PALAEONTOLOGICAL AND SEDIMENTOLOGICAL STUDIES ON THE UPPER SILURIAN LUDLOW - DOWNTON SERIES TRANSITION IN THE WELSH BORDERLANDS AND SOME PHANEROZOIC BONE - BEDS

By

David Dorab Jamshed Antia, B.Sc., F.G.S.

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INTRODUCTION

The thesis (volume 1) has dealt with two major themes. The first was an examination of the uppermost Silurian (top Ludlovian - Downtonian) of the Welsh Borderlands. The second was a study of bone-beds and associated phosphorites arising from a study of the Ludlow Bone-Bed and associated deposits dealt with in the first theme.

The purpose of this supplement is to provide a synthesis of the main facts and conclusions which emerged from this study. It is subdivided into three sections. The first section provides a brief synthesis of each stratigraphic unit examined.The second section provides a more detailed synthesis of upper Ludlovian and Downtonian sediments in the Welsh Borderlands, and the third section provides a brief summary of the main facts and conclusions to emerge from the study of bone-beds.

SECTION 1

A SYNTHESIS OF THE SEDIMENTS PRESENT IN THE UPPER LEINTWARDINE BEDS, DAYIA NAVICULA BEDS, LOWER WHITCLIFFE BEDS, UPPER WHITCLIFFE BEDS, THE DOWNTON CASTLE FORMATION, THE TEMESIDE FORMATION, AND THE LEDBURY FORMATION.

A. LUDLOW SERIES

1. Leintwardine Stage.

(a) Upper Leintwardine Beds

LITHOLOGY :- SILTSTONE, buff to greeny brown, occasionally olive grey, firm to moderately hard, occasionally brittle, angular to blocky fracture, occasionally subfissile, clear quartz grains, grain size 0·01 to 0·09 mm (average 0·03 to 0·05 mm), angular to subrounded, high sphericity, moderately to poorly sorted, wackestone to floatstone texture, occasionally grainstone, clay matrix (slightly to very micritic), moderately to very argillaceous, moderately to very calcareous, slightly to moderately micromicaceous, slightly to very shelly, occasionally bioturbated, occasionally parallel laminated, nil to poor visible porosity

WITH OCCASIONAL NODULES OF

LIMESTONE, blue grey, moderately to very hard, angular to blocky fracture, moderately to very silty, very argillaceous (micritic) occasionally shelly. Nil visible porosity

FAUNAL ZONE :- Neobeyrichia lauensis

ENVIRONMENT OF DEPOSITION :- Marine offshore shelf sea with little current activity on the sea bed.

SEDIMENT TYPE :- Rhythmites with thin interspersed shell laminae, patches of intense bioturbation, and occasional calcareous nodules.

FAUNAS :- Moderate to high diversity and density values, low dominance values (see Volume 1, p.33 - 38). Dominated by articulate brachiopods and ostracods (see volume 1,p.256 for summary faunal list).

MAIN REFERENCE IN THESIS :- Volume 1 p.18 - 26.

(b) Dayia navicula Beds (of Kerry)

LITHOLOGY :- MUDSTONE, dark grey, moderately hard, blocky to subfissile fracture, slightly to moderately calcareous, slightly silty, very thinly bedded ($\leqslant$ 1 mm).

INTER-MICROLAMINATED WITH

SILTSTONE, light grey, moderately hard, blocky to angular fracture, slightly to moderately calcareous, clear quartz grains, subangular to subrounded, moderately to well sorted, wackestone to grainstone texture, moderately argillaceous, slightly micromicaceous, Nil visible porosity

THE MUDSTONE/SILTSTONE UNITS ARE INTER-LAMINATED WITH

LIMESTONE, light to medium grey, very argillaceous (micritic), slightly silty, slightly shelly, moderately to very bioturbated. Nil visible porosity

FAUNAL ZONE :- Indeterminate

ENVIRONMENT OF DEPOSITION :- Marine offshore basinal sea with little current activity on the sea bed.

SEDIMENT TYPE :- Rhythmites interbedded with megavarves

FAUNAS :- Low diversity and density values, high dominance value. The articulate brachiopod Dayia navicula was the only skeletal species recorded in this study from these beds.

MAIN REFERENCE IN THESIS :- Volume 1 p. 238 - 241.

NOTE :- These sediments could be of either lowest Whitcliffian or uppermost Leintwardinian age on available biostratigraphic evidence

2. Whitcliffe Stage

(a) Lower Whitcliffe Beds

LITHOLOGY :- SILTSTONE, buff to greeny grey, blocky to angular, occasionally subfissile fracture, very firm to moderately hard, clear quartz grains, angular to subrounded, poorly to moderately sorted, floatstone to grainstone texture, moderately argillaceous, slightly to very calcareous (micritic), slightly to moderately micromicaceous, slightly microcarbonaceous, moderately shelly, with some shell laminae, variably parallel laminated, ripple laminated, bioturbated, channelled and scoured.

FAUNAL ZONE :- Calcaribeyrichia tegula

ENVIRONMENT OF DEPOSITION :- Marine offshore shelf sea, probably fairly shallow (? 50 - 150m water depth)

SEDIMENT TYPE :- Laminated siltstones with storm deposited shell laminae.

FAUNAS :- Moderate diversity values, moderate to high density values, high dominance values. The fauna is dominated by articulate brachiopods (see Volume 1 p. 256 for a summary faunal list).

MAIN REFERENCE IN THESIS :- Volume 1 p. 18 - 66

(b) Upper Whitcliffe Beds

LITHOLOGY :- SILTSTONE, buff to greeny grey, blocky to angular, occasionally subfissile fracture, very firm to moderately hard, clear quartz grains, angular to subrounded, moderately sorted, slightly to very calcareous, (micritic) slightly micromicaceous, slightly microcarbonaceous, moderately shelly with some shell laminae, variable grainstone to floatstone texture, variably parallel laminated, lenticular bedded, wavey bedded and bioturbated.

FAUNAL ZONE :- Calcaribeyrichia torosa

ENVIRONMENT OF DEPOSITION :- Shallow marine near shore shelf sea, occasionally intertidal. Mainly deposited within a region of tidal flow.

SEDIMENT TYPE :- Lenticular bedded siltstones with storm deposited shell laminae.

FAUNAS :- Low diversity values, moderate to high density values, high to very high dominance values. The fauna is dominated by articulate brachiopods with some in situ bivalves. (see Volume 1 p.256 for a summary faunal list)

MAIN REFERENCE IN THESIS :- Volume 1 p. 26 - 305

B. DOWNTON SERIES

(a) Downton Castle Formation

LITHOLOGY :- SANDSTONE, buff, yellow, blocky, occasionally fissile to subfissile fracture, moderately hard, clear quartz grains, very fine to fine grained, angular to rounded, poor to well sorted, packstone to grainstone, occasionally wackestone texture, variably slightly to very micromicaceous, occasionally micaceous, slightly to moderately microcarbonaceous, occasionally moderately to very carbonaceous, slightly to moderately argillaceous, variably cross-bedded to ripple-bedded occasionally present as channel infill, poor visible porosity.

INTERBEDDED WITH

SILTSTONE, buff to grey, blocky, occasionally subfissile fracture, quartz grains, subangular to subrounded, poor to well sorted, occasionally slightly calcareous, moderately limonitic, occasionally shelly, slightly micromicaceous, slightly to moderately microcarbonaceous, slightly pyritic, moderately argillaceous, lenticular, ripple and wavy bedded, occasionally channeled and mudcracked.

AND MINOR

BONE-BEDS, brown, crumbly to blocky fracture, thelodont and acanthodian fish grains, very fine to medium, occasionally coarse grained, subangular to rounded, moderate to well sorted, grainstone texture, occasionally moderately argillaceous, occasionally moderately to very calcareous (micrite and sparite), ripple laminated, moderate to good porosity.

FAUNAL ZONE :- Frostiella groenvalliana

ENVIRONMENT OF DEPOSITION :- Intertidal mudflats and beaches

SEDIMENT TYPE :- Trough cross bedded sandstones, ripple channeled and mudcracked, lenticular bedded siltstones and bone-beds.

FAUNAS :- Low diversity values, high to low density values, high dominance values, The fauna is dominated by ostracods, inarticulate brachiopods and mollusca. (see Volume 1 p.256 for summary faunal list)

MAIN REFERENCE IN THESIS :- Volume 1 p.67 - 193

(b) Temeside Formation

LITHOLOGY :- SILTSTONE, green, firm to moderately hard, clear quartz grains subangular to subrounded, moderately sorted, floatstone to grainstone texture, moderately argillaceous to very argillaceous, occasionally very sandy (fine to medium grained), occasionally calcareous with micritic glaebules, occasionally mudcracked, occasionally parallel and wavy bedded, occasionally shelly, slightly to moderately microcarbonaceous.

FAUNAL ZONE :- Frostiella bicristata

ENVIRONMENT OF DEPOSITION :- Intertidal mudflats with oncolite horizons

SEDIMENT TYPE :- Wavy bedded and mudcracked siltstones

FAUNAS :- Low diversity values, low to moderate density values, high dominance values. The fauna is dominated by ostracods. See Volume 1 p.223 for faunal list.

MAIN THESIS REFERENCE :- Volume 1 p. 220 - 227.

(c) Ledbury Formation

LITHOLOGY :- MUDSTONE, brick red, occasionally green, blocky to rubbly occasionally subfissile fracture, moderately to very calcareous, with micrite pipes and nodules, slightly micromicaceous, slightly silty, slightly carbonaceous, occasionally channelled.

WITH MINOR

SANDSTONE, grey, quartzose, fine to coarse grained, subangular to subrounded, moderately well sorted, grainstone to packstone texture, calcite matrix, slightly to moderately argillaceous, slightly carbonaceous, poor visible porosity.

FAUNAL ZONE :- Aparchites sinuatus

ENVIRONMENT OF DEPOSITION :- Supratidal mudflats

SEDIMENT TYPE :- Laminated red mudstones with superimposed caliche structures

FAUNAS :- Moderate diversity values, very low density values, low dominance values. Faunas dominated by ostracods. See Volume 1 p. 256 for a summary faunal list.

MAIN REFERENCE IN THESIS :- Volume 1 p. 203 - 220

SECTION 2

SEDIMENTS, FAUNAS, AND PALAEOENVIRONMENTS OF THE UPPER SILURIAN

The stratigraphy of the British Upper Silurian is tabulated in Volume 1 p. 196. The rocks examined in this study may be summarised as follows :-

(a) Leintwardinian Stage

Only three sections within the Leintwardinian Stage were examined Two were in Mortimer Forest near Ludlow in the Upper Leintwardine Beds (GR SO 497 725;497 717). The third section was in the *Dayia navicula* Beds near Kerry (GR SO 156 859). The Mortimer Forest sections are in a'shelf' region (sensu Holland & Lawson,1963) while the Kerry section is in a'basinal' area (sensu Holland & Lawson,1963).

The uppermost Leintwardinian sediments examined in Mortimer Forest (Volume 1 p.18 - 26) consist of calcareous blue grey siltstones and micritic calcarenites containing minor quantities of shell debris.

This shell debris tends to be scattered throughout the rock as rare ($<4\%$) fragments of bryozoans,brachiopods,bivalves,cephalopods,gastropods, hyoliths,ostracods and trilobites. These fragments have a maximum dimension which rarely exceeds 2mm and are frequently rounded. This rounding may be a result of abrasion and/or diagenetic solution. They show no fungal or algal borings. The thinner molluscan shells (e.g. hyoliths and bivalves) are frequently replaced by micrite or limonite.Larger shells and shell debris are scattered throughout these sediments.

Limonite is fairly abundant in the matrix of the more weathered siltstone specimens examined,and may have been derived from the breakdown of pyrite and clays within the original sediment by recent weathering processes.An alternative and perhaps more probable source for the iron in the limonite is from percolating ground waters. It is interesting to note in this context that the base of the Recent topsoil immediately overlying the Upper Leintwardine Beds frequently contains a thin (1 - 10 mm thick) discontinuous bright orange ferruginous soil layer.

Locally within the parallel laminated siltstones shell laminae are present. These shell laminae are thin (≤ 5mm thick) and occur as discontinuous layers which are traceable laterally for 1 to 2 m within individual sections. These shell laminae tend to be fairly well sorted and usually show a unimodal grain size distribution (mean 2 - 4 mm). The shells in these layers are dominated by brachiopods and/or ostracods. The ostracods consist of valves and rare carapaces, which in some instances have provided the anchorage for bryozoan colonies such as *Leioclema* sp.. The brachiopod shells are both entire and fragmentary. Robust thick-shelled forms with strong hinges (e.g. Microsphaeridiorhynchus nucula) commonly occur as articulated valves, while 'thin'shelled forms with weak hinges (e.g. Salopina lunata, Protochonetes ludloviensis, Craniops implicatus, Aegiria grayi, Shaleria ornatella etc) commonly occur as disarticulated and often fragmentary valves. The shell laminae contain orthoconic nautiloids and bivalves as fragmentary remains, which have in many instances been colonised by both boring and encrusting bryozoans.

Locally, micritic nodule bands are present (Volume 1, p.22, 23). Two such bands were noticed. One of them consisted of small compact nodules which were partially encrusted by bryozoa, suggesting that they were exposed to the sea surface after formation. The other nodule band consisted of more elongate and larger nodules which were not colonised by bryozoa.

The third section visited briefly in the Leintwardine Stage was near Kerry (GR SO 156 859) in the Dayia navicula Beds (Volume 1 p. 238 - 241) of the Ludlovian basin. Here the sediments consisted of rhythmite units comprised of alternating microlaminations of dark grey clays and light grey siltstones interbedded with thicker (1 - 10 cm. thick) bioturbated grey micrite units containing the brachiopod Dayia navicula as their dominant skeletal fossil.

The palaeoenvironments represented by these three sections are not easily interpreted and the sediment types present could have been deposited in any one of a number of different palaeoenvironments i.e. shallow shelf seas, various basinal environments, intertidal and supratidal environments. The sediments present in the Mortimer Forest sections were deposited within the traditional Ludlovian shelf sea (sensu Holland & Lawson, 1963), and contain no diagnostic sedimentological features which could confirm or deny this interpretation. The Kerry section contains sediments, which were deposited in the traditional Ludlovian basinal sea (sensu Holland & Lawson, 1963). Although conclusive proof would require a very detailed sedimentological study, the preliminary results discussed here (Volume 1 p. 238-241) show that the sediments in this section bear some resemblance to the Holocene rhythmites and megavarves described by Deegans et al (1978). Such sediments could have formed in a subtidal basinal environment.

(b) Whitcliffian Stage

Studies on the Whitcliffian Stage were concentrated within the Ludlow - Much Wenlock region, though some more distant sections near Kerry Builth Wells, and Tites Point and from the Brookend Borehole and the Long Mountain were examined (Volume 1, p.13-281, 285-305, 433-498). The top of the stage was recognised by the first appearence of the ostracod Frostiella groenvalliana and its base by the first downward appearence of the ostracod Neobeyrichia lauensis (cf. Shaw,1969;Lawson & Whitaker,1968). Biostratigraphical subdivisions are not recognisable within the stage in the area studied. Whitcliffian sections whose exact relationship to the top or base of the stage is unclear are termed here unlocalised Whitcliffian sections. A total of 37 sections containing Whitcliffian sediments were examined from the Ludlow-Much Wenlock district. The sediments contained within them may be summarised as follows :-

1. Lower Whitcliffian sections

The two sections examined in Mortimer Forest in this time interval are at GR SO 497 725 and 497 717. They are described in volume 1 on pages 18 - 26 and consist of buff to greeny grey,shelly bioturbated siltstones which contain both ripple and parallel laminations. All the Lower Whitcliffian sediments were weathered and it is not clear what proportion of the original calcium carbonate present within them has been leached out by weathering processes. Locally within the section thin shell laminae and channels up to 80 cm deep are present.

The sections through the entire Whitcliffian at Tites Point and the Brookend Borehole (Volume 1,p.440,442-444,477) were briefly examined and differ from the Whitcliffian of the Ludlow District in containing abundant bone-beds and phosphorite horizons.

2. Whitcliffian sections of uncertain age

A number of sections within the Ludlow-Much Wenlock district which are biostratigraphically unlocatable within the Whitcliffian with respect to the stages top or base were examined (see Volume 1,p.16-33). They all contain calcareous shelly siltstones,which are bioturbated ripple and parallel laminated. Occasional slump horizons and shell laminae were observed (Volume 1 p.16-33).The siltstones are occasionally scoured (Volume 1,p.16-33). The amount of micritic calcite in these sediment is highly variable having been greatly reduced by recent weathering.

3. Uppermost Whitcliffian sections

A number of sections within the uppermost part of the Whitcliffian Stage were examined in the Ludlow-Much Wenlock area. They are described in Volume 1 p.67-193.. The rocks contained within these sections consist of lenticular,parallel and ripple bedded siltstones. The ripple bedding present varies from symmetric crescentic current ripples (wavelength 5-20cm:amplitude 3 - 30mm) to "lingoid" and miniripples. The parallel laminated bedding consists of alternating microlaminations of fine and medium/coarse silt horizons of a floatstone and wackestone texture.The sediments are bioturbated and occasionally contain micrite intraclasts (Volume 1 p.83).

The mineralogy of these sediments is described in Volume 1 p. 84, 164,455,471. Its dominant constituent is quartz occurring as grains varying in diameter from 0.005 to 0.18 mm. The smaller quartz grains tend to be elongate. Some quartz grains greater than 0.1mm in length are strained, others are composite.Most are angular,though some rare well rounded quartz grains are present. Details of the relative elongation (sphericity) of the quartz grains are given in Volume 1 ,p.81 and discussed in volume 1 p.108-111. The relative sphericity of these grains suggests that they were deposited in a tidally influenced low energy accreting environment. Leucoxene is the most common heavy mineral and may result from the diagenetic replacement of ilmenite. Micas are present as platy,rounded and angular grains (0.08-0.35 mm in length) frequently containing frayed edges. Clays and micritic clays form 30-70% of these weathered sediments and show several phases of diagenetic growth. ~~The initial growth~~. The initial growth appears to have been of platy and honeycomb clays around quartz nuculei,followed by a subsequent microcrystalline co-precipitation of clays and calcite within the 'newly' created sediment pores. At the present time chlorite is the dominant clay,though traces of montmorillonite, kaolinite and illite are present.

Disarticulated and fragmentary shells are scattered throughout these sediments and occasionally form shell laminae. However,the composition of these shell laminae is highly variable laterally (Volume 1,p.88,90). Within the articulated brachiopod and bivalve shells present in these sediments different diagenetic microenvironments appear to have operated with respect to those of the micritic siltstones which entomb them. Most contain a geopetal infill of micrite overlain in some instances by a coarse sparite.Many of the calcareous shells have been replaced by sparite,though some micrite envelopes are present.

4.Whitcliffian shell laminae (Volume 1 p. 51-66)

Shell laminae are common throughout the Whitcliffian.They vary greatly in their mode of occurrence,particle densities and thicknesses. Most are less than 5 mm thick,but may in places reach thicknesses in excess of 150 mm. They have all been buried by an argillaceous micritic silt. Occasionally geopetal fabrics and sparitic calcite are preserved inside univalves and articulated brachiopod and bivalve valves. The actual faunal composition of individual shell laminae is highly variable,vertically and laterally. An indication of their composition is given in Table 1. A total of 51 species have been recorded from these laminae and are listed in Table 2. Bivalves,brachiopods,orthoconic nautiloids and hyoliths occur in all the shell laminae as disarticulated valves and shell fragments. The proportions of articulated, disarticulated and fragmentary valves and and shells varies both within and between individual shell laminae,both laterally and vertically. This variation gives many of the thicker shell laminae a graded appearence. This grading need not be a primary depositional feature,but could result from post-depositional sorting and settling effects within the deposit.

The fauna present within the shell laminae includes benthic swimming brachiopods (e.g.Protochonetes ludloviensis) adapted for an epifaunal existence on a soft muddy substrate,epifaunal pedically attached brachiopods (e.g. Microsphaeridiorhynchus nucula), nectonic cephalopods,encrusting bryozoans and annelids,epifaunal gastropods and both epifaunal and infaunal bivalves. Some of the animals (e.g. bryozoans and ostracods) probably colonised the shell laminae; they may, when found in an apparent life orientation or as carapaces,be regarded as representing an *in situ* fauna which post dates the deposition of the shell laminae (see Volume 1,p.40-43;61-62).Encrusting cemented epizoans such as Schizocrania striata,Spirorbis sp. and some annelids,which are only found on orthoconic nautiloids,probably represent an encrustation phase on living or floating orthocones (Volume 1,p.285 - 305,521-530). All the bivalve and brachiopod species occur in apparent life orientations in the micritic silts surrounding the shell laminae,thus suggesting that the shell laminae represent local concentrations of shell material derived from neighbouring areas of low shell density.

The thinner shell laminae ($<$5 mm thick) occur either as discontinuous layers,which are traceable laterally within a section for 2-10 m or as shelly ripple trough infill. The thicker shell laminae either form part of shelly megaripples (wavelength 0.5-10 m;amplitude 4-15cm) or they infill small scour channels.Although most of the thin shell laminae overlie laminated or bioturbated siltstones,some are associated with sand sheets,vertebrate remains and small semiphosphatised pebbles. Both the thin and thick shell laminae contain shell densities of 400,000 - 20,000,000 shell particles in a cubic metre of shell material.

These shell laminae formed as a result of non-cyclic random depostional processes (Volume 1,p.51 - 66). Among the thinner shell laminae a positive correlation between the degree of bioturbation of the sediments immediately underlying the shell laminae and the proportion of concave-up oriented shells contained within them. A similar correlation was observed between the proportion of concave-up oriented shells and the number of bryozoan colonies on the shells of a thin shell laminae immediately overlying a bioturbated substrate. The shell sheets are interpreted in this study (Volume 1,p.51 - 66) as having been concentrated by water turbulence caused by storms and the orientation relationships as resulting from biogenic activity within a 'short' break in sedimentation following the storm.

5.Whitcliffian environments

The Whitcliffian sediments of the Ludlow-Much Wenlock district are commonly regarded as subtidal shelf sea deposits (see Holland & Lawson,1963). Although no sedimentary evidence to confirm or deny this viewpoint has been recorded in this study. It is my opinion that this interpretation is probably correct, for the vast majority of the Whitcliffian. However, the uppermost Whitcliffian sediments were probably deposited in a low energy tidal environment. This is indicated by their lenticular bedded nature and partially confirmed by a quartz grain elongation study (Volume 1, p. 108-111). This study suggested that the uppermost Whitcliffian sediments accumulated in an accreting tidal environment of diminishing energy conditions in which alternating tidal currents varied in strength and duration.

At Siefton (Volume 1, p. 127-140) the higher Whitcliffian sediments contain some anti-ripplets, thus suggesting that at least some of the uppermost Whitcliffian sediments were deposited in an intertidal or supratidal environment (Volume 1 p. 127 - 140).

6. Whitcliffian faunas

Whitcliffian faunas are dominated by articulate brachiopods (e.g. Protochonetes ludloviensis, Salopina lunata and Microsphaeridiorhynchus nucula), though other species occur (Table 1 and 2). They are listed in Volume 1 p. 17, 20, 21, 27, 30, 32, 77a-79, 130, 146, 152, 154, 156, 161, 163, 167, 168, 172, 191, 242, 247, 443-447.

The faunas have a fairly low diversity averaging about 15 species for every thousand fossils found (Volume 1, p. 24). Diversity usually either increases markedly or drops markedly when shell laminae are encountered (Volume 1, p. 24). This is presumably because in the first instance 'exotic' species have been introduced and concentrated by sedimentological processes, while in the latter the same processes have resulted in a greater sorting of shells and hence depletion of their faunal diversity. Post-depositional colonisation of the shell laminae may account for some of the increase in diversity.

Faunal diversity appears to decrease from the Leintwardinian into the uppermost Whitcliffian, while at the same time faunal dominance appears to increase over the same time interval (Volume 1, p. 33 -37). This negative relationship between faunal dominance and faunal diversity coincides with a positive relationship between faunal dominance and the diversity of the dominant species. These relationships are interpreted (Volume 1, p. 33) as reflecting an increase in environmental instability and sedimentological sorting between the Upper Leintwardine Beds (top-most Leintwardinian) and the Upper Whitcliffe Beds (top-most Whitcliffian). Over this time interval there is also a marked change in the 'similarity' of the faunas. This change (Volume 1 p. 258) relates to an increase in the diversity of the dominant species and to changes in the diversity and relative abundance of the various species in these sediments (Volume 1, p. 258).

No major vertical changes occur in faunal composition of this time interval (see Volume 1,p.256). The only noticable change is a reduction upwards in the number of species present. However, it is interesting to note that Calcaribeyrichia tegula occurs in the basal Whitcliffian and not in the upper Whitcliffian, while C.torosa occurs in the Upper Whitcliffian and not in the basal Whitcliffian. Although these two species may eventually be usable biostratigraphically, they occur in such low densities that it is difficult at the present time to prove that the two species do not occur together,

7. Whitcliffian faunas and sediments outwith the Ludlow District

Some Whitcliffian sediments in the Builth Wells, Kerry, Long Mountain and Tites Point districts were examined briefly (Volume 1,p.239 - 249,443,444) In the Kerry and Long Mountain districts they consist of thin rhythmite units interbedded with grey bioturbated micrites and occasional allodapic limestones and distal turbidites, containing flute marks and shelly soles. In the Builth district the sediments are similar to those at Ludlow and consist as at Ludlow of rippled and bioturbated shelly siltstones while at Tites Point and in the Brookend Borehole they only differ from the sediments at Ludlow in containing biotite bands, phosphorite horizons and bone-beds. The faunal compodition of all these sections is very similar to that observed near Ludlow in the Whitcliffian.

C. DOWNTON SERIES

The Downton Series contains three formations, i.e. the Downton Castle Formation, the Temeside Formation, and the Ledbury Formation. Only the base of the Downton Castle Formation has been examined in any detail in this study.

1. The Downton Castle Formation

The Downton Castle Formation rests on the Upper Whitcliffe Beds and contains the Ludlow Bone-Bed at its base in the Ludlow District. This deposit is overlain by mudstones and fine grained sandstones. The sections examined in this formation are principally described in Volume 1 (p. 67-193, 195-201, 344-347, 371-375, 414-432, and intermittantly between 433 and 498) and occur between Ludlow and Much Wenlock. The fauna of this formation differs greatly from that of the underlying Upper Whitcliffe Beds in being dominated by ostracods, inarticulate brachiopods, bivalves and gastropods. Three sedimentary facies have been recognised in this study within the formation. They are a bone-bed facies, a mudflat facies and a beach facies

(a) The basal bone-bed facies (including the Ludlow Bone-Bed)

This facies has been extensively described within the thesis (e.g. Volume 1,p. 67-193, 195-201, 344-347, 371-375, 414-498). It contains at its base a bone-bed deposit of patchy distribution which has been termed (elaewhere) the Ludlow Bone-Bed and covers an area of about 5,000 sq km. This bone-bed rests, in the Ludlow-Much Wenlock district, on a rippled micritic siltstones, containing a crescentic rippled upper surface (wavelength 5 - 10 cm; amplitude 5 - 10 mm). The ripple troughs are commonly bioturbated containing Bifungites burrows infilled with coarse silt, vertebrate debris and occasionally as at Corfton, glauconitic fecal pellets. Over this sediment surface burrow densities vary from 0 to 75 Bifungites burrows per square metre. Other burrow types present on this bedding plane surface include Agrichnium, Dendrotichnium, Lobichnus and Skolithus (e.g. Volume 1,p.151). Occasional specimens of Goniophora cymbaeformis occur half buried in the sediment on this bedding plane in apparent life orientation.

The basal bone-bed consists of a thin discontinuous (normally about 1 - 6 mm thick, occasionally thickening to 150mm) gingerbread-coloured vertebrate sand infilling ripple troughs and scour hollows in the underlying sediment, grading laterally into a rippled vertebrate sand (e.g. Volume 1 p.449,476). It is composed largely of thelodont scales in a packstone to grainstone, occasionally wackestone texture, with some acanthodian debris and phosphatised shell fragments and phosphatised casts and moulds of hyoliths, gastropods, brachiopods and bivalves (Volume 1,p.93-103,414-432,462). These thelodont scales posses exoscopic abrasion features, fungal borings (on their outer surfaces) and syndepositional weathering features (e.g. Volume 1,p.99,306-321,371-375,378-380,402-405, 414-432). Silicified fungal remains also occur on some quartz grains in this deposit (Volume 1,p. 414-432). The matrix of this bone-bed varies greatly in composition from a sparite to a micrite and a silty micrite The mean grainsize of the quartz grains in this silt is about 0.045 mm (Volume 1,p. 94). Calcareous shell debris is absent from the bone-bed However, the larger quartz grains and fish debris in this layer have commonly acted as centres for diagenetic calcite, micrite, chlorite and silica growth . The vertebrate remains have been altered to fluorapatite and carbonate apatite during diagenesis and the bone-bed is not considered here to be a prefossilised deposit (Volume 1,p.323-404).

This bone-bed is overlain by a thin (3-5 cm thick) layer of grey calcareous parallel laminated and lenticular bedded mudstones and siltstones containing a brachiopod fauna and the moulds of ostracods and molluscs (e.g. bivalves and gastropods). Also present within these mudstones are isolate bedding planes strewn with fish debris and shell fragments. Some rippled sediments and thin bone-beds are also present. Locally within this facies a soft clay, rich in chlorite, quartz, muscovite and sengiorite occurs. It is chemically and morphologically similar to bentonitic clays present elsewhere in the uppermost Whitcliffian of the Ludlow - Much Wenlock district. (Volume 1, pp. 470 - 471)

The environment represented by this facies in the Ludlow - Much Wenlock region (as indicated by the sediments, sedimentary structures, grain size and sphericity analyses made in the text (e.g. Volume 1, pp. 67 - 189, 414 - 432), was probably a slowly accreting low energy tidal region in which alternating tidal currents varied in strength and duration, over a low inter-tidal or high subtidal 'mudflat' environment, containing patches of vertebrate sand strewn over its surface. Perhaps a morphologically similar environment is represented today by the Mellum mudflat complex on the North sea coast of West Germany. Here bone-beds are currently forming on mudflats as large thin discontinuous patches of vertebrate material (e.g. Volume 1, p. 338). If the environment represented by the facies is intertidal, then the presence of bentonitic clays within it is interesting, because it provides a possible explanation for the high concentrations of fish debris present within the bone-beds. Consequently, it has been suggested within the thesis (Volume 1, pp. 344 - 347, 470) that the bone-beds may have formed by the re-working of fish killed by the settling of volcanic ash on to the sea. Subsequently winnowing of the sediment on the sea bed would have removed much of the bentontic clay from the surface layers and the decomposition of the fish would have resulted in their floation and transport into the intertidal zone as a series of discontinuous vertebrate sand patches around the low tide mark. This hypothesis is supported by the presence of euhedral biotite (a common constituent of many Ludlovian bentonites) within the bone-beds, the evidence from bone weathering, fungal colonisation studies and grain sphericity studies (Volume 1, pp. 81, 306 - 321).

Within the Ludlow - Much Wenlock region the transition from subtidal calcareous siltstone deposition (top Whitcliffian) through to intertidal bone-bed deposition appears, on available biostratigraphic evidence (Volume 1 67 - 193), to have been synchronous, suggesting that, perhaps, the localities examined were located along a line parallelling a late Silurian shore. Such a shoreline could have been located to either the South-east or North-west of this line. The presence ~~of~~ at Siefton (Volume 1, pp. 127 - 140) of intertidal sedimentation in the top Whitcliffian suggests that the shoreline lay to the North-west of the Ludlow Much Wenlock line. To the North-west of Siefton and the Ludlow - Much Wenlock line is a fault bounded Precambrian block. It is suggested in this thesis (Volume 1, pp. 228 - 237, 434 - 439) that tectonic compression effects caused by the closure of the Iapetus Ocean and the East Midlands Aulacogen forced many of these fault bounded Precambrian blocks to rise towards the end of the Ludlovian. The net result was the formation of an intertidal environment around the margins of these blocks in the earliest Downtonian. Although carbonate sedimentation continued in the Long Mountain during this time it is interesting to note that to the South-east of the Ludlow - Much Wenlock line, the Bone-Bed facies is replaced by either a quartz sand containing some fish debris or a black clay rich in fish debris and phosphate nodules. This latter deposit, which is present near Birmingham, at Mayhill and Woolhope appear to grade southwards into a phosphorite in the Brookend borehole. It is considered in the thesis to represent a subtidal equivilent of the Ludlow Bone-Bed, which signifies a major chemical change in the sea water along a line south-east of the Early Downtonian shoreline which may have stretched from Much Wenlock to the south of Kington (see Volume 1, p. 435). This region may also have been bounded by a shoreline stretching from North of Birmingham to Malvern (see Volume 1, P. 435) but this is less certain.

These clays may be described as black/brown soft organic rich clays containing gypsum, phosphorite nodules and fish debris and are described in detail in Volume 1 p. 165 - 170, 190 - 193, 433 - 498. As with the bone-bed facies, they mark a major change between faunas and sediments of the top Ludlovian and basal Downtonian. Such changes are greater than would normally be expected in a transition from a subtidal to an intertidal environment (Volume 1, P. 127 - 189, 532 - 542) and have led many geologists to regard the junction as an unconformity. Consequently, much space has been given to interpreting these clays in the thesis, (Volume 1, p. 165 - 182, 190 - 193, 433 - 498) and expanding the implications of their interpretations. Throughout I have assumed that these clays were formed in a subtidal environment, rather than resort to the more improbable hypotheses that, either, the bone-bed facies represented a widespread unconformity or a sequence of intertidal sediments which were deposited synchronously throughout the Welsh Borderlands.

In preference to these two hypotheses I have suggested that the Ludlovian - Downtonian transition to the South-east of the Longmyndian - Kington Landmass coincides with a major change in sea water chemistry. Though this is clearly not true in the Long Mountain region situated to the North-east of the Longmyndian landmass, where 'carbonate' sedimentation occurs across the transition (Volume 1, P. 248 - 252)

The evidence is presented as follows :-

(1) Within the top Ludlovian, changes from subtidal to intertidal environments resulted in the presence of abundant transported shells of articulate brachiopods and other subtidal species within the carbonate sediments of the intertidal zone. (Volume 1, p. 127 - 140) Similar distributions of shells are present in modern intertidal environments (Volume 1, p. 532 - 542). However, at the Ludlovian - Downtonian boundary both faunas and sediments change abrubtly at the intertidal - subtidal boundary with a shelly carbonate rich sediment being replaced by a shelly limonite rich sediment in which the subtidal brachiopod fauna has been totally replaced by a molluscan - ostracod fauna (Volume 1, p. 67 - 189). This change even takes place abrubtly within an intertidal zone (Volume 1, p. 129). Such changes are much greater than would normally be encountered at a subtidal - intertidal transition (e.g. Volume 1, p. 532 - 542).

(2) Within the dark clays of the 'Ludlow Bone-Bed'. Phosphorite nodules are present, which appear to have formed within the sediment in which they are now entombed (e.g. Volume 1, p. 433 - 498). Their presence implies a change in environmental chemical parameters. This has been discussed at length in Volume 1, p. 433 - 498.

(3) Beneath the phosphatic clays at Netherton a thin gypsiferous dark clay rests on the Ludlovian carbonate sediments. This gypsum may be a late stage product of diagenesis, but could equally well have formed during early diagenesis. The available evidence is insufficient to say which is correct, but even if the first hypothesis is correct, the second could also be correct with the gypsum present being an alteration product of original authigenic gypsum. The basic implications of authigenic gypsum within a dark clay underlying a dark clay containing authigenic phosphate has been discussed in Volume 1, p. 190 - 193. The resulting hypothesis lends support to the major conclusions which had already emerged from the faunal and sedimentological studies, namely that the Ludlovian - Downtonian boundary corresponds (within the narrow sea inlet between the postulated Longmyndian land mass and Birmingham - Malvern land mass) to a change in the chemical composition of the Silurian Ocean. This change in seawater chemistry from an initial (Ludlovian) $CaCO_3$ saturated bottom waters to oxygen rich calcium carbonate depleted bottom waters, could account for all the changes seen, including the deposition of phosphorites. It could have occurred as a result of any number of processes including current-switching associated with up-welling ocean currents or the inflow of fluvial waters into this region. This latter hypothesis is preferred in the thesis because it allows the development of the late Downtonian and Dittonian fluvial systems to occur as a natural continuation of processes initiated in the late Ludlovian. It is likely that local periodic vulcanicity only led to the development of bone-beds within the sequence and did not initiate the major chemical changes in the Silurian ocean postulated.

The palaeoenvironments at this time horizon are reconstructed both sedimentologically (Volume 1, p. 423 - 475) and paleoecologically and environmentally in Volume 1 p. 171 - 182.

(b) Other Downton Castle Formation Facies

The sediments above the bone-bed facies may be assigned to two facies i.e. a (1) lower Mudflat facies and(2) an upper 'beach' facies. They have been extensively described in Volume 1 between pages 67 and 281, but may be summarised as follows :-

(i) Lower Mudflat facies

The facies consists of lenticular-bedded mudstones, siltstones and fine grained sandstones. Shell debris and streaks of bone-sand are fairly common, wrinkle marks, mini ripples, current ripples and wave ripples occur in these sediments in association with gutter casts, mud cracks and scour channels. Limonite - replaced burrows and shells are present. Fuller descriptions of this facies are given in Volume 1, p. 103 - 106, 141 - 189. Grain size, sphericity distributions and mineralogy are discussed within Volume 1, p. 67 - 126. The sediments are considered here to have been deposited within an intertidal mudflat environment (Volume 1, p. 103 - 106, 141 - 189).

(ii) Upper 'beach' facies

This facies consists of micaceous buff sandstones containing mega-ripples (wave length 0.5 - 10 m, amplitude 5 - 50 cm) with secondary ripples, interference ripples and sand volcanoes superimposed on their surfaces. Small patches of vegetal debris are present in the ripple troughs. These sandstones are frequently interbedded with parallel laminated siltstones, which are locally bioturbated. They are regarded here as high intertidal and low supratidal beach or back beach deposits (Volume 1, p. 67 - 281)

(c) Downton Castle Formation faunas

The faunas of the Downtonian examined are listed in Volume 1, p. 77a - 79, 97, 130, 147, 148, 152, 154, 156, 161, 163, 164, 167, 168, 172, 174, 191, 443 - 447, 450, and 462. They differ greatly from the underlying Whitcliffian faunas in being dominated by ostracods, bivalves, molluscs and inarticulate brachiopods - see Volume 1, p. 256 and Table 3. They are described and illustrated throughout the thesis in environmental, ecological and taxonomic contexts. The principal sections are in Volume 1, p. 171 - 182, 241 - 246, 306 - 321, 417 - 429, 483 - 487.

2. The Temeside Formation

Only one section in the Temeside Formation, (i.e. at Onibury), was examined (Volume 1, p. 220 - 226). Here, the sediments varied from biotite rich quartzites to olive green siltstones and mudstones containing carbonate nodules (considered here to be oncolites and stromatolites) and mudcracks. They were probably deposited in an intertidal mudflat environment.

3. The Ledbury Formation

One section in the Ledbury Formation was examined (Volume 1, p. 205 - 270). Here, the sediments consist of red thinly bedded (laminae 1 - 2 mm thick and slightly discordant) clays with caliche structures and channels infilled with clayey bone-beds overlain by hard micaceous slightly carbonaceous grey sandstones with a sparitic clayey matrix containing ripple lamination. They are interpreted as a sequence of supratidal occasionally emergent sediments (Volume 1, p. 203 - 220). Fossils are rare and when present are dominated by ostracods or thelodont fish scales.

(d) Summary of the top Ludlovian and Downtonian

The thesis has noticed that the transition from the top Ludlovian into the Downtonian is one of oscillating but generally continuous marine regression in which a distinct subtidal marine basin and shelf region in the top Ludlovian was replaced by a sequence of intertidal and supratidal sediments in the Downtonian. A hypothesis has been advanced in which much of this change is attributed to local and regional tectonics resulting in a number of fault bounded Pre-Cambrian blocks ~~became~~ becoming emergent land masses. Within the Much Wenlock - May Hill region it is suggested that many of the changes, both sedimentological and palaeontological at the Ludlow Downton series boundary are due to the inflow of fluvial waters in the stretch of sea between the postulated Longmyndian, and Birmingham - Malvern land masses. The main evidence for this comes from the nature of the sediments(e.g. carbonate - limonite rich sediment matrix) and the vast change in faunal composition at the boundary. Additional support for the hypothesis comes from the presence of 'authigenic' gypsum in some of the black carbonaceous clays immediately overlying the Ludlovian carbonate sediments.

Both late Whitcliffian and Downtonian sediments show that the general regression was oscillatory with (1) reversions back to a sub-tidal environment from an intertidal environment occurring within the late Whitcliffian. (2) Relict emergent mudflat structures (e.g. mudmound type topographies) occurring within the Lower Downtonian and (3) caliche horizons with partially eroded crusts within a sequence of supratidal sediments in the Late Downtonian.

The faunas in the Whitcliffian are dominated by articulate brachiopods while those in the Downtonian by, ostracods, molluscs, inarticulate brachiopods and thelodont fish.

SECTION 3

BONE-BEDS

Bone-beds have been extensively studied in this thesis (Volume 1, p. 323 - 509), the major part of this study has concentrated on the Ludlow Bone-Bed (Volume 1, p. 415 - 498) and has been summarised earlier in this volume. The remaining part of this study investigated a number of aspects of bone-beds which may be summarised as follows :-

(a) Classification

Bone-beds and their relationship to phosphatic deposits are examined and three major types recognised. They are pelbonebeds, biobonebeds and lithobonebeds (Volume 1 p. 325 - 328). The term bone-bed is taken to encompass a single layer or lens of a vertebrate rich deposit containing $\geqslant 4.5\%$ phosphatic material, of which $\gtrsim 30\%$ is fragmented and disarticulated vertebrate material.

(b) Genesis

A number of models of bone-bed genesis have been proposed in the past. These are reviewed and critically examined in Volume 1 p. 328 - 371. Three major models have emerged over time. The first suggests that they are condensed ~~ation~~ deposits and hence associated with major and minor unconformities. This model appears to apply to bone-beds such as the Recent Rockall Bone-Bed. The second suggests that they formed from the contempory reworking of mass mortality deposits. The third is the prefossilisation model. This suggests that the vertebrate material under consideration has been buried after its death and diagenetically altered (phosphatised) at a low Eh and normal to alkali pH's in the sediment prior to it's exhumation and concentration into a bone-bed.

Bone-Beds have been recorded in a variety of intertidal and subtidal environments and tend to form as lag concentrates. They may result from the reworking of older vertebrate poor sediments to produce a secondary bone-bed or form from a primary concentration of drifting vertebrate debris on the sea-floor. However, this examination of bone-beds through time suggests that no single model of bone-bed deposition will suffice and that for most of the deposits insufficient data exists for a valid environmental model of bone-bed genesis to be made.

(c) Weathering

A time related scale of bone weathering has been established (Volume 1,p. 371 - 375) for marine vertebrate remains and used to establish :-

(i) An estimate of the time interval between the death of the marine vertebrates and their permanent burial within the bone-bed.

(ii) The amount of grain size biasing in a bone-bed caused by weathering.

(iii) Whether or not a given bone-bed developed as a 'direct' result of a mass mortality.

(d) Microbiotas

The presence of both encrusting and boring microbiotas has been established on individual grains within bone-beds (Volume1, p. 99 - 101, 306 - 321, 377 - 380, 400 - 404, 417 - 429, 454, 476, 543 - 547). They occur on fish debris, quartz grains, phosphate nodules and shell fragments within bone-beds.

(e) Quartz euhedra

Quartz euhedra occur within Silurian, Devonian and Triassic bone-beds. In this study the euhedra from the British Upper Silurian Ludlow Bone-Bed, and the British Triassic Rhaetic Bone-Bed were examined. It was demonstrated that the quartz euhedra in the Ludlow Bone-Bed show exoscopic evidence of detrition, while those of the Rhaetic Bone-Bed had grown within the bone-bed during diagenesis (Volume 1, p. 414 -432, 499 - 509).

(f) Phosphate nodules within bone-beds

Phosphatic nodules occur commonly within many bone-beds, and their nature is currently being assessed by a number of bone-bed specialists. Reif, Mayall and Duffin (personal communication) have demonstrated that many of the phosphate nodules in Triassic Bone-Beds have a coprolitic origin. Reid (1890) has demonstrated that many of the phosphate nodules in the Suffolk Bone-Bed consist of phosphatised nodules of London Clay. Within this study phosphate nodules in British Whitcliffian Bone-Beds and the British Ludlow Bone-Bed have been examined (Volume 1, p. 102 - 103, 169, 170, 190 - 193, 380 - 381, 414 - 498) and shown to have formed by the phosphatisation of late Ludlovian micritic siltstones and carbonaceous clays.

The Whitcliffian Bone-Beds of Tites Point and the Brookend borehole are not associated with faunal changes and contain phosphate nodules which formed by the replacement of micritic clays (e.g. Volume 1, p. 443, 444, 477). The Ludlow Bone-Bed contains phosphatic steinkerns some small phosphatic fecal pellets and phosphatic nodules. The phosphate nodules contain a high proportion of organic material, quartz grains and fish debris. The phosphate in these nodules appears to have replaced authigenic clays (Volume 1, p. 102, 103, 169, 170, 174, 190 - 193, 380 - 381, 414 - 498).

(g) Geochemistry

The geochemistry of phosphate nodules and fish debris in some bone-beds (Ludlow, Rhaetic, Muschelkalk) has been examined (Volume 1, p. 323 - 404, 413 - 498) using XRF, XRD and microprobe techniques. These studies have shown that the chemical composition of the fish debris is frequently dependent on post depositional diagenesis within the sediment and that many of the phosphate nodules have phosphate enriched rims.

CONCLUDING COMMENTS

This summary/supplement is by necessity brief. The thesis itself is well indexed (Volume 1, p.i - xviii) with all major subheadings, plates, figures and tables listed. It was written to be read as a series of separate reports rather than one large report.

Only one new technique was developed in this study. It was for mounting grains on a scanning electron microscope stub for rapid examination (Volume 1, p. 510 - 514). This technique, using a dry glue (Pritt) as a mounting medium, allows specimens to be examined on a scanning electron microscope (S.E.M.) one hour after mounting. Most other currently used S.E.M. mounting methods are costly, and have a 24 hour lag time between mounting and examination, and are not really suited to statistical work on a S.E.M. Consequently the Pritt technique developed by Saad Al-Sheikly and myself represents a 'major' saving in cost and time. All the other advantages of this method are discussed in Volume 1, p. 510 - 514.

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TABLE 1

Relative abundances of fragmentary biogenic remains in Whitcliffian shell laminae. x & SD = mean abundance and standard deviation of a faunal group in the shell laminae in which it occurs. N = Number of shell laminae containing the faunal group. P = the total mean percent abundance of the faunal group in shell laminae.

SHELL LAMINAE

Biogenic remains	UPPER WHITCLIFFE BEDS				LOWER WHITCLIFFE BEDS			
	X	SD	N	P	X	SD	N	P
ANNELIDS	5.04	7.25	26	1.73	2.24	2.12	37	0.71
BIVALVES	7.75	8.88	39	4.00	9.70	13.04	81	6.77
BRACHIOPODS	84.34	18.16	77	85.95	80.37	20.65	115	79.67
BRYOZOANS	3.08	4.36	30	1.22	6.15	7.72	54	2.86
CEPHALOPODS	1.81	1.75	30	0.71	5.32	7.31	50	2.29
HYOLITHS	0.67	0.64	20	0.17	1.93	2.38	20	0.32
MONPLACOPHORANS	0.97	0.85	5	0.06	2.01	2.33	8	0.13
OSTRACODS	4.00	5.81	22	1.61	11.06	16.02	49	4.67
OTHER FOSSIL GROUPS	14.78	19.61	23	4.40	2.02	4.16	10	1.74
GASTROPODS	2.06	2.17	17	0.46	3.54	4.72	26	0.79
Mean Number of species per laminae	8.47				7.98			
No. of layers considered	77				115			

TABLE 2

Faunas from Whitcliffian shell laminae. Astrixed species have been found in apparent life orientation in the shell laminae.

1. LOPHOPHORATES

a. Encrusting forms
(1) Bryozoa - *Ceramporа sp., *Leioclema sp
(2) Brachiopods - *Schizocrania striata (J. de C. Sowerby)

b. Boring forms
(1) Bryozoa - *Rhopalonaria sp.

c. Benthic swimming forms
(1) Brachiopods - Protochonetes ludloviensis Muir Wood, Shagamella ludloviensis Boucot & Harper, Aegiria grayi (Davidson)

d. Shallow infaunal burrowers
(1) Brachiopods - Lingula lewisii J. de C. Sowerby, L. lata J. de C. Sowerby, Lingula corftonensis sp nov.

e. Epifaunal nestlers
(1) Brachiopods - Craniops implicatus (J. de C. Sowerby), Dayia navicula (J. de C. Sowerby), Orbiculoidea rugata (J. de C. Sowerby)

f. Epifaunal pedically attached forms
(1) Brachiopods - Salopina lunata (J. de C. Sowerby), Microsphaeridiorhynchus nucula (J. de C. Sowerby), Howellella elegans (J. de C. Sowerby), Isorthis sp.

2. SUSPENSION FEEDERS

a. Encrusting forms
(1) Annelids - *Spirorbis sp.
(2) Echinoids - Crinoids

b. Shallow infaunal burrowers
(1) Bivalves - Fuchsella amygdalina (J. de C. Sowerby), Grammysia sp. Nuculites antiquas (J. de C. Sowerby), N. ovata (J. de C. Sowerby)

c. ?Sessile infaunal species
(1) Annelids - Keilorites sp. 'Serpulites' longissimus J de C. Sowerby

d. Semi-infaunal forms
(1) Bivalves - Goniophora cymbaeformis (J de C. Sowerby)

e. Endobyssate forms
(1) Bivalves - Modiolopsis sp.

f. Epibyssate forms
(1) Bivalves - Cardiola docens (Barrande), *'Pterinea' tenuistriata (McCoy), *Pteronitella retroflexa (Wahlenberg)

3. DETRITIVORES

a. Hyoliths - Hyolithes forbesi (Sharpe)

b. Annelids - Arabellites sp.

c. Gastropods - Cyclonema corallii (J. de C. Sowerby), Liospira sp., Naticopsis cf. trevorpatriciorum Peel, Murchisonia sp. Loxonema obsoletum (J. de C. Sowerby), L. conicum (J. de C. Sowerby) L. gregarium (J. de C. Sowerby)

4. GRAZERS

a. Monoplacophorans - Bucanopsis expansus (J. de C. Sowerby) - Note B. Akpan (Glasgow University) has recorded (pers. com. 1979) graze marks on Pteronitella shells from a Whitcliffian shell laminae collected by the author, which he considers to have been produced by a 'monoplacophorans radula'.

5. NEKTONIC PLANKTON FEEDERS

a. Fish - Thelodus parvidens Ag.

6. NEKTONIC CARNIVORES

a. Cephalopods - Kionoceras angulatum (Wahlenberg), Paraphragmites ibex (J. de C. Sowerby), Orthoceras sp.

7. ?INTERSTITIAL, ?HERBIVEROUS, AND ?PLANKTIC OSTRACODS

Calcaribeyrichia torosa (Jones), C. tegula Siveter, Cavellina primaria Sarv, Cytherellina siliqua (Jones), Hebellum tetragonum (Krause), Kuressaria circulata (Neckaja), Nynamella sp., Scaldianella simplex (Krause)

TABLE 3

Faunas from Downtonian shell laminae

1.LOPHOPHORATES

(a) Shallow infaunal burrowers

(1) Brachiopods :- Lingula cornea J.de C.Sowerby, Lingula minima J.de C.Sowerby

2.SUSPENSION FEEDERS

(a) Endobyssate forms

(1) Bivalves :- Modiolopsis complanata J.de C.Sowerby

(b) Shallow infaunal burrowers

(1) Bivalves :- Solenomya sp., Grammysia sp., Leodispis barrowsi Reed

3. DETRITIVORES/GRAZERS

(1) Gastropods :- Turbocheilus helicites (J.de C. Sowerby), Loxonema gregarium (J.de C.Sowerby)

4.NEKTONIC PLANKTON FEEDERS

(1) Fish:- Thelodus spp., Logania ludlowiensis Gross

5.?INTERSTITIAL,?HERBIVEROUS AND ?PLANKTIC OSTRACODS

Frostiella groenvalliana Martinsson, Londinia kiesowi Krause