THE TEMESIDE BONE-BED AND ASSOCIATED SEDIMENTS FROM WALES AND THE WELSH BORDERLAND

by

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Summary

The sedimentology, faunas and biostratigraphy of the type section of the Temeside Bone-Bed in the Ludlow District has been examined. It is considered to have been deposited in a high intertidal environment and contains both Upper Silurian and Lower Devonian marine fossils. The transition, both sedimentological and faunal, from the top Ludlovian into the higher Downtonian has been examined in the Builth Wells, Cennan Valley, Kerry, and Long Mountain districts in order to place the Temeside Bone-Bed in its overall environmental situation.

The biostratigraphy and lithostratigraphy of the British Upper Silurian is clarified, both with respect to the Ludlow-Pridioli and Ludlow-Downton Series boundaries and the local Ludlovian lithostratigraphy of the Ludlow district. Three ostracod zones are recognised in the Downtonian. The Cennen Beds of the Cennen Valley are reassigned to the Middle Downtonian.

Some recent ostracods from the intertidal zone of Sales Point, Bradwell, Essex, are studied to help elucidate ostracod distribution in the Downtonian.

Introduction

The Temeside Bone-Bed was first recorded at Ludlow (SO 520 742) by Murchison (c. 1850-1854; 1856). Subsequently Elles & Slater (1906) termed the deposit the Temeside Bone-Bed and suggested that it also occurred at Onibury (SO 457 795) and at Downton (SO 444 742). Since then Turner (1973) has claimed that it is present in the now inaccessible Ludlow Railway cutting section (cf. Murchison 1850-1854; text-fig. 1c) and King & Lewis (1912) have recorded it at Birmingham in now inaccessible canal sections.

In this study the type section of the Temeside Bone-Bed at Ludlow and the nearby section at Onibury are examined, and the rocks placed in their environmental setting. The faunas and sediments ranging from the upper Ludlovian into the Temeside Formation (Upper Silurian) near Kerry, the Long Mountain and Builth Wells are also examined in an attempt to determine why the Temeside Bone-Bed is absent from these regions.

(text contd. p.167)

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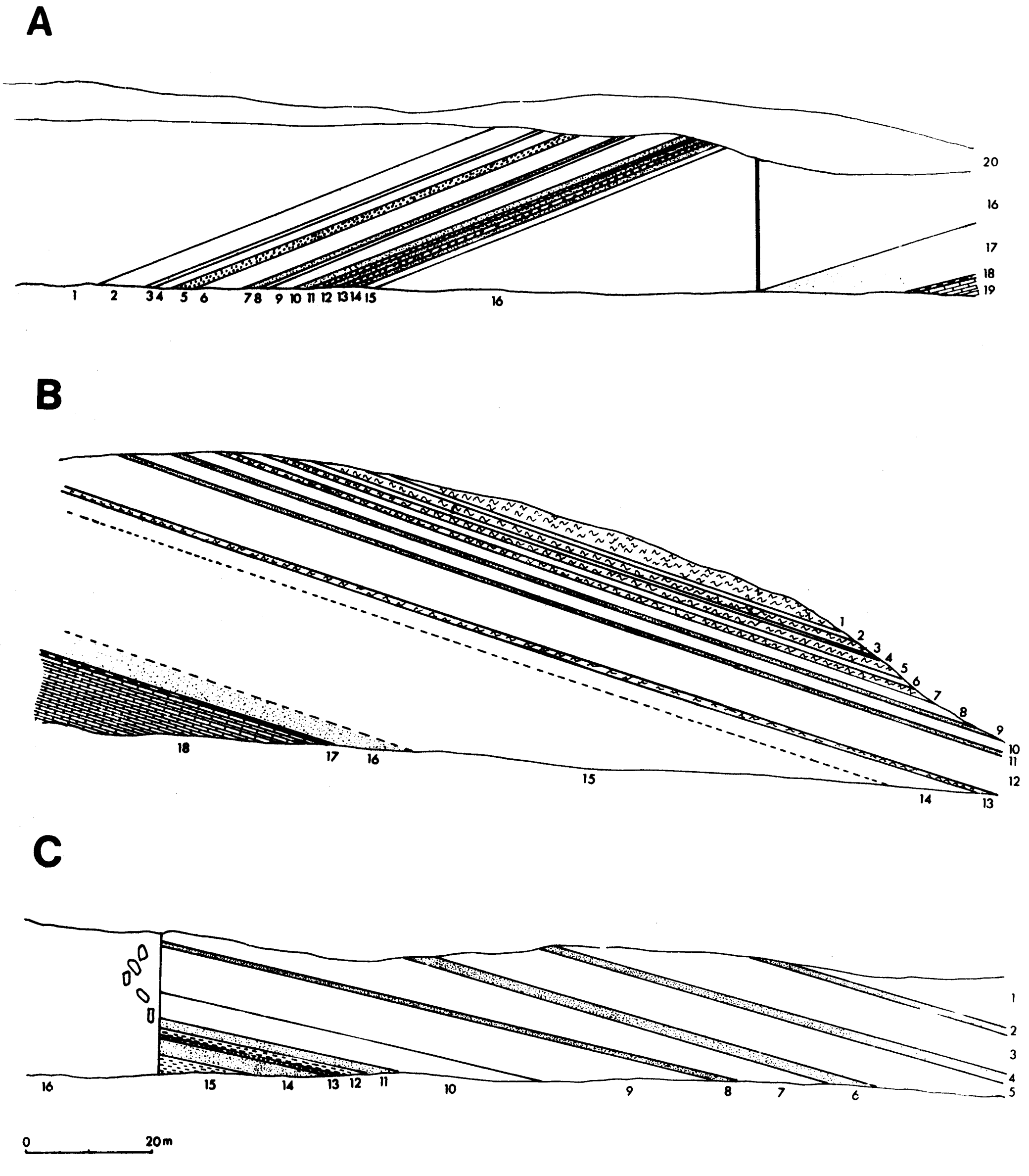
pp.163-215, Pls. 6-7, 17 text-figs., 2 App.



Text-fig. 1: Tracings of 3 unpublished sections, thought to have been produced by Sir R. I. Murchison in about 1852 (ca. 1850-1854) and now deposited in Ludlow Museum. Detailed explanation opposite.

Explanation for Text-fig. 1

A. Ludlow (GR SO 520 742)

The individual sediment layers are given as follows:

1, 3, 16. Probably red marls - key not given; 2, 4. Yellow shale; 5. Grey grit with *Auchenaspis*, *Cephalaspis*, *Onchus*, *Pterygotus*, *Lingula*. This is the fish band referred to by Murchison (1856) and the ?Temeside Bone-Bed of Elles and Slater (1906); 6. Reddish marl; 7. Red sandstone; 8. Green mudstone; 9. Red mudstone; 10. 3 inch thick grey sandstone; 11, 13. Grey grit; 12. Brown sandstone; 14. Brown sandstone; 15. Brown rubbly micaceous sandstone; 17. Downton sandstone; 18. Ludlow Bone-Bed; 19. Upper Ludlow rock; 20. 6 - 8 feet coarse gravelly deposit.

B. Onibury (GR SO 520 742)

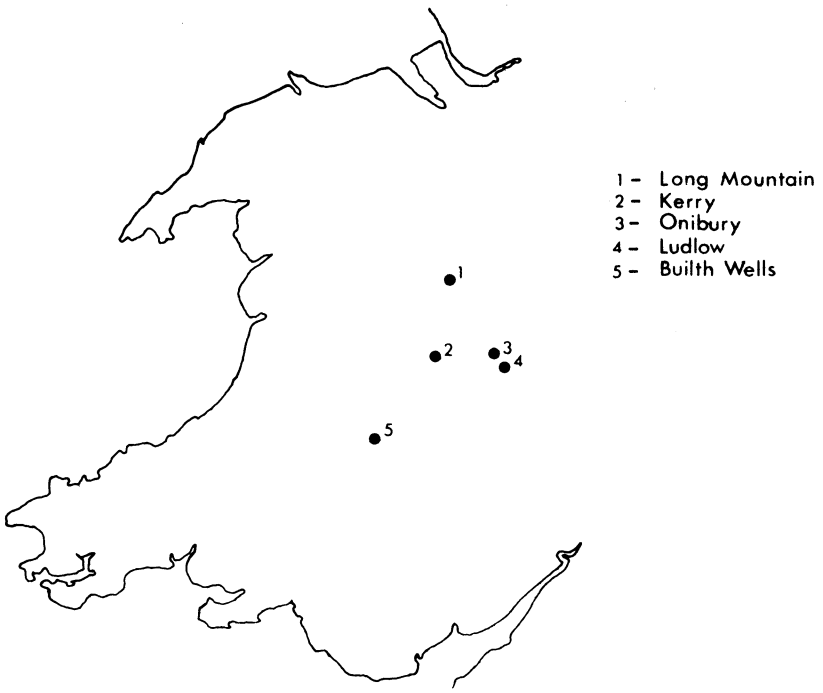
The individual sediment layers are given as follows:

1, 3, 5, 7, 13. Green rubbly shale; 2, 4, 6. Red marl; 8. Brown shale; 9, 11. Grey grit bands; 10, 12, 14. Green shale; 15. This space uncertain (probably red and green marls); 16. Downton sandstone; 17. Ludlow Bone-Bed 2 inches thick; 18. Upper Ludlow rock.

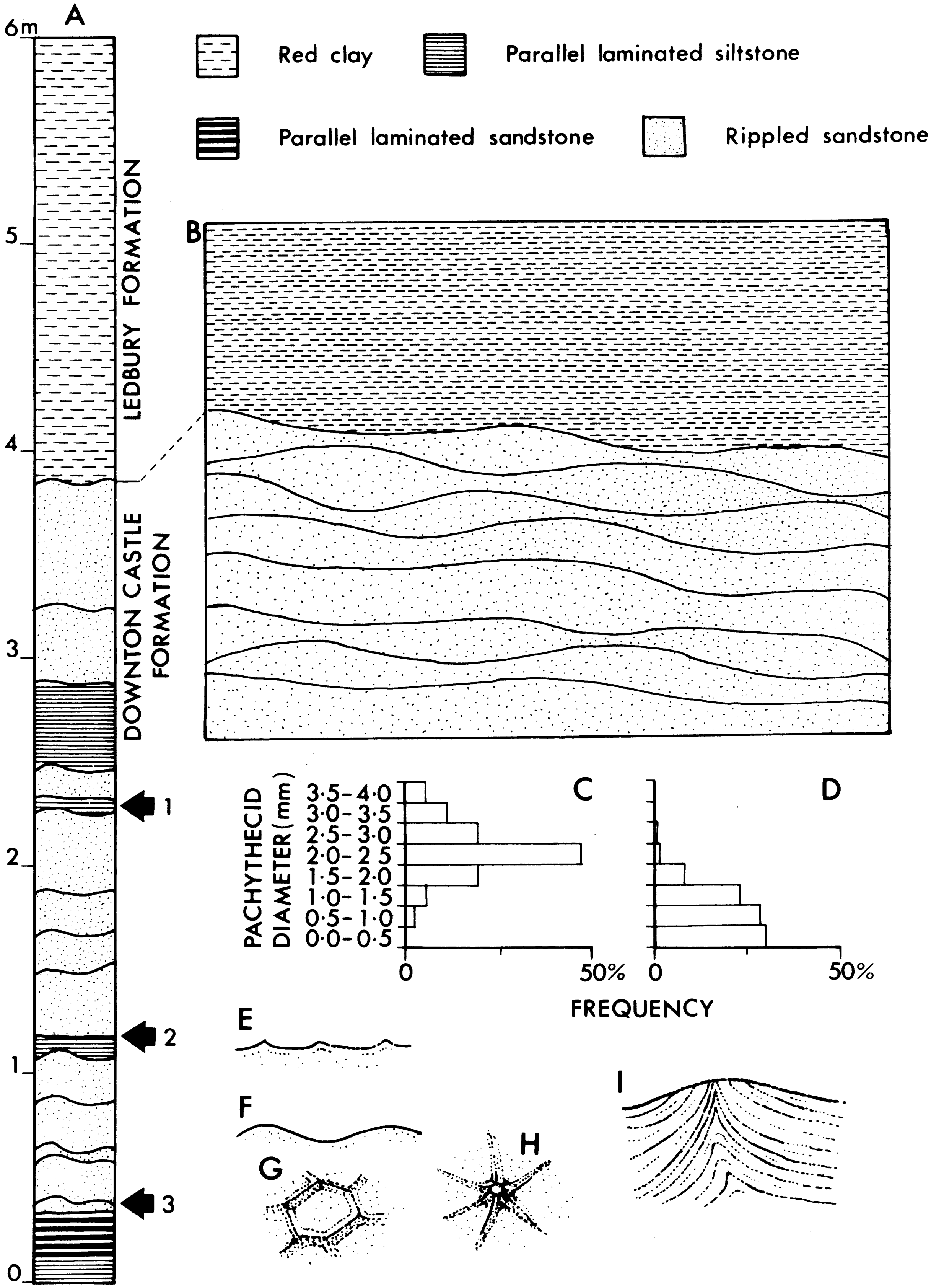
C. Ludlow Railway cutting (GR SO 574748-517746)

The individual sediment layers are given as follows:

1, 3, 5, 7, 9, 16. Red marl; 2, 4, 6, 8. Red sandstone; 10. Brown and grey beds (10 feet thick); 11. Yellow sandstone; 12, 15. Green shale; 13. Grit band with *Cephalaspis*, *Auchenaspis*, *Pterygotus*, eurypterids, *Lingula*, *Lerpiditia* and *Modiola*. This bed may be the Temeside Bone-Bed referred to by Turner (1973); 14. Sandstone band.



Text-fig. 2: Location map of Wales and the Welsh Borderlands showing the Long Mountain, Kerry, Ludlow, Onibury and Builth Wells localities.



Text-fig. 3: The Downton Castle Formation - Ledbury Formation junction at Downton (GR SO456 742).

(Explanation on opposite page)

Explanation for Text-fig. 3

A. Sediment profile observed in the section. Fossils were recorded at three points in the section (arrowed). At point 1, 623 disarticulated shells and shell fragments of *Lingula minima* were observed on a bedding plane surface area of 1 m^2. Associated with them were 40 specimens of *Pachytheca sphaerica*, whose size distributions are given in text-fig. 3D. At point 2, 1 fragment of *Lingula minima*, 1 eurypterid fragment, 20 *Protaxites* sp. fragments, 192 *Pachytheca sphaerica* and 11 *Hostinella* sp. fragments, and 7360 plant fragments (probably derived from *Hostinella*, *Psilophytites*, *Cooksonia* and *Nematophyton*) were recorded on a bedding plane surface area of 368 cm^2. The size frequency distributions of the pachythecids recorded in this layer are given in text-fig. 3C. At point 3, 48 disarticulated shells and fragments of *Lingula minima*, 1 broken spine of *Gomphonchus tenuistriata* and 9 scales of *Thelodus parvidens*, and 305,008 plant fragments derived from *Hostinella* (20-30%), *Pachytheca* (10-15%), *Psilophytites*, *Prototaxites*, *Cooksonia*, and *Nematophyton* were recorded on a bedding plane surface area of 13864 cm^2. The sediment surface at this point was covered in ripples (text-fig. 3G) concentrating vegetal debris in their ripple troughs. The diameter of the ripple units varied from 4-6 cm and height 0.5 - 1.2 cm. Also present on the sediment surface were sand volcanoes (text-fig. 3H). A cross-section across one such sand volcano is illustrated in text-fig. 3I. The laminated siltstone below this point contained 3 eurypterid fragments and 1 ***Lingula** minima* fragment over a bedding plane surface of 1 m^2.

B. Sketch of the section showing that the rippled sandstones occur as megaripples (wavelength 3 - 8 m, height 10 - 40 cm). The surface of these megaripples are covered in smaller ripples (text-fig. 3E,F,G). Width of the section is about 25 m.

C. Size-frequency distribution of *Pachytheca sphaerica* at sample point 2. Sample size = 192.

D. Size-frequency distribution of *Pachytheca sphaerica* at sample point 1. Sample size = 40.

E. Oscillation wave ripples from the surface of a megaripple 85 - 88 cm above the base of the section. (Wavelength 35 - 40 cm; height 1.6 - 2.3 cm.)

F. Ripple on the surface of a megaripple, 65 cm above the section base. (Wavelength 55 - 60 cm; height 4 - 7 cm.)

G. Ripple on the sediment surface at point 3. (Diameter 4 - 6 cm; height 0.5 - 1.2 cm.)

H. Sand volcano on the sediment surface at point 3. The centre of this volcano has an elevation of 1.8 cm. Its diameter is 3 - 4 cm.

I. Section through a sand volcano at point 3.

Characteristics of the various stratigraphical units of the British Upper Silurian summarised in Table 1

The general stratigraphy of the British Upper Silurian is summarised in table 1, pp. 170-1. The sediments examined in this study range in age from the Upper Silurian (Upper Ludlow Series) into the very earliest Devonian. The characteristics of the various biostratigraphical and lithostratigraphical units outlined in table 1 may be described as follows:

1. The Silurian-Devonian Boundary

The absence of a graptolite zoned marine sequence in the topmost part of the British Silurian in the Welsh Borderlands, has hindered the recognition of this boundary. However, in this study the boundary is taken (see Kaljo, 1978) to be indicated by the first appearance of the conodont *Ozarkodina remscheidensis*. Its earliest known occurrence in the Welsh Borderlands is in the type section of the Temeside Bone-Bed at Ludlow (see Antia, 1979a, also table 4), in the basal bone-bed.

2. Intra-Silurian Series Boundaries

Two series have been recognised (Holland *et al.*, 1963) in the British Upper Silurian. They are the Ludlow Series and the Downton Series. The boundary between the Downton Series and the underlying Ludlow Series is recognised by the appearance of the ostracods *Frostiella groenvalliana* and *Londinia kiesowi*, in the earliest Downtonian (see Antia, 1980a). Although widely accepted within Britain, the Downton Series has very little support abroad. Increasingly both in Britain and elsewhere the Series is being replaced by the term Pridioli Series. The bases of the Downton and Pridioli Series are not drawn at the same stratigraphical horizon. The base of the Pridioli Series extends down (Kaljo, 1978) into the Ludlow Series as defined by Holland *et al.* (1963, 1980) and is recognised by the first appearance of the conodont *Ozarkodina eosteinhornensis*.

3. Intra-Downtonian stages

No formal stages have been erected in the British Downtonian. However, three distinct ostracod zones are present in the Downtonian. A basal zone containing *Frostiella groenvalliana* and *Londinia kiesowi*, a middle zone containing *Hermannia phaseola*, *H. marginata*, *Frostiella bicristata*, *F. groenvalliana*, and *Londinia kiesowi*, and an upper zone containing the ostracods *Aparchites sinuatus*, *Cavellina* cf. *plana*, *Aechimina* sp., *Kuresaaria circulata*, *Hermannia marginata* and ?*Gotlandella* sp.. At the present time the precise top and base of each zone is ill-defined (due largely to poor rock outcrop). However, the lower zone is well defined at Ludlow (see Antia, 1980a) in the type section of the Ludlow-Downton series boundary. The middle zone is well represented by the sections through the Temeside Formation (described on pp. 182-185 at Onibury and in the Long Mountain and in the Cennan Beds of the Cennan Valley (see Appendix 2). The upper zone is well represented in the type section of the Temeside Bone-Bed described on pp. 172 *et seq.* text-fig. 4 and tables 3 and 4.

4. Intra-Ludlovian Stages

Four stages have been defined in the Ludlow Series. They are from base to top the Eltonian, Bringewoodian, Leintwardinian and Whitcliffian stages (see Holland *et al.*, 1963). In this study sediments from the Leintwardinian and Whitcliffian stages have been examined. The boundary between these two stages is recognised by the abundant presence of the ostracod *Neobeyrichia lauensis* in the topmost Leintwardinian (Lawson & Whitaker, 1968). The criteria for identifying the top of the Whitcliffian stage are the same as those used to recognise the Ludlow-Downton series boundary.

Recently Holland *et al.* (1980) have condensed the Eltonian and Bringewoodian Stages into the Gorstian Stage, and the Leintwardinian and Whitcliffian stages into the Ludfordian Stage. The scientific grounds for this change (Holland *et al.* 1980) are that only one graptolite zone has been identified in the Leintwardinian, none in the Whitcliffian or Upper Leintwardinian (Holland *et al.*, 1963) and that the Eltonian is not easily recognisable outside the Welsh Borders area even though the rocks here contain abundant graptolites.

5. Alternative Chronostratigraphy

Until recently (Kaljo, 1978) the Pridioli and Downton series were thought to have been synonyms. However, it has been shown conclusively (Kaljo, 1978) that this is not so and that the base of the Pridioli extends in the Ludlovian as defined by Holland *et al.* (1963). The base of the Pridioli series may, for practical purposes, in the graptolite-poor British Upper Silurian be defined (Kaljo, 1978) by the first appearance of the conodont *Ozarkodina eosteinhornensis.* This places the boundary within the Whitcliffian Stage of Holland *et al.* (1963). Since both the Downton and Pridioli series names are in common usage at the present time, and the Whitcliffian Stage spans both the Ludlow and Pridioli series. It is proposed that the term Ludfordian (Holland *et al.* 1980) should be used to cover the time interval from the base of the Leintwardian Stage to the base of the Pridioli Stage. Thus the term excludes the highest Whitcliffian. The type sections of the amended term are the type Leintwardinian and the lowest Whitcliffian sections described by Holland *et al.* (1963).

6. Upper Silurian Lithostratigraphic Groups

(a) Downton Group: This group is characterised by an interbedded sequence of yellow, green and red mudstones, siltstones and sandstones, containing few marine fossils, some fish and plant debris. It is divided into three formations:

(i) Ledbury Formation: This formation is characterised by red mudstones and shales with some coarse-grained sandstones. Pedogenic nodules are present. It contains no members, but it does contain the Temeside Bone-Bed. A typical section through this formation is described on pp. 172-182 of this study.

(ii) Temeside Formation: This formation is characterised by olive green mudstones and shales with some sandstones. It contains no named members or beds. Two typical sections through this formation are described on pp. 182-3, 194.

(iii) Downton Castle Formation: This formation is characterised by green mudstones, siltstones and shales, and buff sandstones. The formation has one named bed at its base, the Ludlow Bone-Bed. This bed and the remainder of the formation are described on p. 197 of this study and by Antia & Whitaker (1979), Antia (1979a, 1980a).

(b) Ludlow Castle Group: In the Ludlow district the Downton Group overlies the Ludlow Castle Group. This group, named after Ludlow Castle, includes most of the post Wenlockian sediments in the Ludlow district of Ludlow age. Its sediments consist of rippled and bioturbated grey to greeny grey calcareous siltstones, mudstones and limestones containing shell beds, scour channels and a diverse marine shelly fauna. In its upper part it can be divided into two formations. (Antia 1980b). The Overton Formation (named after Overton village) and the Sunnyhill Formation (named after Sunny Hill quarry in Mortimer Forest). The Overton Formation contains two members, the Upper Whitcliffe Beds and the Lower Whitcliffe Beds. The Upper Whitcliffe Beds are characterised by rippled and lenticular bedded calcareous siltstones. The Lower Whitcliffe Beds are characterised by scoured channelled, rippled parallel laminated and occasionally intensely bioturbated shelly calcareous siltstones. These two members grade into each other with no distinct boundary. At present this is taken to be at the base of a slump band (Holland *et al.* 1963). Recently, Holland *et al.* (1980) elevated the members to formation status. However, because of their lithological similarity they are regarded here as members of the Overton Formation (Antia 1980b). The underlying Sunnyhill Formation contains two members, the Lower and Upper Leintwardine Beds. They consist of bioturbated micritic siltstones with some thin shell laminae. They contain layers of *in situ* and reworked diagenetic micrite nodules, minor layers of intraclasts and the occasional rippled and parallel laminated siltstone layer (cf. p. 194).

Table 1. The stratigraphy of the British Upper Silurian in the type area (after Elles & Slater, 1906; Holland *et al.*, 1963, 1980; Copeland, 1964; Kaljo, 1978; Cooper, 1980; Antia, 1979a, 1980a, 1980b and this paper)
*Stages after Holland *et al.*, 1963, now superceded by Ludfordian (Holland *et al.*, 1980)

A. Chronostratigraphy

System	Series		Stage		Formation	Zones			
						a. Ostracod	b. Conodont	c. *Lingula*	d. Fish
Devonian			Not assigned		Ledbury	*Aparchites* sp.	*Ozarkodina remscheidensis*	*Lingula* cf. *missendenensis*	*Logania - Thelodus - Hemicyclaspis*
SILURIAN	Pridioli	Downtonian			Temeside	*Hermannia - Londinia*	*Ozarkodina eosteinhornensis*	*L. cornea* *L. minima*	*Logania - Thelodus*
					Downton Castle	*Frostiella - Londinia*			*Thelodus - Logania - Gomphonchus*
		Ludlovian		*Whitcliffian	Overton	*Calcaribeyrichia torosa*		*L. lata - Lingula* sp. nov.	*Thelodus - Gomphonchus*
			Ludfordian (Antia)			*C. tegula*	*Ozarkodina Crispa*	*L. lata - L. lewisii*	
				*Leintwardinian	Sunny Hill	*Neobeyrichia lauensis*			

Table 1 (Contd.)

B. Lithostratigraphy

System	Series	Stage	Group	Formation	Member	Bed	Palaeoenvironment
Devonian		Gedinnian	Downton	Ledbury	1		Supratidal mudflats
						Temeside Bone-Bed	
Silurian (Upper)	Downtonian Pridioli	Not assigned		Temeside	2		Intertidal mudflats and beaches
				3 Downton Castle	Yellow Downtonian		
					Green Downtonian	*Platyschisma* Beds	
				4		Ludlow Bone-Bed	
	Ludlovian	Ludfordian (Antia) *Whitcliffian	Ludlow Castle	Overton 5	Upper Whitcliffe Beds		Subtidal muds and silts
				6	Lower Whitcliffe Beds		
		*Leintwardinian		Sunnyhill	Upper Leintwardine Beds		
					Lower Leintwardine Beds		

Nos. 1-6 indicate sections described in the text. 1 = Type section of the Temeside Bone-Bed (text-fig. 4), 2 = Onibury section (text-fig. 6), 3 = Downton section (text-fig. 3), 4 = Ludlow section (text-fig. 9), 5 & 6 = Sections on Whitcliffe Common and Mortimer Forest which are described in text, pp.194-201.

*See above.

Regional studies

Methods adopted for each of the regions studied (text-fig. 2) were essentially the same. The sections were measured and the lithologies noted. A continuous sequence of sediment was collected, 2-3 kg of sediment being removed from each sample point. The sediment was then broken down and examined for macro- and in some instances microfossils. For some samples X.R.D. analyses were made to identify the clay minerals.

Although it is a widely held belief that the Temeside Formation is always present (Robertson, 1927; Allen, 1974a), it appears to be absent at Downton (SO 456 742) where the Ledbury Formation rests directly on the Downton Castle Formation. Here, the Downton Castle Formation consists of buff micaceous sandstones (text-fig. 3, pt. a,b) containing mega-ripples (wavelength 0.5 - 10 m; height 5 - 50 cm) with secondary ripples, interference ripples and sand volcanoes superimposed on their surface (text-fig. 3, pt. e-i). Small patches of vegetable debris containing *Nematophyton* sp., *Prototaxites* sp. and *Pachytheca* sp. are present in the ripple troughs. The pachythecids are well sorted and dominated by individuals of differing modal sizes in different vegetal patches (text-fig. 3, pt. c,d) suggesting that they may have been transported into the sand environment.

The overlying red clays of the Ledbury Formation appear to rest conformably on the underlying sandstones. They contain no distinct lamination but some micrite nodules are present.

The type section of the Temeside Bone-Bed

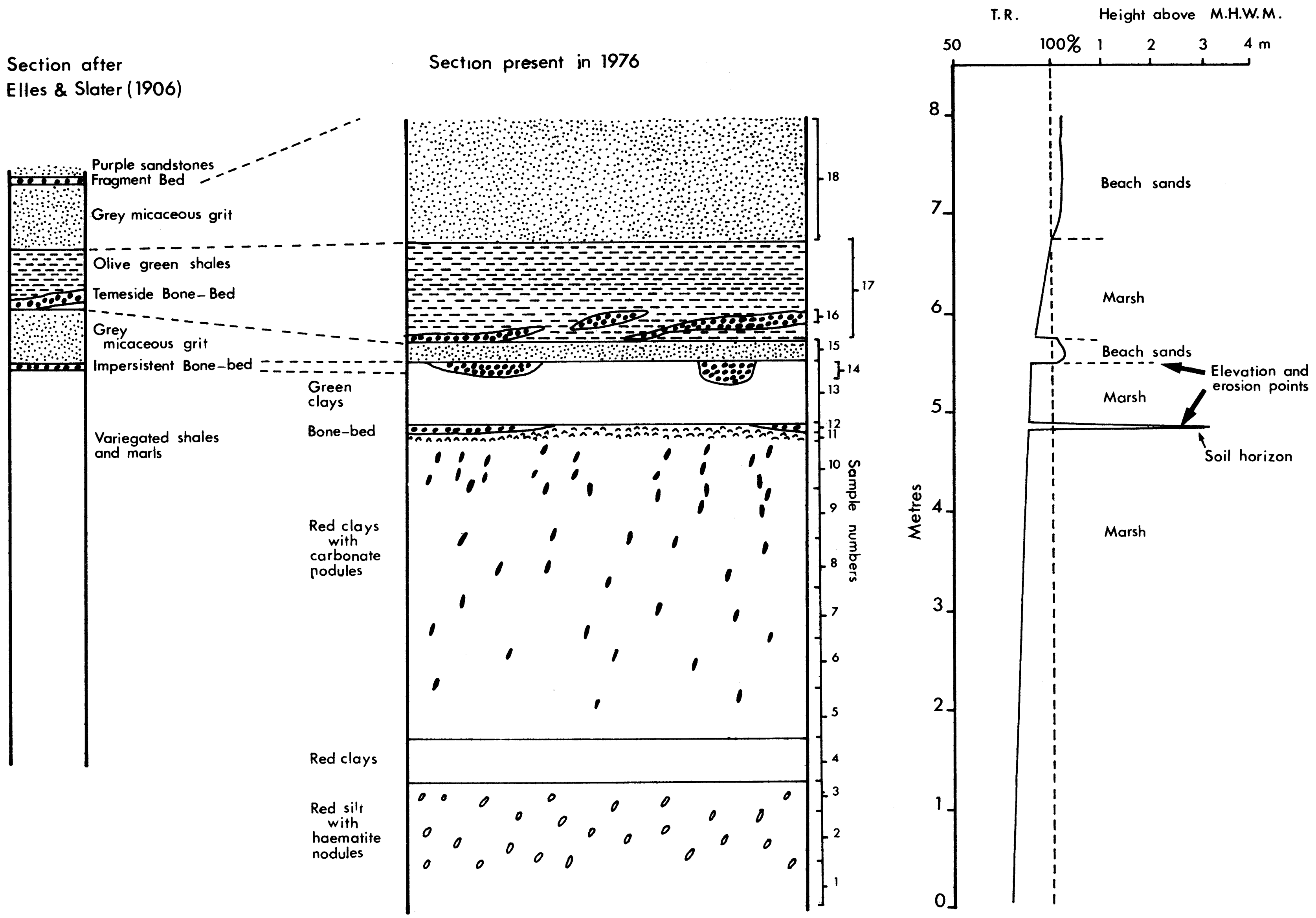
This section was first noted by Murchison (1850-1854; 1856) and later by Elles & Slater (1906). They recorded the sedimentological and faunal succession of the section. Later, Allen (1974a) noted the presence of sand sheets, and Antia (1979a) briefly described the bone-beds in the section.

In this study both the faunas and sediments are described and some conclusions drawn. The section observed is graphically described in text-fig. 4.

Palaeontology

The fossils recorded from each sampled layer of the section are listed in tables 2 and 3. The faunas present show a distinct division into two groups. The first (layers 1 - 11) contain an ostracod - foraminifera assemblage (averaging 3 fossils per kg of sediment). This ostracod fauna contains the marine species *kuresaaria circalata* (Neckaja) (see Shaw, 1971), *Aechimina* sp., *Cavellina* cf. *plana* Neckaja, *Hermannia* sp. and ?*Gotlandella* sp. All of the species except *Aechimina* sp. and *Hermannia* sp. occurred as carapaces. The latter species was present as a fragmentary valve, which could possibly be assigned to *Hermannia marginata* (Keys). This genus is considered (Warshauer & Smosna, 1977; Smosna, personal communication, 1978) to have lived in a supratidal or high intertidal environment, but since it is found as rare fragmentary remains, its presence may not be diagnostic of the environment of sediment deposition.

The low density of the ostracod fauna (table 3) may help to indicate the nature of the environment, as in modern marine sediments ostracod density decreases through the intertidal zone into the supratidal zone (table 4). For example, in the Essex mudflats at Sales Point, Bradwell, their density varies from about 8 ostracod carapaces/10,000 cm^3 of surface sediment at or around the mean high water mark to about 2,200 carapaces/10,000 cm^3 of surface sediment at the mean low water mark (see table 4).



Text-fig. 4. Measured section with interpretation of the Ledbury Formation at Ludlow. T.R. = Tidal Range.

Table 2. Fauna recorded from layers 1 - 11 at the Teme River Section, at Ludlow. Numbers indicate the number of specimens present in 1 kg. of sediment sampled. A key to the sampled layers is given in text-fig. 4.

Species	1	2	3	4	5	6	7	8	9	10	11
Ostracods											
Aechimina sp.	-	-	-	-	-	-	-	-	1	-	-
Aparchites sinuatus (Hall)	-	-	-	2	-	-	-	2	9	-	-
Cavellina cf. *plana* Neckaja	-	-	-	-	-	-	-	2	1	1	-
Kuresaaria circulata (Neckaja)	-	-	-	-	-	-	-	-	1	-	-
?*Gotlandella* sp.	-	-	-	-	-	-	-	-	1	-	-
Hermannia cf. *marginata* (Jones)	-	-	-	-	1	-	-	-	-	-	-
Foraminifera											
Hyperamnia sp.	-	3	5	-	-	-	1	-	-	-	1
Brachiopods											
Lingula cornea J. de C. Sowerby	-	-	-	-	-	-	-	3	-	-	1
Fish											
Thelodus parvidens Ag.	-	-	-	-	-	-	1	-	-	1	1

Table 3. Fauna recorded from layers 12 - 18 at the Teme River Section at Ludlow. Numbers indicate the number of specimens present in 1 kg. of sediment sampled. Layer 12 = Bone-bed BK1; Layer 14 = Bone-bed BK2; Layer 16 = Bone-bed BK3 (The Temeside Bone-Bed of Elles & Slater, 1906). A key to the sampled layers is given in text-fig. 4.

Species	12	13	14	15	16	17	18
Brachiopods							
Lingula cornea J. de C. Sowerby	-	-	7	-	-	-	-
Lingula cf. *missendenensis* Straw	-	-	-	2	-	-	-
Fish							
Corvaspis cf. *kingi* Woodward	-	-	-	-	2	-	-
Cephalaspis spp.	22	-	-	-	61	-	-
Gomphonchus tenuistriata (Ag.)	6	-	3	-	3	-	-
Gomphonchus sp.	2	-	-	-	4	-	-
Logania cunetea Gross	-	-	2	-	-	-	-
Logania ludlowiensis Gross	70	-	90	-	2	-	-
Thelodus bicostatus (Hoppe)	1	-	-	-	-	-	-
Thelodus parvidens Ag.	55	1	15	-	3	-	-
Thelodus trilobatus (Hoppe)	28	-	9	-	2	-	-
Indeterminate fish fragments	40	-	65	-	21	-	-
Foraminifera							
Hyperamnia sp.	-	1	-	-	-	-	-
Plants							
Pachytheca sphaerica Hooker	2	-	5	-	-	-	-
Plant debris	382	-	643	38	424	-	-
Conodonts							
Ozarkodina remscheidensis (Walliser)	1	-	-	-	-	-	-

Table 4. Ostracod carapace densities at Sales Point, Bradwell, Essex, on 18/3/1977, expressed as number per 10,000 cm^3 of sediment surface.

Percent of tidal range	0	10	20	30	40	50	60	70	80	90	100
Ostracod Carapace density	2200	2123	1986	1438	1265	894	531	268	134	45	8

Table 5. Faunas from the Onibury Section (Temeside Formation). The relative position of each fossiliferous sample is given with respect to the base of the section, illustrated in text-fig. 6c. p = Present

	Sample Position (cm)							
Species	0	282	370	390	405	434	515	964
Brachiopods								
Lingula cornea	-	23	54	21	95	133	25	
Lingula minima J. de C. Sowerby	-	2	-	-	-	2	-	
Ostracods								
Cytherellina cf. *siliqua*	-	3	10	883	3	10	5	
Frostiella bicristata Shaw	-	8	-	1	1	-	-	
Frostiella groenvalliana Martinsson	-	-	-	-	1	-	-	
Londinia kiesowi Krause	-	31	-	87	11	-	6	
Hermannia marginata (Keys)	-	1	-	-	-	-	3	
Other fossils								
Eurypterid fragments	-	p	-	-	-	-	p	
Leodispis barrowsi Reed	-	2	-	-	-	-	-	
?*Kionoceras* sp.	-	1	-	-	-	-	-	
Pachytheca sp.	-	-	-	-	1	-	1	
Plant debris	-	p	-	-	-	-	p	
Thelodont scales	-	-	-	-	-	-	81	
Sample size in Kg of sediment	2	3	1.8	1	3	5	11	

Since 10,000 cm^3 of sediment has a dry weight of between 1.2 and 6 kg in this instance (the variation depends on the original moisture and air content of the sediment), and the carapace densities recorded in the section varied from 0 to 11 specimens per kg of sediment, it could be suggested that the original carapace density of the sediment was in the region of < 1 to 60 carapaces/10,000 cm^3 of surface sediment, indicating that the sediments were deposited in the intertidal zone, occupying a region somewhere between 85 and 100% of the tidal range (cf. table 4). However, if marked calcite dissolution has taken place in the sediment during diagenesis, then it is probable that the original carapace densities present in the sediment were higher than those observed. Further details concerning the Sales Point Ostracods are given in Appendix 1 (p. 201).

The thelodont scales observed show predepositional weathering features on their outer surface. These features can be assigned to weathering stage 3 and, as outlined by Antia, (1979a, p. 142) indicate that the specimens may have been drifting on the substrate surface for 15 or more years.

The second faunal group (layers 12 - 17) is characterised by abundant organic (plant) and vertebrate debris with some shell fragments of *Lingula cornea* J. de C. Sowerby (table 3). The presence of a fish fauna rich in ?*Corvaspis* sp. and various cephalaspids is interesting, since it represents a major change in the vertebrate composition of the sea from a *Gomphonchus* dominated fauna in the Middle Ludlow to a thelodont dominated fauna in the Upper Ludlow and Lower Downtonian, to a thelodont - cephalaspid fauna in the Upper Downtonian. Elles & Slater (1906) recorded *Hemicyclaspis murchisoni* (Egert.), *Ctenacanthus* sp. *Hemiaspis* sp. and *Auchenaspis salteri* Egert. from these layers, and the cephalaspid fragments observed may belong to these species. A corvaspid - *H. murchisoni* fauna has been recorded from the Downtonian of Canada (Broad & Dineley, 1973; Dineley & Loefler, 1976), and suggests a late Downtonian age for this section (Dineley & Loefler, 1976, p. 52). The conodont (table 3) *Ozarkodina remscheidensis* recorded from layer 12 of this section (Antia, 1979a) indicates (Aldridge, personal communication, 1978) a possible lowest Gedinnian age for this layer.

The sediments

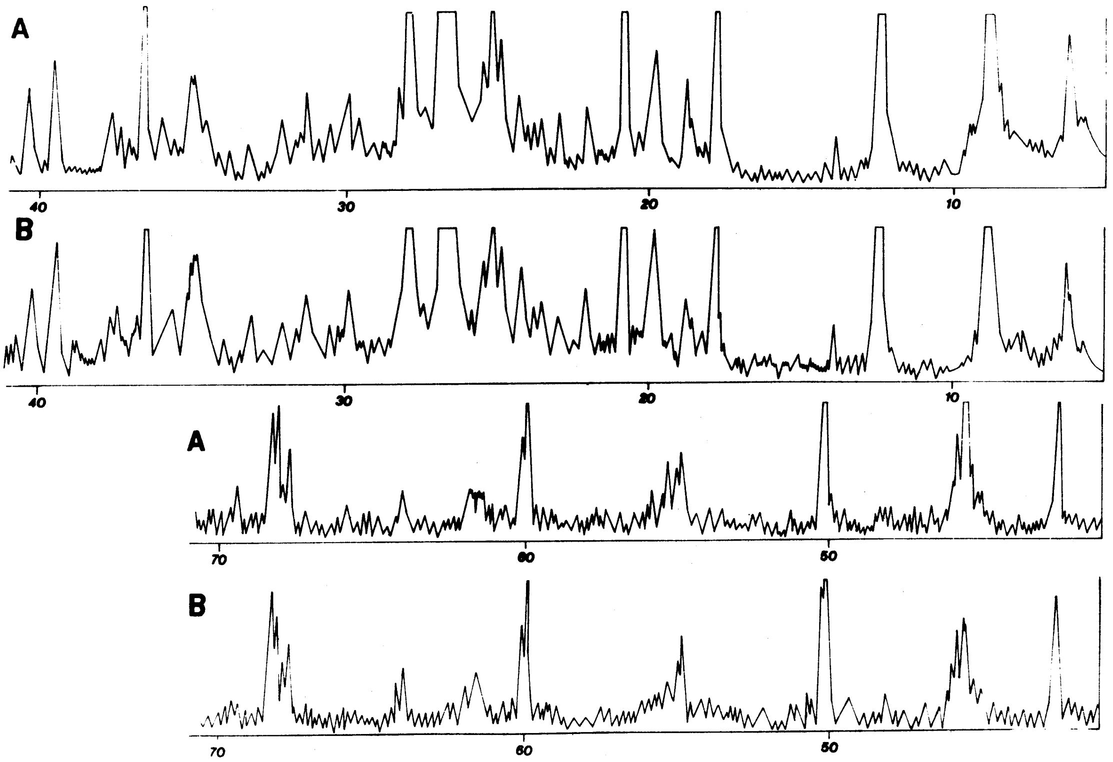
In the field the section is divisible into 2 parts. The lower part (layers 1 - 11) of the section consist of a sequence of red silts while the upper part consists of green clays and sandstones (layers 12 - 18).

Selected layers from the sequence were examined in thin section. They indicate that the lower part of the sequence is comprised principally of clay, micrite and quartz. The grains are all heavily coated in haematite giving a red colouration to the sediment sequence. In the sieved residues examined for the palaeontological part of this study, rare topaz grains (up to 3 mm in diameter) and marcasite grains are present (both grain types were identified by D.S. Weedon and N. Holgate). The upper part of the section contained green clay, (similar to the underlying clays), quartz rich sandstones and a bone-bed. Grain size distributions of the quartz grains in some of the layers in the section are indicated in text-fig. 5b.

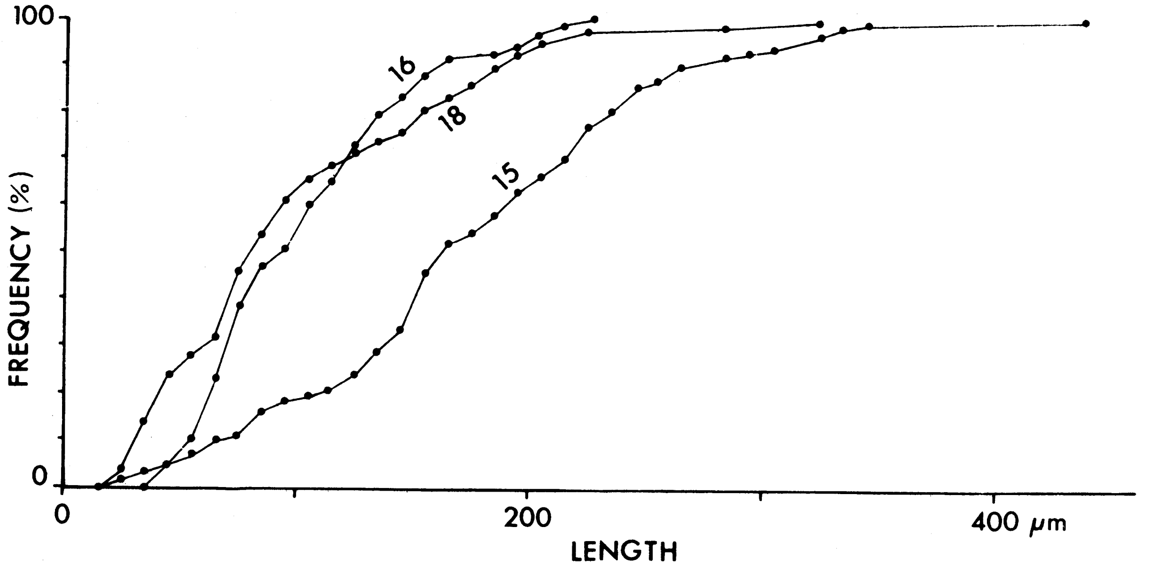
Environment of formation (layers 1 - 11)

Layers 1 - 11 of the section can be described from base to top as a basal red silt clay unit with reduction spots (layers 1 to 4) overlain by 3 m of carbonate rich red clays (layers 5 to 11). These sediments are thinly bedded (laminae 1 - 2 mm thick) with wavy slightly discordant laminae of poorly sorted muddy silt and clay laminae. Similar bedding has been observed by Greensmith *et al.* (1973), Greensmith & Tucker (1967, 1976) and Reineck & Singh (1973), in supratidal marsh sediments. If this is a correct interpretation, then the thin discontinuous bone-bed rich in plant debris (layer 12), resting on top of the red clays, may represent a plant debris-vegetal mud similar to those found on the surface of many marsh deposits (cf. Jardine, 1963; Reineck & Singh, 1973).

If the layers 1 - 11 are marsh sediments, then they would contain authigenic pyrite (Reineck & Singh, 1973; Greensmith & Tucker, 1976), which would be subsequently oxidised to limonite (Greensmith & Tucker, 1976; p. 137). Prolonged oxidation of the sediment would



Text-fig. 5a: XRD. traces of sampled layers (text-fig. 4) 13 (A above) and 10 (B above) They indicate that the sediment consists of chlorite clay and some quartz. Numbers on x-axis = value of θ.



Text-fig. 5b: Grain size distributions of three layers in the type section of the Temeside Bone-Beds. The layer numbers indicated on the grain size distributions corresponds to the sample numbers in text-fig. 4.

result in the formation of haematite (Czyscinski *et al.*, 1978). Consequently, red beds formed in a supratidal marsh environment have no palaeoclimatic significance since sulphide bearing sediments are found everywhere around the globe (Kawelec, 1973). Similarly, iron for pyrite formation is derived *in situ* (Howarth, 1979) and oxidised to haematite in its basin of deposition (Berner, 1970). However, the presence of haematite suggests a prolonged period of oxidisation by oxygen-rich waters shortly after the sediments were deposited and may indicate a relative drop in sea level (Czysciniski *et al.*, 1978).

Confirmation of this suggestion is indicated by the presence of superimposed caliche structures on the red bed sequence which are formed by reduced sea level oscillations. The structures may be described with respect to the section as follows:

1. The basal layers of the section (layers 1 - 4) contain no calcite, but do contain abundant haematite and haematite nodules (plate 6, fig. 1).
2. Micrite starts to appear about 3 m below the oxidised/reduced layer interface (layer 11/12 boundary), as small micrite pipes infilling small cracks and fissures (plate 6, fig. 3) grading up the section into vertical micrite pipes and glaebules up to 20 cm in length (plate 6, fig. 4). These pipes become very common in the upper parts of the section and culminate in the formation of a calcareous nodular mudstone (plate 6, fig. 2) rich in pipes which destroy all evidence of primary bedding.

This situation in which the original unaltered host sediment is enclosed by micritic carbonate crusts to produce minor *in situ* brecciation at its top, with subsurface micrite stringers and pipes underneath, has been recorded and described in detail from thick (1 - 3 cm) caliche sequences in the Welsh Borderlands by Allen (1974b) and in Barbados by Harrison (1977). They occur where caliche profiles have been developed on and within a host substrate (Harrison & Steinen, 1978; p.389).

In the sediment immediately above the red beds micrite is absent, suggesting that the sediment illustrated in plate 6, fig. 2, represents the 'crust' of a caliche profile. The overlying plant debris rich bone-bed (layer 12) has an erosive contact with the red bed sequence and infills a scour hollow on the upper surface of the red beds.

The subaerial exposure and subsequent caliche development of the supratidal sediments described here might not be the result of a simple marine regression, in which the environments changed from marine conditions in the Ludlow through to supratidal conditions in the Downton Series but could result from a complex marine regression, containing minor transgressive phases within the overall regression cycle. Consider the following:

1. In the Temeside and Ledbury Formations, caliche crusts have been superimposed onto intertidal and supratidal sediments (Allen, 1974a,b).
2. In the supratidal sediments of this section the upper surface of the crusts are scoured and their laminae are discordant with those of the overlying sediment, suggesting a difference in the depositional dip of. the two sediments.
3. The presence of micrite subsurface stringers extending down to 3 m below the subaerial surface (i.e. the caliche crust), implies a drop in relative sea level of at least that amount. Otherwise the sediment pores would have been filled with fresh or marine phreatic waters, precluding any possibility of vadose diagenesis and resultant caliche formation (Harrison & Steinen, 1978; p.394).
4. The presence of caliche horizons with fabrics illustrated (plate 6, figs. 1-4) here and described by Allen (1974a,b), clearly indicate the presence of gravitational vadose waters, and prove that exposure above the phreatic lense (water table) must have occurred (Gile *et al.*, 1966; Goudie, 1973; Allen, 1974b; Harrison, 1977; Harrison & Steiner, 1978).

5. The presence of haematite in the sediment suggests a period of prolonged oxidation by percolating warm (10 - 30°C) oxygenated water (Norris, 1969; Czyscinski *et al.*, 1978; Setlow, 1978). The oxidation may have been contemporaneous with the relative uplift of the sediment since the haematite is absent from sediments deposited after the formation of the caliche crust in the section.

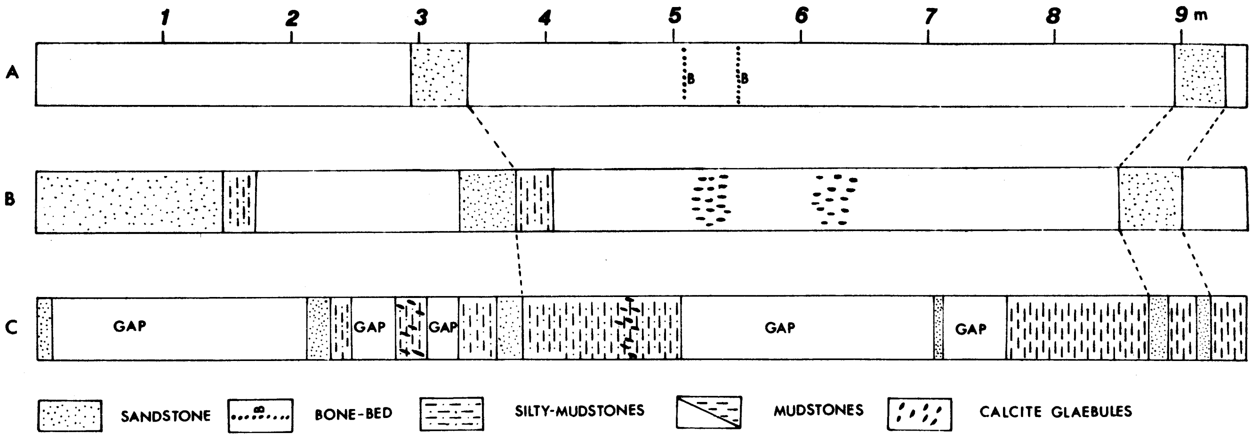
The haematite nodules in the base of the section (plate 6, fig. 1, layers 1 - 3) may have formed as ferricretes (cf. Goudie, 1973). It is, however, more probable that both they and the haematite in the red beds (layers 1 - 11) formed by the intrastratal alteration of ferromagnesium silicate grains, pyrite and authigenic iron bearing minerals (Walker, 1976; Waugh, 1978) by percolating oxidising pore waters (Czyscinski *et al.*, 1978; Waugh, 1978). Many of the biotite grains in these sediments have been heavily impregnated in crystalline haematite between their cleavage laminae (cf. Walker, 1976; Walker *et al.*, 1978; Waugh, 1978). Some of the clays in these sediments possess no crystalline form and occur as grain coatings, suggesting (cf. Crone, 1974; Walker, 1976; Walker *et al.*, 1978; Waugh, 1978) that they have mechanically infiltrated the sediment. However other clays in the sediment have a definite crystalline structure (plate 7, fig. 3) which may have formed during later sediment diagenesis (Waugh, 1978) or shortly after sediment deposition (Ospipov & Sokolov, 1978).

Environment of formation (layers 12 - 18)

This part of the section contains three vertebrate rich clay horizons (layers 12, 14, 16) which have been described as bone-beds (Elles & Slater, 1906; Antia, 1979a. Layer 16 was designated the Temeside Bone-Bed, and layer 14 as an impersistent bone-bed (Elles & Slater, 1906, pp.204-205). The presence of a discontinuous clayey sub-bone-bed infilling scour hollows (layer 12) on the surface of the calcrete crust of the red beds may mark a change from a non-marine to a marine environment. The presence of mud balls, highly abraded and weathered fish scales, comminuted shell fragments and algal plant debris suggest a possible depositional site within the supratidal zone (cf. Antia, 1979a). Similar supratidal bone-beds are found in the British Rhaetic and Carboniferous where they mark the onset of a marine transgression (Richardson, 1911; Nickless *et al.*, 1976). The overlying green clays containing slightly discordant parallel laminae may have been deposited in a supratidal marsh environment similar to those of the underlying red beds (cf. Greensmith *et al.*, 1973; Greensmith & Tucker, 1976). Cut into these clays are two channels (15 x 20 cm and 10 x 35 cm), one of which is flat based. They contain an apparent mineralogical cyclothemic sequence of sedimentation which may be described as follows:

1. A basal lag rich in heavy minerals, grey clay pellets (up to 1 cm in diameter) and fish debris.
2. This grades up into a quartz rich layer and then into a quartz and mica rich layer. This cyclic sequence (usually less than 3 cm thick) may suggest that the sediment was deposited from either a density current or from a sediment laden current gradually decreasing in strength. The order of settling suggests that the vertebrate grains were denser than the quartz grains at the time of deposition. Such an observation could be explained only if the vertebrate remains were second cycle (Reif, 1969, 1971, 1976), that is, had been reworked after they had been deposited in an older sediment and been diagenetically enriched in phosphate.

The vertebrate remains are black in colour and highly weathered (see Antia, 1979a) and highly abraded. An X.R.D. analysis of these grains shows that they are made of a pure carbonate apatite, while the vertebrate remains in the underlying red beds are a translucent yellow colour suggesting that they might be made of a fluorapatite enriched in organic debris (Antia, 1979a). Similar colour variations have been recorded elsewhere in the geological column on fish debris, but not interpreted (for example, the Triassic - see Sykes & Simon, 1979). The most likely explanation for the highly corroded worn and weathered nature of



Text-fig. 6: The Temeside Beds at Onibury. A. Section after Elles & Slater (1906)
B. Section after Allen (1974a) C. Section present in 1976

Explanation for Text-fig. 8

A. Stromatolitic carbonate sediments showing incipient cracks on the upper surface of the stromatolite. Those cracks probably arose from areal exposure of the stromatolite in a supratidal or intertidal zone (cf. Bathurst, 1975, p.219) and may have been responsible for the slight doming at the top of the stromatolite (cf. Bathurst, 1975, p. 219). Interleaved with the green silt sediment are thin carbonate bands, which may have formed thin algal mats on the sediment surface. The oncolites present in the sediments may both represent bits of larger stromatolites which were broken off during storms and later redeposited in the sediment and small motile accreting stromatolites similar to those described by Schäfer and Stapf (1978). Scale bar = 4 cm: specimen from 4.7 m above the base of the section.

B. Domed laminar stromatolite growing on a siltstone containing stromatolite laminae and oncolites. The irregular dome structure on the stromatolites upper surface surrounded by silt (arrowed) probably represents the growth of younger laminae over the upturned edges of older desiccated laminae (cf. Bathurst, 1975, p.221). Scale bar = 4 cm. Specimen from 4.7 m above the base of the section.

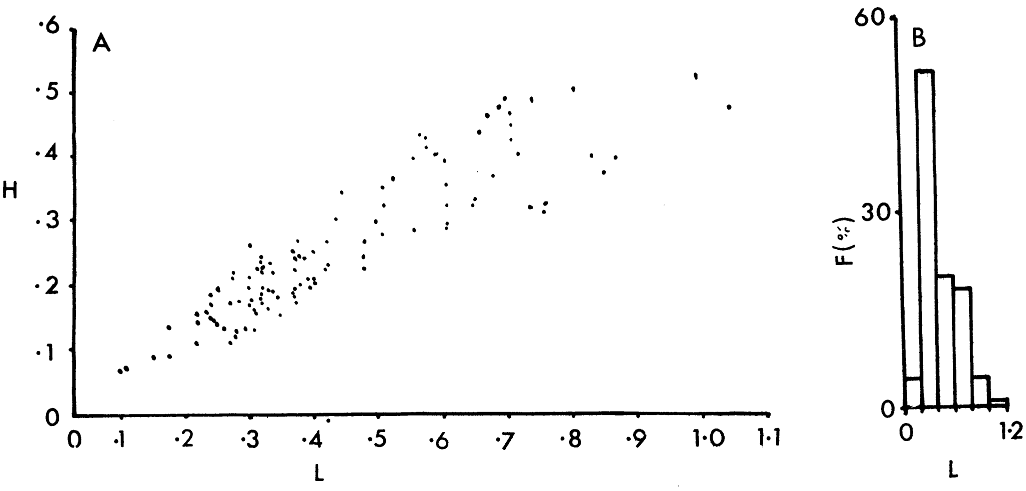
C. Mudcracks in olive green clays draped by brown quartz silt containing plant debris, eurypterid fragments and ostracods. Scale bar = 2 cm. Specimen from 8 m above the base of the section.

D. Algal oncolite containing characteristic concentric ring structure (cf. Schäfer and Stapf, 1978) and algal borings. Specimen from 4.7 m above the base of the section.

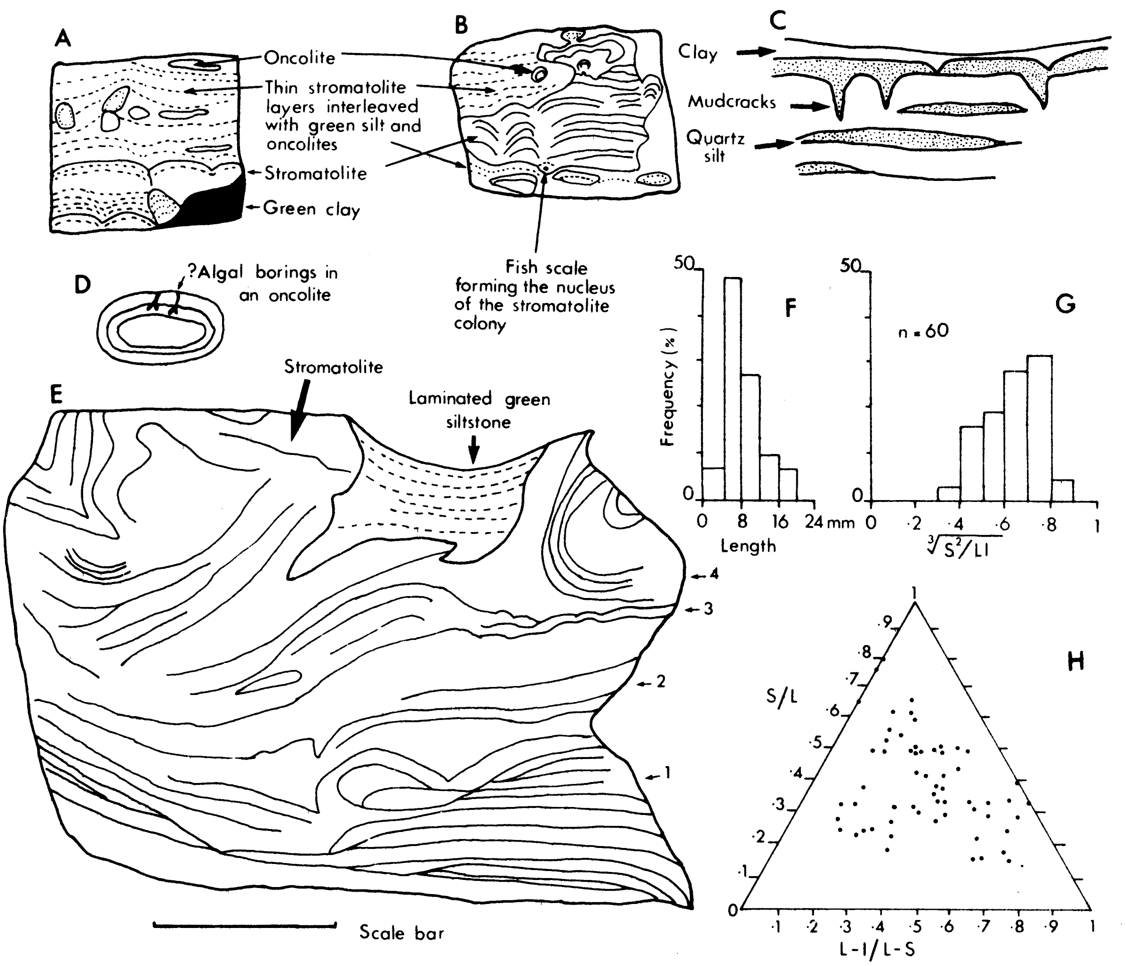
E. Micrograph tracing of an algal stromatolite. Note the original domed paired laminae, (1) were overgrown to produce a sequence of horizontal laminae (2) these were later replaced by a single dome structure, (3) subsequence disiccation of the stromatolite surface was followed by recolonisation of the surface of algal domes separated by laminated green siltstones, (4) scale bar = 1 cm. Specimen from 4.7 m above the base of the section.

F. Size/frequency histogram for the oncolites, specimen from 4.7 m above the base of the section.

G. Effective settling sphericity/frequency histogram for the oncolites, specimen 4.7 m above the base of the section.



Text-fig. 7: (a) Length (L)/height (H) scattergram for *Cytherellina* cf. *siliqua*.
(b) Length (L)/frequency (F) histogram for *C.* cf. *siliqua*.
Size measurements in mm.



Text-fig. 8: Sediments at Onibury. Explanation on opposite page.

these fish scales, which appear opaque black in all three bone-beds, is that they have been eroded out of the underlying red beds and have been redeposited in the vertebrate lags in which they are now found (Reif, 1971, 1976), suggesting that the layer 12/layer 11 boundary may represent a disconformity and that an unknown amount of sediment may have been removed. It is interesting to note that the conodont specimen was unworn, and had a translucent fresh appearance suggesting that it might be a contempory fossil of bone-bed BK1 age, unlike the fish which were almost certainly reworked from an older sediment (cf. Reid, 1890; Reif, 1969, 1971; Frey *et al.*, 1975).

Overlying the channels and clays is a sand sheet made up of a micaceous quartz sand and containing some cross-bedding (layer 15) and layers of plant debris. Diagnostic environmental features were not observed in this sandstone. Its quartz grain size distribution is given in text-fig. 6. The quartz grains include composite igneous grains, highly strained grains (often with biotite inclusions) and unstrained grains.

The overlying clays containing bone-bed BK3 are olive green and contain parallel and slightly discordant laminae. They are overlain by rippled sandstone (layer 18) which may represent a supratidal sand deposit related to a beach environment (cf. Allen, 1974a).

An environmental interpretation of the section has been presented in text-fig. 4, p. 173.

Boreholes through modern Flandrian sediments suggest that marsh sediments can accrete at a rate of about 1 mm a year (e.g. Greensmith & Tucker, 1976). From this figure a chronology of events can be determined for the section.

1. Lagoonal marsh deposition (layers 1 - 11) took place for at least 4,730 years. If an appreciable amount of sediment has been removed between layers 11 and 12, it is possible that the period of lagoonal marsh deposition may have been appreciably longer.
2. This period of deposition was followed by a period of elevation, to at least 3 m above sea level, and a period of caliche and haematite formation ensued.
3. The subsequent minor marine transgression deposited lagoonal marsh sediments.
4. For some reason this marsh deposition ceased and a channelled surface was developed. These channels and the erosion surface were then transgressed by a sand sheet (possibly a beach ridge (Allen, 1974a)).
5. Over the next period marsh accretion continued and eventually buried the sand sheet. The marsh accretion continued and was later buried by another beach ridge.

It is here suggested that the sediments observed in the section may represent some 10,000 - 15,000 years of sediment accretion, contain some erosive surfaces and may contain an unconformity at the junction of layers 11 and 12. This junction may straddle the Silurian-Devonian Boundary in Britain.

The Onibury Section (SO 455 794)

The Onibury section was first recorded by Murchison (1850-1854; also text-fig. 1) and later by Elles & Slater (1906) who recorded the Temeside Bone-Bed in the section. Shaw (1969) recorded a rich ostracod fauna in the bone-bed and Allen (1974a, p.133) documented the sediments present in the section, without recording a bone-bed. The sediment sections recorded by Elles & Slater (1906), Allen (1974a) and the author are presented in text-fig. 6. As with the Ludlow section both the faunas and sediments present in the Onibury section are described and some environmental conclusions drawn.

Palaeontology

The fossils recorded from each sampled layer of the section are listed in table 5. The brachiopods *Lingula cornea* and *L. minima* J. de C. Sowerby occurred both *in situ* and as disarticulated transported valves and fragments. Most of the ostracods were present as isolated valves. However, some species (e.g. *Londinia kiesowi* Krause and *Cytherellina* cf. *siliqua* (Jones) were found as complete carapaces and probably lived in the environment in which they are now found (cf. Oertli, 1971, also appendix 1). The species *C.* cf. *siliqua* is the same as that figured by Shaw (1971) and now kept in the Institute of Geological Sciences Museum in London. A length/height scattergram for this species is presented in text-fig. 7. The eurypterid fragments and segments were seen to be in association with abundant transported plant debris. The fish debris in the section consisted of *Gomphonchus murchisoni* Ag., *Thelodus parvidens* Ag., *T. trilobatus* Hoppe and *Logania ludlowiensis* Gross, and were present as isolated spines and scales in the sediment. Fish debris did not occur in sufficient abundance so as to constitute a bone-bed (Antia, 1979a, p.94-98). The bone-bed recorded by Elles & Slater (1906) is currently not exposed in the section (text-fig. 6c).

Sediments

The sediments in the section (text-fig. 6c) vary from a biotite-rich quartzite to olive green mudstones containing carbonate nodules (Allen, 1974a; p.133) and mudcracks (text-fig. 8c). These sediments and their environmental situations are illustrated in text-fig. 6.

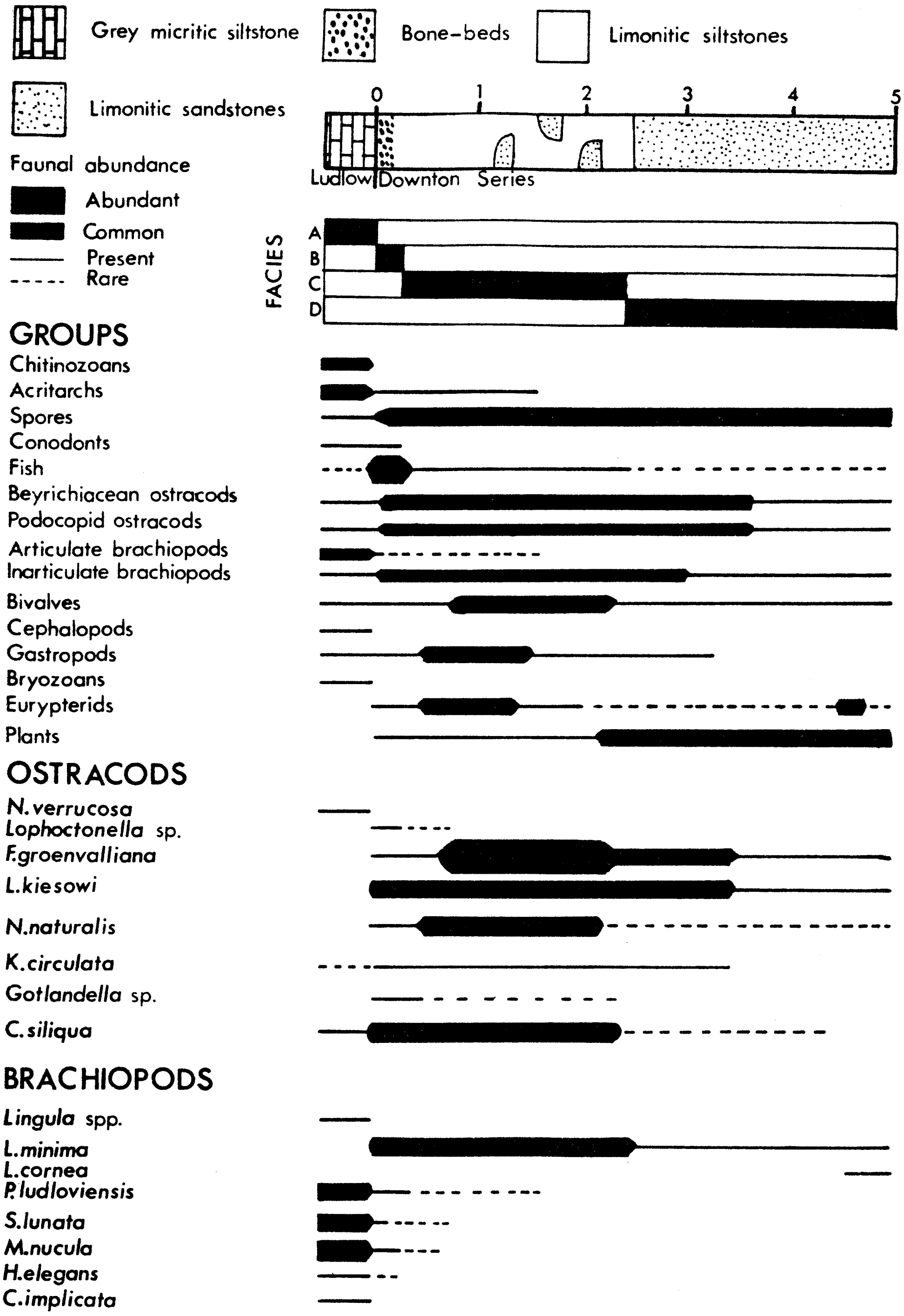
Allen (1974b) considers the carbonate nodules in this section to be pedogenic. However, some of these nodules are bored (text-fig. 8d) and contain an internal lamination (text-fig. 8a,b,c). This lamination can either consist of concentric rings or of wavy laminae and domes, and suggests (cf. Allen, 1974a; Harrison & Steinen, 1978) that the nodules are not pedogenic concretions, but are probably stromatolites and oncolites (cf. Bathurst, 1975). Although the original internal structure of these nodules has been replaced by sparite, it is possible to note that many of these stromatolites (e.g. plate 7, figs. 1,2) consisted of wavy and horizontal laminae (plate 7, figs. 1,2; text-fig. 8a,b,e), containing occasional mud-filled depressions (e.g. plate 7; text-fig. 8e). Similar structures (figs. 1 & 2) have been recorded in modern intertidal and supratidal environments (Kendall & Skipwith, 1968; David, 1970). Interbedded with some of these stromatolites are quartz rich silt sheets which are similar to the storm deposits interbedded with modern stromatolites (Davis, 1970).

The oncolites/stromatolite fragments are well sorted (text-fig. 8f,g,h) and vary from a platy to an elongate to a compact shape, and frequently contain quartz grain or fish scale nuclei (e.g. text-fig. 8b). Associated with these nodules are rare lerpiditid ostracods *Hermannia* sp. The algal-leperditid ostracod associations have been interpreted as indicating that the leperditids fed on the blue green algae forming the carbonate nodules (Warshauer & Smosna, 1977, p.478). Similar feeding relationships exist between ostracods and non-calcareous algae at the present time.

The presence of *in situ* lingulids, algal stromatolites, mudcracks and lenticular bedded sediment in the section suggests that its sediments were deposited in an intertidal or shallow subtidal environment (cf. Paine, 1970; Reineck & Singh, 1973; Allen, 1974a). The sand in the section may be chenier deposits (Allen, 1974a, p.134). Although such an interpretation seems plausible (cf. Bernard & Le Blanc, 1965; Greensmith & Tucker, 1967, 1969), transported shells and shell fragments which are abundant in many modern chenier sand sheets (Greensmith & Tucker, 1967; Antia, 1977) are absent. Consequently, it is possible that they represent subtidal or intertidal (beach) sand

The Temeside Bone-Bed in an environmental context

The Ledbury Formation in which the Temeside Bone-Bed occurs was deposited during a general marine regression which started in the early Ludlovian (McKerrow, 1979, p. 139) and continued through the Downtonian into the earliest Devonian of Wales and the Welsh Borderlands (Allen, 1974a). Traditionally the Ludlovian has been divided into a basin and shelf region (Holland & Lawson, 1963; Watkins & Berry, 1977; Cherns, 1977, etc.). The basin is characterised by a thick sediment pile (Holland & Lawson, 1963) containing a diverse fauna of nektonic species



Text-fig. 9: Faunal distributions across the Ludlow-Downton Boundary at Ludlow (scale in m) showing the distribution of sediments, major faunas and facies:

Facies A = subtidal tidally influenced environment
Facies B = intertidal muddy sandflats
Facies C = intertidal mudflats
Facies D = high intertidal - supratidal, beach siltstones and back beach lagoonal siltstones.

Note the continuation of some subtidal Ludfordian faunas into the intertidal Downtonian.

and a rare but very diverse benthic fauna; whilst the shelf is characterised by an abundant low diversity benthic fauna (cf. Holland, 1959; Holland *et al.*, 1963; Jones, 1969; Calef, 1972, 1973; Calef & Hancock, 1974; Hancock *et al.*, 1974; Watkins, 1978, 1979; Cherns, 1977) which may be facies controlled in its distribution (Hurst & Watkins, 1977). The transition between shelf and basin is rapid (about 15 km wide), spread over the Church Stretton fault zone (Stamp, 1918; Holland & Lawson, 1963), and is cut by a series of submarine canyons (Whitaker, 1962, 1968, 1974, 1976a,b; Cherns, 1977). This separation into shelf and basin areas has been a feature of the palaeogeography of the region since the early Ordovician (Davies & Cave, 1976; Hurst *et al.*, 1978).

However, at the close of the Ludlow Series the distinction between shelf and basin sediments disappeared and was replaced by a sequence of carbonate depleted limonite and haematite enriched sandstones, siltstones and clays containing a molluscan-ostracod fauna (Stamp, 1923; Cave & White, 1972; Holland, 1957; Lawson, 1954). This transition appears to have been instantaneous in most localities, for example, Siefton (Antia, 1979c), but in others, e.g. Ludlow (text-fig. 9), the transition was more gradual with rare Ludlovian fossils continuing into the Downtonian (Antia, 1980a). It has been suggested (e.g. Allen, 1974a; Antia, 1979a) that the transition represents a change from marine through to non-marine and fluvial sediments in the Ledbury Formation and overlying Ditton Group.

Areas without the Temeside Bone-Bed

The Kerry region

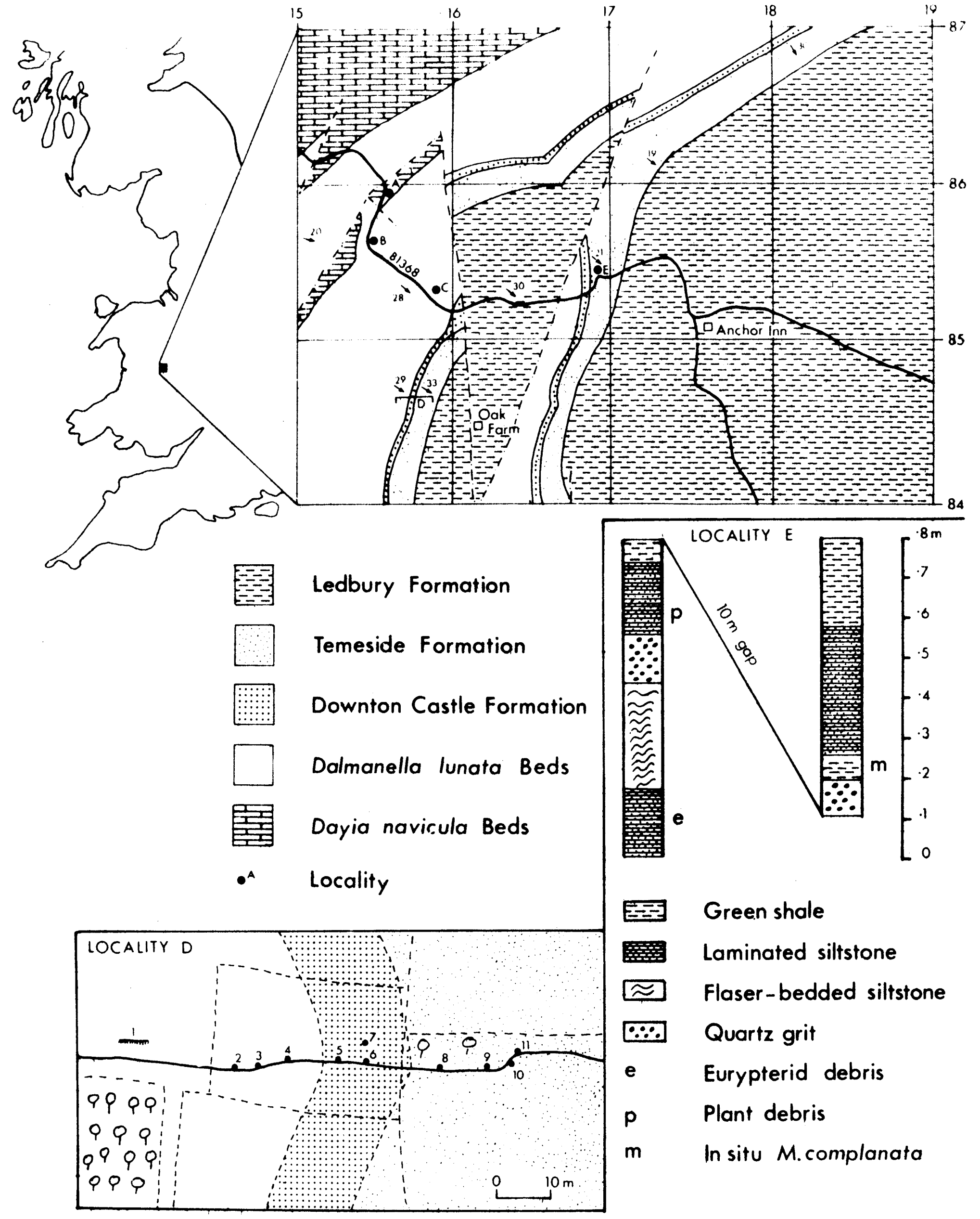
The region studied and sample localities are indicated in text-fig. 10. The sediments observed have been mapped by Earp (1938) and may be described as follows:

1. *Dayia navicula* Beds (Ludfordian, Locality A)

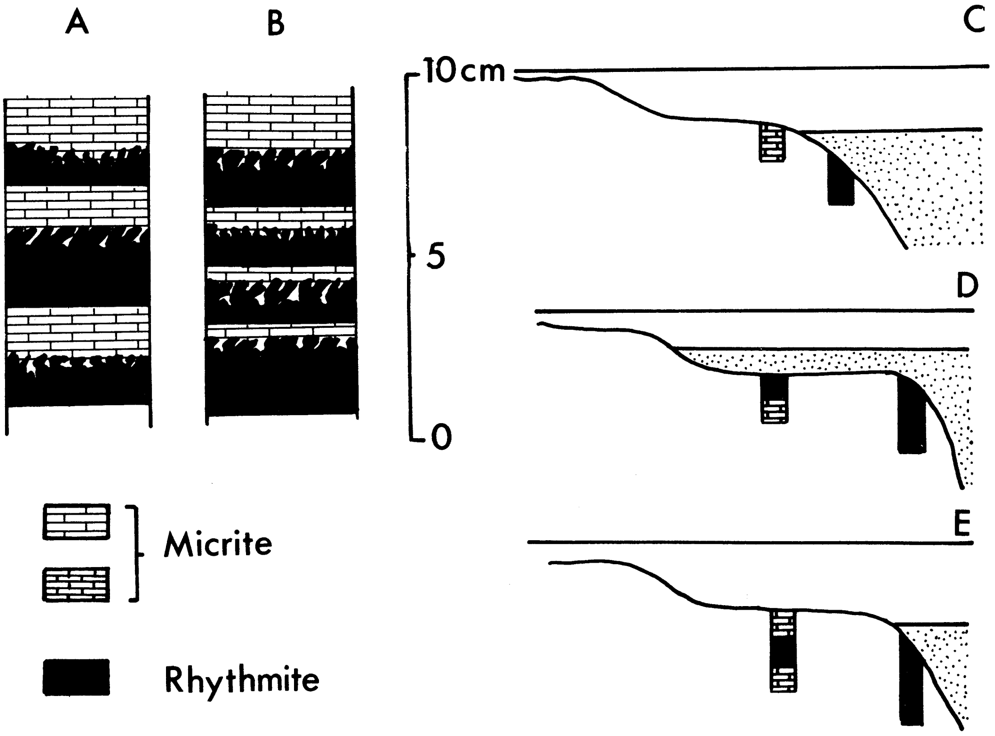
The *Dayia* beds may be described as bioturbated grey micrites (1 - 10 cm thick) containing a low density monospecific assemblage of articulated ?*in situ* brachiopods belonging to the species *Dayia navicula* J. de C. Sowerby (density of 62.4 articulated ?*in situ* shells of *D. navicula* per m^2 bedding plane surface area: 10 m^2 examined), alternating with well laminated grey clay/ silt rhythmites containing no fauna (6 m^2 bedding plane surface area examined). The upper surface of these rhythmites are occasionally burrowed by tubes extending down into the sediments from the overlying micrites (text-fig. 11). These rhythmites also contain layers rich in limonite specks (originally pyrite framboids?).

At the present time similar sediment structures are produced as a direct result of an oscillating thermohaline stratification of the water body (Degens & Stoffers, 1976; Degens *et al.*, 1978). It is known that the Ludlovian basin (Holland & Lawson, 1963) in which Kerry is situated, had a stratified water body (Cherns, 1977). The contrasting environments above and below the pycnocline differed in oxygen and hydrogen sulphide content (Cherns, 1977) and other chemical parameters. The carbonate system is particularly sensitive, in that $CaCO_3$ may precipitate above and dissolve below the interface (Degens *et al.*, 1978, p.507). Consequently regions on the margin of a basin may be affected by minor depth fluctuations in the position of the pycnocline resulting in the deposition of megavarves similar to those recorded in this study (text-fig. 11). The carbonate fraction of the megavarve is deposited while the pycnocline is lowered (text-fig.11c). A subsequent upward migration of the pycnocline would kill off the extant marine community and result in anoxic rhythmite deposition at this point (text-fig. 11d). A later downward migration of the pycnocline would allow the deposition of carbonates (text-fig. 11e) and the recolonisation of the region by a soft bodies infauna and epifauna. Subsequent changes in the relative position of the pycnocline would result in the deposition of the sediments observed in the *Dayia* Beds.

The *Dayia* Beds are overlain by the *Dalmanella lunata* Beds (Earp, 1938). The latter name is retained here and not updated to *Salopina lunata* Beds in order to conform with current stratigraphic procedure (cf. Hedberg, 1976; Lawson, 1979a,b).

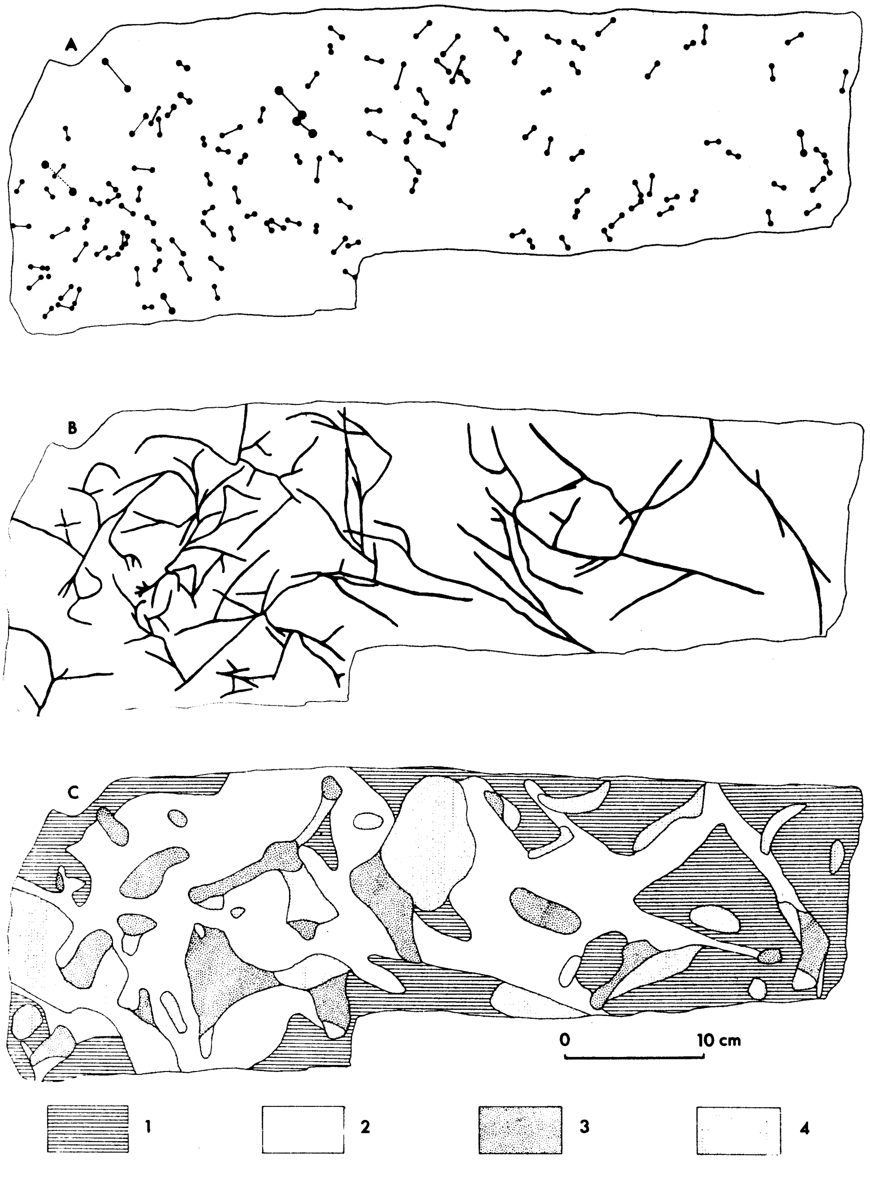


Text-fig. 10. Geological map of the Kerry district with insets of
(1) minor localities within Locality D and
(2) the sediment section at Locality E.



Text-fig. 11: (A) Megavarves in the *Dayia navicula* Beds at Locality A, text-fig. 10.
(B) Megavarves from the Black Sea D.S.D.P. borehole 379A, Section 60-2 (after Degens *et al.*, 1978). Note their similarity to the Ludlovian megavarves in text-fig. 11a.
(C) Stratified water body with an oxygenated upper zone and anoxic (stippled) lower zone depositing micrite and rhythmites above and below the pycnoline respectively.
(D) A raising of the pycnocline establishes euxinic rhythmite depositing conditions in the shallower part of the basin.
(E) A subsequent lowering of the pycnocline establishes oxic micrite depositing conditions, supporting a benthic infauna in the shallower parts of the basin.

Repetitions of this cycle (text-fig. 11 c-e) will result (Degens *et al.*, 1978) in the deposition of megavarves and could account for the megavarves in the *Dayia navicula* Beds (text-fig. 16a).



Text-fig. 12: (A) *Bifungites* sp. burrows from the Downton Castle Formation (at Kerry, Locality D/7 - text-fig. 10) on a bedding plane.
•—• Size and orientation of burrows.
The black circles represent the positions of the vertical tubes of the burrows and are joined by a line representing the horizontal part of the burrow. The orientation of this line was used to determine burrow orientations (text-fig. 13a). The distance between the two vertical tubes was used to determine the length/frequencies of the burrows.

(B) Other trails on the same bedding plane.

(C) Distribution of trace fossils on the bedding plane:
- (1) No trace fossils
- (2) Trails only
- (3) *Bifungites* + trails
- (4) *Bifungites* only

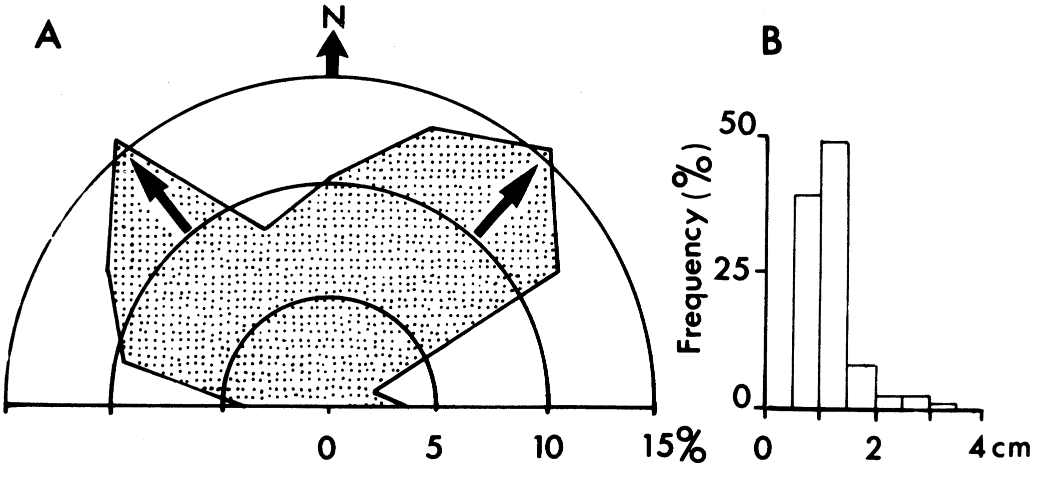
2. The *Dalmanella lunata* Beds

The *Dalmanella lunata* Beds may be described as a sequence of megavarves and rhythmites similar to those present in the *Dayia* Beds without *Dayia navicula* with interspersed distal turbidites (5 - 15 cm thick) frequently containing transported shells at their base. For example, one turbidite layer contained the following fossils, *Salopina lunata* (n = 58; 55.7%), *Protochonetes ludloviensis* Muir Wood (n = 6; 5.7%), *Microsphaeridiorhynchus nucula* J. de C. Sowerby (n = 4; 3.8%), *Fuchsella amygdalina* (n = 1; 0.9%), *Murchisonia corallii* J. de C. Sowerby (n = 1, 0.9%) and round crinoid columnals (n = 34; 32.6%) in a 3 m^2 area over its base. The relative thickness of the individual light and dark layers of the rhythmites is indicated in text-fig. 12b-d. The uppermost *Dalmanella lunata* Beds are exposed near Oak Farm, Kerry (text-fig. 10). Here they consist of symmetrical current rippled sediments (wavelength 5 - 11 cm; height 5 - 8 mm; ripple index 10 - 22) containing a typical Whitcliffe fauna (table 6). The overlying sediments consist of micrite sheets in more silty micrites containing shells at their base. The overlying sediments (text-fig. 15, locality D5-7) are current rippled and parallel laminated bioturbated limonite rich silts containing dense shell sheets enriched in *Turbocheilus helicites* (J. de C. Sowerby) and *Modiolopsis complanata* (J. de C. Sowerby). These beds have been termed the *Platyschisma* Beds by Earp (1938) and others.

Two types of trace fossil are common on these sediments. The first assigned here to the genus *Bifungites* sp. (plate 3, fig. 7) occurs in densities of up to 850 individual burrows to a metre square. Bedding plane surface area (text-fig. 12) in which individual burrows are oriented (text-fig. 13a) and have the size distribution indicated in text-fig. 13b. They were dwelling burrows which were probably produced by a suspension feeding polychaete or arthropod (Pye pers. com. 1979).

These sediments are overlain by the Temeside Formation (the Green Downtonian of Earp, 1938) which consists of micaceous siltstones and coarse sandstones containing some large calcareous concretions. The faunas present in these sediments are documented in table 7.

Another section through the Temeside Formation (text-fig. 10) contains some plant debris, a eurypterid fragment and a single *in situ* specimen of *Modiolopsis complanata*.



Text-fig. 13: *Bifungites* burrows from the Downton Castle Formation (Locality D/7) at Kerry
(A) Orientation. Note Bimodal orientation.
(B) Length/frequency distributions of the same burrows.

Table 6. Faunas recorded from locality D at Kerry.
The position of each sample site is indicated in text-fig. 10.
Faunal abundances are expressed as percentage of specimens per sample

	Sample site										
Species	1	2	3	4	5	6	7	8	9	10	11
Brachiopods											
Craniops implicatus (J. de C. Sowerby)	7.5	5.8	-	-	-	-	-	-	-	-	-
Lingula cornea	-	-	12.5	-	-	0.4	-	-	0.4	-	3.3
Microsphaeridiorhynchus nucula (J. de C. Sowerby)	-	-	-	5.0	-	-	-	-	-	-	-
Orbiculoidea rugata (J. de C. Sowerby)	-	5.8	-	-	-	-	-	-	-	-	-
Protochonetes ludloviensis Muir Wood	25.0	23.5	-	65.0	-	-	-	-	-	-	-
Salopina lunata (J. de C. Sowerby)	65.0	52.9	-	15.0	-	-	-	-	-	-	-
Molluscs											
Bucanopsis expansus (J. de C. Sowerby)	2.5	-	-	5.0	-	-	-	-	-	-	-
Leodispis barrowsi	-	5.8	12.8	-	0.0	3.0	62.1	-	77.0	-	6.6
Modiolopsis complanata J. de C. Sowerby	-	-	-	-	57.3	14.1	7.3	14.0	8.3	66.6	86.6
Solenamya sp.	-	-	-	-	-	-	6.3	-	-	-	-
Turbocheilus helicites (J. de C. Sowerby)	-	-	-	-	-	67.8	-	-	-	-	-
Ostracods											
Cytherellina siliqua Jones	-	-	5.1	10.0	-	-	1.0	-	-	-	-
Frostiella groenvalliana	-	-	-	-	-	-	-	0.7	-	-	-
Hermannia marginata	-	5.8	53.8	-	3.7	6.4	14.7	3.7	3.1	33.3	-
Hermannia phaseola (Jones)	-	-	-	-	-	1.7	5.2	5.9	5.9	-	-
Londinia kiesowi	-	-	2.5	-	38.8	1.2	-	71.1	1.5	-	3.3
Lophoctonella sp.	-	-	-	-	-	-	1.0	-	-	-	-
Other fossils											
Eurypterid fragments	-	-	2.5	-	-	2.5	-	-	-	-	-
Fish skin (*T. parvidens*)	-	-	-	-	-	-	-	-	0.4	-	-
Gomphonchus murchisoni (Ag.)	-	-	10.2	-	-	-	-	-	0.4	-	-
Logania ludlowiensis	-	-	-	-	-	2.5	2.1	-	5.5	-	-
Thelodus parvidens	-	-	-	-	-	-	-	4.4	0.4	-	-
Number of fossils observed	40	17	39	20	1068	233	95	135	253	3	30
Number of kg. of sediment processed (ca.)	7	5	7	5	8	2	2	2	2	2	3

Table 7. Faunas from the Builth District. Locality positions are indicated in text-fig. 14: 3a indicates fauna from a shelly layer; 3b indicates a fauna from poorly fossiliferous muddy siltstones. 4 is a fauna from the Causemountain Formation of the Long Mountain. Faunal abundances are expressed as percentage of specimens per sample.

	Locality				
Species	1	2	3a	3b	4
Brachiopods					
Craniops implicatus	0.09	-	0.74	-	-
Dayia navicula (J. de C. Sowerby)	4.07	-	0.29	-	-
Microsphaeridiorhynchus nucula	6.89	3.04	3.37	22.85	7.40
Orbiculoidea rugata	-	-	0.10	-	-
Protochonetes ludloviensis	70.58	86.58	7.80	5.71	11.11
Salopina lunata	1.06	0.40	47.40	8.57	7.40
Bivalves					
Fuchsella amygdalina (J. de C. Sowerby)	-	2.03	-	-	-
Goniophora cymbaeformis (J. de C. Sowerby)	0.48	0.81	-	-	-
Modiolopsis sp.	-	0.40	-	-	-
Nuculites antiquas (J. de C. Sowerby)	0.58	1.21	1.56	8.57	-
Paracyclas sp.	-	-	0.52	14.28	-
'*Pterinea*' *tenuistriata* (McCoy)	0.09	-	-	-	-
Pteronitella retroflexa (Wahlenberg)	-	-	0.07	-	-
Cephalopods					
Kionoceras angulatum (Wahlenberg)	0.09	-	-	-	-
'*Orthoceras*' sp.	0.19	1.21	0.29	-	44.44
Paraphragmites ibex (J. de C. Sowerby)	0.09	0.40	-	-	-
Other Molluscs					
Bucanopsis expansus	0.19	-	-	-	-
Loxonema obsoletum (J. de C. Sowerby)	-	-	0.81	11.42	-
Hyolithes forbesi (Sharpe)	0.58	-	-	-	-
Ostracods					
Calcaribeyrichia tegula Siveter	0.38	-	-	-	-
Cytherellina siliqua	0.09	-	0.52	-	11.11
Hebellum cf. *tetragonum*	-	-	0.07	-	-
Hermannia cf. *marginata*	-	-	0.89	11.42	-
Kuresaaria circulata	0.38	-	1.40	-	7.40
Lophoctonella sp.	-	-	-	-	7.40
Bryozoan colonies					
Ceramopora sp.	-	0.20	0.07	11.42	-
Leioclema sp.	1.35	0.20	-	-	-
Rhopalonaria sp.	-	-	0.07	-	-
Fish					
Gomphonchus murchisoni	-	-	0.07	-	-
Logania ludlowiensis	-	-	0.07	-	-
Nosteolepis sp.	-	-	0.07	-	-
Thelodus parvidens	-	-	0.14	-	-
Other fossils					
Round crinoid columnals	11.65	3.04	36.23	5.71	-
Number of fossils observed	1030	498	1344	35	27
Number of kg. of sediment processed (c.)	3	2	4	5	?7

The Builth region

In the Builth region the transition from the top Ludlovian into the Temeside Formation has been documented by Straw (1937) near Ynys Wye Farm (text-fig. 14). In this study a quarry in each of Straw's three uppermost Ludlow units (Ludfordian) were examined. The overlying Temeside Formation is poorly exposed and was only seen as small blocks of unfossiliferous green siltstone. The samples exposures are indicated in text-fig. 14.

1. Transition Beds

The transition beds are exposed in a small quarry opposite Ynys Wye Farm. They consist of shelly rippled, bioturbated siltstones containing a benthic fauna of articulate brachiopods (e.g. *Dayia navicula*, *Salopina lunata*, *Microsphaeridiorhynchus nucula* and *Protochonetes ludloviensis*), bivalves, bryozoans and ostracods. The observed fauna is indicated in table 7.

2. *Chronetes striatella* Beds

The quarry in the *Chonetes striatella* Beds indicated in text-fig. 14 consists of dark siltstones with unfossiliferous fine grained rippled sandstone sheets (up to 8 cm thick) containing trace fossils (plate 6, fig. 4). The observed fauna is indicated in table 7.

3. *Holopella* Beds

The *Holopella* Beds consist of dark siltstones containing minor slump structures (crinkle marks), vertically orientated crinoid stems, and rippled buff fine grained sandstone sheets containing layers of comminuted shell debris at their bases. The faunas of these two sediment types are indicated in table 8.

The overall impression obtained from this vertical transect through the Upper Ludfordian was that brachiopod diversity decreased through the sequence, and the overall environment changed from an aerated benthic environment of shelly siltstones supporting a soft bodied benthic infauna in the Transition Beds through to a more segregated environment in the *Chonetes striatella* Beds where sand sheets (?storm deposits) alternated with bioturbated dark siltstones containing shell patches. These sandstones contain escape burrows and have been burrowed into from the overlying sediment surface (plate 7, fig. 4).

The overlying *Holopella* Beds contained bioturbated dark siltstones containing slump structures and an *in situ* fauna of crinoids. In addition there are sandstone sheets with shell debris bases indicating that the environmental conditions which had developed in the *Chonetes striatella* Beds continued into the *Holopella* Beds.

Unfortunately the contact between the *Holopella* Beds and the overlying sediments of the Temeside Formation is not exposed at the present time and the exposures seen of the Temeside Formation were too scanty to allow proper environmental interpretations to be drawn concerning the relationship between the marine Ludlovian sediments and the overlying 'Downtonian' Temeside Formation in the Builth region.

Long Mountain

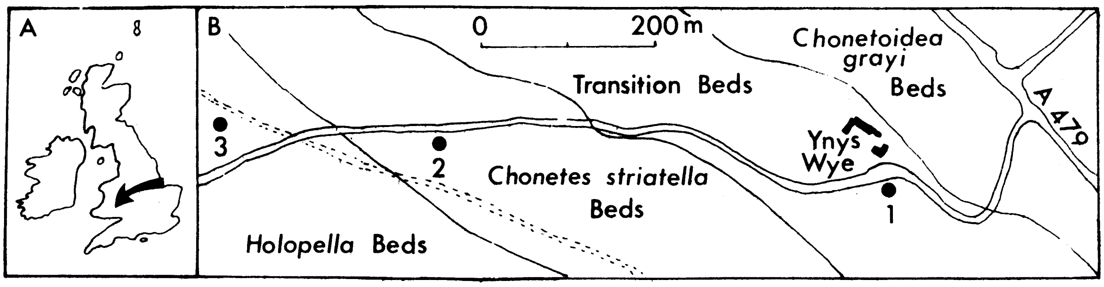
The transition from the Ludlovian into the Downtonian Downton Castle Formation and Temeside Formation has been recorded by Austin (1925) and Palmer (1972) near Wallop Hall. For the present study faunal collections were made from the Upper Ludfordian sediments and Temeside Formation at the Wallop Hall locality.

1. Upper Ludfordian (= Causemountain Formation of Palmer, 1972)

These sediments are exposed in a quarry 500 m south of Wallop Hall (S.J. 311 307) and consist of irregularly bedded, shaley - massive, muddy siltstones with a poorly developed rhythmite type carbonate sedimentation, similar to the basinal Ludfordian sediments (*Chonetes striatella* Beds) of Kerry. The fauna is rare consisting largely of scattered fragmentary nektonic species (e.g. orthoconic nautiloids). However, at the base of the crystalline carbonate rich bands (?distal turbidite bands) shell debris belonging to benthic species (e.g. brachiopods

Table 8. Faunas from the Temeside Formation at Wallop Hall.
Sample positions are given with respect to the base of the section illustrated in text-fig. 15. An additional 10 samples totalling about 30 kg of rock were made from the section. However, they proved to be unfossiliferous.
Faunal abundances are expressed as percentage of specimens per sample.

	Sample Positions				
Species	0.3m	1.1m	1.6m	2.2m	3.0m
Brachiopods					
Lingula cornea	15.62	-	0.39	5.76	5.88
Bivalves					
Leodispis barrowsi	15.62	5.55	74,71	56.73	21.58
Modiolopsis complanata	-	72.22	8.04	5.76	-
Solenamya sp.	-	-	-	3.84	-
Ostracods					
Cytherellina siliqua	6.25	-	-	0.96	-
Hermannia marginata	-	-	5.74	5.76	11.76
Hermannia phaseola	43.75	19.44	3.06	12.50	25.49
Londinia kiesowi	3.12	2.77	1.53	-	5.88
Lophoctonella sp.	-	-	-	1.92	-
Other fossils					
Eurypterids	-	-	-	-	11.76
Gomphonchus murchisoni	12.50	-	0.39	-	5.88
Logania ludlowiensis	-	-	5.36	6.73	11.76
Nosteolepis sp. (Fish skin)	3.12	-	0.39	-	-
Thelodus parvidens	-	-	0.39	-	-
Number of fossils counted	32	36	261	104	51
Number of kg of sediment processed	3	4	5	3	6



Text-fig. 14: Sampled localities in the Builth region.

and molluscs) is present. A faunal list for this quarry is given in table 7. The environment of deposition is considered here to be similar to that seen in the *Chonetes striatella* Beds at Kerry.

2. Upper Ludlovian/Downtonian Boundary (= Wallop Hall Formation of Palmer, 1972)

The lower part of the Wallop Hall Formation may be equated with the upper Whitcliffe Beds of Ludlow. It consists of poorly fossiliferous hard calcareous non-turbiditic coarse siltstones - fine sandstones (2 - 10 cm thick) with planar and/or current ripple laminae. Generally the beds are well sorted but may show grading in the form of shelly soles with an abundant current derived fauna including characteristic shallow water Upper Ludlovian brachiopods. The calcareous siltstones with richly fossiliferous shelly soles on their lower surfaces become more abundant towards the middle of the Formation. The interbedded shaley micaceous siltstones also become increasingly fossiliferous with some laminae covered in sorted shell assemblages and vertebrate debris (composed of thelodont denticles). This sediment sequence is present (e.g. Palmer, 1972, p.150) at Wallop Hall (S.J. 311 307) and contains an abrupt transition from Ludlovian to Downtonian faunas within a shallow water marine carbonate siltstone.

3. The Temeside Formation

The Temeside Formation can be seen in Wallop Hall quarry (S.J. 331 307) where it consists initially of a sequence of silty parallel laminated mudstones containing an abundant flora (plate 6, fig. 5). These mudstones grade up into a sequence of mudcracked and wrinkle marked blocky micaceous muddy siltstones containing dense sheets of transported bivalve and ostracod shell debris. The siltstones are overlain by a sequence of alternating parallel laminated siltstones and fine sandstones with micaceous laminae and weathered calcareous pellets (0.5 - 2 cm in diameter - ?oncolites), containing both *Lingula cornea* and *Leodispis barrowsi in situ.* These sediments are overlain, first by a sequence of rubbly muddy siltstones containing weathered calcareous pellets and then a sequence of cross-bedded fine-grained sandstones. The observed sediment log is given in text-fig. 15. The lerpiditid ostracods are illustrated in plate 3, figs. 5,6, and the fauna recorded is listed in table 8. The sediments in this section probably represent a low energy accreting mudflat environment at the base, passing up into higher intertidal or even back beach lagoonal muds and 'beach' sandstones (cf. Allen, 1974a).

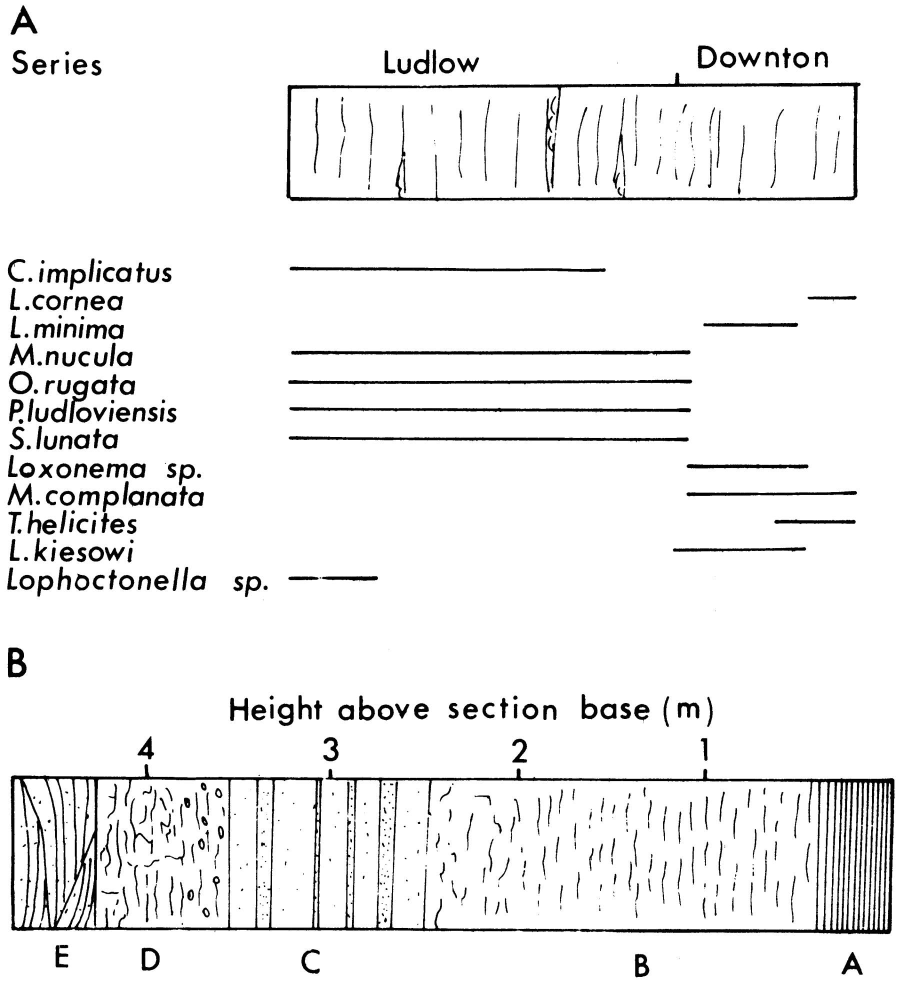
Although the overlying Ledbury Formation was not seen, it has been described (Palmer, 1972) as a red bed sequence of conglomeratic, micaceous fine-grained sandstones interbedded with micaceous muddy siltstones containing a fauna of *Lingula cornea*, *Hermannia* sp. and rare small bivalves.

Summary of environmental change at Ludlow

The transition from the top marine Ludlovian Sunnyhill Formation, into the the Downtonian Ledbury Formation in the Ludlow district has been intensively studied (e.g. Elles & Slater, 1906; Holland *et al.*, 1963; Allen, 1974a, Antia & Whitaker, 1979; Antia, 1980a,b). These studies have recognised nine sedimentary facies, the stratigraphical position of each facies is shown in text-fig. 16 and may be described as follows:

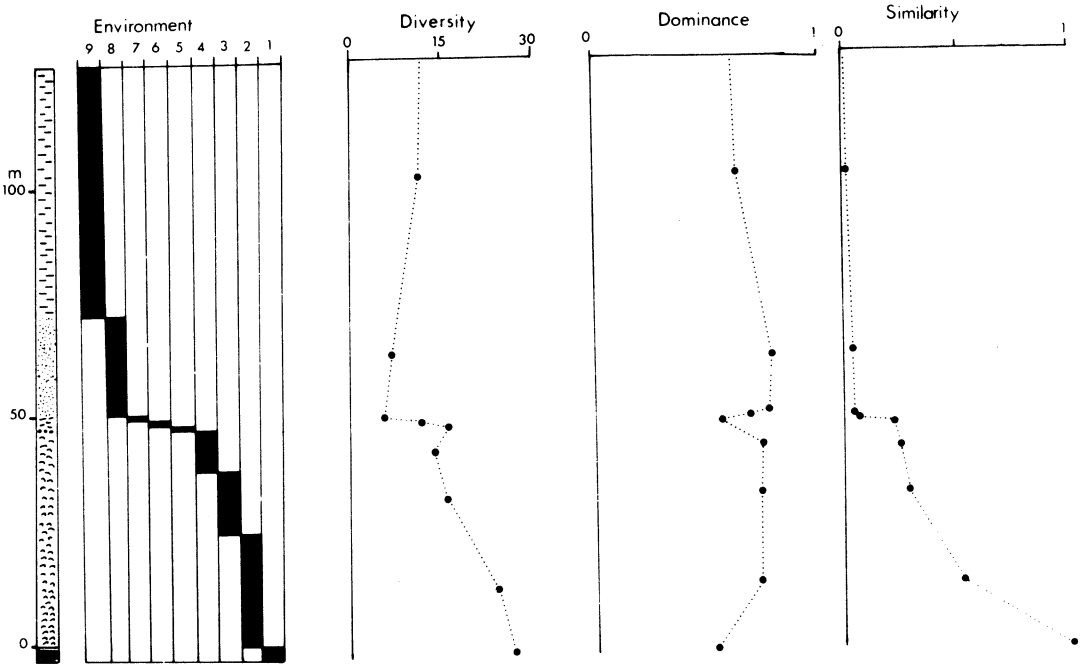
1. Rhythmite facies (SO 487 712) Sunnyhill Formation

Parallel laminated carbonate silts containing 7 - 15 alternations of light (carbonate rich) and dark silt laminae in a 1 cm vertical section. Local erosion surfaces are present and are usually covered with abundant shell debris, frequently forming sheets 3 - 15 mm thick. These shell sheets are considered to have formed as storm deposits (Hurst & Watkins, 1977). The laminae resemble the rhythmites described by Seibold (1955, 1958) and others (see Reineck & Singh, 1973). They are considered by analogy with modern rhythmites to represent a water depth of between 40 and 600 m (Seibold, 1955, 1958; Byrne & Emery, 1960; Calvert, 1964) and may represent the deepest water environment seen.



Text-fig. 15: (A) Faunas across the Ludlovian - Downtonian Boundary at Wallop Hall (after Palmer, 1972).

(B) Sediments in the Temeside Formation at Wallop Hall:
A = Silty mudstones; B = Blocky, micaceous muddy siltstones;
C = Interbedded flaggy siltstones and micaceous fine grained sandstones;
D = Blocky-rubbly silty mudstones with calcareous pellets;
E = Cross bedded fine grained sandstones.



Text-fig. 16. Sediment environments, diversity, faunal dominance and similarity distributions in a vertical section through the Upper Ludlow and Downtonian sediments in the Ludlow region, 0 m = Base of the Overton Formation. Ludlow - Downton Boundary is at the base of environment 5. Faunal dominance is calculated as the abundance of the two most abundant species.

2. Rippled carbonate silt facies (SO 487 712) Overton Formation

Shelly rippled carbonate silts interbedded with parallel laminate silts, containing local slumps and channels. Shell laminae, bioturbation and a shelly infauna are common.

The transition from this environment to the underlying rhythmite environment is gradual with an initial influx of bioturbating organisms succeeded by the development of ripples and deposition of some fine-grained rippled sand sheets. This environment appears to be less stagnant than the rhythmite environment and probably represents a slightly shallower environment in which both the coarse sands and shell sheets were deposited by storms (Antia, 1980b). The depth represented by this facies was probably within the range -25 to -100 m O.D. (Allen, 1970; Reineck & Singh, 1973; Antia, 1979a).

3. Scoured Rippled Carbonate facies (SO 508 741) Overton Formation

Shelly rippled laminated silts containing alternating clay and shelly silt lenticles, local scour channels, shell gravel megaripples, shell sheets, rippled sand sheets, local slumping, and some parallel laminate storm deposited silts. These sediments probably formed below surf base (ca. 10 m depth) and above wave base (ca. 30 - 50 m depth) (Allen, 1970; Reineck & Singh, 1973).

4. Lenticular bedded silt facies (SO 512 742) Overton Formation

Lenticular bedded calcareous clays silts and shell sheets (Reineck & Singh, 1973). These sediments are thought (Allen, 1970; Antia, 1979a,b; Antia & Whitaker, 1979) to have been deposited in a shallow subtidal environment within 15 m of the low water mark, above surf base (Allen, 1970; Reineck & Singh, 1973).

5. The Bone-Bed facies (SO 512 742) Downton Castle Formation

The bone-bed environment may be described as a lenticular bedded sequence of clays, silts, fine sands and vertebrate coquina. It includes the Ludlow Bone-Bed and has been described in detail by Antia (1979a; 1980a) and Antia & Whitaker (1979). It is considered (Allen, 1962, 1974; Allen & Tarlo, 1963; Antia, 1979a, 1980a; Antia & Whitaker, 1979) to have been deposited within the lower part of the intertidal zone as a series of lag concentrates on a mudflat environment.

6. The Rippled Mudflat facies (SO 512 742) Downton Castle Formation

Lenticular bedded clays, silts and sands, with some rippled sand sheets and rare bioturbation. The sediments of this environment have been described by Allen (1974a) and Antia (1979a) and are thought to have formed in the lower part of intertidal environment.

7. Mud mound facies (SO 512 742) Downton Castle Formation

This environment consists of a series of channels (up to 1.2 m wide, 0.3 m deep and 10^+ m in length) cut into lenticular bedded silts and infilled with shell debris, silts, sands and muds. The associated mounds often have mud cracks and plant debris on their upper surfaces, and contain limonitised shells and burrows. Similar environments have been recorded in the highest parts of a recent intertidal zone by Greensmith & Tucker (1967).

8. Beach sand facies (SO 512 742) Downton Castle Formation

Series of megaripples and dunes which are locally channelled and trough cross-bedded and contain local parallel laminate paper silts. They contain no acritarchs (Richardson & Lister, 1969) and were probably deposited as beach sands (Allen, 1974). Local plant debris horizons are common. Details of one section exposing this environment are given in text-fig. 3, p.

9. Back beach clay facies (SO 521 741) Ledbury Formation

Overlying the beach sands are a series of red clays, locally parallel laminated, containing soil horizons. They are considered (Allen, 1974a; Antia, 1979a) to represent a series of back beach, high intertidal to supratidal sediments and marine sediments, and contains the Temeside Bone-Bed.

Palaeontology

Each of these environments was sampled by the author in the Ludlow District. Samples consisted of 2 - 80 cm thickness of sediment throughout each section. The faunas of each sample were counted (ca. 140 individuals, per sample) and the percentage of each species present determined. The samples were then grouped into environments. The percentages of each species in each environment were summed. These summed percentages (SP) for each species in a given environment were then divided by the number of unit samples (N) collected from the environment to obtain an expected mean value (EMV) of the abundance of each species in the environment.

$$EMV = (SP/N)$$

The values of EMV were used to calculate the rarefied diversity of the calcareous invertebrate faunas in each environment.

The ranked abundances of each species in each environment is indicated in table 9. Also indicated in this table are the modal environment and range of environments each species present. The total sample size used in compiling this table is about 85,000 fossils. Details of their distribution in the individual sections examined will be published elsewhere.

Table 9. Ranked faunal distributions from 9 palaeoenvironments in the Ludlow District.
A key to the palaeoenvironments is given in the text (p.
The changes in faunal diversity and dominance, with environment, are summarised in text-fig. 16.
M.E. = Modal environment. R = The range of environments in which an individual species is present.

	Palaeoenvironment										
Species	1	2	3	4	5	6	7	8	9	M.E.	R
Brachiopods											
Aegeria grayi	8	33	-	-	-	-	-	-	-	1	1 - 2
Atrypa recticularis	17	34	-	-	-	-	-	-	-	1	1 - 2
Craniops implicatus	6	31	17	5	13	-	-	-	-	4	1 - 5
Dayia navicula	12	5	-	-	-	-	-	-	-	2	1 - 2
Howellella elegans	22	37	-	6	23	-	-	-	-	4	1 - 5
Isorthis sp.	32	17	-	-	-	-	-	-	-	2	1 - 2
Lingula sp. nov.	-	-	16	7	18	-	-	-	-	4	3 - 5
Lingula cornea	-	-	-	-	-	-	-	13	2	9	8 - 9
Lingula lata	41	15	19	4	14	-	-	-	-	4	1 - 5
Lingula lewisii	14	36	-	-	-	-	-	-	-	1	1 - 2
Lingula minima	-	-	-	-	1	3	2	4	-	5	5 - 8
Lingula cf. *missendenensis*	-	-	-	-	-	-	-	-	5	9	9
Microsphaeridiorhynchus nucula	2	2	2	3	6	-	-	-	-	1 - 3	1 - 5
Orbiculoidea rugata	27	20	6	10	-	-	-	-	-	3	1 - 4
Protochonetes ludloviensis	5	1	3	2	10	-	-	-	-	2	1 - 5
Salopina lunata	1	3	1	1	4	-	-	-	-	1,3,4	1 - 5
Shagamella ludloviensis	25	-	-	-	-	-	-	-	-	1	1
Shaleria ornatella	18	-	-	-	-	-	-	-	-	1	1
Sphaerirhynchia wilsoni	27	-	-	-	-	-	-	-	-	1	1
Bryozoan colonies											
Ceramopora sp.	15	9	17	-	-	-	-	-	-	2	1 - 3
Leioclema sp.	7	7	11	-	25	-	-	-	-	1,2	1 - 5
Rhopalonaria sp.	-	50	-	16	30	-	-	-	-	4	2 - 5
Bivalves											
Cardiola docens	-	10	-	-	-	-	-	-	-	2	2
Fuchsella amygdalina	9	4	5	11	-	-	-	-	-	2	1 - 4
Goniophora cymbaeformis	-	18	13	8	25	-	-	-	-	4	2 - 5
Grammysia sp.	-	40	-	-	-	18	-	-	-	6	2 - 6
Leodispis barrowsi	-	-	-	-	-	-	-	-	10	9	9
Modiolopsis complanata	-	-	-	19	9	2	4	2	-	6,8	4 - 8
Modiolopsis sp.	-	37	-	-	-	-	-	-	-	2	2
Nuculites antiquas	-	23	-	-	-	-	-	-	-	2	2
Nuculites ovata	20	24	-	19	25	-	-	-	-	4	1 - 5
Pterinea lineata	-	43	-	-	-	-	-	-	-	2	2
'Pterinea' tenuistriata	-	19	20	18	22	-	-	-	-	4	2 - 5
Pteronitella retroflexa	37	29	-	15	24	-	-	-	-	4	1 - 5
Solenomya sp.	-	42	19	-	-	13	-	11	-	8	2 - 8
Gastropods											
Cyclonema corallii	37	28	-	-	-	-	-	-	-	2	1 - 2
Cymbularia carinata	-	-	-	-	-	15	-	-	-	6	6
Liospira sp.	37	47	-	-	-	-	-	-	-	1	1 - 2
Loxonema conicum	-	-	15	-	29	-	-	-	-	3	3 - 5
Loxonema gregarium	-	44	-	-	8	8	8	-	-	5 - 7	2 - 7
Loxonema obsoletum	-	12	-	12	21	15	-	-	-	2,4	2 - 6
Murchisonia sp.	-	41	-	-	-	-	-	-	-	2	2
Naticopsis cf. *trevorpatriciorum*	-	26	-	-	-	-	-	-	-	2	2
'Platyschisma' williamsi	-	-	-	-	10	17	-	-	-	6	5 - 6
Turbocheilus helicites	-	-	-	-	7	5	6	6	-	6	5 - 8

Table 9 (Contd.)

Cephalopods											
Kionoceras angulatum	25	21	-	-	-	-	-	-	-	2	1 - 2
'Orthoceras' sp.	23	6	9	-	-	-	-	-	-	2	1 - 3
Paraphragmites ibex	40	25	22	-	-	-	-	-	-	3	1 - 3
Other molluscs											
Bucanopsis expansus	-	27	-	19	-	-	-	-	-	4	2 - 4
Hyolithes forbesi	35	22	15	14	-	-	-	-	-	4	1 - 4
Trilobites											
Calymene sp.	10	-	-	-	-	-	-	-	-	1	1
Encrinuris sp.	16	44	-	-	-	-	-	-	-	1	1 - 2
Annelids											
Arabellites sp.	35	35	10	-	-	-	-	-	-	3	1 - 3
Keilorites sp.	-	-	4	-	-	-	-	-	-	3	3
'Serpulites' longissimus	13	11	7	-	-	-	-	-	-	3	1 - 3
Spirorbis lewisii	-	39	-	-	-	-	-	-	-	2	2
Ostracods											
Amygdalina sp.	50	-	-	-	-	-	-	-	-	1	1
Aparchites sinuatus	-	-	-	-	-	-	-	-	1	9	9
Aechimina sp.	-	-	-	-	-	-	-	-	6	9	9
'Beyrichia' sp.	20	16	-	-	-	-	-	-	-	2	1 - 2
Calcaribeyrichia tegula	-	14	-	-	-	-	-	-	-	2	2
Calcaribeyrichia torosa	-	-	22	-	13	-	-	-	-	5	3 - 5
Cavellina sp.	29	-	-	-	-	-	-	-	-	1	1
Cavellina cf. *plana*	-	-	-	-	-	-	-	-	4	9	9
Cavellina primaria	32	51	-	-	-	-	-	-	-	1	1 - 2
Cytherellina siliqua	8	30	12	16	5	7	5	3	-	8	1 - 8
? *Gotlandella* sp.	-	-	-	-	-	-	-	-	6	9	9
Hebellum tetragonum	4	13	-	-	17	9	9	-	-	1	1 - 7
Hebellum triviales	29	-	-	-	-	-	-	-	-	1	1
Hermannia cf. *marginata*	-	-	-	-	19	-	-	-	6	9	5 - 9
Frostiella groenvalliana	-	-	-	-	2	1	1	1	-	6 - 8	5 - 8
Kuresaaria circulata	11	48	22	-	15	12	-	12	6	9	1 - 9
Londinia kiesowi	-	-	-	-	3	4	3	5	-	5,7	5 - 8
Lophoctonella sp.	-	-	-	-	25	-	-	-	-	5	5
Neobeyrichia lauensis	19	-	-	-	-	-	-	-	-	1	1
Neobeyrichia sissica	32	-	-	-	-	-	-	-	-	1	1
Nodibeyrichia verrucosa	-	-	-	9	16	-	-	-	-	4	4 - 5
Nynamella sp.	29	50	-	-	12	9	9	-	-	6 - 7	1 - 7
Primitia mundula	-	-	-	-	-	14	-	-	-	6	6
Scaldianella simplex	3	8	-	-	-	-	-	-	-	1	1 - 2
Other fossils											
Calcareous tubes	-	-	-	-	-	10	7	7	-	7 - 8	6 - 8
Coral colonies	-	32	-	-	-	-	-	-	-	2	2
Cornulites sp.	25	-	-	23	23	-	-	-	-	4 - 5	1 - 5
Crinoid columnals	-	44	21	-	-	-	-	-	-	3	2 - 3
Hypermania sp.	-	-	-	-	-	-	-	-	2	9	9
Ozarkodina sp.	26	48	-	-	-	-	-	-	-	1	1 - 2

Diversity

Almost all studies of the Overton Formation show that the fossil diversity decreases towards its top (e.g. Holland *et al.*, 1963; Hurst & Watkins, 1977; Watkins, 1978a, 1979). This diversity change has been measured in this study using the rarefaction index. This index measures the diversity of different sized collections at a common sample size. The diversity values were calculated using the formula (see Heck *et al.*, 1975; Antia, 1977; Tipper, 1979):

$$E(s) = s - \sum_{i=1}^{s} (1 - N_i/N)^n$$

$E(s)$ = species richness (diversity), N_i = species population size for $i = 1....s$,
N = total number of individuals, s = number of species, n = required sample size.

The diversity values were standardised to a sample size of 100 individuals and calculated for each environment. These diversity values (text-fig. 16) show that there is a general decline in diversity through the Upper Ludfordian and into the Downtonian in both trace fossil and calcareous faunas. The distinctness of the faunas in each environment was determined using the distinctness, or similarity index (d) calculated as:

$$d = s/st$$

where s = the number of species the two assemblages have in common and st = the total number of species present in the two assemblages.

The results are plotted graphically in text-fig. 16 which shows the similarity of each of the environments 1 - 9, to environment 1.

The graph of faunal diversity (text-fig. 16) shows that the change in diversity can be related to environment. For example, (table 10) some groups (e.g. bryozoa) are confined to the presumed subtidal environments. Other groups (table 10) contain vastly different faunas in the intertidal and subtidal environments (e.g. the brachiopods). The general trend appears to be an increase in diversity with increasing depth (text-fig. 16). Similar observations have been noted in recent oceans (Sanders, 1968; Sanders & Hessler, 1967; Bosch, 1971). It has also been demonstrated (Antia, 1977) that gross changes in the diversity of a live calcareous fauna are echoed by changes in the diversity of the dead fauna. However, the derived dead shell fauna will have a higher diversity than the living calcareous shelled fauna because post mortem shell transport frequently introduces exotic species into an environment (Antia, 1977). See also appendix 1.

Palaeoenvironmental significance of the Temeside Bone-Bed

The Temeside Bone-Bed appears to have formed as a lag channel deposit in back beach lagoonal muds at Ludlow, during a long and gradual marine regression in which a diverse fauna of subtidal benthic species diminished in diversity and was replaced by a low diversity fauna. Throughout the marine regression faunal dominance appears to have increased (text-fig. 16) reflecting the changing environmental conditions from a relatively stable low stress rhythmite type of environment through to the relatively unstable high stress intertidal environments of the Downtonian. The gradual nature of this transition, presumably resulting from a fairly constant slow uplift of the Ludlow region, coupled with an inflow of fresh nutrients (derived from the southward migrating fluvial systems which covered the area in the Dittonian (Allen, 1974a,b), provided a gradual stability and improvement of the overlying waters.

This improvement and stability undoubtedly allowed a rich planktonic and nektonic fauna (e.g. fish) to develop, resulting in the eventual deposition of bone-beds in the intertidal zone (e.g. The Ludlow Bone-Bed).

In the Kerry and Long Mountain regions the general uplift was more rapid (Holland & Lawson, 1963; Cherns, 1977; McKerrow, 1979) and resulted in a major rapid environmental change in the top Ludlovian from comparatively deep water basinal Whitcliffian sediments through to shallow shelf and intertidal sediments containing limited quantities of fish debris. In South Wales this rapid uplift resulted in an unconformity at the base of the Temeside Beds (see Appendix 2). The faunas and sediments in the Temeside Beds at these localities varied greatly in lithology and fauna to the sections observed at Onibury (p. 182). These differences are probably a direct consequence of the variations, speed and magnitude of the environmental change from marine to non-marine conditions in the basinal and shelf areas of the Ludlovian sea (cf. Holland & Lawson, 1963). It is interesting to note that horizons rich in vertebrate debris developed in the basal Downtonian of the Long Mountain and that the magnitude of environmental change was less there than that at Kerry over a similar time period; whilst in the Cennan Valley (S. Wales) the top Ludlovian and basal Downtonian is missing.

In the Builth region poor exposure did not allow the transition from top Ludlovian to Temeside Bone-Bed bearing strata to be studied completely. However, the gradual change to more basinal type sediments through the Upper Ludfordian may suggest that in this region the sea was deepening during the top Ludlovian. It is not clear at the present time how the Downtonian sediments relate to the Upper Ludfordian sediments in this region.

However, the major point to emerge from this study is that Bone-Beds of the Temeside Bone-Bed type only appear to have formed in high intertidal to back beach environments in regions where the marine regression has been both slow and constant.

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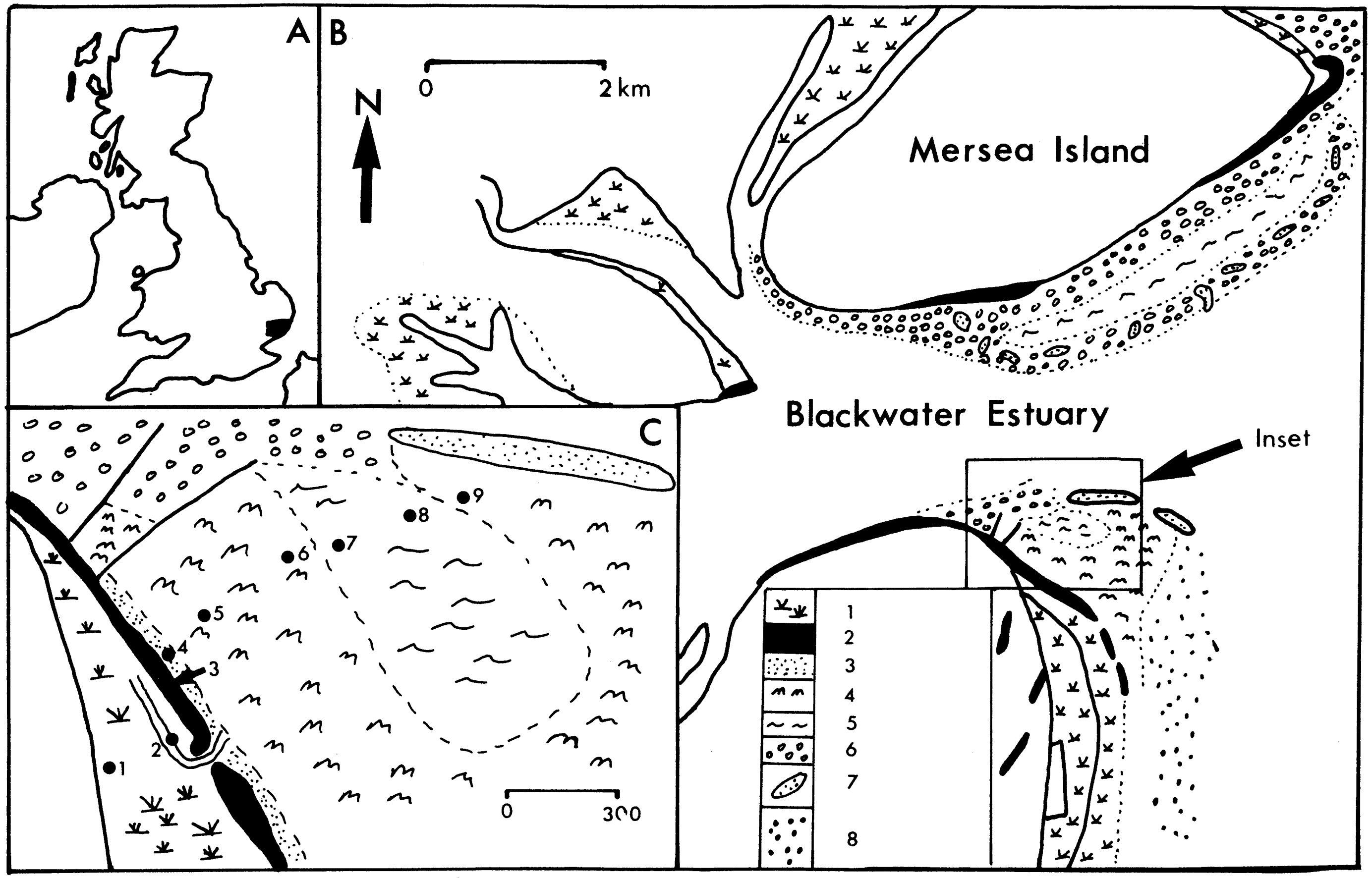
Appendix 1

On the distribution of recent live and dead ostracod faunas from the intertidal zone of Sales Point, Bradwell, Essex

Introduction

The aims of this study were to determine whether or not an assemblage of dead ostracods from a number of intertidal mudflat environments is representative of the live fauna of the same environments. All the ostracod material examined in this study has been deposited with Ludlow Museum.

The results of the work at Bradwell can be applied to the fossil record in intertidal and supratidal sediments deposited in a similar palaeoenvironment. For example, as a result of this study it can be suggested that if a fossil ostracod species present in a particular palaeoenvironment occurs as carapaces then it is probably indigenous to that environment. However, if the species commonly occurs as isolate valves, then the probability that the species is exotic to that particular environment is high.



Text-fig. 17: (A) Location map of the Blackwater Estuary.
(B) The mouth of the Blackwater Estuary showing sediment distribution and position of sketch map (C).
(C) Sketch map of the Sales Point area indicating sample localities and numbers.

Key to sediment types:
(1) Salt marsh; (2) Chenier sands; (3) Shell, pebble and muddy sand;
(4) Mud mounds; (5) Rippled muds; (6) Silt and gravel;
(7) Offshore gravel banks; (8) Sand deposits.

Table 10. Appendix 1. Rank order distribution table of the ostracod faunas at Sales Point The position of each locality is given in text-fig. 17 .
(L) = live fauna, (D) = dead fauna

Sample Location Number		*Carinocythere* cf. *carinata*	*Cythere lutea*	*Pontocythere elongate*	*Heterocythereis* cf. *albomaculata*	*Leptocythere pellucida*	*Loxochoncha rhomboidea*	*Urocythere* sp.	Environment
1	(L)	-	-	-	-	1	-	-	Upper Salt Marsh
	(D)	-	1	-	2	-	-	-	
2	(L)	-	1	-	-	2	-	3	Lower Salt Marsh
	(D)	-	1	-	2	3	5	4	
	(L)	-	1	-	3	2	-	-	Lower Salt Marsh - Runnel floor
	(D)	4	1	-	2	-	-	3	
3	(L)	-	-	-	-	-	-	-	Chenier ridge
	(D)	4	1	3	2	-	-	-	
4	(L)	-	1	-	-	2	-	-	Shelly, pebbly, muddy sand
	(D)	-	1	4	2	5	6	3	
5	(L)	-	1	3	-	2	-	-	Mudmounds (Upper surface) in the higher part of the intertidal zone
	(D)	-	1	3	2	4	-	-	
	(L)	-	1	-	-	2	-	-	Mudmounds (Channel floor) in the higher part of the intertidal zone
	(D)	-	2	3	1	4	-	-	
6	(L)	-	2	-	-	1	-	3	Mudmounds (Upper surface) in the middle part of the intertidal zone
	(D)	-	1	-	2	-	3	-	
	(L)	-	2	-	-	1	4	3	Mudmounds (Channel floor) in the middle part of the intertidal zone
	(D)	-	1	-	2	-	-	3	
7	(L)	-	2	-	3	1	4	-	Rippled muddy sands
	(D)	-	1	4	2	5	6	3	
8	(L)	5	2	1	-	3	-	4	Rippled muddy sands
	(D)	-	1	2	5	-	4	3	
9	(L)	-	3	2	4	1	5	6	Mudmounds (Upper surface) in the lower part of the intertidal zone
	(D)	6	1	2	3	4	5	-	
	(L)	-	1	3	-	2	-	-	Mudmounds (Channel floor) in the lower part of the intertidal zone
	(D)	-	1	3	4	5	2	1	

The area of Sales Point, Bradwell was chosen because the sequence of environments present in a transect from the low water mark to the high water mark (Greensmith & Tucker, 1967; Antia, 1977) closely resembles the postulated sequence of environments present in the Downtonian which culminate in the deposition of the Temeside Bone-Bed (see Allen, 1974a; Antia & Whitaker, 1979; Antia, 1979a).

Methods

On the 19th March 1977 the habitats on the prograding muddy coastline of the river Blackwater's estuary mouth, recorded by Antia (1977), were sampled for Ostracoda, text-fig. 17. Samples consisted of a 400 cm^2 area of sediment collected to a depth of 1 cm. Sample locations are given in text-fig. 17.

In the laboratory the sediment was stained with Bengal Rose in order to identify the ostracods which were alive when the sample was collected. The sediment was then broken down in hydrogen peroxide and hot water, prior to sieving, sorting and counting of the ostracods. An ostracod was recorded as live if it contained its limbs, head and thorax and was stained by the Bengal Rose.

The rank order abundances of the live and dead faunas and their trophic nuclei are presented in table 10. The trophic nucleus is used here to identify those species which numerically form 80% of the fauna (Neyman, 1966). The composition of the dead faunas is tabulated in table 11.

Faunal distributions

A total of eight species were recorded in the intertidal zone. Abundances and distributions through the zone are illustrated in tables 10 and 11. The relative diversity of the live fauna varies from 1 species in the highest salt marsh to 6 species in the lowest mud mounds. A similar diversity change may be observed for the dead faunas where for the same habitats, the change is from 2 to 7 species.

In general among the larger ostracod species (e.g. *Cythere lutea*) there is little difference between the rank placings of the live and dead faunas (table 10). However, the smaller species (e.g. *Leptocythere pellunica*) show a marked depletion in the dead faunas with respect to their rank placings in the live faunas (table 10), thus suggesting that (1) some sedimentological sorting and reworking of the dead shells has occurred, (2) differential destruction of some forms has taken place, thus enriching the fauna in the more robust forms, and (3) that the smaller species have only recently colonised the area. In view of the general stability of the environment, the presence of marked sedimentological sorting and reworking of the sediments in the intertidal zone (Greensmith & Tucker, 1967; Greensmith, 1977; Antia, 1977), and the great abundance of these smaller species in the live fauna, it seems likely that a combination of (1) and (2) has contributed to the differences observed in the rank placings of the live and dead faunas.

The commonest species in the live faunas of the lower Salt Marsh and upper intertidal zone was *Cythere lutea.* Although this species dominates the dead faunas (table 10), it is perhaps worth noting that dead articulated valves of the species (minus internal animal) were only found in the habitats inhabited by the species in life (table 11). *Leptocythere pellunica* was the dominant species in the live faunas of the highest salt marsh and the mud mound habitats (table 10). As already noted, the species is grossly under-represented in the dead faunas. Presumably its inability to withstand sedimentological transport (i.e. thin shell and ?weak hinge) accounts for the absence of paired valves in the dead fauna (table 11). *Hemicytheris elongata* formed the dominant species in the live faunas of the rippled mud habitat, and a minor component of the mud mound faunas (table 10).

Table 11. Appendix 1. Distribution of dead Ostracods at Sales Point, Bradwell, Essex
A key to the locality numbers is given in text-fig. 17.
R refers to runnel infill. C refers to channel infill.

(a) *Cythere lutea*

	Locality												
% valves	1	2	2R	3	4	5	5C	6	6C	7	8	9	9C
Paired	-	10.6	5.2	1.3	2.8	13.4	9.2	43.8	2.7	11.5	12.2	13.5	18.8
Left	9.0	31.8	31.2	30.1	40.1	35.0	31.8	23.0	38.9	21.8	21.9	37.8	28.3
Right	9.0	36.9	15.6	19.2	28.0	30.8	27.2	28.1	44.4	46.2	39.0	37.8	30.1
Fragments	82.0	21.2	46.9	49.3	28.9	20.7	31.8	5.1	14.0	20.5	26.8	10.8	22.6

(b) *Carinocythere* cf. *carinata*

% valves	1	2	2R	3	4	5	5C	6	6C	7	8	9	9C
Paired	-	-	-	-	-	-	-	-	-	-	-	-	-
Left	-	-	-	-	-	-	-	-	-	-	-	100.0	-
Right	-	-	100.0	-	-	-	-	-	-	-	-	-	-
Fragments	-	-	-	100.0	-	-	-	-	-	-	-	-	-

(c) *Pontocythere elongata*

% valves	1	2	2R	3	4	5	5C	6	6C	7	8	9	9C
Paired	-	-	-	-	-	28.7	-	-	-	-	-	-	-
Left	-	-	-	-	33.3	28.5	-	-	-	33.3	47.0	46.6	50.0
Right	-	-	-	-	-	42.8	-	-	-	-	35.2	40.0	30.0
Fragments	-	-	-	100.0	66.6	-	100.0	-	-	66.7	17.6	13.3	20.0

(d) *Loxochoncha rhomboidea*

% valves	1	2	2R	3	4	5	5C	6	6C	7	8	9	9C
Paired	-	-	-	-	-	-	-	-	-	-	-	-	-
Left	-	-	-	-	100.0	-	-	-	-	33.3	-	57.1	55.0
Right	-	-	-	-	-	-	-	-	-	-	100.0	28.5	45.0
Fragments	-	100.0	-	-	-	-	-	-	-	66.7	-	14.2	-

(e) *Leptocythere pellucida*

% valves	1	2	2R	3	4	5	5C	6	6C	7	8	9	9C
Paired	-	-	-	-	-	-	-	-	-	-	-	-	-
Left	-	-	-	-	100.0	100.0	100.0	-	-	25.0	-	50.0	60.0
Right	-	50.0	-	-	-	-	-	-	-	-	-	25.0	20.0
Fragments	-	50.0	-	-	-	-	-	-	-	75.0	-	25.0	20.0

(f) *Heterocythereis* cf. *albomaculata*

% valves	1	2	2R	3	4	5	5C	6	6C	7	8	9	9C
Paired	-	-	11.1	-	-	-	-	-	-	-	-	11.8	-
Left	-	23.5	44.4	40.0	55.0	37.5	36.8	57.1	72.4	-	-	41.1	71.4
Right	-	70.5	44.4	50.0	35.0	31.3	36.8	7.1	21.2	-	100.0	35.2	-
Fragments	100.0	5.9	-	10.0	10.0	31.2	26.3	35.7	6.4	100.0	-	11.8	28.5

(g) *Urocythere* sp.

% valves	1	2	2R	3	4	5	5C	6	6C	7	8	9	9C
Paired	-	-	-	-	-	-	-	-	-	-	-	-	-
Left	-	50.0	100.0	-	77.7	-	-	-	50.0	-	100.0	-	-
Right	-	-	-	-	22.3	-	-	-	50.0	80.0	-	-	-
Fragments	-	50.0	-	-	-	-	-	-	-	20.0	-	-	-

The reasons for the distribution of each of these three common species in the live faunas may lie in their general morphology. For example, the thin shelled small species, *Leptocythere pellunica* dominates habitats which are of a protected 'low' energy nature such as the highest salt marsh and lower mud mounds. The more robust smooth cylindrical species *Pontocythere elongata*, which is almost devoid of ornamentation is commonly found in perhaps the most rigorous environment of the intertidal zone, the rippled mud habitat, and is presumably best adapted to a shifting silt environment. *Cythere lutea* dominates the faunas of the upper mud mounds (table 10) in its angular robust thick shelled form. It is well adapted to the coarse-grained often shelly nature of this 'high energy' habitat. It is also interesting to note that the mud mound surfaces in this region contain a rich algal growth.

Dead valve ratios, articulation and fragmentation

Dead ostracods occurred as either paired articulated valves, single valves, or fragments (table 11) which also illustrates the proportional distribution of articulated, fragmented, and single valves for each species in each habitat. The same table shows that the relative proportion of paired articulated valves is a function of the environment. For example, *Cythere lutea* contains a higher proportion of paired valves on the surface of the lower marsh and higher mud mounds than in the adjacent channels and runnels, presumably because the valves are more likely to be disarticulated by the constant movement in the latter of sediment. As can be seen from the comparative abundance of left and right valves, some sorting of the disarticulated carapaces must have occurred. The proportion of shell fragments for the commoner dead shell species *Cythere lutea* and *Heterocytheris* cf. *albomaculata* increases to a maximum in the highest intertidal zone, presumably because whole valves were too heavy to be transported into the highest salt marsh habitat. The proportion of fragments in the channels and runnels is higher than in the adjacent mounds, presumably reflecting the high proportion of reworking which channel infill undergoes.

Shell abrasion

In general the surface of the live shells are relatively free from abrasion. However, some 'live' carapaces of *Pontocythere elongata* show abrasive etch marks. The dead ostracod valves may be unworn or show surface pitting. Some of the surface ornament pits have provided microhabitats for epipsammic diatoms.

Conclusions

In this study eight species were recorded from 9 sample stations (text-fig. 17) across the intertidal zone at Sales Point, although none of the commoner species were recorded only at a single sample station. *Cythere lutea* was commonest in the upper part of the intertidal zone (table 10). *Pontocythere elongata* was most abundant in the mid intertidal zone in the rippled mud habitat, while *Leptocythere pellunica* was commonest in the very highest and middle - lower parts of the intertidal zone.

Neither the relative abundances or rank distributions of the dead fauna (table 10) accurately reflect the composition of the live fauna, though a reasonably accurate representation can be obtained on a presence - absence basis.

Regions of high sediment movement (i.e. channel infill) tend to contain a high proportion of disarticulated and fragmented carapaces in their dead faunas, when compared to the surrounding substrate. The results of this study suggest that the presence of ostracod carapaces in a particular environment in the Silurian is a reasonable indication that the species actually lived in that environment. Consequently the faunas listed in table 2, p. 174, probably lived in low densities on the sediments in which they are now entombed.

Appendix 2

Pridiolian marine fossils from the supposedly Lower Ludfordian (Ludlovian) Cennan Beds of the Cennan Valley

by

D.R. Atkins (B.N.O.C., Glasgow) and D.D.J. Antia

Introduction

The object of this supplementary study was to demonstrate that the Cennan Beds of the Cennan Valley are of Downtonian (Pridiolian) age, and not Upper Leintwardinian (Lr. Ludfordian) as suggested by Squirrell and White (1978).

The sample was collected by D.R.A. from the lowermost fossiliferous sediments of the Cennan Beds, about 0.56 m above the base of the unit, in the Cennan Valley. The section was exposed in the A 476 road cutting (SN 6102 1906) 4 km south-west of Llandeilo, Dyfed, Wales. The sample was examined by D.D.J.A. for fossils under a binocular stereomicroscope.

Fauna recorded

The following species were observed in the sample (actual numbers present are given in brackets):

Brachiopods
Craniops aff. *implicatus* (J. de C. Sowerby) (17); *Lingula cornea* J. de C. Sowerby (1); *Microsphaeridiorhynchus* sp. (17); ?*Orbiculoidea* sp. (1); *Protochonetes* cf. *missendensis* Straw or *P.* cf. *novascoticus* Mclearn (7); *Salopina* aff. *lunata* (J. de C. Sowerby) (28); ?*Brachyzga* sp.* (1).

Bryozoans
Ceramopora sp. (1); *Leioclema* sp. (11).

Ostracods
Frostiella groenvalliana Martinsson (6); ?*Frostiella* sp. (115); *Frostiella* cf. *bicristata* Shaw (1); *Londinia kiesowi* (Krause) (8); *Hermannia* cf. *marginata* (Jones) (2); ?*Nyhamnella* sp. (1).

*The specimen was identified by Dr. C.J. Burton.

Other fossils
Orthoceras sp. (2); *Kionoceras* sp. (2); pterinoid bivalve (1); ?*Hormotoma* sp. (3); *Hyolithes* cf. *forbesi* (Sharpe) (1); ?*Modiolopsis* sp. (1); *Tentaculites* sp. (6); *Gomphonchus murchisoni* (Ag.) (6); round crinoid columnals (77).

Faunal conclusions and implications

The ostracod species *F.* cf. *bicristata*, *F. groenvalliana*, *L. kiesowi* and *H.* cf. *marginata* prove (see Appendix 1) a Downtonian (Pridiolian) age for the Cennan Beds (cf. Elles & Slater, 1906; Martinsson, 1967; Siveter, 1978; Shaw, 1969, 1971).

The implications of this interpretation of the fauna are that the unconformity at the base of the Cennan Beds extends from the Lower Leintwardinian into the Downtonian and not as previously suggested into the Upper Leintwardinian. The Tilestones of Potter & Price (1965) and Squirrell & White (1978) which rest unconformably on the Cennan Beds, may be of middle to highest Pridiolian (Silurian) or lowest Gedinnian (Lower Devonian) age, although they themselves lack any diagnostic fossils. Marine conditions prevail into the Downtonian in South Central Wales, and finally no sediments representing the Upper Ludlow Series are present in the Cennan Valley.

Plate Captions

Plate 6, Fig. (1) Haematite nodules (white) in red clays at Ludlow in the Ledbury Formation. (Negative print.) (x 8)

(2) Calcareous nodular red clays at Ludlow in the Ledbury Formation, Ludlow. (Negative print.) (x 4)

(3) Micrite pipes infilling small cracks (black) in red clays in the Ledbury Formation at Ludlow. (Negative print.) (x 4)

(4) Micrite pipe from the red clays of the Ledbury Formation at Ludlow. (x 1)

(5) Plant remains on a bedding plane in the Temeside Formation at Wallop Hall, including ?*Cooksonia* sp. and *Hostinella* sp. (x $\frac{1}{2}$)

Plate 7, Fig. (1) Stromatolites in the Temeside Beds at Onibury. (x 3)

(2) Stromatolites in the Temeside Beds at Onibury. (x 3)

(3) Clays in the Ledbury Formation (red beds) at Ludlow. (x 1000)

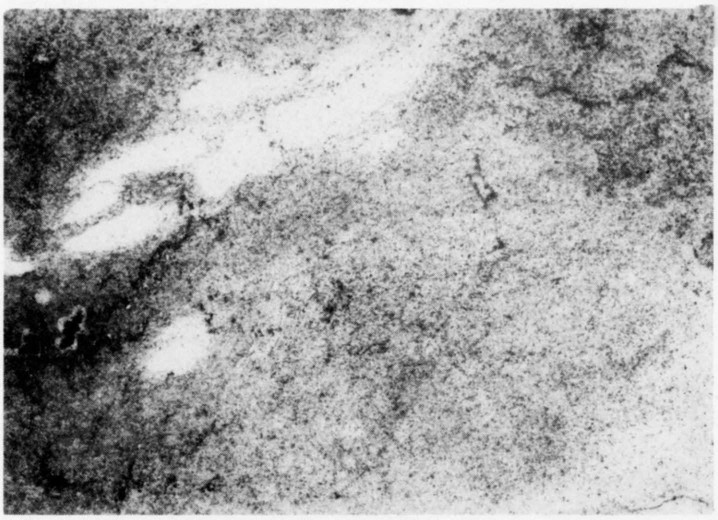
(4) Burrows in a sandstone sheet at Builth Wells (locality 2, text-fig. 14). (x 2)

(5) *Hermannia phaseola* from the Temeside Formation at Wallop Hall. (x 3)

(6) *H. marginata* from the Temeside Formation at Wallop Hall. (x 3)

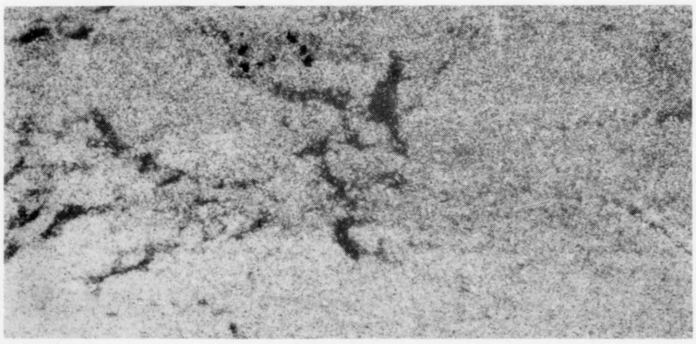
(7) *Bifungites* sp. from the Downtonian of the Kerry district.

1.

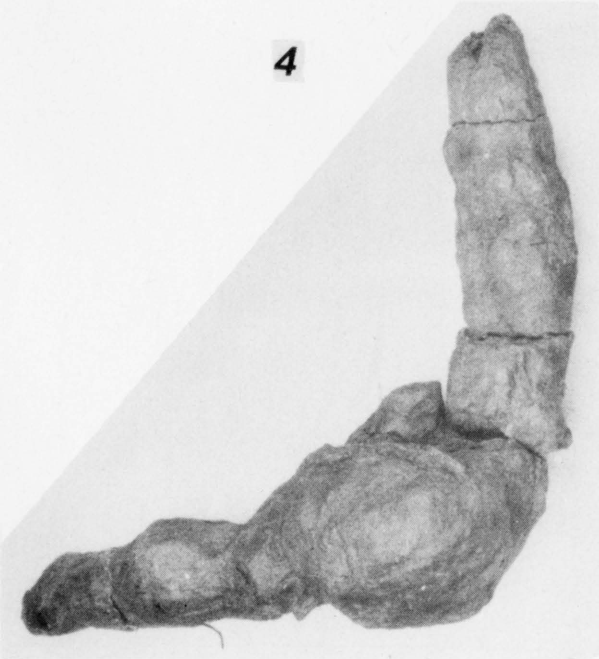


2

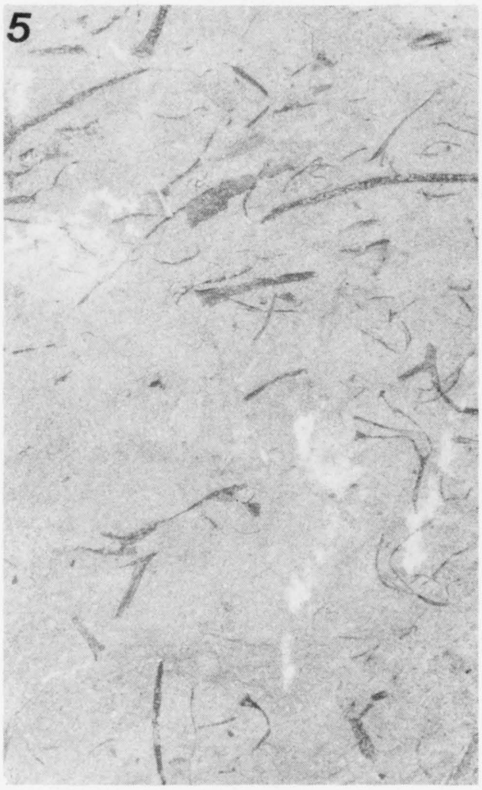
3



4



5

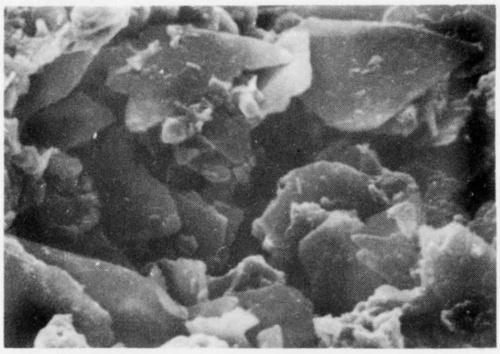


Antia - Temeside Bone-Bed.
Explanation opposite.

1

2

3

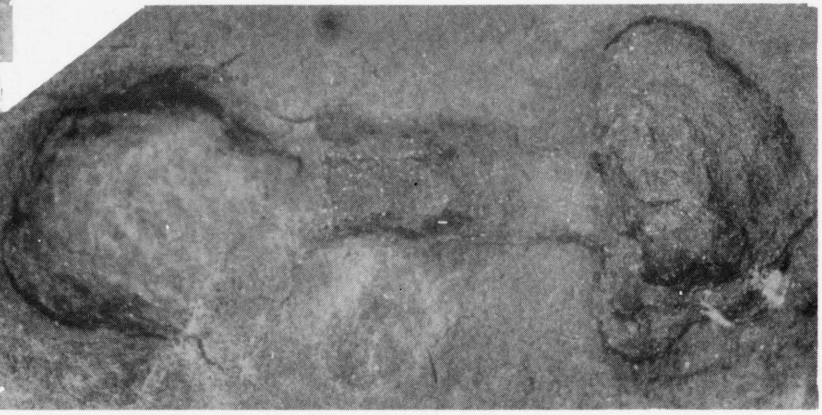


4

5

6

7



Antia - Temeside Bone-Bed.
Explanation p. 208.

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