formation intraclast/peloidal limestones, micritic/cryptalgal litho-facies Heterolith comprising and oolitic aggregate/intraclast lithofacies)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>several lithofacies including: dark pel-bio limestones, Carbonaceous shale, Simple Ooid, Micritic and Cryptalgal, Sandy Limestone and oolitic aggregate /intraclast lithofacies.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= Cyl-Yr-Ychen Member: Dominantly thick bedded dark pel-bio limestones and carbonaceous shales)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= Penyffilt Member: dark pel-bio limestones interspersed with lighter oolitic sequences fining up to cryptalgal limestones and micrites. Some sandy limestones)</td>
</tr>
<tr>
<td></td>
<td>Chadian Pendine Conglomerate</td>
<td>= Limestones with yellow clays, karstic horizons + associated pedogenic features</td>
</tr>
<tr>
<td></td>
<td>Arundian Llanelly Formation</td>
<td>= (Gilwern Clay Member: red and green clays overlain by seatearth with coal development)</td>
</tr>
<tr>
<td></td>
<td>Courceyan Lower Limestone Shales</td>
<td>= Dark carbonaceous shales overlain by buff/fawn weathering neomorphosed limestone, grey shale with nodules</td>
</tr>
</tbody>
</table>
5.1 INTRODUCTION

Holkerian age rocks crop out on the northern edges of the South Wales Coalfield and the Pembrokeshire Coalfield. Collectively these outcrops are referred to as the North Crop (Fig. 5.1). The Holkerian sequences are in excess of 90m thick over most of the area, but thin to a feather edge at the western end of the outcrop, near Haverfordwest. At Cwm Quarries, near Gilwern in the east, Namurian overstep reduces the thickness of the Holkerian sequence to less than 60m.

The Holkerian sequences are represented entirely by the Dowlais Limestone Formation (Section 2.1). This is split into three members; the Penwyllt Member, the Cyl Yr Ychen Member and the Pontsticill Member (Figs. 5.2 and 5.3). The Dowlais Limestone Formation contains lithofacies characteristic of the heterolithic Back Barrier Lagoon Lithofacies Association. These lithofacies are described below.

This heterolithic sequence was created by a complex mosaic of environments formed in a protected area shorewards of the barrier sequences described in Sections 3.3 and 4.3. Intra-back barrier lagoon processes created one characteristic set of lithofacies. These include the Dark Pel-Bio Limestone Lithofacies, the Carbonaceous Shale Lithofacies, the Simple Ooid Lithofacies and the Micritic and Cryptalgal Lithofacies. They are described in Section 5.2 as autochthonous. The introduction of sediments with an origin external to the back-barrier lagoon created a separate set of lithofacies. These include the Sandy Limestone Lithofacies and the Oolitic Aggregate/Intraclast Lithofacies. They are described in Section 5.3 and are referred to as allochthonous.
FIG. 5.2  LOGS OF HOLKERIAN SECTIONS AT
PENDINE SANDS AND CYL YR YCHEN QUARRIES

Key:

- VERY CARBONACEOUS PERIDIAL LITHOFACE
- LESS CARBONACEOUS PERIDIAL LITHOFACE
- SIMPLE GOOD LITHOFACE
- CARBONACEOUS SHALE LITHOFACE
- CORALS
- OOLITIC Aggregate
- MICRITIC LITHOFACE
- MICRITIC INTRALAST LITHOFACE
- SHELLY DEBRIS
- PROMINENT CROSS-BEDDING
- BIOFABRICATION
- VUGGY MICROFAVE
- RHIZOLITHS

PENDINE

LITHOSTRAT.

Greenhall Limestone

Pontsticill Member

Cyl Yr Ychen Mbr.

Penwyllt Member

Dowlais Limestone Formation

UP TURNED CORRID LITHOSTRAT. (FIG. 5.1)

PENDINE CONGLOMERATE

LITHOSTRAT.

Greenhall Limestone

Pontsticill Member

Cyl Yr Ychen Member

Penwyllt Member

Lower Limestone Shales
FIG. 5.3 LOGS OF HOLKERIAN SECTIONS AT PENWYLLT QUARRY AND TWYNAU GWYNION QUARRY

Key: see fig. 5.2
5.2 **LITHOFACIES ASSOCIATION D: Back Barrier Lagoon**

(a) Autocthonous Lithofacies

These lithofacies were all formed by processes acting in the back barrier lagoon area. They represent the lagoonal background sediments which formed in a mosaic of environments. The many lateral and vertical lithofacies transitions within the Dowlais Limestone Formation (see Figs.5.2 and 5.3) are characteristic of a facies mosaic (Laporte 1967). The lithofacies are described and interpreted below.

5.2.1 **Dark Pel-Bio Limestone Lithofacies**

5.2.1.1 Description and Distribution

This Lithofacies comprises generally thick bedded (dm/m) peloidal/bioclastic packstones and grainstones and these are the most common lithologies within the Dowlais Limestone Formation. Most of these lithologies are very carbonaceous. In extreme cases the limestones appear black and are interspersed with carbonaceous shale partings. The origins of these carbonaceous shales are discussed in Section 5.2.2. Less carbonaceous lithologies show a marked similarity to the Pel-Bio Limestone Lithofacies of the Marginal Back Barrier Lithofacies Association described in Chapters 3, 4 and 6.

The very carbonaceous lithologies dominate the Cyl Yr Ychen Member and occur sporadically in the Penwyllt and Pontsticill Members (Figs.5.2 and 5.3). The less carbonaceous lithologies are more common in the Ponsticill and Penwyllt Members.

In thin section the very carbonaceous lithologies are dominated by peloids between 100 microns and 500 microns in diameter (Fig.5.4). Most of the peloids are well rounded, micritic grains and are probably faecal pellets. Others by comparison with partially micritised allochoems, were probably
intraclasts, or bioclasts which became micritised by endolithic algae. In some cases bioclasts are a common component (Fig. 5.5, Spec. 309). These may include foraminifera, echinoderm fragments, algal debris and a replaced aragonitic gastropod fauna.

Finely disseminated carbonaceous material and pyrite combine to make some peloids almost opaque. This contributes to the very dark appearance of these lithologies in the field. Packstone textures dominate, although in most cases the interstitial micrite has been neomorphosed to a neomorphic spar.

The less carbonaceous lithologies often contain micritic intraclasts and may become oolitic. They also contain large productids and are commonly associated with the Micritic and Cryptalgal Lithofacies as in the Marginal Back Barrier Lithofacies Association sequences of the South Crop (Chapters 3, 4 and 6).
5.2.1.2 Sedimentary Structures

Preservation of sedimentary structures within the very carbonaceous lithologies of the Pel-Bio Limestone Lithofacies is rare. Large scale trough cross bedding, or large planar foresets are not recorded. However, coquinas of almost monospecific shelly debris (gastropods, or brachiopods) are sometimes found within the dm/m thick beds. These are frequently abruptly disrupted and the component shelly debris redistributed throughout the bed (Fig.5.6). The paucity of preserved sedimentary structures, the peloidal nature of the sediment and the redistributed shelly lags are all features which suggest thorough bioturbation of the very carbonaceous lithologies.

In one rare example, large ceriod Lithostrotion colonies are recorded in a convex-down position (Fig.5.7). Other Lithostrotion colonies, both fasciculate and cerioid, are recorded from the same horizon in unstable orientations. It seems that these large
The North Crop 216

colonies were disturbed by a high energy event, probably a storm.

Fig. 5.6 Dark Pel-Bio Limestone Lithofacies. Coquina of Composita valves disrupted and redistributed by bioturbation (next to ruler). Pendine. Penwyllt Mnr. 34 m.

Fig. 5.7 Cerioid Lithostrotion colonies in convex down position due to storm event. Pendine. Penwyllt Mnr. 4.5 m.
Thus the record of sedimentary structures suggests that the very carbonaceous lithofacies were mostly unaffected by high energy currents. Thorough bioturbation combined with the fine grained nature of the sediment has produced the largely structureless beds characteristic of the lithology.

The less carbonaceous lithologies are also heavily bioturbated. However, they represent slightly higher energy conditions of deposition as they contain rare examples of small scale trough cross bedding (sets less than 10cm thick).

5.2.1.3 Interpretation

The Dark Pel-Bio Limestone Lithofacies is interpreted to be part of a widespread back-barrier subtidal sand facies. The less carbonaceous end member is equivalent to those environments found near the trailing edge of the prograding shoal/barrier complex (see Section 4.4.4). The more carbonaceous lithologies represent hydrodynamically restricted environments which interfingered with the intertidal to swamp conditions represented by the carbonaceous shales (see Section 5.2.2.3).

5.2.2 Carbonaceous Shale Lithofacies

5.2.2.1 Introduction

Carbonaceous shaly partings are recorded from many parts of the Dowlais Limestone Formation, although they are most common in the Cyl Yr Yochen Member. They occur on a variety of scales, from mm to dm thickness. Similar features in the Stormy Limestone Formation on the South Crop have been interpreted as tidal channel overbank deposits (see Section 3.4.3.3).

On the North Crop, the carbonaceous shaly partings are often associated with the very carbonaceous lithologies of the Pel-Bio Limestone Lithofacies. These lithologies account for most facies transitions, but there are also a variety of other lithological
transitions, diagenetic features and fauna recorded. These suggest a variable history of formation for the partings, but most features are consistent with a very shallow subtidal to emergent interpretation of depositional environment.

5.2.2.2 Description and Interpretation

The Carbonaceous Shale Lithofacies contains three characteristic lithologies. These include; discreet shales with gradational bases and sharp tops, stylolitised anastamosing horizons with gradational bases/tops and thin shales which overlie "scalloped" erosion surfaces, or cryptalgal mound/encrusted surfaces.

The discreet shales with gradational bases are most frequently bounded by the very carbonaceous peloidal limestones of the Dark Pel-Bio Limestone Lithofacies (Fig.5.8). In general they are laterally continuous, but some examples do exhibit lateral discontinuities.
Pel-Bio Limestone Lithofacies with a gradational contact. Rhizolith (R) penetrates from base of shale into underlying peloidal lithology. Carbonaceous shale contains autochthonous marine brachiopod fauna. Polished slab vertical scale is 15cm. Specimen 280, Pendine. Penryhn Mbr. 3m

In thin section, the shales contain small (less than 200 micron) bioclastic fragments in a neomorphosed micritic matrix (Fig.5.9). This contains opaque carbon and finely disseminated pyrite. Anastamosing microstylolites concentrate opaque insoluble material and contribute to the friable nature of the shales.

Occasionally, the shales contain an in situ fauna of brachiopods (Fig.5.10). This contrasts with the fauna of the peloidal limestones which generally forms allochthonous coquinas. More frequently though, the shales contain scattered coral and brachiopod debris. Dismembered corallites of Syringopora and fasiculate Lithostrotion have been flattened by burial compaction within the shales (Fig.5.11).
Fig. 5.10 Autochthonous marine brachiopods in Carbonaceous Shale Lithofacies. Pendine Penygylt Mr. 3m

Fig. 5.11 Carbonaceous Shale Lithofacies with a crushed fauna of fasiculate Lithostrotion and Syringopora corallites with brachiopods. An allochthonous fauna characteristic of some carbonaceous shaly partings. Pendine. Penygylt Mr. 34.5m

In rare cases, rhizoliths have been detected within the
shales, on their basal surfaces and penetrating the underlying lithologies (Fig.5.8). This is a reliable indicator of subaerial exposure (Esteban and Klappa 1983). Thus some shale horizons have undergone periods of both subaerial exposure and marine submergence.

Although the discreet shales were primary sedimentary features, they have subsequently been subjected to a variety of tectonic modifications. These range from microstylolitisation (Fig.5.9) to formation of slickencrysts during Variscan folding events and associated flexural slip (Fig.5.12).
these slickencrysts can create a layered effect due to sandwishing of the carbonaceous shale which may be confused with laminar calcrete development (Fig. 5.22). Cyl. X Xhen Quarry, Penmygill Hbr.

In contrast some shaly horizons in the Dowlais Limestone Formation have been formed almost entirely by pressure solution effects. Carbonaceous material is concentrated along anastamosing pressure solution seams (Fig. 5.13). These are gradational with the surrounding carbonaceous limestones which have probably contributed the insoluble residue. The shaly horizons do not contain any primary sedimentary features e.g. fauna, bioturbation, rhizoliths etc. to distinguish them from the surrounding limestones. Thus they appear to be pressure solution artefacts.

Fig. 5.13 Anastamosing pressure solution seams produce concentrations of carbonaceous material from the surrounding Dark Pel-Bio Limestone Lithofacies. These artefacts contrast with the primary sedimentary origin of other examples of the Carbonaceous Shale Lithofacies. Pendine

Occasionally, thin carbonaceous shales overlie irregular surfaces (Fig. 5.14). These have a trough and mound topography
which sometimes overlies and truncates tidal flat deposits of the Micritic and Cryptalgal Lithofacies (Fig.5.15). Apart from their mamillated topography, they show no other features typically associated with karst development e.g. caves, leached fossils, or vadose silts. However some of these surfaces are encrusted by Chaetetes (Fig.5.16), corals and coated by a variety of cryptalgal structures.

Fig.5.14 Irregular trough and mound topography underlies thin carbonaceous shale parting. This feature is characteristic of many examples of the Carbonaceous Shale Lithofacies in the eastern parts of the North Crop. They are interpreted as intertidal erosion surfaces. Twynau Gwynion.

The most common encrusters are Chaetetes and Syringopora. These suggest that a period of subtidal conditions existed during the depositional history of the surfaces. In rare examples the surfaces have been coated by discreet cryptalgal structures.
Fig. 5.15 Irregular trough and mound topography underlying carbonaceous shale development. The irregular surface cuts down through a micrite - by notebook (Micritic and Cryptalgal Lithofacies). Erosion of underlying intertidal deposits is one criteria used in the recognition of intertidal erosion surfaces. (The dark brown stain is a superficial feature caused by water seepage). Penwyllt Quarry.

Fig. 5.16 Irregular surface underlying carbonaceous shale is formed by encrustation by Chaetetes (centre of photo.) corals and cryptalgal structures (Twynau Gwynion).
FIG. 5.17  SKETCH OF THIN SECTION 268, PENDINE SANDS (7.4m).

COMPLEX CRYP~ALGAL STRUCTURE COATING SURFACE OF CARBONACEOUS SHALE
Fig. 5.17 shows an example of a compound type of cryptalgal structure with a SS-C/LLH-C to SH-V morphology. This compound structure suggests a change in environment of deposition from agitated subtidal/low intertidal to attached intertidal (Logan et al. 1964).

Additional evidence for environmental change is recorded from the alternation of fibrous calcite laminae with porostromate algal laminae in oncolites. One of these was collected from a carbonaceous shale horizon near the base of the Penwyllt Member at Pendine (Figs. 5.17 and 5.18). The fibrous calcite laminae exhibit features such as undulose bush extinction, twin lamellae with concave curvature away from substrate, inclusion patterns, which both parallel substrate and radiate away from it, and brownish pseudopleiochroism. These features are typical of fasicular optic calcite (Kendall 1977). Some parts of the laminae also exhibit dissolution features e.g. replacement by drusy void filling non-ferroan calcite. The fibrous calcite laminae also appear to be primary as they have sharp contacts with the surrounding algal laminae and are encrusted by vermiform gastropods.

These features are very similar to algal-aragonite pisoids described from the underlying Llanely Formation at Blaen Onneu (Wright 1981). The Blaen Onneu pisoids were interpreted to have been formed in a schizohaline environment. Periods of hypersalinity produced acicular aragonitic crusts and alternated with more normal marine conditions when porostromate algae grew and vermiform gastropods attached themselves to the structure. Periods of low salinity resulted in partial dissolution of the aragonitic layers (Wright 1981).

A similar interpretation can be applied to the compound
cryptalgal structure shown in Fig. 5.17. Only two major laminae of fibrous calcite are recorded, one coats the initial nucleus (?a vermiform gastropod) and the other coats the external surface of the cryptalgal structure. Both coats are laterally discontinuous, but this is also a characteristic feature of the Blaen Onneu pisoids (Wright 1981).

Recent vermetid gastropods have been recorded living in saline to brackish conditions (25 p.p.thou. to 37 p.p.thou. Shier, 1969). There is evidence that Dinantian vermetid gastropods were also euryhaline (Burchette and Riding 1977). Thus both the original nucleus of the cryptalgal structure and the intermediate vermetid encrusters could have withstood a wide range of salinities.

The nucleus was initially subjected to hypersaline conditions and was coated with an acicular aragonitic crust. Normal marine conditions then returned to allow growth of the porostromate algae. These were probably initially in agitated shallow subtidal or intertidal conditions to create the SS-C structure. Stabilisation of the structure then occurred and SH-V type growth followed which attached the structure to the substrate. Subsequently hypersaline conditions returned to allow a second generation of acicular aragonite to coat the cryptalgal structure. This did not last long as undersaturated (?meteoric) conditions caused partial dissolution of the aragonitic laminae. Subsequently carbonaceous shale/pack/wackestone deposition buried the encrusted/coated surface.

5.2.2.3 Summary

Of the three main types of carbonaceous shaly parting, the stylolitised anastamosing horizons with gradational bases and
tops are pressure solution artefacts. They do not represent primary sedimentary features, but do highlight the extremely carbonaceous nature of the bounding lithologies of the Pel-Bio Limestone Lithofacies.

The two other types of carbonaceous shaly parting contain a variety of features which represent either shallow subtidal, intertidal, or supratidal depositional environments. Some carbonaceous shaly partings may preserve several features representing a complex depositional history involving a variety of environments. In other cases only a single depositional environment is represented.

The shallow subtidal environment is represented by the in situ marine fauna such as corals, brachiopods and Chaetetes. Similarly the presence of SS-C type cryptalgal structures implies an agitated subtidal environment with low rates of sedimentation (Chapter IV Section 4.4.3.3). Encrustation by Chaetetes probably indicates a lithified substrate which would support the inference about low rates of sedimentation. However no evidence of boring, or isopachous fringing cements has been recorded in the surfaces below.

The intertidal environment is represented by the presence of compound cryptalgal structures (c.f. Fig.5.17). SH-V type structures are characteristic of the intertidal zone. The individual hemispheroids are maintained by the prevention of algal growth between them. This is due to several factors including prolonged wetting by tidal, or splash water and mechanical scouring during runoff (Logan et al 1964). Another feature characteristic of the intertidal environment is the irregular surfaces which overly and truncate tidal flat deposits. These have many features in common with Ordovician scalloped
erosion surfaces which are interpreted to have had an intertidal origin (Read and Grover 1977). These include their stratigraphic position above peritidal deposits, but below subtidal marine deposits, local encrustation and absence of vadose features. The presence of more acid rainwater in intertidal areas and daily pH fluctuations due to local photosynthetic activity increases rates of intertidal erosion compared with inland erosion of limestones (Sweeting 1972). Recent analogs of these intertidal erosion surfaces have also been documented (Emery 1946 and Hodgkin 1964).

Supratidal environments are interpreted from some of the features of the rare compound cryptalgal structures (Fig.5.17 and Section 5.2.2.2). The presence of fasicular opitic calcite laminae suggests that the original mineralogy of the laminae was acicular aragonite (Kendall and Tucker 1973, Kendall 1977 and Mazullo 1980). The aragonite laminae are similar to aragonitic crusts which are forming in Recent hypersaline environments (Lucia 1968 and Purser and Loreau 1973). The presence of these hypersaline conditions for the Holkerian carbonaceous shaly partings is inferred from the presence of the fasicular opitic calcite laminae. These environments were probably created by evaporation of ponded supratidal seawater.

Evidence for early dissolution of the aragonite laminae and replacement by void filling drusy calcite cement implies that the complex cryptalgal structures also existed in undersaturated (?meteoric) waters. This rapid alternation of salinities could easily occur in a ponded supratidal environment where evaporation was followed by rainwater dilution.

The highly organic-rich nature of the carbonaceous shaly partings combined with the presence of rare rhizoliths imply
periods of subaerial exposure and plant-growth. This subaerially exposed surface was occasionally submerged in varying depths and salinities of water. This provided a restricted swamp-like environment within which the variety of subtidal, intertidal and supratidal features described and interpreted above could be formed. The schizohaline nature of the environment was controlled by variable runoff from the low lying areas to the north. Recent mangrove swamps in Florida Bay produce a similar mixed deposit of dark fibrous peat, lime mud and shells either widely dispersed, or concentrated in lenses (Enos and Perkins 1979).

Most carbonaceous shaly partings in the Dowlais Limestone Formation are interpreted to represent restricted intertidal to swamp environments marginal to an Holkerian palaeoshoreline.

5.2.3 Simple Ooid Lithofacies

5.2.3.1 Description

Within the Back Barrier Lagoon Lithofacies Association there are rare oolitic beds which are dominated by single, simple ooids. This lithofacies is confined to the Penwyllt Member in the eastern part of the North Crop. It becomes more widespread in the western part of the North Crop, occurring both in the Penwyllt and Pontsticill Members (Figs.5.2 and 5.3).

The sequences containing these ooids are generally less than 1m thick and commonly have gradational contacts with surrounding lithofacies. They are most frequently found overlying Oolitic Aggregate/Intraclast Lithofacies sequences, but they also overlie the Carbonaceous Shale Lithofacies and Micritic and Cryptalgal Lithofacies. Transitions to overlying lithofacies are mostly accounted for by the more carbonaceous lithologies of the Pel-Bio Limestone Lithofacies. Sedimentary structures are rarely observed, but trough cross bedding and reactivation surfaces on
foreset laminae have been recorded.

In thin section (Fig. 5.19) the most common textures are neomorphosed packstones, or grainstones and the dominant allochem is the single, simple ooid (Fig. 5.20, A). The ooids range in size from 200 microns to 500 microns and the most common cortical texture is concentric/radial (Fig. 5.20, B). These features are similar to those recorded for the Simple Ooid Lithofacies described from the South Crop (Section 4.3.2.2). Overall there is a lack of bioclastic material and the facies is well sorted (Appendix One, Table 1.5.2).

Fig. 5.19 Partly neomorphosed simple ooid micritic grainstone. Note dominance of single, simple ooid allochems with twofold cortical structure; sparry central area and dark often irregular outer layer. See text for discussion. Field of view is 4.5mm. Photomicrograph - Thin Section 284, Pendine.

Many ooids have a twofold cortical structure consisting of a spherical, sparry central area within a dark, often irregular micritic outer area (Fig. 5.19). In the spar dominated central areas, micritic rays (less than 5 microns thick) define a radial
FIG. 5-20  POINT COUNT DATA STEREOPLOT
SIMPLE OOID LITHOFACIES - DOWLAIS LMST. FMTN.
SPEC. 284

A: LITHOFACIES

B: OOID TYPE
pattern with subordinate central rings. In the outer areas slightly thicker (less than 10 microns) micritic rings define a concentric pattern with subordinate radial rays. These outer areas are pigmented by very dark, almost opaque material, which in places is oxidised to a light tan colour. In some cases the outer areas show irregular growth forms, resembling "vadoids" of Peryt (1983).

5.2.3.2 Interpretation

The stratigraphic position of the lithofacies within the Dowlais Limestone Formation corresponds to an overall increase of oolitic sequences towards the west. This is related to the increase in hydrodynamic communication of the back barrier lagoon with the open shelf areas in that direction.

The structure of the ooids gives some clues to the hydrodynamic conditions affecting their growth. The concentric/radial cortical textures suggest that the ooids underwent a succession of growth and sleeping stages (Davies et al 1978). The twofold structure of the ooids, with a dominantly radial central portion and an outer micritic area reflects a twofold process of formation. Radial fabrics were formed when the ooids were small and in suspension and the micritic textures were formed when the ooids were large enough to be transported as bed load (Heller, Komar and Povear 1980). The eccentric nature of the outer laminae was formed during phases of quiet water growth alternating with erosion during transport (Gasiewicz 1984). This growth was associated with organic matter recognised by the presence of the oxidised, light tan material in these outer laminae (Burchette 1977).

The common association of the lithofacies with underlying Oolitic Aggregate/Intraclast Lithofacies sequences suggests that
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the two Lithofacies are related. The Oolitic Aggregate/Intraclast Lithofacies sequences are interpreted (Section 5.3.2.) as flood tidal delta deposits. Thus the simple ooids were generated on delta flanks in a similar manner to those recorded from Recent tidal deltas near Abu Dhabi on the Trucial Coast (Loreau and Purser 1973).

The less protected western parts of the back barrier lagoon provided an alternative setting for simple ooid formation. The lack of underlying Oolitic Aggregate/Intraclast Lithofacies sequences suggests that these ooid shoals did not develop on flood tidal delta deposits. Instead isolated aggradation in these western areas generated highs on which the simple ooid deposits found in the Penwyllt and Pontsticill Members of Pendine and Cyl Yr Ychen Quarry were generated (Fig.5.2). Further eastwards, during the Early Holkerian, similar isolated tidal sand bars generated the intra-lagoon simple ooids found in the Penwyllt Member at Penwyllt and Twynau Gwynion (Fig.5.3).

Recent oolitic tidal bars are found at the western end of the Khor al Bazm Lagoon on the Trucial Coast (Loreau and Purser 1973). These are similar to the environments postulated for the western end of the Dowlais back barrier lagoon. Recent Bahamanian platform sequences are less analogous to this situation. Most active ooid sand bodies are found at the shelf edge (Ball 1967, Hine 1977, Hine and Neumann 1977). However during the early Holocene transgression, intra-platform sand bodies were active in the Bahamas (Hine 1983). This is analogous to the situation in the eastern parts of the Dowlais back barrier lagoon, where simple ooids were being deposited during the early parts of the Holkerian. This is evidenced by the simple ooid facies preserved
in the Penwyllt Member of the eastern parts of the North Crop.

5.2.3.3 Summary

The simple ooid sequences are the deposits of back barrier lagoon processes. The ooids were initially formed in shallow agitated environments near sources of higher hydrodynamic energy relative to conditions prevailing in the rest of the back barrier lagoon. These include the flanks of flood tidal deltas, localised highs by the more open western parts of the back barrier lagoon and early Holkerian intra-lagoon oolitic sand bars in the eastern areas. Subsequent redeposition in quieter conditions led to the formation of irregular outer laminae and association of the sequences with the Micritic and Cryptagal Lithofacies.

5.2.4 Micritic and Cryptagal Lithofacies

5.2.3.1 Introduction

This lithofacies contains similar lithologies to the equivalent lithofacies described from the Marginal Back Barrier Lithofacies Associations of the South Crop (Chapters 3, 4 and 6). Three main lithologies are described below. These are "porcellanous" micrites with their various textural modifications, cryptagal laminates and oncolitic coquinas.

The lithofacies is restricted to the Penwyllt and Pontsticill Members and frequently forms the fine grained tops to sequences with grainy oolitic bases included in the Oolitic Aggregate/ Intraclast Lithofacies (Figs.5.2, 5.3 and Section 5.3.2). These are interpreted to be the result of aggradation on oolitic washover deposits (Section 5.3.2.5).

5.2.4.2 Description of Component Lithologies

Micrites:

Micritic lithologies are variations of the isotropic "porcellanous" micrite lithology described from the equivalent...
lithofacies on the South Crop (Section 3.4.3). Variations include intercalations of fine grained bioclastic laminae, 1cm to 5cm thick and fenestral fabrics. The latter comprise small spar-filled vugs, whose morphology ranges from mm thick tubules to rare cm sized irregular fabrics. Alternations of fenestral micrites with bioclastic laminae are shown in Fig. 5.21. The smaller, subvertical tubular fenestrae are occasionally associated with altered halos of sediment. These are interpreted to be root cast types of rhizolith (Klappa 1980).

Fig. 5.21 Alternations of fenestral micrites (light grey colour) with sharp based bioclastic grainstone laminae (darker grey colour). Tubular fenestrae are rhizoliths, irregular fenestrae were formed by the desiccation and shrinkage of mucilagenous
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algal mat in the middle to intertidal zone. Bioclastic laminae represent washover deposits on micritic tidal flats caused by high level storm tides. Pendine.

Near the base of the Pontsticill Member in the eastern part of the North Crop, a prominent pale micritic horizon (Fig.5.3, Twynau Gwynion, 66m) contains more evidence of caliche facies. This can be traced for several km from Morlais Quarry (SO 054097) to Llanelly Quarry (SO 223124). The feature contains a shallowing up sedimentary sequence which is overprinted by two main phases of caliche facies development within micrites (Fig.5.22).

In detail, the base of the sequence is formed by a carbonaceous peloidal lithology (part of the Pel-Bio Limestone Lithofacies) which fines up to a micrite. The latter forms one host sediment for caliche facies development. It is overlain by a second micritic lithology which forms the host sediment for a second phase of caliche facies development. This, in turn, is followed by a carbonaceous shale parting (Carbonaceous Shale Lithofacies) and a return to the Dark Pel-Bio Limestone Lithofacies.

Within the two micrites several important features indicative of subaerial exposure are present. Within the first micrite a vertical and horizontal radiating fracture pattern is developed (Fig.5.23). This is edged by a halo of darker (altered) host micrite. The fracture pattern is subsequently infilled by the overlying pale micrite and penetrated by a spar/geopetal sediment filled, tubular void system. This void system is associated with a small scale (less than 10 micron diameter) spar filled radial fissure system (Fig.5.24). Both these features are surrounded by a halo of altered fracture fill micrite. The micrite which overlies and infills this fractured surface contains a mottled fabric of glaebules in neomorphosed micrite.
FIG. 5.22 EXPOSURE HORIZON AT TWYNAU GWYNION QUARRY
66m, c.f. FIG. 5.3

DESCRIPTION
- Layered Graphite and Calcite
- Mottled Micrite with Glaebules and Aveular Texture
- Vertical and Radial Offshore Pattern Infilled with Overlying Pale Micrite
- Bioturbated (Zoophycos) Horizon

INTERPRETATION
- Calcite Veining Developed During Flexural Slip on Carbonaceous Shale Horizon
- Peritidal Micrite Subsequently Calichified
- Soil Cracks with Rhizolith (Root Cast) Centres
- Restricted Shallow Subtidal Environment
- Restricted Intertidal to Swamp Environment
Fig. 5.24 Detail of radiating fracture pattern shown in Figs. 5.22 and 5.23. Dark micrite infill of fracture (M) is penetrated by later spar filled radial fissure system (S). This alters the surrounding micrite to a darker colour. Field of view is 4.5mm. Photomicrograph - Thin Section 2094. Twynau Gwynion.

This sequence suggests at least two periods of subaerial exposure and subsequent overprinting of caliche facies textures. The vertical and horizontal radiating fracture pattern developed in the top of the first micrite represents a desiccation feature. The darker micrite edge to this fracture pattern was then formed by rhizoliths. Deposition of the second micrite partly infilled the fracture pattern and a nodular caliche facies (Esteban and Klappa 1983) was developed within it.

The significance of these complex caliche facies developments within the Micritic and Cryptalgal Lithofacies is considered in Section 5.2.4.3.

Cryptalgal Textures:

This group of lithologies contains a set of features associated with an algal origin. These include; planar laminae
with small scale disconformities, sparry calcite (and fluorite) filled fenestral textures, various types of stromatolitic, thrombolitic, or oncolitic structures, breccias consisting of fragments of the above textures and peloids in a dense, often dolomitic, micritic matrix. These features occur, either as isolated structures, or grouped together in sequences which reflect lowering or raising of relative sea-level.

An example of a deepening sequence is recorded within the Penwyllt Member at Twynau Gwynion Quarry (Fig.5.3, 33.5m to 34m). Stromatolites with an SH-C morphology are followed by oncolitic textures (Fig.5.25). This represents a change from low intertidal (SH-C) to shallow subtidal (SS-C) conditions (Logan, Rezak and Ginsburg 1964).

A shallowing sequence is recorded also in the Penwyllt Member at Penwllt Quarry (Fig.5.3, 26m to 26.5m). In a broad
sense, oncotic textures are overlain by cryptalgal laminates, but in detail the sequence is more complex (Figs. 5.26 and 5.27). A threefold division of cryptalgal structures overlies sediments of the Dark Pel-Bio Limestone Lithofacies. The first cryptalgal horizon is a pel-intra-oncolitic wackestone. Complex cryptalgal structures with an SS-C/LL-H to SH-V morphology have intraclast nuclei of fine to medium irregular fenestral texture. The second cryptalgal horizon contains thrombolitic textures (Aitken 1967). This also has a coarsely laminoid fenestral texture. These fenestrae have a hierarchy of infills starting with geopetal peloidal wackestone (a), followed by thrombolitic textures (b) and finally sparry calcite with late stage fluorite (c), (letter coding refers to Fig. 5.27). The third cryptalgal horizon is dominated by cryptalgal laminae defined by peloidal packstones and wackestones. This has subordinate, coarse irregular fenestral and thrombolitic textures. The top of this horizon (not shown in Fig. 5.27) is mudcracked and intraclasts of the cryptalgal textures are incorporated in the overlying Oolitic Aggregate/Intraclast Lithofacies. This complex set of cryptalgal structures reflects the variety of algal mat and hydrodynamic conditions which prevailed during the overall shallowing sequence (Logan, Rezak and Ginsburg 1964, Logan 1974, Logan, Hoffman and Gebelein 1974).

Oncolitic Coquinas:

At several horizons of the Micritic and Cryptalgal Lithofacies, within the Penwyllt and Pontsticill Members, there are examples of oncolitic coquinas (Figs. 5.2 and 5.3). These consist of almost monospecific coquinas (usually Composita) and micritic intraclasts. Both the brachiopods and the intraclasts are sometimes coated with laminae of porostromate algae. These
commonly form the bases to small scale (20cm to 100cm) fining upwards sequences. The upper parts of these sequences are formed of peloidal packstones and grainstones (Section 4.4.3.3).

Details of a group of repeated fining upwards sequences are figured (Fig.5.28) from the Pontsticill Member at Twynau Gwynion Quarry (Fig.5.3). In both scale and grain content, these sequences exhibit a marked similarity to the fining upwards oncolitic coquinas described from the Stormy Limestone Formation of Gower (Section 4.4.3.3). These were interpreted as stacked tidal channel/inlet sequences. The same interpretation applies to these North Crop examples.

FIG. 5-28  ONCOLITIC COQUINAS AND FINING UPWARDS SEQUENCES. (STACKED TIDAL INLET/CHANNEL SEQUENCES). Pontsticill Member, Micritic and Cryptalgal Lithofacies, Twynau Gwynion 73m (Back Barrier Lithofacies Association).
5.2.3.4 Interpretations

The lithologies and sequences found within the Micritic and Cryptalgal Lithofacies of the Dowlais Limestone Formation are interpreted to represent a variety of tidal flat environments. This is by analogy with the similar lithologies and sequences found in the Stormy Limestone Formation of Gower and Pembrokeshire (Sections 3.4.3 and 4.4.3.3).

The micritic lithogies are interpreted to represent intertidal to supratidal areas on muddy tidal flats. Evidence to support this is found in the associated root casts suggesting periods of subaerial exposure. The intercalations of sharp based graded bioclastic laminae are interpreted to be washover deposits formed during high level storm tides (Shinn 1983a, Section 3.4.3.2).

The coarse irregular fenestral fabrics were formed by algal mat activity. Thus they could also be described as cryptalgal textures and included under that heading. However they occur in micrites and are therefore described as a variation of that lithology. Desiccation and shrinkage of mucilagenous algal mat formed the large irregular voids which were subsequently infilled with spar (Logan 1974). At Shark Bay, Western Australia, the type of mat associated with this texture (gelatinous mat, Logan, Hoffman and Gebelein 1974) is found in protected pond-like depressions in the lower to middle intertidal zones of tidal flat areas.

The development of caliche facies in the micrite lithologies implies periods of subaerial exposure (Esteban and Klappa 1983). The prominent pale micritic horizon near the base of the Pontsticill Member in the eastern part of the North Crop represents several periods of subaerial exposure within only 30cm.
of sediment. This horizon represents a period of low sedimentation rates on a subaerially exposed tidal flat area. At equivalent horizons in the western parts of the North Crop deposits of the Simple Ooid Lithofacies and the Dark Pel-Bio Limestone Lithofacies represent normal rates of subtidal accumulation.

The above observation fits in with the observed distribution of the oncolitic coquina fining upwards sequences. These are most common within the Pontsticill Member of the eastern parts of the North Crop. Their interpretation as the deposits of tidal channel/inlet sequences (Section 4.4.3.3) implies that in the Late Holkerian, the eastern parts of the back barrier lagoon were dominated by low energy tidal flat environments. During the same period, in the western parts of the back barrier lagoon, higher energy conditions prevailed which controlled the deposition of the Simple Ooid Lithofacies (Section 5.2.3.2) and the less carbonaceous lithologies of the Dark Pel-Bio Limestone Lithofacies.

The cryptalgal textures are associated with the other lithologies of the Micritic and Cryptalgal Lithofacies throughout the Penwyllt and Pontsticill Members. They represent features formed in the shallow subtidal to intertidal zones of tidal flat areas. The shallowing and deepening sequences represent small scale oscillations in relative sea-level. These are controlled by variation in the relative rates of sediment accumulation on tidal flats and rates of eustatic sea-level rise, or fall. The scale of these sequences (10cm to 20cm) is much smaller than for most shallowing, or deepening sequences recorded in ancient tidal flat deposits, 1m to 10m (Aitken 1978, Fischer 1975). This reflects
the importance of small scale variations in relative rates of sea-level and sediment accumulation in tidal flat sequence formation. The evidence from Recent tidal flats supports this contention, in that growth of algal mats and formation of different cryptalgal structures is controlled by a variety of factors (sediment supply, exposure time, salinity, hydrodynamic conditions). However the overriding control on sequence formation is oscillation of relative sea-level (Logan, Hoffman and Gebelein 1974).

The overall distribution of the Micritic and Cryptalgal Lithofacies within the Dowlais Limestone Formation reflects the development of tidal flat environments in the Holkerian back barrier lagoon. During the Early Holkerian, tidal flats were distributed throughout the back barrier lagoon, but more were situated in the eastern areas. However, by the Late Holkerian, there was a marked increase of tidal flats in the eastern parts of the lagoon. Towards the western areas the lagoon became too deep for tidal flat deposition to occur. At the more open western end of the lagoon a complex of oolitic tidal sand bodies (Simple Ooid Lithofacies, Section 5.2.3) occasionally aggraded and accumulated tidal flat deposits on their protected leeward edges.

5.3.1 LITHOFACIES ASSOCIATION  D:Back Barrier Lagoon

(b) Allochthonous Lithofacies

The mosaic of lithofacies described in Section 5.2 was formed by aggradation of micritic tidal flats within a shallow subtidal peloid sand environment. Intertidal to swamp conditions characterised the Holkerian palaeoshoreline, whilst the overall control on back barrier lagoon hydrodynamics was the opening of the lagoon westwards. This influenced the position of oolitic sand bodies and associated tidal flat environments.
All these back-barrier lagoonal sediments were formed and reworked in situ. However, two other types of sediment were introduced into the back barrier lagoon from external sources. These were quartz sands from the land areas to the north and oolitic aggregates/micritic intraclasts from the oolitic shoal barrier complex and marginal back barrier areas to the south of the back barrier lagoon. These interacted with the prevailing back barrier processes to create characteristic environments and lithofacies.

5.3.1 Sandy Limestone Lithofacies

5.3.1.1 Introduction

This lithofacies occurs near the base of the Penwyllt Member, east of Careg Yr Ogof (Fig. 5.1). It consists mainly of fine to medium grade quartz sand, although pebble grade conglomerates are recorded at Careg Yr Ogof itself (SN 771216).

The quartz grains of the lithofacies are associated with two main calcareous lithologies. One consists mainly of peloidal and bioclastic grains, the other contains cryptalgal laminated micrites. In the former the sandy limestones form beds 10cm to 60cm thick. In the latter the quartz grains are distributed
within thin laminae. The two lithologies are described in more detail below.

5.3.1.2 Descriptions

Sandy Peloidal and Bioclastic Lithologies:

These lithologies are dominated by bioclastic, peloidal and quartz grains in packstone, or grainstone textures. Some grains have a thin oolitic coating with concentric/radial cortical textures. On this microfacies evidence alone, the lithologies are similar to the less carbonaceous lithologies of the Dark Pel-Bio Limestone Lithofacies (Section 5.2.1.1). However it is distinguished from that lithofacies by the presence of quartz grains.

The quartz grains, in most examples, are of fine to medium sand grade and are angular to subrounded (Fig.5.29). Quartz grains account for over 25% and up to 50% of counts in point counted samples (Fig.5.30 and Appendix One, Table 1.5.4). They often form the nuclei to ooids, which in common with the background calcareous grains, have concentric/radial cortical textures. At Penwyllt Quarry (SN 857161) ooids with quartz nuclei occur in 1m to 2m thick beds.

Other occurrences of non-oolitic Sandy Limestone Lithofacies include thin (5cm to 10cm) beds which are sometimes graded, but otherwise have been thoroughly bioturbated (Fig.5.31). Rare small scale trough cross bedding (10cm cosets) is recorded from the outcrops at Cefn Yr Ystrad (SO 179133). At Careg Yr Ogof these thin bedded developments underlie and overlie coarser pebble grade conglomerates. These form fining upwards sequences on a 50cm scale. The quartz clasts are dominated by white vein quartz and are aligned on the foresets of medium scale trough cross beds (25cm to 30cm, Fig.5.32).
Fig. 5.29 Peloidal and bioclastic lithology of Sandy Limestone Lithofacies. Fine to medium sand grade quartz grains are angular to subrounded. Some have oolitic coatings. Field of view is 4.5mm. Photomicrograph - Thin Section 2101 Cefn Yr Ystrad (SO 179133).

**Fig. 5.30** POINT COUNT DATA STEREOPLOT

SANDY LIMESTONE LITHOFACIES

DOWLAIS LIMESTONE FORMATION

LITHOFACIES
Fig. 5.31 Peloidal and bioclastic lithology of Sandy Limestone Lithofacies weathering to show extensive bioturbation. Cefn Yr Ystrad (SO 179133).

Fig. 5.32 Pebble grade clasts of white vein quartz on foresets of medium scale trough cross bedding. Peloidal and bioclastic lithology of Sandy Limestone Lithofacies. Careg Yr Ogof (SN 771216)
Sandy Micritic, Cryptalgal and Peloidal Lithologies:

In these lithologies silt grade to medium sand grade quartz grains are found in lithologies and sequences which are similar to those of the Micritic and Cryptalgal Lithofacies. At Cefn Yr Ystrad, fining upwards peloidal sequences with bases of oncoidal coquinas (usually Composita) contain quartz grains. These sequences occur on a 10cm to 20cm scale.

At Careg Yr Ogof, the peloidal and bioclastic sequences, described above are overlain by micritic cryptalgal laminates. These are developed as stratiform sheets, approximately 1cm thick, which are composed of mm thick, micritic cryptalgal laminae with scalloped surfaces (Fig. 5.33). These contain sharp based, laterally discontinuous laminae of peloidal, ooidal, bioclastic and quartz grains. The quartz grains are angular to
subangular and the ooids are small, less than 100 microns in
diameter (Fig. 5.34). The ooids have a twofold cortical structure,
with a sparry concentric/radial inner layer followed by a
micritic concentric/radial irregular outer layer. This cortical
structure is the same as that described for the ooids of the
Simple Ooid Lithofacies (Section 5.2.3.1)

5.3.1.3 Interpretation

The two groups of lithologies represent two different
environments of deposition for the Sandy Limestone Lithofacies.
These were a marine shallow subtidal environment and a tidal flat
environment.

The peloidal and bioclastic lithologies are, by analogy with
the calcareous Dark Pel-Bio Limestone Lithofacies, shallow
subtidal in origin. This is supported by the evidence of Thalassinoïdes - type bioturbation. Furthermore, the well sorted nature of the sediments, the evidence for current activity, the common oolitic coatings and the quartz cored ooids all suggest that the quartz grains were reworked, for some time, in agitated shallow subtidal environments. These environments were the same ones in which some of the Simple Ooid Lithofacies were formed in (Section 5.2.3.2).

The rare trough cross bedded pebble grade conglomerate at Careg Yr Ogof is interpreted to represent a shallow subtidal sand body. Similar Recent subtidal calcareous coarse quartz conglomerates are recorded from the south east coast of Qatar (Shinn 1973). The origin of the quartz grains is postulated to have been the Lower Palaeozoic land mass to the north. This shoreline of clastic rocks would have been exposed to storm generated reworking and to denudation of localised uplifts.

The tidal flat environment is represented by the micritic, cryptalgal and peloidal lithologies. This is by analogy with similar calcareous lithologies and sequences in the Micritic and Cryptalgal Lithofacies described in Section 5.2.4.3. The oncolitic coquina, peloidal fining upwards sequences represent sandy tidal channel/inlet deposits. The scalloped strataform cryptalgal laminae, shown in Fig.5.33, are interpreted to be algal mat deposits formed in the intertidal zone. Recent tufted mats forming similar textures at Shark Bay, Western Australia are found in the middle and upper intertidal zones of tidal flats (Hagan and Logan, 1974b). The associated sharp based, discontinuous bioclastic, oolitic and quartz grain laminae are interpreted to be storm tide washover deposits (Shinn, 1983). The lack of oolitic coatings on the quartz grains implies that they
have not been reworked in the shallow subtidal environment, but have been rapidly redeposited on the tidal flat areas.

The introduction of quartz sands into the back barrier environment required transport from the surrounding Lower Palaeozoic source areas. The lack of diagnostic features e.g. interbedded clay layers, channel sequences, or coarsening upwards motifs precludes a deltaic origin. Similarly the lack of quartz grain maturity (well rounded shapes) precludes an aeolian transport mechanism. The preferred mechanisms are small scale fluviatile systems combined with storm wave scour of exposed Lower Palaeozoic rocks. Once the quartz sands were introduced into the back barrier lagoon areas, they were reworked, or redeposited in the shallow subtidal, or tidal flat environments described above.

Similar transport mechanisms are recorded forming Recent calcareous quartz sand environments. At Shark Bay, quartz sands are introduced into a carbonate sequence by storm wave erosion, this is subsequently redeposited in subtidal sheet sands, or on intertidal flats (Hagan and Logan 1974a).

The Garn Caws Sandstone has been interpreted as a fluviodeltaic deposit (Barclay and Jackson 1982) associated with the Drybrook Sandstone of the Forest of Dean area. This has also been interpreted as a fluviodeltaic deposit (George 1958, Welch and Trotter 1961, MacQuown and Bloxham 1972). However the lack of evidence for deltaic deposits and the low textural maturity of parts of the Sandy Limestone Lithofacies implies that some of the sources were local. An origin related to westerly redistribution of fluviodeltaic sands from the Forest of Dean area is unlikely due to uplift in the Usk Anticline area.
The stratigraphic setting of the Sandy Limestone Lithofacies implies that the source was temporally restricted to the Early Holkerian. This lends more credence to the local sand production theory, as fluviodeltaic sands were deposited in the Forest of Dean area throughout the Holkerian (George 1958, Welch and Trotter 1961, MacQuown and Bloxham 1972). Local sources of quartz sands would be covered by the carbonate sediments of the back barrier lagoon as transgression continued throughout the rest of the Holkerian. Thus as new sources of quartz sand were uncovered, deposition of the Sandy Limestone Lithofacies would have occurred further north of the present day outcrop.

5.3.2 Oolitic Aggregate/Intraclast Lithofacies

5.3.2.1 Introduction

This lithofacies forms the sharp bases to fining upwards sequences on a scale of 3m to 10m. These are especially common in the Penwyllt Member and near the base of the Pontsticill Member. The lithofacies does not occur in the Cyl Yr Ychen Member (Figs. 5.2 and 5.3).

The lithofacies overlies a variety of other lithofacies and these junctions are always sharp and, in places, erosive. Lithofacies which are frequently found overlying the Oolitic Aggregate/Intraclast Lithofacies include the Simple Ooid Lithofacies, the Dark Pel-Bio Limestone Lithofacies and the Micritic and Cryptalgal Lithofacies.

The most characteristic component allochom of the lithofacies is the oolitic aggregate grain (see Section 4.3.2.1 for description). This is a common component of the barrier sequences described in Sections 3.3 and 4.3. On this and other evidence, presented below, the Oolitic Aggregate/Intraclast Lithofacies sequences are interpreted to be storm washover
deposits. These formed topographic highs in the back barrier lagoon which subsequently became areas of preferential carbonate production and deposition influenced by tidal currents. This tidally influenced reworking and deposition created flood tidal delta sequences above the initial oolitic aggregate/intraclast washover deposits.

5.3.2.2 Description

The lithofacies is characterised by trough cross bedded units, 1m to 3m thick (Fig. 5.35). These have sharp, erosive bases which often contain intraclasts formed of the underlying lithologies and micrite. A basal lag of abraded fauna is also a common feature. This contains elements typical of the South Crop barrier sequences (Table 5.3, Section 5.5) e.g. small horn corals, thick shelled gastropods, brachiopods and rare crinoid ossicles.
Lithofacies is sharply truncated by the overlying washover deposits and represents autochthonous lagoonal sediments. Overlying Carbonaceous Shale Lithofacies represents shallow subtidal/intertidal conditions. Length of fully extended ladder is 4m. Pendine.

In thin section, the dominant allochem is the oolitic aggregate (Fig.5.36). These are usually heavily micritised grains composed mainly of single simple ooids with interstitial micrite. Early isopachous fringing cements, surrounding the constituent ooids and preceeding the interstitial micrite, are not recorded. Thus the grains do not conform to the definition of an intraclast given in Section 4.3.2.1. The grains also have a botryoidal outline and have an average diameter of 2mm.

Fig.5.36 Oolitic aggregate grains typical of Oolitic Aggregate/Intraclast Lithofacies. Ghosts of oolitic cortical textures and botryoidal outlines of grains indicates oolitic components for these aggregate grains. Compare with oolitic aggregate grains recorded from the oolitic sequences of the South Crop (Fig.3.11, Section 3.3.1.1). Field of view is 4.5mm. Photomicrograph - Thin Section 2115, Penwyllt Quarry.
FIG.5-37 POINT COUNT DATA STEREOPLOT
OOLITIC AGGREGATE/ INTRACLAST
LITHOFACIES, SPEC. 2115

A: LITHOFACIES

B: OOID TYPE
These features are the same as those recorded for the oolitic aggregate grains described from the South Crop oolitic barrier sequences. The genesis of this grain type has been discussed in Sections 4.3.2 and 3.3.1.1. The petrographic similarities between the Oolitic Aggregate/Intraclast Lithofacies and the Oolitic Aggregate Lithofacies is highlighted by point count data. Examples of both facies plot in the same space on lithofacies and ooid type plots (Fig.5.37, compare with Figs.3.12 and 4.26).

Fig.5.38 Trough cross bedded Oolitic Aggregate/Intraclast Lithofacies has sharp base overlying Dark Pel-Bio Limestone Lithofacies. Base is marked by a lag (L) of bioclastic material characteristic of the Oolitic Barrier Lithofacies Association (small horn corals, crinoid ossicles and brachiopods). Top parts of trough cross bedded unit are bioturbated (B). Twynau Gwynion.

The trough cross bedded units which form the bases of the fining upwards sequences often have bioturbated tops (Fig.5.38). There is no evidence for subsequent hydrodynamic reworking of these. The overlying lithofacies are usually the Simple Ooid, or Dark Pel-Bio Limestone Lithofacies. Rarely the units are overlain
by the Carbonaceous Shale Lithofacies (Fig.5.35), or by the tidal flat deposits of the Micritic and Cryptalgal Lithofacies. The variety of lithofacies transitions, within a representative sample of these sequences, is highlighted in Fig.5.39.

5.3.2.3 Interpretation

There is an affinity between some components of the Lithofacies and similar components found in the oolitic barrier sequences and marginal back barrier sequences of the South Crop. These components (oolitic aggregates and abraded South Crop faunas) are not found in the other lithofacies of the Back Barrier Lagoon Lithofacies Association. Similarly, micritic intraclasts are characteristic of the Pel-Bio Limestone Lithofacies on the South Crop. They are also characteristic of the Oolitic Aggregate/Intraclast Lithofacies. This evidence implies that the lithofacies was sourced from the oolitic shoal barrier complex and marginal back barrier areas situated to the south of the back barrier lagoon.

The sequences, which the lithofacies forms the bases of, are interpreted to represent flood tidal delta deposits (Fig.5.39). The coarse lags of abraded fauna associated with the sharp erosive bases and trough cross bedding are characteristic features of the basal deposits of Recent, wave dominated, clastic flood tidal deltas (Hubbard, Oertel and Nemmedal 1979). These are situated by tidal inlets which penetrate barrier islands and which are initially formed by storm induced washovers. These washover deposits are subsequently reworked by fair weather processes to form flood tidal deltas. A similar role is postulated for the trans-barrier complex channels described in Section 4.5. Although the Holkerian shoal barrier complex was
FIG. 5.39 FLOOD TIDAL DELTA SEQUENCES, PENWYLLT MEMBER, DOWLAIS LIMESTONE FORMATION.

TWYNHAU GWYNION

Subfacies: Micritic-Cryphalgal
- Dark Pel-Bio Limestone
- Simple Ooid
- Dark Pel-Bio Limestone
- Oolitic Aggregate/Intraclast
- Dark Pel-Bio Limestone

Interpretation: Tidal Flat Deposits - Abandonment

Cyl Yr Ychen

Subfacies: Dark Pel-Bio Limestone
- Simple Ooid
- Dark Pel-Bio Limestone
- Oolitic Aggregate/Intraclast
- Micritic-Cryphalgal

Interpretation: Lagoonal Background Sediment

Penyffold

Subfacies: Oolitic Aggregate/Intraclast
- Carbonaceous Shale
- Dark Pel-Bio Limestone
- Micritic-Cryphalgal

Interpretation: Storm Washover - Flood Tidal Delta

Pendine

Subfacies: Carbonaceous Shale
- Dark Pel-Bio Limestone
- Oolitic Aggregate/Intraclast
- Carbonaceous Shale
- Dark Pel-Bio Limestone

Interpretation: Intertidal/Neap to Shallow Subtidal Conditions - Abandonment

The North Crop 261
largely submerged, most trans-barrier flow was concentrated in the barrier complex channels.

The Oolitic Aggregate/Intraclast Lithofacies deposits are laterally persistent on a quarry outcrop scale (50m to 100m) but can not be correlated over distances greater than 1km. Similar sequences can be traced between Morlais Quarry and Twynau Gwynion (Fig.5.1) but not between these quarries and Penwyllt, only 20km westwards. This scale is consistent with the broad lobate morphology characteristic of Recent flood tidal deltas, adjacent to wave dominated tidal inlets, which debouch into wide shallow, complex lagoons (Hayden and Dolan 1979, Hubbard, Oertel and Nummedal 1979). Recent clastic examples of these are found on the North Carolina Coast, U.S.A. (Dolan and Lins 1986).

Some of the trough cross bedded units of the lithofacies show little evidence for reworking by back barrier lagoon currents, but have been subject to bioturbation. In some Recent clastic examples rapidly deposited, storm induced washovers are not subsequently reworked by low energy, fair weather, lagoonal currents. However they are subject to bioturbation (Price 1963, Hubbard, Oertel and Nummedal 1979).

Once the trough cross bedded units of the lithofacies were deposited, they subsequently became preferred sites of carbonate production. This was due to their topography and their proximity to the higher energy, oxygenated water flowing into the back barrier areas via the barrier complex channels. Thus the trough cross bedded units were overlain by the deposits of the Dark Pel-Bio Limestone Lithofacies and the Simple Ooid Lithofacies (Fig.5.39). Recent ooid production occurs on the flanks of tidal deltas within the Trucial Coast Barrier Island Complex (Evans et al 1973).
The production of autochthonous material after initial deposition is characteristic of Recent carbonate tidal deltas. Examples in South Florida develop into carbonate banks due to aggradation (Ewbanks and Bubb 1975). This is in contrast to clastic equivalents which depend upon transported material for their growth (Enos 1977).

The fining upwards sequences associated with the overlying Oolitic Aggregate/Intraclast Lithofacies usually culminate in the deposits of intertidal environments. Occasionally these deposits directly overlie the trough cross bedded units themselves. This reflects the complete aggradation of the sequences and is equivalent to an abandonment facies. This is related to the migration of the trans-barrier complex channels.

From the scale of the lithofacies outcrops, its internal structures, its relationships with surrounding facies sequences and by analogy with modern clastic and carbonate examples the lithofacies is interpreted to represent storm induced washovers introduced into the back barrier lagoon. These were subsequently developed as wave dominated, flood tidal delta deposits. The siting of these was related to the positions of the trans-barrier complex channels described in Section 4.5.

5.4 SUMMARY OF LITHOFACIES SCHEMES

5.4.1 General Environment and Processes

The Dowlais Limestone Formation represents the deposits of a restricted back barrier lagoon. The restricted nature of which is reflected in a number of features. These include overall low faunal diversity, low energy shorelines and more, or less random transitions between dominantly micritic, low energy lithofacies (a facies mosaic, Laporte, 1967). The variety of different
environments within the facies mosaic resulted in the formation of the heterolithic Back Barrier Lagoon Lithofacies Association.

The dominant processes acting within the back barrier lagoon were low energy ones. This is particularly evident in the more restricted parts of the sequence e.g. the Cyl Yr Ychen Member. Reducing bottom conditions are represented by the pyritic, carbonaceous lithologies of the Dark Pel-Bio Limestone Lithofacies. These interfingered with the complex intertidal to swamp conditions represented by the Carbonaceous Shale Lithofacies. Thus these sequences represent the low energy, swamp-like environments adjacent to the Holkerian palaeoshoreline.

Further evidence of low energy conditions is seen in the abundance of micritic tidal flat deposits. These are represented by the Micritic and Cryptalgal Lithofacies. The occurrence of these deposits in both the Penwyllt and Pontsticill Members indicates the importance of tidal flat deposition throughout the development of the back barrier lagoon.

High energy processes were less characteristic of the back barrier area. However, during the Holkerian intermittent high energy processes operated within the dominantly low energy environments. Storm erosion of barrier sequence and of surrounding, weakly consolidated shoreline rocks, resulted in the formation of characteristic sediment bodies. These modified the back barrier, low energy environments by being reworked, or by becoming preferred sites of sedimentation.

5.4.2 **Sequence of Events**

As transgression commenced, the oolitic shoal barrier complex was established on the middle parts of the South Wales Shelf. Thus a protected back barrier lagoon was established.
Initially the shoal barrier complex was not an efficient barrier, due to its limited areal extent. Higher energy processes (Section 5.4.1) were prevalent throughout the lagoon during the early phases of development. In general, circulation was not so restricted as in later phases of development, since the lagoon was open at both ends. Thus discreet oolitic bodies were developed throughout the back barrier area during this early phase.

Compounded with this, storm washovers of barrier sequence sediments were introduced into the back barrier lagoon and were subsequently reworked as flood tidal deltas by currents flowing through trans-barrier complex channels. The flood tidal deltas became preferred sites of carbonate production, due to their topography, and nutrient content. Thus flood tidal delta/carbonate bank sequences were established. The flanks of these were sometimes the sites of ooid production. Aggradation of the sequences resulted in tidal flat deposition.

An early indication of uplift in the eastern parts of the back barrier lagoon was the input of the Sandy Limestone Lithofacies. Coastal exposures of Lower Palaeozoic rocks were eroded by storm wave swash action. The liberated clastic sediment was then redistributed and reworked in the back barrier lagoon environment.

As the shoal barrier complex prograded to the south, it became a more effective barrier. Storm washover style sedimentation became less prevalent and circulation within the back barrier lagoon became more restricted. This resulted in the deposition of the restricted environments represented by the Cyl Yr Ychen Member.
Uplift in the eastern parts of the back barrier lagoon resulted in an asymmetric development of these environments. The lagoon was effectively closed in the east, by uplift on the Usk Axis. Supporting evidence for this is recorded by Holkerian sediments in the Forest of Dean area. A lateral facies change occurs, westwards towards the Usk Axis, from the marine Drybrook Limestone to the fluviodeltaic Drybrook Sandstone (George 1956, Kellaway and Welch 1955).

In the eastern part of the North Crop, the presence of intertidal erosion horizons, within the Cyl Yr Ychen Member, demonstrates the shallow and emergent nature of the back barrier lagoon at that time. The western parts of the back barrier lagoon were open to wave and tidal current action. This formed a facies mosaic of oolitic sand bodies and shoal barrier washover sediments, which aggraded to micritic tidal flats. Only a thin remnant of the Cyl Yr Ychen Member, at Pendine, records the presence of local restricted environments.

This asymmetric pattern of back barrier lagoon development continued to the end of Holkerian deposition. The eastern parts of the lagoon were dominated by tidal flat environments. There was also at least one period of subaerial exposure which lasted long enough for caliche facies to develop. Further evidence for the uplift associated with movement on the Usk Axis.

A widespread peloidal sand (Dark Pel-Bio Limestone Lithofacies) dominated the back barrier areas, with subordinate tidal flat deposition. In the extreme western areas, oolitic deposition continued as the back barrier lagoon expanded and became transitional with the open shelf.

As in the South Crop areas, Holkerian deposition was abruptly ended by a drop in relative sea level resulting in a
5.5 A COMPARISON OF DOWLAIS LIMESTONE FORMATION FAUNAS WITH TYPICAL SOUTH CROP OPEN SHELF AND OOLITIC BARRIER LITHOFACIES ASSOCIATION FAUNAS

The Dowlais Limestone Formation contains a characteristic Holkerian biofacies. However, this differs from typical Open Shelf and Oolitic Barrier Lithofacies Association Holkerian biofacies found on the South Crop. This section aims to describe some of these differences. However, it does not represent an exhaustive palaeontological study, but only serves to highlight some of the more obvious differences which have a bearing on the sedimentological interpretations made in this thesis.

In general, the Dowlais Limestone Formation contains fewer genera, but larger numbers of individuals than in the Open Shelf and Oolitic Barrier Lithofacies Associations of the South Crop. Tables 5.2 and 5.3 (included at the end of this section) summarise the general occurrence of characteristic North Crop and Open Shelf and Oolitic Barrier South Crop faunas. They are not exhaustive faunal lists, but only highlight certain features e.g. facies control and relative diversities. More comprehensive faunal lists can be found in Vaughan (1905), Dixon and Vaughan (1911), Dixon (1921) and George (1927).

A characteristic feature of the North Crop fauna is the occurrence of aberrant growth forms. This is particularly seen in the fasiculate Lithostroton corals. The overall morphology of the colonies appears to be flattened (Figs. 5.40 and 5.41) as opposed to the pear shaped morphologies recorded from the Open Shelf and Oolitic Barrier sequences on the South Crop.
Fig. 5.40 Plan view of fasciculate Lithostrotion colony exhibiting flattened growth form. Corallites radiate at a low angle from a point just below and to the right of the lens cap. This morphology is interpreted to be due to growth in very shallow water depths. Dark Pel-Bio Limestone Lithofacies. Dowlias Limestone Formation, Kiln Quarry.

Fig. 5.41 Side view of Lithostrotion colony described in Fig. 5.40 emphasises flattened growth form of colony. Kiln Quarry.
Individual coralites of the North Crop fasiculate *Lithostracion* corals may also exhibit constrictions spaced on a cm scale. Rare examples are recorded where the coralites are flattened (Fig. 5.42). This appears to be an original feature and not a product of burial compaction, as other corals in the same horizon are not affected in the same way. Bellerophontid gastropods are thick shelled and compact in the South Crop Open Shelf and Oolitic Barrier sequences, but are thinner shelled and larger in the Dowlais Limestone Formation.

![Fig. 5.42 Fasiculate Lithostracion colony with unusual flattened corallites. Note this is not a compactional feature as other corals in the same bed do not show this feature. Pendine.](image)

The abundance of individual genera, or species within the Dowlais Limestone Formation is highlighted by the occurrence of almost monospecific brachiopod coquinas (Fig. 5.43). Small biostromes composed almost entirely of *Lithostracion martini* have also been recorded near the base of the Penwyllt Member at many places along the North Crop (Figs. 5.2, 5.3 and Robertson and...
George 1929). Foraminifera may also be extremely abundant, accounting for up to 50% of point counted grains in some parts of the Dark Pel-Bio Limestone Lithofacies (e.g. Appendix One, Table 1.5.1 Specimens: C.Y.Y.305, C.Y.Y.374).

Fig. 5.43 Brachiopod coquina consisting only of Composita valves. Evidence of high abundance and low diversity, characteristic of back barrier lagoon biofacies. Pendine.

These features of low diversity, but great abundance of individuals and aberrant growth forms are characteristic of "restricted shelf" environments (Enos 1983). By comparison the more diverse Open Shelf and Oolitic Barrier South Crop faunas suggest a more "normal" marine environment.

Within the Dowlais Limestone Formation, fauna more characteristic of the South Crop Open Shelf and Oolitic Barrier Lithofacies Associations is found within the Oolitic Aggregate/Intraclast Lithofacies sequences. These sequences are interpreted to be the deposits of a washover facies from the shoal/barrier complex to the south (Section 5.3.2). Thus faunas
more characteristic of the South Crop Open Shelf and Oolitic Barrier Lithofacies Associations were injected into the back barrier lagoon environment.

**TABLE 5.2 - Fauna Characteristic of the North Crop**

<table>
<thead>
<tr>
<th>Common</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composita ficoides*</td>
<td>Fauna marked with an asterisk is particularly common throughout these Holkerian sequences.</td>
</tr>
<tr>
<td>Composita ambigua*</td>
<td></td>
</tr>
<tr>
<td>Davidsoninacarbonaria*</td>
<td></td>
</tr>
<tr>
<td>Productus corrugatus-hemisphericus*</td>
<td></td>
</tr>
<tr>
<td>(Linoprotonia corr-hemi)</td>
<td></td>
</tr>
<tr>
<td>Siphonodendron martini</td>
<td></td>
</tr>
<tr>
<td>Axophyllum</td>
<td></td>
</tr>
<tr>
<td>Bellerophon(G)</td>
<td></td>
</tr>
<tr>
<td>Macrocheilina(G)</td>
<td></td>
</tr>
<tr>
<td>Spararollus(G)</td>
<td></td>
</tr>
<tr>
<td>Foraminifera:</td>
<td></td>
</tr>
<tr>
<td>Eostafella</td>
<td></td>
</tr>
<tr>
<td>Pseudoendothyra</td>
<td></td>
</tr>
<tr>
<td>Brunsia</td>
<td></td>
</tr>
<tr>
<td>Nibelia</td>
<td></td>
</tr>
<tr>
<td>Dainella</td>
<td></td>
</tr>
<tr>
<td><strong>Rare</strong></td>
<td></td>
</tr>
<tr>
<td>Chonetes</td>
<td></td>
</tr>
<tr>
<td>Siphonodendron basaltiforme(P)</td>
<td>Corals marked (P) + Siphonodendron martini common in Penwylit Mbr.</td>
</tr>
<tr>
<td>Siphonophyllia cylindrica(P)</td>
<td></td>
</tr>
<tr>
<td>Syringopora</td>
<td>Common in Ponsticill Mbr. at Cyl Yr Ychen Quarry.</td>
</tr>
<tr>
<td>Phillipsia</td>
<td></td>
</tr>
<tr>
<td><strong>Very Rare</strong></td>
<td></td>
</tr>
<tr>
<td>Echinoderm Spines</td>
<td></td>
</tr>
<tr>
<td>Zaphrentids</td>
<td>Found only in compound ooid washover facies.</td>
</tr>
<tr>
<td>Orthocone</td>
<td>Only one specimen found.</td>
</tr>
<tr>
<td>Fish tooth</td>
<td>ditto</td>
</tr>
</tbody>
</table>

Table entries marked with an asterisk (*) are particularly common throughout these Holkerian sequences. Many lithostrotions exhibit unusual growth forms e.g. flattened coralites, constrictions on coralites and overall flattened shape of colonies. Gastropods (G) are generally large and thin shelled.
TABLE 5.3 - Fauna Characteristic of the Open Shelf and Oolitic Barrier Lithofacies Associations of the South Crop

(Fauna marked with an asterisk is particularly common throughout these Holkerian sequences.)

<table>
<thead>
<tr>
<th>Common</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composita ficoides*</td>
<td>Common esp. in non-oolitic facies.</td>
</tr>
<tr>
<td>Composita ambigua*</td>
<td>Common in oolitic facies.</td>
</tr>
<tr>
<td>Delepinea comoides</td>
<td></td>
</tr>
<tr>
<td>Megalochonetes papillaceous</td>
<td></td>
</tr>
<tr>
<td>Productus corrugatus-hemisphericus*</td>
<td></td>
</tr>
<tr>
<td>(Linoprotonia cor-hemi)</td>
<td></td>
</tr>
<tr>
<td>Axophyllum</td>
<td></td>
</tr>
<tr>
<td>Zaphrentids (LS)</td>
<td>Fauna marked (LS) common in Lmst shale lithofacies and in bioclastic limestone lithofacies.</td>
</tr>
<tr>
<td>Siphonophyllia cylindrica (LS)</td>
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<tr>
<td>Siphonodendron irregulare (LS)</td>
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<tr>
<td>Siphonodendron martini*</td>
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</tr>
<tr>
<td>Lithostroton araneum</td>
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<tr>
<td>Lithostroton minus</td>
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<tr>
<td>Syringopora</td>
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<tr>
<td>Bellerophon (G)</td>
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<td>Stracocid (G)</td>
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<tr>
<td>Loxonema (G)</td>
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<tr>
<td>Crinoids*</td>
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<td>Koninckopora</td>
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<tr>
<td>Foraminifera:</td>
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<tr>
<td>Dainella holkeriana</td>
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<td>Nibelia</td>
<td></td>
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<tr>
<td>Koskinotextularia</td>
<td></td>
</tr>
<tr>
<td>Archaeodiscids</td>
<td></td>
</tr>
<tr>
<td>Rare</td>
<td></td>
</tr>
<tr>
<td>Davidsonina carbonaria</td>
<td>Fauna marked (S) esp. common in shales of Overton Cliff Fmtn. and Stackpole Lmst Fmtn.</td>
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<tr>
<td>Cleiothyridina (S)</td>
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<td>Phillipsia (S)</td>
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<td>Fenestellid bryozoa (S)</td>
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<td>Chaetetes</td>
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<td>Solenopora</td>
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5.6 THE TRANSGRESSIVE NATURE OF THE HOLKERIAN DOWLAIS LIMESTONE FORMATION

The transgressive nature of the Dowlais Limestone Formation (and by implication, the Holkerian Stage) is highlighted by its overstep of progressively older sediments northwards and westwards. To illustrate this, the nature of the transitions between the basal Holkerian sediments and the underlying rocks is considered below.

5.6.1 The Llanelly Formation

The junction between the Llanelly Formation and the Dowlais Limestone Formation is exposed at a number of localities east of Penderyn. These include Baltic Quarry (SO 156169), Blaen Onneu Quarry (SO 065178), Llanelly Quarry (SO 223124) and Cwm Quarry (SO235129).

Llanelly Quarry is the type locality of the Llanelly Formation, which is Arundian in age (Wright, Raven and Burchette 1981). The topmost member of the Formation is the Gilwern Clay Member. At Llanelly Quarry it is developed as 6m of mottled red and green clays. These are overlain by a grey seatearth development and an impersistent coal. Elsewhere (e.g. Blaen Onneu Quarry) the member is developed as coarse sandstones and conglomerates. These facies are interpreted as fluvial sandstones and overbank deposits (Wright, Raven and Burchette 1981).

At Llanelly Quarry the grey seatearth and impersistent coal of the Gilwern Clay Member are sharply overlain by the Micritic and Cryptalgal Lithofacies of the Dowlais Limestone Formation. These sediments represent tidal flat deposits and imply that the Holkerian transgressive event was, locally, not erosive.
5.6.2 Lower Limestone Shales

The junction between the Dowlais Limestone Formation and the Lower Limestone Shales (Courceyan) is exposed in the North Face of Penwyllt Quarry (SN 857162) Fig. 5.44. At the base of the quarry, the lithological sequence through the Lower Limestone Shales starts with approximately 9m of fine grained limestones. These contain peloidal/crinoidal intercalations which alternate with silt and mud grade material. Above this are approximately 4m of buff, fawn weathering, light grey limestone, with some thin shales. The limestone contains neomorphic textures. This sequence culminates in a nodular limestone in light grey shale, which contains lenses of ochreous, yellow clay. The limestone nodules contain pyrite and rhizoliths in a mottled neomorphic spar matrix.

Fig 5.44 North Face of Penwyllt Quarry showing junction between Lower Limestone Shales (Courceyan) and Dowlais Limestone Formation (Holkerian). Prominent fawn/grey band marks topmost unit of the Lower Limestone Shales. Height of face is approximately 37m.
This sequence is interpreted to represent the third cycle of barrier sequence development in the Lower Limestone Shales. (Burchette 1977, Burchette 1984, Wright, Raven and Burchette 1981).

Fig. 5.45 Detail of junction between the Lower Limestone Shales and the Dowlais Limestone Formation shown in Fig. 5.44. Cobble grade intraclasts (arrowed) of the underlying Lower Limestone Shale caliche facies development are incorporated within the lowermost bed (Dark Pel-Bio Limestone Lithofacies) of the Dowlais Limestone Formation. The junction is marked by a palaeokarst.

Overlying this sequence are dark, carbonaceous limestones (Dark Pel-Bio Limestone Lithofacies) of the Dowlais Limestone Formation. These contain clasts of the underlying nodular limestone horizon (Fig. 5.45). An early Courceyan fauna
characterises the underlying buff weathering limestones (George 1927). A typical Holkerian fauna characterises the overlying Dark Pel-Bio Limestone Lithofacies of the Dowlais Limestone Formation. Thus the junction marks a long period of non-deposition. During this time, subaerial exposure has resulted in the development of caliche facies in the underlying Lower Limestone Shales.

5.6.3 Pendine Conglomerate

At Pendine the Dowlais Limestone Formation overlies the Pendine Conglomerate which is of Chadian age (George et al 1976). Approximately 2.5m to 5m of interbedded micritic and cryptalgal lithologies with ochreous yellow clays overlie a mamillated palaeokarstic surface (Fig.5.46). Within the sequence, there is evidence of multiple karst and caliche facies developments. The top surface of the Pendine Conglomerate is also a palaeokarst.

Fig.5.46 The junction between the Pendine Conglomerate (Chadian) and the Dowlais Limestone Formation (Holkerian) at Pendine Steps. Lowermost bed of the Dowlais Limestone Formation is marked by yellow sign painted "DANGER".
This top palaeokarst is overlain and infilled by a Micritic and Cryptalgal Lithofacies development of the Dowlais Limestone Formation (Fig.5.47). This transition from subaerial exposure features to non erosive tidal flat deposits is similar to that recorded above the Llanelly Formation on the eastern parts of the North Crop.

Fig.5.47 Detail of junction between the Pendine Conglomerate and the Dowlais Limestone Formation shown in Fig.5.46. Lowermost bed of the Dowlais Limestone Formation consists of peloidal and micritic lithologies (Micritic and Cryptlagal Lithofacies) and infills the underlying palaeokarstic topography developed on top of the Pendine Conglomerate. Marker pen is 10cm long.
5.6.4 The Lower Palaeozoic

Between Pendine and Haverfordwest, the Dowlais Limestone Formation overlies progressively older rocks. Critical outcrops are referred to in the last geological survey memoir for the area (Strahan et al. 1914) but are now badly overgrown. During that survey rocks equivalent to the Dowlais Limestone Formation were found to overlie the Lower Limestone Shales east of Templeton (SN112112). West of Templeton to the west bank of the Cleddau River they were found to overlie the Old Red Sandstone and further west still, they were found to overlie Silurian age rocks.

At Haverfordwest, the transition between the Dowlais Limestone Formation and the underlying rocks is more clearly exposed than at any other locality mentioned above. In a road cutting, south of Haverfordwest (SM 960143) dolomitic calcareous sandstone and carbonaceous grey shales overlie, with angular discordance, dark grey siltstones. These siltstones are considered to be Silurian in age (Strahan et al. 1914). The dolomitic calcareous sandstones and grey shales are interpreted to be part of the Penwyllt Member. Faunal evidence to support this contention is found in a quarry west of Haverfordwest, at Merlin's Bridge (SM 960143). There, carbonaceous grey shales and carbonaceous peloidal limestones, which overlie dark grey siltstones, contain coquinas of Composita.

5.6.5 Summary

During the Holkerian Stage, sediments which subsequently formed the Dowlais Limestone Formation, were deposited northwards and westwards over a previously subaerially exposed surface. This pre-Holkerian land surface was composed of Silurian to Arundian age rocks, which were arranged in a sequence which younged
southeastwards. Thus the southeasterly areas, now represented by the eastern parts of the North Crop and at Pendine, contained the youngest, Arundian age, rocks.

Initial Holkerian sediments were tidal flat deposits, formed in the low energy back barrier lagoon environment. The inclusion, within the basal beds of the Dowlais Limestone Formation at Penwylt Quarry, of cobble grade nodules from the underlying caliche profile demonstrates a local, high energy event. This is interpreted to have been due to the action of storm wave swash. A similar mode of formation is postulated for the sandy dolomitic beds south of Haverfordwest. Lower Palaeozoic rocks exposed during the Holkerian, were eroded by a similar process (compare with Section 5.3.1).

The transitions between the basal beds of the Dowlais Limestone formation and the underlying rocks demonstrate the transgressive nature of the Holkerian sediments. In general, the earliest Holkerian facies represent low energy environments typical of the back barrier lagoon. However some localised facies, which record higher energy events, are attributed to the action of storm wave swash.
The North Crop 280
FIG.6-1  DINANTIAN OUTCROP AND HOLKERIAN SECTIONS IN THE VALE OF GLAMORGAN

KEY:

[ ] Dinantian Outcrop
Table 6.1 **Summary Lithostratigraphic Descriptions - Vale of Glamorgan**

<table>
<thead>
<tr>
<th>Chronostrat.</th>
<th>Lithostrat.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asbian</td>
<td>Oxwich Head Limestone</td>
<td>= (Pant Mawr Sandstone Member: Fine to medium grained calcareous sandstone)</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Stormy Limestone Formation:</td>
<td>Heterolith comprising pel-bio Dominantly oolitic limestone and micritic/</td>
</tr>
<tr>
<td></td>
<td>Hunt's Bay Group</td>
<td>cryptalgal sequence lithofacies.</td>
</tr>
<tr>
<td>Holkerian</td>
<td>Argoed Limestone Member:</td>
<td>Thin bedded, dolomitised, bioclastic limestones.</td>
</tr>
<tr>
<td>Arundian</td>
<td>Cefnyrhendy Oolite Member:</td>
<td>Massive, partly cross bedded, oolitic limestones with minor bioclastic</td>
</tr>
<tr>
<td></td>
<td>Dominated by bioclastic and</td>
<td>limestones with minor amounts of oolitic limestone.</td>
</tr>
<tr>
<td></td>
<td>peloidal limestones</td>
<td></td>
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</table>
6.1 INTRODUCTION

The Holkerian sequences in the Vale of Glamorgan are represented by the Hunt's Bay Oolite Group (Section 2.1.2, Fig.2.1, Table 6.1, Figs.6.1 and 6.2). Their general lithostratigraphy has been described in detail during the recent B.G.S. resurveys of the Cardiff and Bridgend areas (Waters and Lawrence in press, Wilson et al in press). A brief summary of the stratigraphy is given below.

In the western parts of the Vale of Glamorgan, near Porthcawl (Fig.6.2) the Hunt's Bay Group has two broad lithological divisions. These are represented by the dominantly oolitic Cornelly Oolite Formation and the heterolithic Stormy Limestone Formation.

Further east, the stratigraphy becomes more complex due to a facies change (Fig.6.2). North of Cowbridge (Fig.6.1) in the central parts of the Vale of Glamorgan there are two oolitic sequences split by a thin bioclastic limestone intercalation. The lowermost oolitic sequence (the Cefnyrhendy Oolite Member) is Arundian in age and is overlain by a thin bioclastic limestone (the Argoed Limestone Member) which is Holkerian in age. Overlying this is a dominantly oolitic sequence which is equivalent to the Cornelly Oolite Formation. However this contains intercalations of lithologies characteristic of the Stormy Limestone Formation. Finally this is succeeded by the Stormy Limestone Formation itself.

In the eastern Vale of Glamorgan, near Creigiau (Fig.6.1) a twofold oolitic sequence is also recorded. The lower oolitic sequence is overlain by a thin bioclastic limestone and these are recognised as the Cefnyrhendy Oolite Member and the Argoed Limestone Member respectively. The overlying oolitic sequence,
FIG. 6.2 GENERALISED LITHOSTRATIGRAPHY FOR THE VALE OF GLAMORGAN

WESTERN VALE

Cornelly Quarry
Stormy Down Quarries

STORMY LIMESTONE FORMATION

CONNELLY OOLITE FORMATION

HUNT'S BAY GROUP

HIGH TOR LIMESTE

CENTRAL VALE

Ruthin Quarry
Forest Wood Quarry

OXWICH HEAD LIMESTONE

STORMY LIMESTONE FORMATION

CEFNYRHENDY OOLITE MBR.

ARGOED LIMESTONE MBR.

BIRNBECK LIMESTONE

GULLY OOLITE

EASTERN VALE

Bute Quarry
Cefnyrhendy Quarry

CEFNYRHENDY OOLITE MBR.

ARGOED LIMESTONE MBR.

HUNT'S BAY GROUP

HIGH TOR LIMESTE
The Vale of Glamorgan has many intercalations of lithologies characteristic of the Stormy Limestone Formation which become more prevalent up section. In this area the distinction between the Cornelly Oolite Formation and The Stormy Limestone Formation is not recognised. East of Creigiau, dolomitisation above the Argoed Limestone Member makes further stratigraphic resolution difficult.

Due to time constraints and to avoid duplication of current B.G.S. work, a detailed study was made of only one section in the Vale of Glamorgan. This was the Lock's Lane Borehole (SS 881777, Fig.6.1) which was drilled in July 1984 to determine the thickness of the Dinantian lithostratigraphic units present.

The borehole penetrated approximately 70m of Oxwhich Head Limestone before reaching Holkerian age rocks (Fig.6.3). These were represented by approximately 60m of Stormy Limestone Formation and approximately 65m of Cornelly Oolite Formation. Drilling ceased at 198m within the Cornelly Oolite Formation.

The slabbed core allowed examination of a continuous section through an unweathered Holkerian sequence. This was especially valuable in determining the nature of lithological contacts and facies transitions within the complex heterolithic sequences of the Stormy Limestone Formation. The borehole sequence contains an oolitic barrier lithofacies association and a marginal back-barrier lithofacies association which are described and interpreted below.
FIG. 6-3 SUMMARY LOG OF LOCK'S LANE BOREHOLE

DESCRIPTION

MADE GROUND

PALAEOKARST

CAVITY

OXWICH HEAD LIMESTONE

PELOIDAL LIMESTONES WITH PSEUDOBRECCIAS

PALAEOKARST

CAVITY

PALAEOKARST

PART HAWR 557 MB

PELODIAL/OLITIC BASE

CALCAREOUS SANDSTONE

STORMY LIMESTONE FORMATION

MARGINAL BAY BARRIER LITHOFACTORIES ASSOCIATION WITH PEL-BIO LIMESTONE LITHOFACTORIES AND MELITIC AND CRYPTALGAL LITHOFACTORIES

SEE FIG. 6A FOR DETAILED LOG

1ST CALCITE NODULES OF STORMY LIMESTONE FORMATION

CORNELLY OOLITE FORMATION

OOLITIC BARRIER AND OPEN SHELF LITHOFACTORIES ASSOCIATIONS WITH BIOLASTIC LIMESTONE AND OOLITE, OOLITIC AGGREGATE AND SIMPLE OOID LITHOFACTORIES

BASE OF HOLE
6.2 LITHOFACIES ASSOCIATIONS A and B: Open Shelf and Oolitic Barrier

These sequences are represented, in the Lock's Lane Borehole, by lithofacies 3, 4, 5 and 6 (Fig. 2.2). They are found within the Cornelly Oolite Formation (Fig. 6.3). A detailed log and description of the top 30m of the Formation is given in Enclosure Four.

6.2.1 Description

The oolitic sequences in the top 30m of the Cornelly Oolite Formation are interbedded with fine grained skeletal/peloidal lithologies. These are broadly similar to those lithologies characteristic of the bioclastic limestone lithofacies described from Pembrokeshire and Gower. However, the lithologies are frequently, sharply overlain by the oolitic lithologies. The bases of the latter are also occasionally bioturbated by a Monocraterion/Skolithos-type trace. This is similar to the sequences characteristic of lithofacies 3, described from the Gower sequences (Section 4.2.3). Thus these thick intercalations of fine grained skeletal/peloidal lithologies with oolitic lithologies are interpreted to represent lithofacies 3.

Within the oolitic sequences, the oolitic aggregate is the dominant allochem. These grains are commonly found in association with crinoid columnals, small horn corals, brachiopod and algal (Koninckopora) debris. This assemblage of allochems occurs in poorly sorted beds, 1m to 3m thick where the allochems are usually heavily micritised. Oolitic intraclasts (up to 4cm in diameter) are often found in floatstone textures at the bases of these beds. Low angle foresets, defining cross bedding with a vertical scale of 20cm, are recorded from some beds. The form of the cosets is difficult to determine from the limited outcrop
Much of the oolitic sequence consists of well sorted, well rounded peloidal grains and single, simple ooids in a grainstone texture. Between 147.20m and 151.60m a coarsening upwards sequence is recorded (Enclosur/Four). In this, the upper 2m contains mainly simple ooids with very little bioclastic material. This corresponds to the simple ooid lithofacies described from the oolitic barrier lithofacies associations of Pembrokeshire and the Gower (see Sections 3.3.2.2 and 4.3.2.3). Cross bedding is recorded from these well rounded pel-oo grainstones. At one horizon (133.30m) a muddy top to cross beds is eroded by the overlying cross beds, this represents a reactivation surface.

6.2.2 Interpretation

The intercalations of fine grained skeletal (mainly crinoidal) / peloidal lithologies, in the dominantly oolitic sequence, are interpreted to represent the background shelf sediments. These would have floored re-entrants within the dominantly oolitic sediments of the shoal/barrier complex. They were intermittently covered by oolitic sediment during storm events and by the migration of the "ragged" barrier edge (see Section 4.5.2 for discussion).

Within the oolitic sequences, the dominance of the oolitic aggregate allochem points to the importance of early cementation processes on the shoal/barrier complex (Section 3.3.1.1). The presence of the well rounded oolitic intraclasts lends further support to this interpretation. The paucity of cross bedding features and the frequently poorly sorted nature of the oolitic aggregate beds suggests thorough bioturbation.
The simple ooid lithofacies is more common at this stratigraphic level than in similar sequences in Pembrokeshire, or Gower. The occurrence of coarsening upwards simple ooid sequences suggests the presence of discreet ooid shoals. The lack of oolitic aggregate grains reflects the predominance of ooid production over early cementation. The evidence for cross bedding and reactivation surfaces imply that these ooid shoals were formed by tidal currents. This is in agreement with their inferred position at the rear edge of the shoal/barrier complex, where wave current action would be subordinate to tide current action.

Overall the oolitic sequences of the top 30m of Cornelly Oolite Formation, in the Lock's Lane Borehole, represent the transition from "ragged" barrier edge to isolated ooid shoals situated at the rearward edge of the shoal/barrier complex.

6.3 LITHOFACIES ASSOCIATION C: Marginal Back Barrier

Over 60m of the Stormy Limestone Formation are preserved between 71.51m and 132.00m in the Lock's Lane Borehole (Fig.6.3 and Enclosure Four). This sequence is dominated by the Marginal Back Barrier Lithofacies Association which is represented by the Pel-Bio Limestone Lithofacies and the Micritic and Cryptalgal Lithofacies. These two lithofacies are described below.

6.3.1 Pel-Bio Limestone Lithofacies

6.3.1.1 Description

This lithofacies is marked out in Fig.6.4 by a stippled ornament. In the lower half of the Stormy Limestone Formation the lithofacies becomes more oolitic and these intervals are marked on Fig.6.4 by a mixed stipple and circle ornament. These oolitic intervals are frequently crossbedded with low angle, planar foresets. Reactivation surfaces are recorded on set boundaries by
FIG. 6.4 DETAIL OF STORMY LIMESTONE FORMATION, SHOWING DISTRIBUTION OF PEL-BIO LIMESTONE LITHOFACIES (STIPPLE ORNAMENT) AND MICRITIC + CRYPTALGAL LITHOFACIES - LOCK'S LANE BOREHOLE FEATURES DESCRIBED IN THE TEXT

Oxwich Head Limestone

Key: see fig. 3.36
micritic drapes which are cut into by the overlying set (Fig. 6.5).

Most of the ooids are not of the oolitic aggregate type, but consist of only a single micritic coat (superficial ooids). The peloids are also well rounded and in general, the lithologies are well sorted. Bioclasts include crinoid ossicles, Koninckopora, small horn corals, Lithostroton and Syringopora corallites.

Although some of the oolitic Pel-Bio Limestone sequences exhibit small scale (0.5m to 1m) coarsening upward trends, most of the more peloidal and bioclastic rich lithologies exhibit
fining upwards trends on a 0.3m to 1.5m scale. Elsewhere the lithofacies forms massive beds with no discernable grain size trends.

6.3.1.2 Interpretation

The widespread distribution of the Pel-Bio Limestone Lithofacies within the Stormy Limestone Formation suggests that peloidal sands were a ubiquitous sediment type within the marginal back barrier area. The more oolitic, cross-bedded lithologies represent the higher energy conditions which prevailed adjacent to the Trans-Barrier Complex Channels (Section 4.5).

The evidence for bimodality of current directions is equivocal due to the limited outcrop of core material. However, combined with the presence of reactivation surfaces, with their implications for variable flow conditions, the cross bedding sets are interpreted to have been formed, at least in part, by tidal currents.

The coarsening upwards trends in the more oolitic lithologies are interpreted to represent small scale progradation of incipient "ool" shoals. The fining upwards sequences represent vertical aggradation and are sharply overlain by storm generated lags of bioclasts and coarser material. The more massive lithologies represent bioturbated units.

6.3.2 Micritic and Cryptalgal Lithofacies

6.3.2.1 Description

This is marked out on fig 6.4 by the non-stippled parts of the Stormy Limestone Formation. A number of lithologies are present, including calcite mudstones with cryptalgal structures and caliche facies development, intraclast/peloidal sequences and
oncolitic/peloidal sequences.

The calcite mudstone lithologies commonly display some kind of cryptalgal structure. These have a variety of morphologies ranging from cryptalgal laminates to thrombolitic structures (Aitken 1967).

Fig. 6.6 Laterally linked hemispheroids with micritic, peloidal and tufted laminae. Micritic and Cryptalgal Lithofacies 87.86m (top). Stormy Limestone Formation, Lock's Lane Borehole.

Stromatolite structures are generally restricted to laterally linked hemispheroids (LLH). Between 87.70m and 87.98m spaced laterally linked hemispheroids (mode LLH-S Logan et al 1962) overlie a peloidal packstone (Fig. 6.6). Within 2cm, the hemispheroids have become close linked (mode LLH-C, Logan et al...
1962) and continue in this mode over the rest of this stromatolitic interval. The laminae consist of mm sized "tufts" of micrite orientated perpendicular to the surfaces of the laminae. These alternate with peloidal and micritic laminae.

Fig. 6-7 Thrombolitic texture. Clotted micrite (dark) within peloidal packstone lithology Micritic and Cryptagal Lithofacies, 91.95m (base). Stormy Limestone Formation. Lock's Lane Borehole.

Thrombolitic structures are recorded in a number of places within the Stormy Limestone Formation (enclosure). Between 91.93m and 92.27m, cm sized patches, or clots of dark micrite occur within a fabric of peloidal packstone (Fig.6.7). The two microfacies are separated by mm to micron sized spar filled
spaces. The overall morphology of the thrombolite is irregular and the structure covers approximately 30cm of core.

Complex cryptalgal structures are also recorded from the Stormy Limestone Formation. Between 93.65m and 93.95m a coarse oncolitic peloidal grainstone is overlain by homogenous to poorly laminated peloidal packstone. The latter contains an irregular fenestral fabric which is infilled with alternating light and dark cryptalgal laminations, dark micrite and finally a sparry calcite (Fig.6.8).

Fig.6.8 Complex cryptalgal structure. Boundary (B) between underlying oncolitic, peloidal grainstone and homogenous, poorly laminated peloidal packstone. Open void system (V) infilled with cryptalgal laminates, dark micrite and spar. Micritic and Cryptalgal Lithofacies, 93.95m (base). Stormy Limestone
In two examples calcite mudstones with cryptalgal structures have caliche facies development (Fig. 6.4). The first mudstone which marks the base of the Stormy Limestone Formation (131.75m) has cryptalgal laminations which are disturbed by sediment filled burrows and, near the top, rhizoliths (Fig. 6.9). The latter are presumed to have been stained red by Triassic groundwater.

Fig. 6.9 Cryptalgal laminated peloidal micrite with sediment infilled burrows (B) and rhizoliths (R) stained red by ?Triassic groundwaters. Micritic and Cryptalgal Lithofacies 131.75m (top). Stormy Limestone Formation. Lock’s Lane Borehole

The second example of caliche facies development in a cryptalgal laminated mudstone occurs at 119.93m. This exhibits
a more mature caliche profile than in the above example. A chalky zone and a laminated and nodular zone overlie a cryptalgally laminated micrite (Fig. 6.10). Glaebules with intragrain spar filled cracks disrupt the laminated calcrete in the upper zone. Rhizoliths infilled with darker neomorphic spar occur throughout the profile.

Fig. 6.10 Cryptalgally laminated peloidal micrite with caliche profile development. Chalky zone (C) is overlain by laminar calcrete (L) and glaebules (G). Scattered rhizoliths (R) occur in both zones. Micritic and Cryptalgal Lithofacies 119.22m (base). Stormy Limestone Formation, Lock's Lane Borehole.

Other lithologies that occur within the Micritic and Cryptalgal Lithofacies include peloidal, intraclast grainstones. These form coarsening upwards units 30cm to 60cm thick eg:
107.90m to 108.50m (Fig.6.4). The intraclasts are micritic, or peloidal and range in size up to 3cm in diameter.

In other places, oncoid-rich peloidal lithologies form fining upwards sequences, 0.3m to 1.5m thick eg: 90.60m to 91.27m (Fig.6.4). The oncoids commonly surround Composita valves and form sharp based lags with other bioclasts and intraclasts. These lags grade up into fine grained peloidal packstones and wackestones.

6.3.2.2 Interpretation

The cryptalgal structures developed within the calcite mudstone lithologies generally represent intertidal deposition on micritic tidal flats. The laterally linked hemispheroid structures were formed in protected areas where wave action was slight (Logan et al 1962). The "tufted" nature of the micritic laminae resembles the tufted-mat structures described by Logan et al 1974 from Shark's Bay, Western Australia. These mats form in the low energy middle to upper intertidal zones.

The irregular fenestral fabric developed within the complex cryptalgal structure described in Fig.6.8 was probably an open one to allow subsequent growth of algal mat and infilling with sediment. Its origin was related to algal activity, desiccation and algal oxidation. These types of structures have been observed in the middle to upper intertidal zones in Shark's Bay also (Logan 1974).

In contrast to the cryptalgal structures discussed above, the thrombolitic sequences developed subaqueously. This is inferred by the absence of lamination recording intermittent wetting and drying associated with intertidal zones (Aitken 1967). They probably formed small features on the sea floor.
adjacent to the micritic tidal flats.

More prolonged periods of exposure than those experienced in the intertidal zone are evidenced by the development of caliche facies in the tidal flat micrites. Plant colonisation and soil formation would have taken place in the supratidal parts of the micritic tidal flats.

The coarsening upwards sequences containing peloidal/intraclast grainstones are interpreted to represent low energy beach sequences (Section 4.4.2.2). These would have formed at the edges of the micritic tidal flats.

The oncolitic/peloidal fining upwards sequences are interpreted to be the deposits of tidal channels (Shinn et al 1969). The oncoids were formed subtidally in moderate, continuous currents away from wave surge, probably in the mouths of tidal channels (Gebelein 1969).

Thus the Micritic and Cryptalgal Lithofacies represents the deposits of active (channeled) micritic tidal flats and of the subtidal areas immediately adjacent to them. These sediments would have been surrounded by the peloidal sands which formed the Pel-Bio Limestone Lithofacies. This explains the intimate association of the two lithofacies within the Marginal Back Barrier Lithofacies Association.

6.4 THE HOLKERIAN/ASBIAN BOUNDARY

At 71.51m in the Lock's Lane Borehole, there is a marked facies change. There is a sharp contact between an underlying (1m) unit of oncolitic peloidal packstone and an overlying (3m) unit of fine grained peloidal packstone/grainstone with quartz sand grains. Within the underlying unit rhizoliths are developed.

This contact is taken to be the boundary between the Stormy Limestone Formation (Holkerian) and the Pant Mawr Sandstone
Member of the Oxwich Head Limestone (Asbian). The contact contrasts with other recorded examples of the same horizon in the Western Vale e.g. Stormy Down Quarry (Fig.6.2) and Pant Mawr Quarry (SS 828802). At these localities the contact is marked by a well developed palaeokarst with an overlying mottled red and grey clay seam (Davies 1982). It is suggested that in the Lock's Lane Borehole the sandy limestones of the Pant Mawr Sandstone have eroded any palaeokarstic development that might have existed. However, evidence for subaerial exposure at this horizon is provided by the underlying rhizoliths.

6.5 SUMMARY

The Lock's Lane Borehole sequence is discussed and summarised below. A comparison with other Holkerian sequences in the Vale of Glamorgan is made in the following section.

6.5.1 The Lock's Lane Borehole

The Holkerian age rocks in the Lock's Lane Borehole represent a progradational shelf sequence. The basal parts of the Cornelly Oolite Formation represent the transition from open shelf bioclastic sediments to the "ragged" seaward edge of an oolitic barrier complex. There is then a gradual change to sequences at the top of the Cornelly Oolite Formation which represent isolated, tidally dominated, ooid shoals situated at the rearward edge of the shoal barrier complex.

The Stormy Limestone Formation consists of the deposits of micritic tidal flats and of the peloidal sands which surround them. These sediments developed adjacent to the shorewards side of the oolitic barrier. The tidal flats were channelled and fringed by low energy tidal currents. Occasionally higher energy conditions prevailed near openings through the shoal barrier.
The Vale of Glamorgan complex (trans-barrier complex channels) and during storms. The former influenced the formation of incipient ooid shoals in the background sediment of peloidal sands.

The end of the Holkerian stage is marked in the Lock's Lane Borehole by a period of subaerial exposure followed by a change in depositional style. This was characterised by deposition of sandy limestones (Pant Mawr Sandstone) during the Asbian.

6.5.2 The Vale of Glamorgan

In the Western Vale (Fig. 6.2) the Holkerian sequences are very similar to those described from the Lock's Lane Borehole. Thus it is inferred that the prograding shelf sequence with oolitic barrier and marginal back barrier environments existed in this part of the Vale of Glamorgan. However, eastwards of the Western Vale there are facies changes within the Late Arundian and Holkerian sequences. These have been documented during the recent B.G.S. resurveys of the Cardiff and Bridgend sheets (Waters and Lawrence in press, Wilson et al in press) and are only briefly summarised below.

Fig. 6.2 illustrates the progressive eastwards breakdown of the twofold lithostratigraphy of the Holkerian rocks in the Vale of Glamorgan. In the Central Vale (Fig. 6.1) the Late Arundian becomes oolitic (Cefnyrhendy Oolite Member) and the basal Holkerian is formed of crinoidal/skeletal packstone (Argoed Limestone Member). Lithologies characteristic of the Stormy Limestone Formation become common within the Cornelly Oolite Formation. Thus this twofold lithostratigraphy becomes redundant and the sequence is referred to as the Hunts Bay Oolite Group (undivided). Further east, in the Eastern Vale (Fig. 6.1) the Cefnyrhendy Oolite Member (Arundian) and the Argoed Limestone Member (Holkerian) are still recognised. However, they are
overlain by 125m of interbedded Oolitic Barrier Lithofacies Association and Marginal Back Barrier Lithofacies Association. These are partly obscured by late diagenetic, commonly epigenetic vein dolomites.

The interpretation of these facies changes is related to a change in shelf morphology in this part of the South Wales Shelf. This influenced the sites of oolitic deposition and the formation of the oolitic shoal barrier.

The Holkerian sequences in the Eastern and Central Vale were deposited on a broader shallower shelf than the sequences described from the Western Vale. The active oolitic shoals of the oolitic barrier were developed further seawards in the Eastern and Central Vale. Thus a broad area of generally uniform shallow deposition existed behind them. This area contained micritic tidal flats which were surrounded by shallow subtidal peloid sands. The latter contained isolated ooid shoals and the whole area was prone to storm generated oolitic washover deposits. This created the mixed lithofacies association sequences recorded above the Argoed Limestone Member in the Eastern Vale. The Argoed Limestone Member represents open shelf deposits which formed in response to the earliest Holkerian period of transgression, before the onset of ooid production.
The Vale of Glamorgan 302
CHAPTER 7

PALAEOGEOGRAPHIES AND MODELS
SUMMARY: A barrier bank type ramp with minor ooid shoal development, in the east and west. Influenced by topography related to movement on structures at depth e.g. Ritec Fault (Pembrokeshire).
7.1 **INTRODUCTION**

In this chapter, the sedimentological observations made in the rest of the thesis are summarised as a series of palaeogeographies. These are presented as a series of time slices from the Pre-Holkerian (Late Arundian) through to the Very Early-, Mid-, Late- and End-Holkerian. These temporal divisions are only relative and do not represent absolute dates.

Each palaeogeography covers the whole of the South Wales Shelf area. Details of environments for each of the four main areas described within this thesis are given in Section 7.2 below.

In Section 7.3 some controlling mechanisms are postulated to account for the patterns of sedimentation which have been observed within the Holkerian Shelf Sequences of South Wales.

7.2 **SUMMARY PALAEOGEOGRAPHIES**

Six palaeogeographies representing the development of the South Wales Shelf throughout the Holkerian are described below. Each description is split into the four main areas of study shown in Fig.1.1, and is accompanied by a summary diagram.

7.2.1 **Pre-Holkerian Palaeogeography (Late Arundian)** Fig.7.1

**Pembrokeshire:** This part of the South Wales Shelf was characterised by a topographic high related to movement on the Ritec Fault at depth. This created a marked facies change from shallow marine carbonate deposition to terrestrial deposition north of the Tenby area (Sullivan 1966). Oolitic deposition occurred at Tenby whilst further offshore crinoid dominated bioclastic sands passed laterally into the deeper water parts of the shelf. These areas being marked by alternating periods of shale and limestone deposition.

**Gower:** In the Gower area, Late Arundian crinoidal and peloidal
sands covered the shelf. These formed a shelf barrier with a variable small scale topography (Simpson 1986)

The Vale of Glamorgan: In this area, the South Wales Shelf became gradually broader and shallower in an northeastwards direction. Oolitic sands prograded in a southerly direction from a barrier complex situated in the eastern parts of the area. Further offshore in a southwesterly direction, crinoidal and peloidal bioclastic sands were deposited.

The North Crop: Over most of this area, the Late Arundian was characterised by subaerial exposure and terrestrial deposition. However the eastern areas, were covered by a mosaic of shallow subtidal peloidal sands, ooid shoals, micritic tidal flats and areas of more prolonged exposure.

7.2.2 Very Early-Holkerian Palaeogeography Fig. 7.2

Pembrokeshire: The major change in palaeogeography of this part of the South Wales Shelf was the encroachment of the crinoidal bioclastic sands and areas of alternating shales and limestone deposition up the shelf. Oolitic production ceased around Tenby, although the inherited Late-Arundian topographic high still acted as an energy barrier to the areas north of Tenby. Thus the earliest Holkerian sediments in these areas were of the restricted back barrier/micritic tidal flat types.

Gower: The most offshore (southwestern) parts of the Gower Shelf became dominated by an area of alternating shale and limestone deposition. Further up the shelf, these sediments faded laterally into peloidal bioclastic sands. In the mid-shelf areas, the relict Late-Arundian shelf barrier topography controlled the sitting of ooid shoals. The onset of ooid production and redistribution was rapid, thus an oolitic shoal barrier complex
SUMMARY: Carbonate ramp dominated by crinoidal sheet sands + muddy outer shelf conditions. Initiation of ooid shoals in mid shelf areas of Gower and rapid distribution of oolitic aggregate grapestone-type facies. Tidal flat and peloid sand developments with complex intertidal shorelines.
was established.

Vale of Glamorgan: In the broader and shallower eastern areas of this part of the South Wales Shelf, oolitic production was shut down. It was replaced by the crinoidal and peloidal bioclastic sands which encroached up the shelf from the south west.

The North Crop: In the North Crop areas there was a gradual drowning of the Pre-Holkerian landsurface. The subdued topography of this surface created an area of very shallow deposition with restricted hydrodynamic conditions. This area was characterised by peloidal sands, micritic tidal flats and intertidal shorelines with variable fresh- and marine-water influences.

7.2.3. Early Holkerian Palaeogeography Fig. 7.3

Pembrokeshire: By this time, the very earliest Holkerian sediments had formed a thin veneer over the area, thus initiating the sedimentary regression that characterised subsequent Holkerian sedimentation. The topographic high around Tenby, although subdued by sediment cover, still existed. This feature controlled the formation and siting of ooid shoals around Tenby and the whole shelf sequence subsequently started to prograde seawards. Thus the broad areas of crinoidal bioclastic sand deposition retreated southwards.

Gower: The oolitic shoal barrier complex, which was initiated during the very earliest Holkerian period on the mid-shelf areas of Central Gower, continued to develop rapidly and to prograde seawards. The bioclastic sands adjacent to the seaward side of the oolitic barrier also prograded seawards. They replaced the areas of alternating shale and limestone deposition which existed further offshore on the Gower Shelf. These areas of bioclastic sand subsequently received intermittent thin veneers of oolitic shoal barrier complex during storms.
SUMMARY: Carbonate ramp with shelfwide oolitic shoal barrier development.
Back barrier lagoon forms complex mosaic of environments prone to oolitic washover from shoal barrier. Offshore, bioclastic sands receive storm re-deposited oolitic sediment.
PAGE NUMBERING AS ORIGINAL
Vale of Glamorgan: The earliest Holkerian sediments provided a veneer which represented the onset of sedimentary regression on this part of the South Wales Shelf. The subsequent shelf morphology was still broader and shallower in the east than in the west. This variable topography influenced the siting of the ooid shoals, which formed further offshore in the eastern parts of the area than in the west.

The North Crop: The initiation of the oolitic shoal barrier sequences to the south immediately created a back barrier lagoon area behind them. This was a broad area of shallow deposition with some areas of emergence within a mosaic of environments. Tidally influenced ooid shoals formed throughout the area, but were more prevalent in the west. This reflected the progressive restriction of hydrodynamic conditions towards the east. In the most northeasterly parts of the area, storm erosion of the coastline introduced pre-Dinantian clastic sediments into the back barrier lagoon, which were subsequently reworked.

7.2.4 Mid-Holkerian Palaeogeography Fig. 7.4

Pembrokeshire: The ooid shoals established in the Early-Holkerian continued to prograde southwards. This created a large shallow area of mainly stabilised oolitic aggregate sediment which formed a hydrodynamic barrier to the areas behind it. In these protected marginal back barrier areas there was widespread deposition of subtidal peloidal sands interspersed with the deposits of micritic tidal flats. Storms created oolitic washover deposits in the back barrier areas. The areas offshore from the oolitic shoal barrier complex were dominated by crinoidal sands which occasionally received storm redistributed oolitic sediment.

Gower: The oolitic shoal barrier was well developed on this part of the South Wales Shelf. Its seaward margin was dominated by
SUMMARY: Ramp with well developed prograding shoal barrier complex. This creates a broad marginal back barrier area. The back barrier lagoon becomes even more isolated from open shelf areas due to progradation of shoal barrier complex and continued uplift in the east.
active ooid shoals flanked by crinoidal bioclastic sediment. This irregular margin prograded over the adjacent bioclastic sands. Behind this seaward edge, the shoal barrier was formed by a broad shallow area of largely stabilised oolitic aggregate sand. This created a hydrodynamically protected marginal back barrier area in Northern Gower, characterised by peloidal sands and micritic tidal flat deposits. The crinoidal bioclastic sands offshore from the shoal barrier received intermittent, storm introduced, thin veneers of oolitic sediment.

Vale of Glamorgan: The ooid shoals, initiated earlier in the Holkerian, prograded out onto the South Wales Shelf. In the Western Vale parts of the Shelf this progradation created an oolitic shoal barrier with a hydrodynamically protected marginal back barrier area. This effect was exaggerated by the broader shallow shelf profile in the Central and Eastern Vale parts of the shelf. These areas became a complex mosaic of shallow depositional environments including, isolated ooid shoals, micritic tidal flats, shallow subtidal peloidal sands, incipient 'pseudooid' shoals and oolitic washover deposits.

The North Crop: The well developed oolitic shoal barrier sequences to the south generally reduced the amount of hydrodynamic communication between the back barrier lagoon and the rest of the South Wales Shelf. This effect was more noticeable in the eastern parts of the back barrier lagoon than in the west. In the east, intertidal shoreline environments prevailed. These experienced varied periods of subaerial exposure with fresh water runoff and periods of marine water submergence. In the west the back barrier lagoon was more open to the rest of the South Wales Shelf. Tidally influenced, isolated ooid shoals occurred within a mosaic of shallow subtidal peloidal sand and
micritic tidal flat environments. Over the rest of the back barrier lagoon, hydrodynamic communication with the Open Shelf was provided by barrier complex channels. These were initiated by storm surge processes and maintained by tidal currents. Oolitic washover deposits developed into flood tidal deltas. These sometimes became sites of ooid production and progradation. Subsequent aggradation of peloidal and bioclastic sands eventually led to micritic tidal flat deposition. Overall, the back barrier lagoon was a complex mosaic of shallow subtidal and peritidal environments, which became shallower to the north and to the east.

7.2.5 Late Holkerian Palaeogeographies Fig 7.5

Pembrokeshire: By this time, the active ooid shoals had prograded out onto the outer parts of the Pembrokeshire Shelf. As progradation started to slow down, the shoals contributed less oolitic sediment to the areas around them. A broad, more-or-less uniformly shallow area now dominated the shelf. This was characterised by a mosaic of environments including shallow subtidal peloidal and bioclastic sands, ooid shoals, micritic tidal flats and oolitic washovers. Thus the discreet divisions of marginal back barrier, barrier and back barrier lagoon had become less obvious.

Gower: This part of the South Wales Shelf developed in a similar way to the Pembrokeshire Shelf described above. The active ooid shoals prograded beyond the Gower Shelf, leaving behind a broad, shallow area. This was dominated by a similar mosaic of depositional environments as described for Pembrokeshire. In the Central Gower parts of the Shelf, low energy, active (channelised) tidal flats were common.
SUMMARY:

Ramp morphology develops into an accretionary rimmed shelf due to continued progradation of ooid shoals (now restricted to Posherton area).

Most of the South Wales Shelf dominated by shallow subtidal peloid sands, rare ooid shoals and tidal flats. Back barrier lagoon becomes less hydrodynamically restricted.
Vale of Glamorgan: As in the Pembrokeshire and Gower parts of the South Wales Shelf, this area developed into a broad shallow shelf. This was due to the progradation of the active ooid shoals onto the outer parts of the South Wales Shelf. The resultant broad, shallow shelf area was characterised by the familiar mosaic of environments described from Pembrokeshire and Gower e.g. shallow subtidal peloidal sands, discreet ooid shoals, micritic tidal flats, incipient "pseudooid" shoals and oolitic washovers.

The North Crop: The gradual breakdown of the barrier and back barrier divisions on the southerly parts of the South Wales Shelf also affected the more northerly parts. The back barrier lagoon area became less distinct from the marginal back barrier area. Hydrodynamic restriction became less obvious and the whole area became dominated by the characteristic mosaic of subtidal peloidal sands, discreet ooid shoals, micritic tidal flats and oolitic washovers, described from other parts of the South Wales Shelf.

7.2.6 End-Holkerian Palaeogeography

The end of the Holkerian stage was marked by widespread subaerial exposure of the South Wales Shelf sediments. Karst and caliche facies developments subsequently formed on this landsurface.

7.3 Controls on Holkerian Sedimentation

7.3.1 Introduction

The palaeogeographies described in the previous section illustrate the sedimentological evolution of the South Wales Shelf during the Holkerian Stage. The controls on this evolution are considered on two scales. The first control involves an explanation of the large scale (shelf-wide) rise in relative sea level, to account for the thickness of shallow shelf carbonates
SUMMARY: Shelfwide relative drop in sea level results in subaerial exposure horizon over all of the South Wales Shelf. Karst and caliche facies development in all areas.
accumulated. The second, smaller scale control, considers the effects of local tectonism and autocyclic sedimentation on shelf morphology and evolution.

7.3.2 Large Scale (Shelf-Wide) Controls on Shelf Evolution

The twin observations that Holkerian age rocks overlie progressively older rock to the north and that a considerable thickness (up to 300m) of shallow water carbonate sediments accumulated, imply that relative sea level rose during the Holkerian. Two theories have been put forward to explain the major control on this sea level rise. Ramsbottom (1973, 1977, 1979 and 1981) proposed a eustatic sea level rise, whilst George (1978), Bott and Johnson (1967) and Bott (1983) suggested a tectonic control.

George (1978) demonstrated that the intra-Dinantian overstep of successive major rock units within the South Wales Shelf deposits was attributed to complex episodes of uplift and erosion. Although discordant dips are not recorded in any one outcrop in South Wales, there is a reduction in sub-Holkerian composite Dinantian thickness of about 800m in 15km. This is interpreted to have been caused by complex and repeated bevelling at multiple surface unconformities related to differential subsidence across the South Wales Shelf.

The evidence of differential subsidence presented in this study e.g. the increase in thickness of Holkerian sediments to the south and a decrease to the north accompanied by intraformational hiatuses within the Dowlais Limestone Formation supports George's views (1978). The overall tensional regime of the British Carboniferous Limestone province provided the control for regional subsidence (Bott 1983). Local structural variation created differential subsidence both on a basin and intrabasin
However, eustatic controls on sea level, although masked by tectonic controls, cannot be totally discounted. A sudden drop in relative sea level at the end of the Holkerian Stage is evidenced by palaeokarst development on the outer shelf facies sequence at St Govan's Chapel (SR 966928) in Pembrokeshire (Chapter III, Section 3.8.2.2). The apparent magnitude of this event may be enhanced by unusually deep palaeokarst erosion levels. However, this widespread event marks a major relative drop in sea level over the whole of the South Wales Shelf. Sudden, basinwide, uplift seems an unlikely control given the overall tensional tectonic setting of the South West Province. Similarly, strike-slip transpressive effects within this tensional regime would only be evidenced on a relatively small part of the area. Thus this basinwide effect is interpreted to have been controlled, at least in part, by an eustatic sea level drop.

To summarise, the major control on Dinantian (and Holkerian) transgressive onlap of sediments onto palaeoland-surfaces in South Wales was a tectonic one. This was related to the overall tensional tectonic regime of the British Carboniferous Limestone Province. Eustatic sea level changes did operate during the Dinantian, but their effects were generally masked by the overall tectonic controls.

Attempts have been made to mathematically model relative amounts of tectonic and eustatic control on deposition of shelf carbonates (Ramsbottom 1981). However these arguments rely on the identification of complete successions and do not take into account intraformational hiatuses, or compactional effects. Thus they cannot be applied with confidence to the Holkerian rocks of
7.3.3 Small Scale (Intrabasin) Controls on Shelf Evolution

These controls originally affected sedimentation only in parts of the South Wales Shelf, but their net effect was to control the evolution of the whole Shelf. Local tectonic controls are discussed below, whilst autocyclic sedimentary controls are discussed in the following section.

7.3.3.1 Local Tectonic Controls

The previous section detailed how the overall tensional regime of the British Carboniferous Limestone Province created areas of differential subsidence, one of which formed the South West Province Basin. The carbonate sediments of the South Wales Shelf were formed on the northern margin of this basin, on the southern flanks of St. George's Land. The general morphology of the shelf was controlled by the increase in subsidence from north to south. This southerly dipping depositional slope was modified by localised topography related to underlying structures.

Three groups of structure are described; the Ritec Fault in Pembrokeshire, related structures parallel to depositional slope and structures related to uplift in the eastern parts of the South Wales Shelf.

Movements on the Ritec Fault at various times during the Upper Palaeozoic have been documented by Sullivan (1966). During the mid-Dinantian (approximately Arundian) uplift related to movement on the Ritec Fault at depth, controlled the position of the St. Georges Land shoreline with subaerial exposure to the north of Tenby (Sullivan 1965). South of Tenby, this topographic feature also controlled Late Arundian oolitic deposition (Chapter 4, Section 7.2). Throughout the Holkerian, the feature was gradually subdued by
sediment draping. During the Early Holkerian it was a major influence on the siting of ooid shoals and thus the subsequent isolation of the back barrier lagoon areas by the developing oolitic shoal barrier.

Further eastwards along the South Wales Shelf, a structure (?the Cardiff/Cowbridge Anticline) in the Central and Eastern Vale areas controlled uplift during the Late Arundian, in a broadly similar way to the Ritec Fault uplift in Pembrokeshire.

The initiation of ooid shoals in these areas and their subsequent progradation during the Late Arundian (Section 7.2) was related to this uplift. Similarly, during the Holkerian, the uplift influenced the initiation of ooid shoals further offshore in the Central and Eastern Vale than in the Western Vale. This also controlled the broader area of shallow shelf (marginal back barrier lithofacies) deposition characteristic of the Eastern Vale.

In Gower, evidence for a similar uplift is lacking. However there was differential subsidence during the Holkerian which accomodated the high rates of ooid shoal sedimentation in Central Gower. The hinge line for this subsidence was a normal fault at depth which was subsequently reactivated during Variscan macrofolding events and now forms the Cefn-Bryn Thrust of Central Gower (Chapter IV).

The uplift in the eastern parts of the Vale of Glamorgan was part of a general uplift in the eastern parts of the South Wales Shelf during the Holkerian. The increase in emergent horizons and lithofacies representing complex intertidal shorelines in the easternmost sections of the Dowlais Limestone Formation points to this fact. These facies changes combined with a thinning of
Holkerian age rocks eastwards suggests upwarping of the South Wales Shelf in the areas around the Usk Anticline. At the same time a facies change to the sandy deltaic deposits of the lower Drybrook Sandstone (Holkerian) in the Forest of Dean, occurred east of the Usk Anticline (Owen 1964, George 1956 and 1958).

The sandy limestone lithofacies found near the base of the Dowlais Limestone Formation in the eastern parts of the North Crop (Chapter 5) may also be indirectly related to this uplift. This possibility was first raised by Sibly in 1918, however an overall model to explain these localised uplifts has not yet been published.

A possible avenue for further research is the occurrence of strike slip movement along some of the major bounding faults in the area eg: the Dinas Fault (Neath Disturbance) the Malvern Line and a Severn Fault Zone. This could have initiated isolated zones of transpression (hence uplift) in an overall transtensional tectonic regime (Sanderson and Marchini 1984) Fig 7.7. Some of the uplifted structures have been recorded as having been initiated during the Dinantian eg: the Usk Anticline (Owen 1964, George 1956 and 1958, the Vale of Neath Disturbance (Owen 1953, George 1954), the Woolhope Anticline (Squirrel and Tucker 1960). However further detailed structural and sedimentological work will have to be done to unravel post-Dinantian structure and to validate the hypothesis.
FIG. 7.7 POSTULATED LOCAL TECTONIC CONTROLS ON SHELF SEDIMENTATION IN SOUTH WALES AND ADJOINING AREAS DURING THE LATE DINANTIAN (POST-ARUNDIAN) PERIOD.

KEY:
- UPLIFTED AREAS
- DEPRESSED AREAS
- FAULTS
- Clastic Input

OVERALL TENSIONAL TECTONIC REGIME

BROAD SHALLOW SHELF AREA CREATED BY UPLIFT IN CENTRAL + EASTERN WALES

ISOLATED ZONES OF UPLIFT DUE TO TRANSPOSITION (KOWEN 1984)

INCREASE IN EXPOSURE + DECREASE IN SEDIMENTATION RATES TOWARDS USK ANTICLINE UPLIFT

WOOLMORE ANTICLINE DEVELOPS ANTITHETICALLY TO THE DINAS FAULT AND TO THE MALVERN LINE (SQUIRES + TUCKER 1960)

MALVERN LINE REACTIVATED (RELLAWAY + HAMBLE 1983)

N

0km 150km

STABLE CENTRAL WELSH BLOCK

UPLIFT ON RITE Fault INFLUENCES OOLIG SHEAL INITIATION IN EARLY HOKRERIAN

BACK BARRIER LAGOON FORMS IN RESPONSE TO SHEAL BARRIER DEVELOPMENT

CARROU. CENTRER DISRUPTION
7.3.3.2. Allocyclic Sedimentary Controls

The initiation of ooid shoal sedimentation on the Very Early Holkerian Shelf had a profound effect on the evolution of the South Wales Shelf throughout the rest of the Holkerian Stage.

Although tectonic controls were partly responsible for ooid shoal siting and initiation (see previous section) Late Arundian sedimentary features were also important factors. The Late Arundian Shelf had a profile which gradually deepened offshore and thus could be described as a ramp (Ahr 1973). However this was modified by a fringing bank of skeletal sands (Simpson 1986) and is thus termed a "ramp with a fringing bank" (Read 1985), similar to Holocene examples of fringing seagrass banks in Sharks Bay, Western Australia (Hagan and Logan 1974). This fringing bank had an irregular topography which controlled the initiation and siting of Very Early Holkerian ooid shoals in the Central Gower portions of the South Wales Shelf (Chapter 4).

Subsequently, the most important control on the evolution of the Holkerian Shelf in South Wales was the progradation of these ooid shoals. As the shoals migrated seawards, early cementation created a widespread shallow area of stabilised oolitic aggregate grains behind them. This created the oolitic shoal barrier described in chapters 3 and 4. The development of the shoal barrier transformed the "ramp with a fringing bank" morphology of the Shelf into a "ramp with barrier ooid shoal complex" (Read 1985) similar to the Holocene Trucial Coast, Persian Gulf (Purser and Evans 1973). Progradation of the ragged seaward edge of the shoal barrier was also responsible for the complex inter-bedding of oolitic and bioclastic lithologies recorded in parts of the Cornelly Oolite Formation (Chapters 3, 4 and 6).

The immediate effect of shoal barrier development was to
create an area of back barrier environments. Initially this area was split into a marginal back barrier area and a back barrier lagoon. The former was characterised by channelised and micritic tidal flats within a background sediment of peloidal sands. This marginal back barrier area increased in size as the ooid shoals (and shoal barrier) continued to prograde seawards (Figs 7.3 and 7.4).

The back barrier lagoon area contained a mosaic of environments. These included isolated ooid shoals, shallow subtidal peloidal and bioclastic sands, micritic and channelised tidal flats, oolitic washovers, mixed carbonate and clastic sands, complex intertidal shorelines and areas of prolonged subaerial exposure. The complex interbedding of lithologies which resulted from this mosaic of environments was controlled by a number of sedimentary processes. These included local ooid shoal progradation, tidal flat aggradation and reworking, storm induced washovers and coastline erosion.

Although these controls were responsible for the facies mosaic of the back barrier lagoon deposits, the overall control on back barrier lagoon morphology was the position of the oolitic shoal barrier system on the South Wales Shelf. This is illustrated by the next stage in the evolution of the Holkerian Shelf.

Continued progradation of the ooid shoals to the outer parts of the shelf (represented by the southernmost outcrops in Pembrokeshire) Fig. 7.5, resulted in the development of a broad area of relatively uniform shallow deposition over the rest of the South Wales Shelf. This area was hydrodynamically protected by a rim of ooid sands, thus the Mid-Holkerian "ramp with barrier
ooloid shoal complex" had developed, by Late-Holkerian times, into a rimmed shelf " (Ginsburg and James 1974). This was a similar situation to the Quaternary south Florida Shelf (Enos and Perkins 1977). The shelf margin does not appear to have been marked by a sharp increase in palaeoslope, although outcrop of the critical outer shelf sequences is lacking. Thus the Late-Holkerian shelf could be termed an "accretionary rimmed shelf" (Read 1985).

The terminology used to describe the evolution of these Holkerian shelf sequences in this study is largely based on the classification of Read (1985). However the term "shelf" has been used in the broadest sense to define the difference between "basin" and "shelf" areas. Thus the term "shelf" would be equivalent to Read's (1985) term "platform".

Tucker (1985) has defined three distinct carbonate facies settings using the terms "platform", "shelf" and "ramp". However the terminology of Read (1985) is more useful when describing transitional carbonate settings and has therefore been used in preference to Tucker's (1985) classification.

The regression at the end of the Holkerian resulted in a widespread exposure horizon. This was subsequently flooded during the Asbian. Although a detailed study of Asbian sedimentology in South Wales has yet to be made, preliminary inspection suggests that the Late Holkerian accretionary rimmed shelf morphology developed further into an area of more, or less uniform depositional depth (a platform sensu Tucker 1985). Evidence to support this interpretation includes the widespread response of the area to relative sea level changes (i.e. repeated exposure horizons, the minor cycles of Ramsbottom 1979).

The postulated Asbian platform edge has not been identified in South Wales as it probably occurs further south than the
present day outcrop limit. Further sedimentological work is required in both the Asbian and Brigantian Stages of South Wales to elucidate their shelf morphology changes in more detail.
APPENDIX ONE

MODAL ANALYSIS

The following modal analyses of Holkerian sediments were carried out using a Swift point-counter and a mechanical stage graduated in 0.5 mm steps. For most specimens, greater than 400 counts were made, but occasionally in thin sections of smaller area fewer than this were possible. In any case not fewer than 150 counts were made on each section. In all cases grains are expressed as number of counts.

The data is collated into tables of lithofacies and, where applicable, lithofacies associations.

APPENDIX ONE: CONTENTS

1.1 Bioclastic Limestone Lithofacies
1.2 Bioclastic Limestone and Oolite Lithofacies
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   1.4.2 Micritic and Cryptagal Lithofacies
1.5 Back Barrier Lagoon Lithofacies Association
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   1.5.2 Simple Ooid Lithofacies
   1.5.3 Micritic and Cryptagal Lithofacies
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1.5 Back Barrier Lagoon Lithofacies Association

1.5.1 Dark Pel-Bio Limestone Lithofacies

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**SUB TOTAL GRAINS:**

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- Conc/Rad: 0, 0, 0
- Radial: 0, 0, 0
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### 1.5.2 Simple Ooid Lithofacies

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### 1.5.3 Micritic and Crystalline Lithofacies (Spec. 332)

#### 1.5.4 Sandy Limestone Lithofacies (Specs. 2101, 2124, 2121)

<table>
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<tr>
<th>Bioclast Type</th>
<th>PENDINE (332)</th>
<th>CEFN YSTRAD (2101)</th>
<th>CAREG OGOF (2121)</th>
<th>CAREG OGOF (2124)</th>
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<td>Micrite</td>
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<td>Spar</td>
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<td>Ooid</td>
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<tr>
<td>Peloid</td>
<td>101</td>
<td>98</td>
<td>31</td>
<td>54</td>
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<tr>
<td>Brach/mollusc</td>
<td>28</td>
<td>35</td>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>Echinoderm</td>
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<td>17</td>
<td>6</td>
<td>43</td>
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<tr>
<td>Algae</td>
<td>94</td>
<td>10</td>
<td>7</td>
<td>38</td>
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<td>Foram.</td>
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<td>17</td>
<td>2</td>
<td>7</td>
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<td>Other (Q TZ.)</td>
<td>0</td>
<td>(Q TZ.)70</td>
<td>(Q TZ.)61</td>
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<td>129</td>
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<td><strong>Sub Total Grains:</strong></td>
<td>236</td>
<td>204</td>
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**OOd Types:**
- Homogenous: 5, 2, 0, 0
- Concentric: 0, 14, 0, 0
- Conc/Rad: 1, 5, 82, 0
- Radial: 0, 0, 44, 0
- Broken: 0, 0, 0, 0
- Composite: 0, 0, 1, 0
### 1.5.5 Oolitic Aggregate/Intraclast Lithofacies

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<td><strong>40</strong></td>
<td><strong>48</strong></td>
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<tr>
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<td><strong>294</strong></td>
<td><strong>321</strong></td>
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