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**Address for Correspondence,**

General information,  
membership details:

The Secretary,  
East Midlands Geological Society,  
311 Mansfield Road,  
Redhill,  
Arnold,  
Nottingham

Tel. No. (0602) 267442

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Front Cover: Transverse section of the coral *Orionastraea placenta* Smith,  
Lower Carboniferous, D<sub>2</sub> Zone, Coombsdale, Derbyshire.



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

by

David D.J. Antia

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.

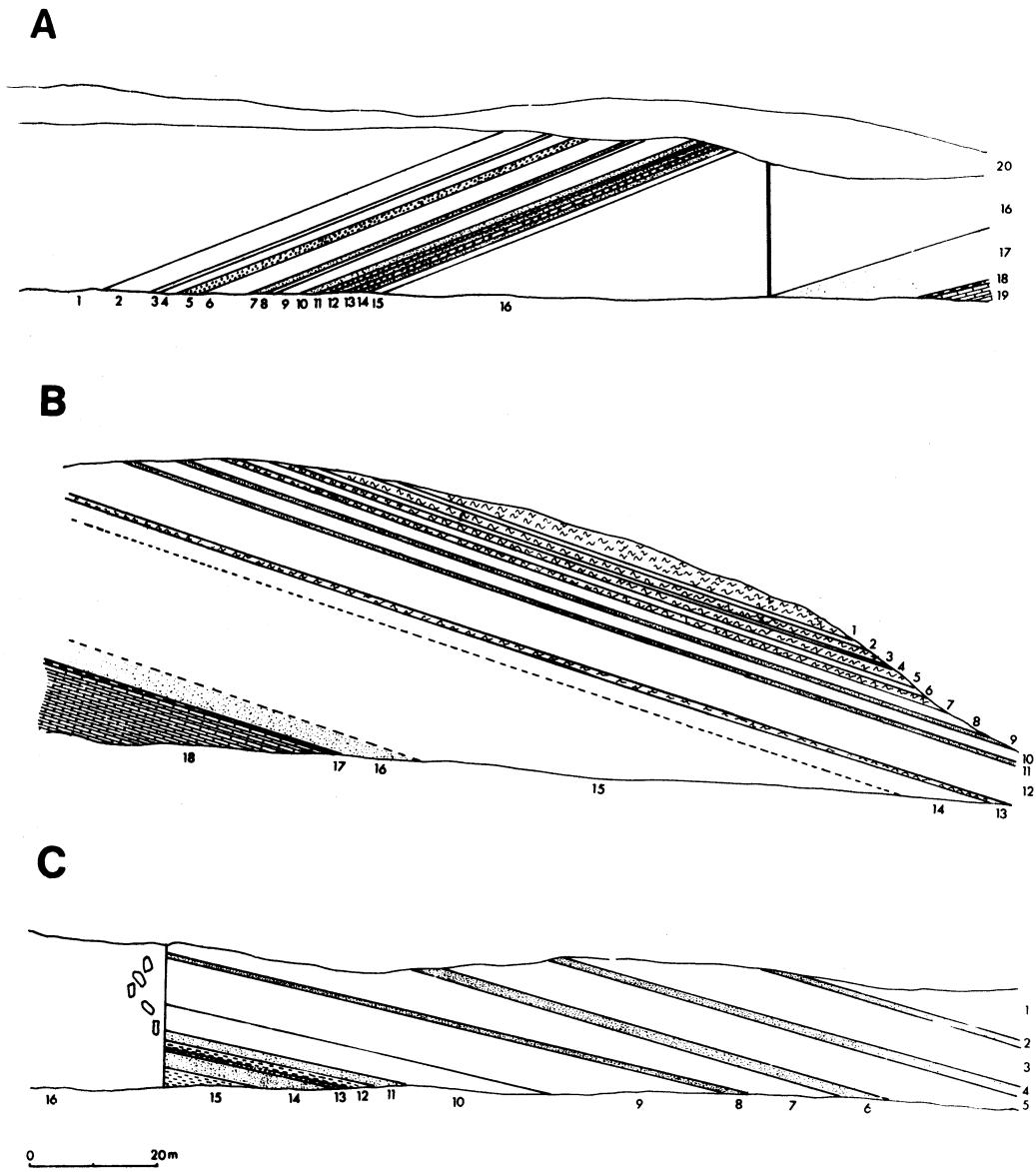
Introduction

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:

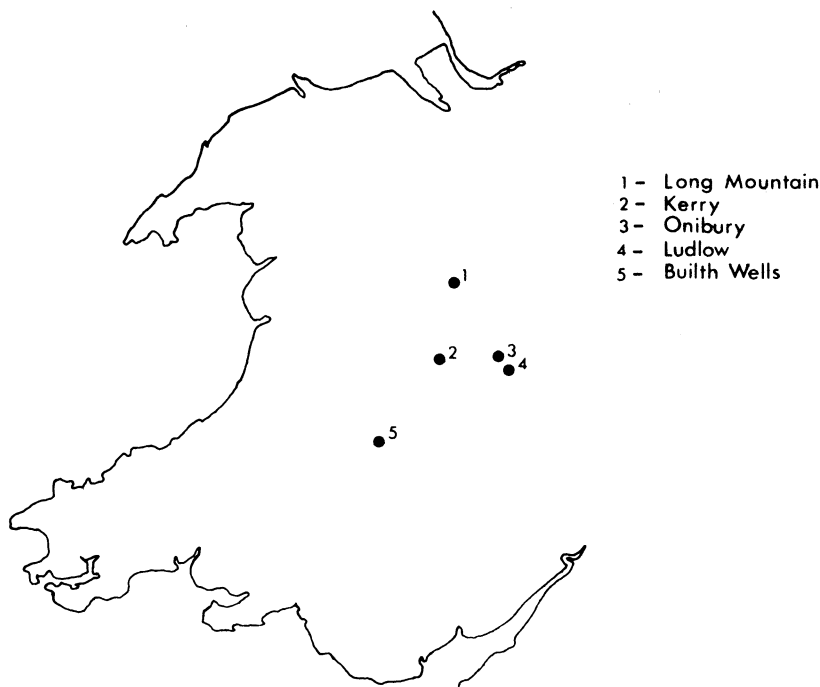
1, 3, 5, 7, 13. Green rubbly shale; 2, 4, 6. Red marl; 8. Brown shale; 9, 11. Grey grit bands; 10, 12, 14. Green shale; 15. This space uncertain (probably red and green marls); 16. Downton sandstone; 17. Ludlow Bone-Bed 2 inches thick; 18. Upper Ludlow rock.

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

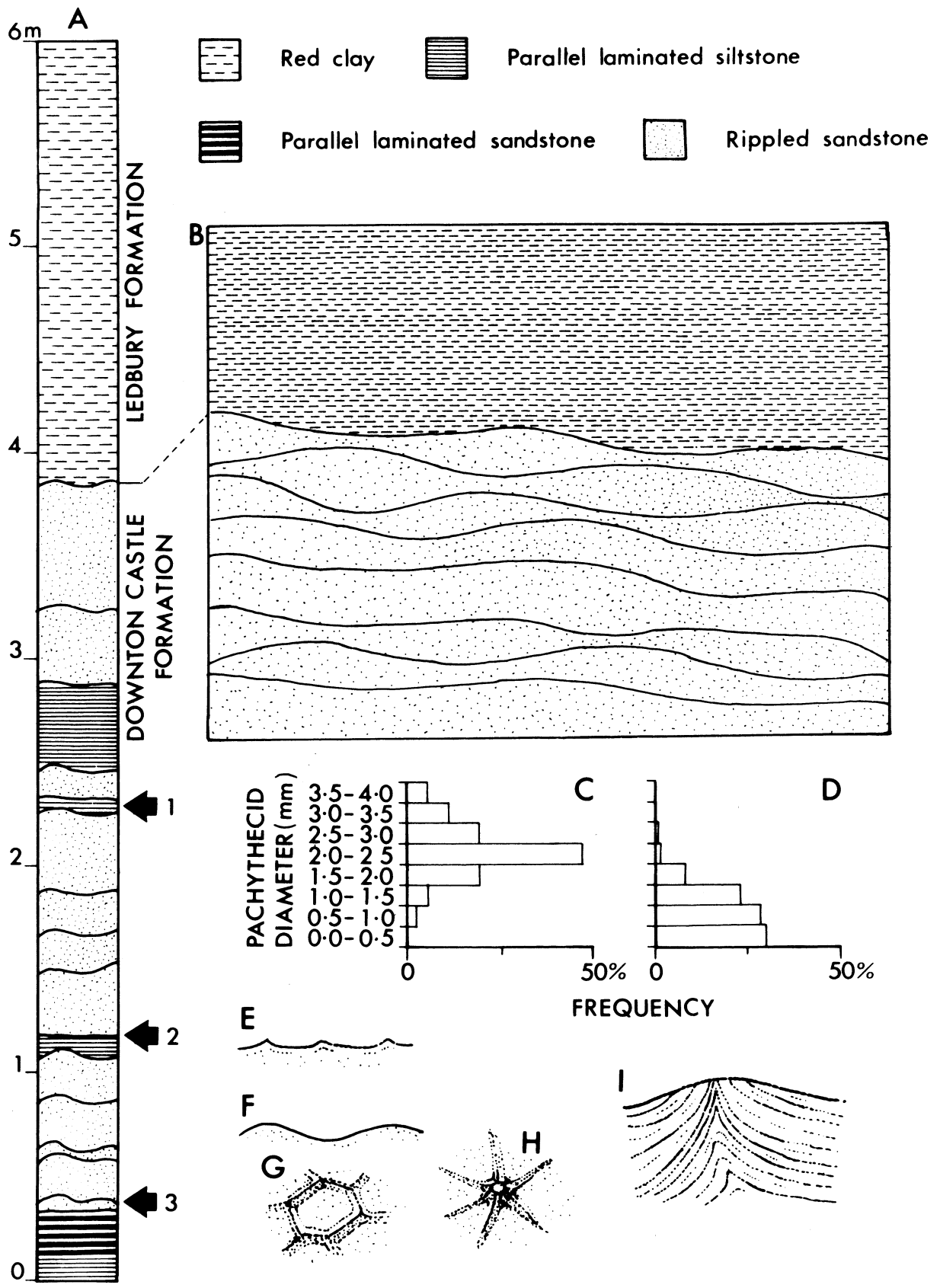
The individual sediment layers are given as follows:

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<sup>2</sup>. Associated with them were 40 specimens of *Pachythea 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 *Pachythea 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<sup>2</sup>. The size frequency distributions of the pachytheacids 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%), *Pachythea* (10-15%), *Psilophytites*, *Prototaxites*, *Cooksonia*, and *Nematophyton* were recorded on a bedding plane surface area of 13864 cm<sup>2</sup>. 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<sup>2</sup>.
- 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 *Pachythea sphaerica* at sample point 2. Sample size = 192.
- D. Size-frequency distribution of *Pachythea 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 Leintwardian 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 greenish 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)

System		Series	Stage	Formation	Zones				
					a. Ostracod	b. Conodont	c. <i>Lingula</i>	d. Fish	
SILURIAN	Devonian	Pridoli	Not assigned	Ledbury	<i>Aparchites</i> sp.	<i>Ozarkodina remscheidensis</i>	<i>Lingula</i> cf. <i>missendenensis</i>	<i>Logania - Thelodus - Hemicyclaspis</i>	
				Temeside	<i>Herrmannia - Londinia</i>	<i>Ozarkodina eosteinhornerensis</i>	<i>L. cornea</i>	<i>Logania - Thelodus</i>	
					<i>Frostiella - Londinia</i>		<i>L. minima</i>		
		Overton	*Whitliffian	Downton Castle	<i>Calcaribeyrichia torosa</i>	<i>Ozarkodina Crispa</i>	<i>L. lata - Lingula</i> sp. nov.	<i>Thelodus - Logania - Gomphonchus</i>	
					<i>C. tegula</i>				
		Ludlowian	Ludfordian (Antia)	*Leintwardinian	Sunny Hill	<i>Neobeyrichia lauensis</i>	<i>Ozarkodina Crispa</i>	<i>L. lata - L. lewisii</i>	<i>Thelodus - Gomphonchus</i>

Table 1 (Contd.)

B. Lithostratigraphy

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

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 *Pachythea* sp. are present in the ripple troughs. The pachytheoids 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

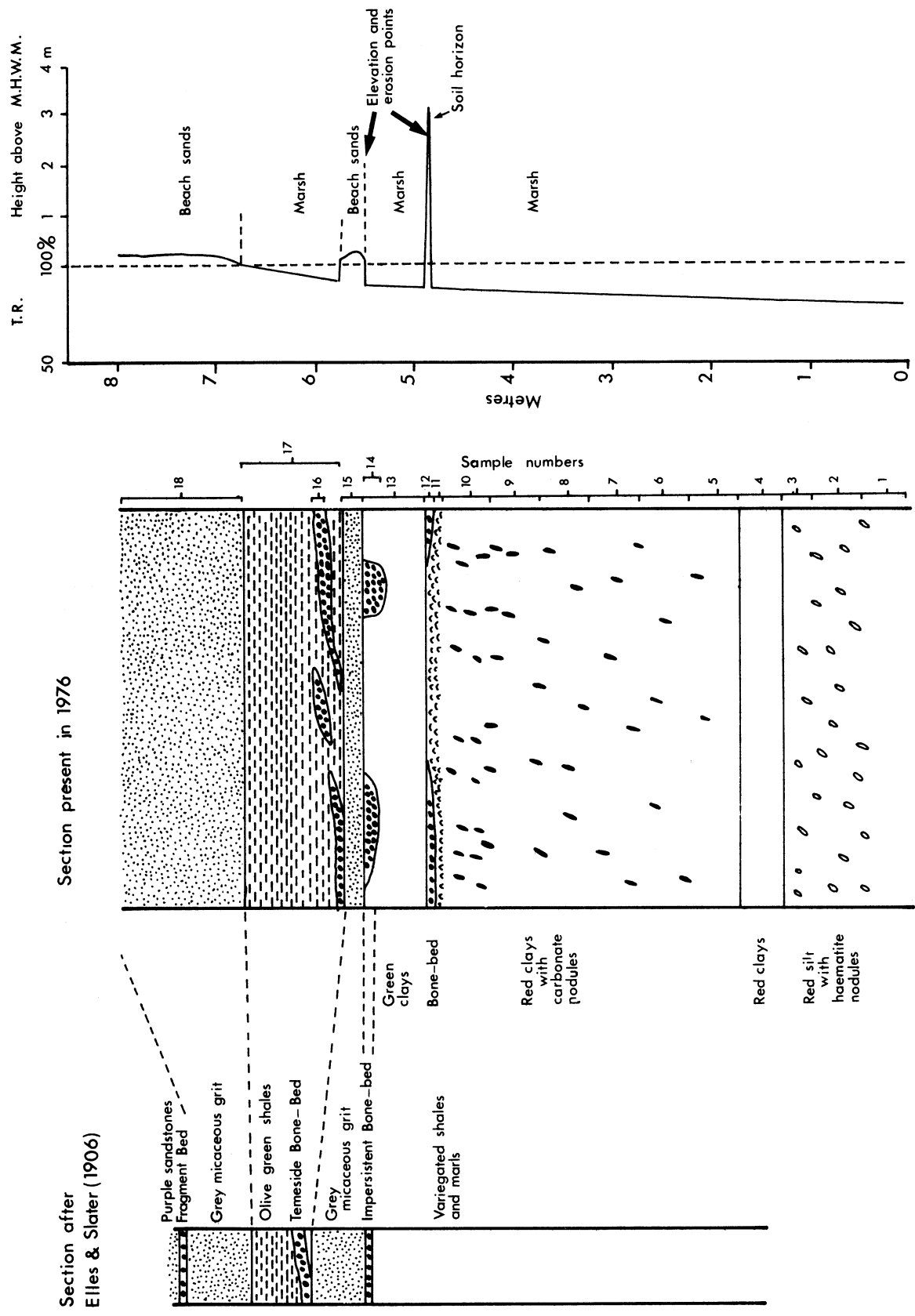
This section was first noted by Murchison (1850-1854; 1856) and later by Elles & Slater (1906). They recorded the sedimentological and faunal succession of the section. Later, Allen (1974a) noted the presence of sand sheets, and Antia (1979a) briefly described the bone-beds in the section.

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 *kuvesaaria 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<sup>3</sup> of surface sediment at or around the mean high water mark to about 2,200 carapaces/10,000 cm<sup>3</sup> 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
<b>Ostracods</b>											
<i>Aechimina</i> sp.	-	-	-	-	-	-	-	-	1	-	-
<i>Aparchites sinuatus</i> (Hall)	-	-	-	2	-	-	-	2	9	-	-
<i>Cavellina</i> cf. <i>plana</i> Neckaja	-	-	-	-	-	-	-	2	1	1	-
<i>Kuresaaria circulata</i> (Neckaja)	-	-	-	-	-	-	-	-	1	-	-
? <i>Gotlandella</i> sp.	-	-	-	-	-	-	-	-	1	-	-
<i>Hermannia</i> cf. <i>marginata</i> (Jones)	-	-	-	-	1	-	-	-	-	-	-
<b>Foraminifera</b>											
<i>Hyperamnia</i> sp.	-	3	5	-	-	-	1	-	-	-	1
<b>Brachiopods</b>											
<i>Lingula cornea</i> J. de C. Sowerby	-	-	-	-	-	-	-	3	-	-	1
<b>Fish</b>											
<i>Thelodus parvidens</i> 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
<b>Brachiopods</b>							
<i>Lingula cornea</i> J. de C. Sowerby	-	-	7	-	-	-	-
<i>Lingula</i> cf. <i>missendenensis</i> Straw	-	-	-	2	-	-	-
<b>Fish</b>							
<i>Corvaspis</i> cf. <i>kingi</i> Woodward	-	-	-	-	2	-	-
<i>Cephalaspis</i> spp.	22	-	-	-	61	-	-
<i>Gomphonchus tenuistriata</i> (Ag.)	6	-	3	-	3	-	-
<i>Gomphonchus</i> sp.	2	-	-	-	4	-	-
<i>Logania cunetea</i> Gross	-	-	2	-	-	-	-
<i>Logania ludlowiensis</i> Gross	70	-	90	-	2	-	-
<i>Thelodus bicostatus</i> (Hoppe)	1	-	-	-	-	-	-
<i>Thelodus parvidens</i> Ag.	55	1	15	-	3	-	-
<i>Thelodus trilobatus</i> (Hoppe)	28	-	9	-	2	-	-
Indeterminate fish fragments	40	-	65	-	21	-	-
<b>Foraminifera</b>							
<i>Hyperamnia</i> sp.	-	1	-	-	-	-	-
<b>Plants</b>							
<i>Pachytheca sphaerica</i> Hooker	2	-	5	-	-	-	-
Plant debris	382	-	643	38	424	-	-
<b>Conodonts</b>							
<i>Ozarkodina remscheidensis</i> (Walliser)	1	-	-	-	-	-	-

Table 4. Ostracod carapace densities at Sales Point, Bradwell, Essex, on 18/3/1977, expressed as number per 10,000 cm<sup>3</sup> 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

Species	Sample Position (cm)							
	0	282	370	390	405	434	515	964
<b>Brachiopods</b>								
<i>Lingula cornea</i>	-	23	54	21	95	133	25	
<i>Lingula minima</i>								
J. de C. Sowerby	-	2	-	-	-	2	-	
<b>Ostracods</b>								
<i>Cytherellina cf. siliqua</i>	-	3	10	883	3	10	5	
<i>Frostiella bicristata</i> Shaw	-	8	-	1	1	-	-	
<i>Frostiella groenvalliana</i>								
Martinsson	-	-	-	-	1	-	-	
<i>Londinia kiesowi</i> Krause	-	31	-	87	11	-	6	
<i>Hermannia marginata</i>								
(Keys)	-	1	-	-	-	-	3	
<b>Other fossils</b>								
Eurypterid fragments	-	p	-	-	-	-	p	
<i>Leodispis barrowsi</i> Reed	-	2	-	-	-	-	-	
? <i>Kionoceras</i> sp.	-	1	-	-	-	-	-	
<i>Pachytheca</i> 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<sup>3</sup> 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<sup>3</sup> 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 purchisoni* (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. purchisoni* fauna has been recorded from the Downtonian of Canada (Broad & Dineley, 1973; Dineley & Loeffler, 1976), and suggests a late Downtonian age for this section (Dineley & Loeffler, 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).

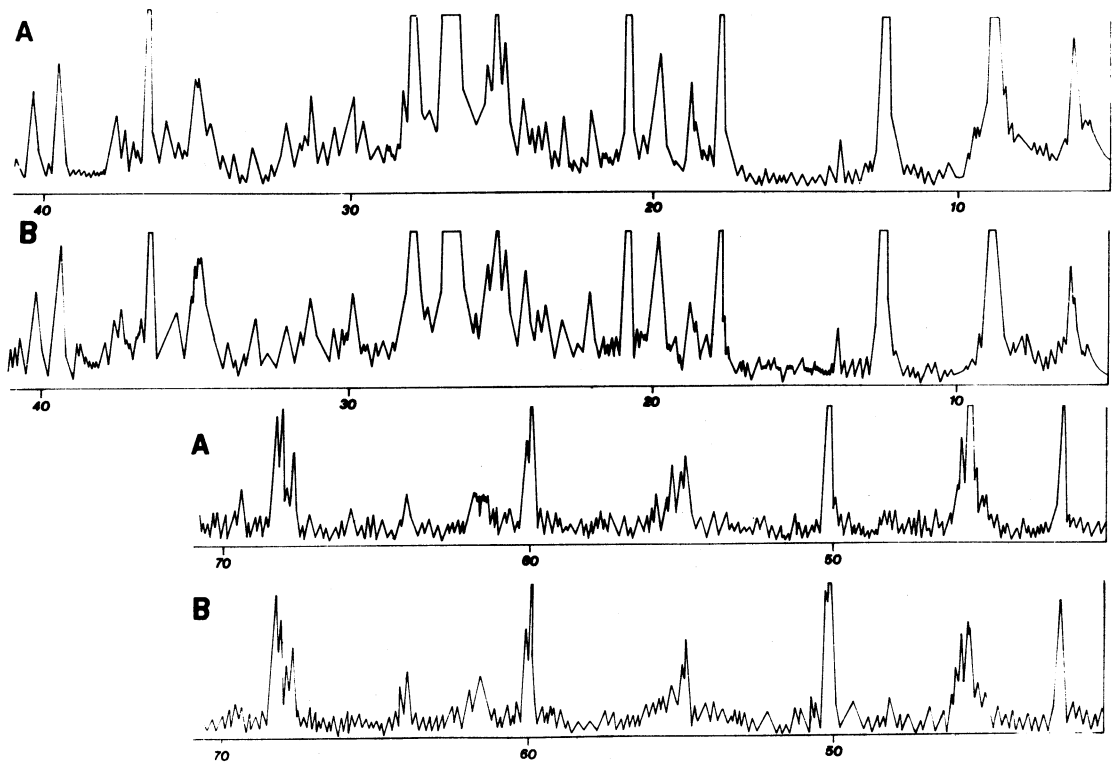
Selected layers from the sequence were examined in thin section. They indicate that the lower part of the sequence is comprised principally of clay, micrite and quartz. The grains are all heavily coated in haematite giving a red colouration to the sediment sequence. In the sieved residues examined for 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)

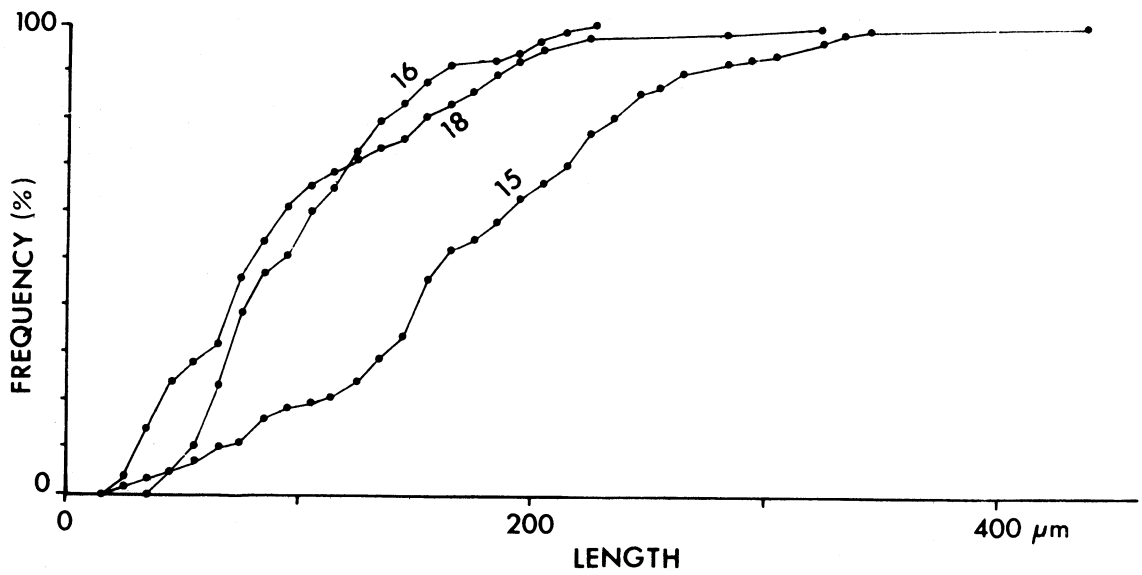
Layers 1 - 11 of the section can be described from base to top as a basal red silt clay unit with reduction spots (layers 1 to 4) overlain by 3 m of carbonate rich red clays (layers 5 to 11). These sediments are thinly bedded (laminae 1 - 2 mm thick) with wavy slightly discordant laminae of poorly sorted 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  $\theta$ .



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 oxidation by oxygen-rich waters shortly after the sediments were deposited and may indicate a relative drop in sea level (Czyscinski *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.

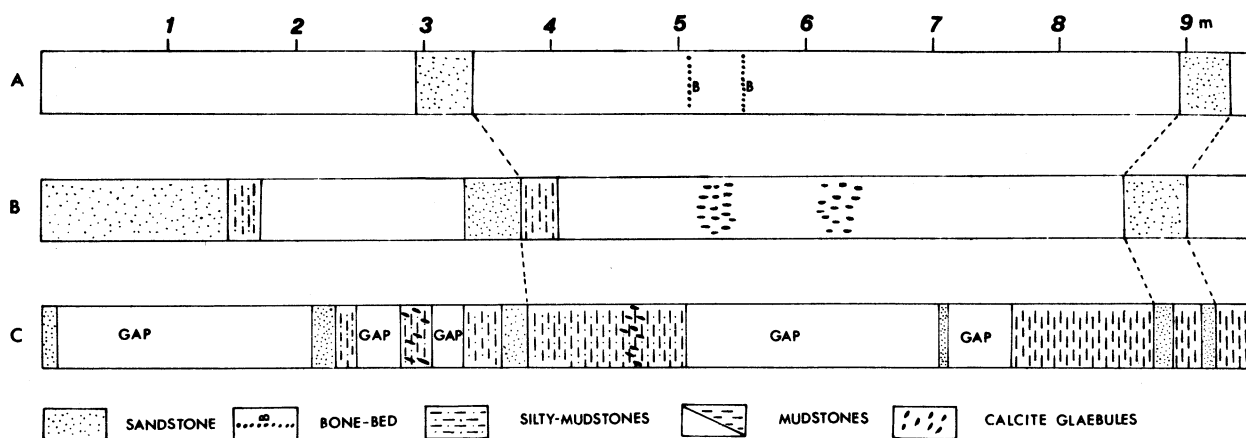
The haematite nodules in the base of the section (plate 6, fig. 1, layers 1 - 3) may have formed as ferricretes (cf. Goudie, 1973). It is, however, more probable that both they and the haematite in the red beds (layers 1 - 11) formed by the intrastratal alteration of ferromagnesium silicate grains, pyrite 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 cyclothem 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.

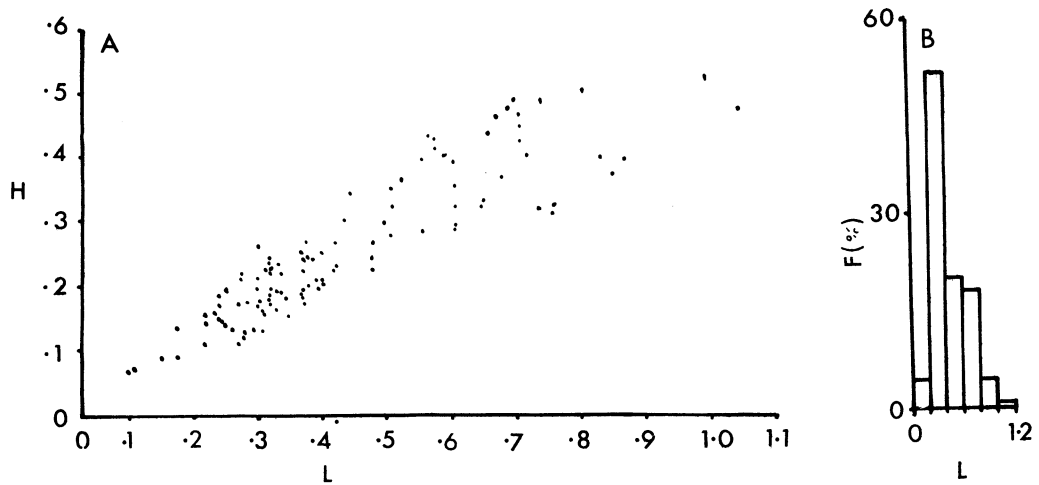
The vertebrate remains are black in colour and highly weathered (see Antia, 1979a) and highly abraded. An X.R.D. analysis of these grains shows that they are made of a pure carbonate apatite, while the vertebrate remains in the underlying red beds are a translucent yellow colour suggesting that they 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



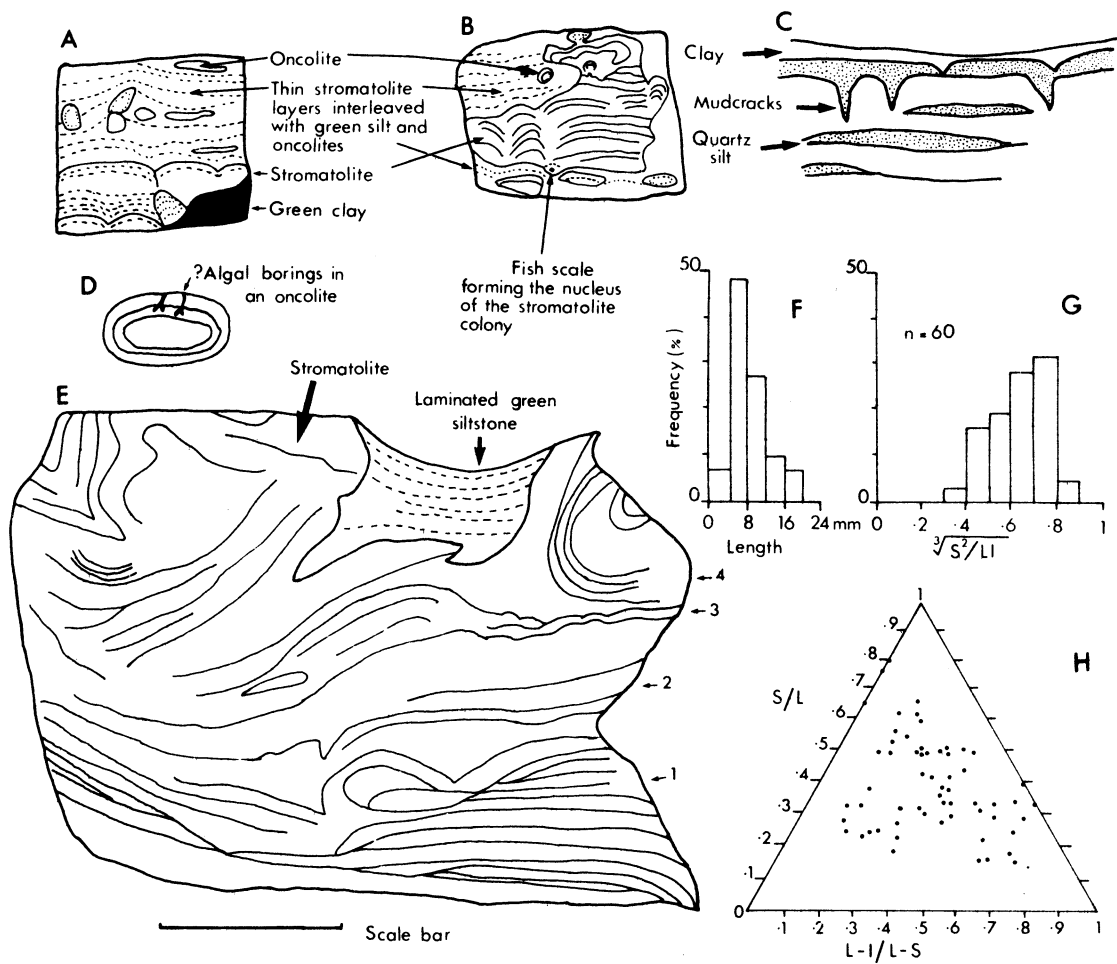
Text-fig. 6: The Temeside Beds at Onibury. A. Section after Elles & Slater (1906)  
 B. Section after Allen (1974a) C. Section present in 1976

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) subsequent desiccation 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 contemporary 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.

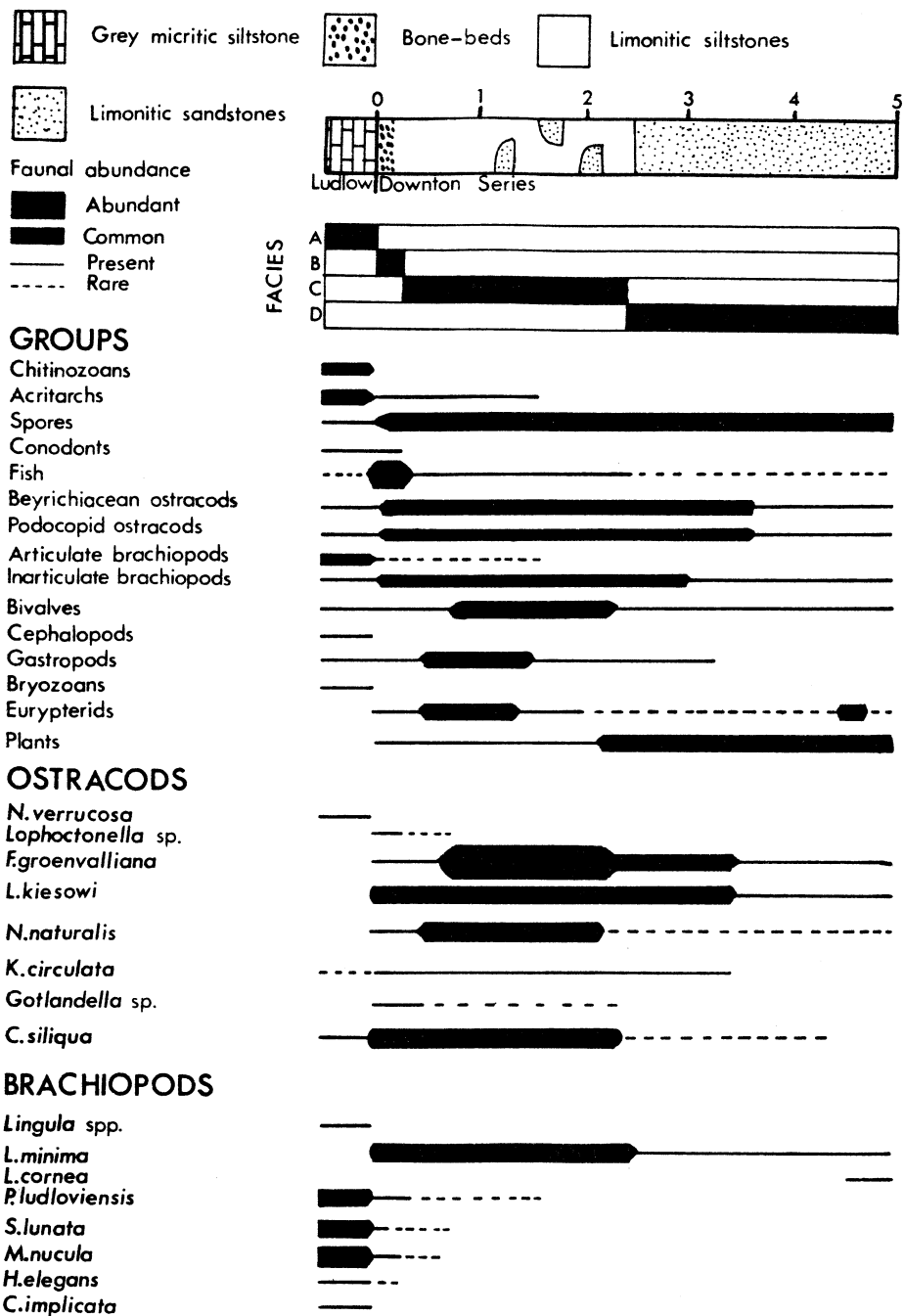
Allen (1974b) considers the carbonate nodules in this section to be pedogenic. However, some of these nodules are bored (text-fig. 8d) and contain an internal lamination (text-fig. 8a,b,c). This lamination can either consist of concentric rings or of wavy laminae and domes, and suggests (cf. Allen, 1974a; 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 leperditid 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, Siefert (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

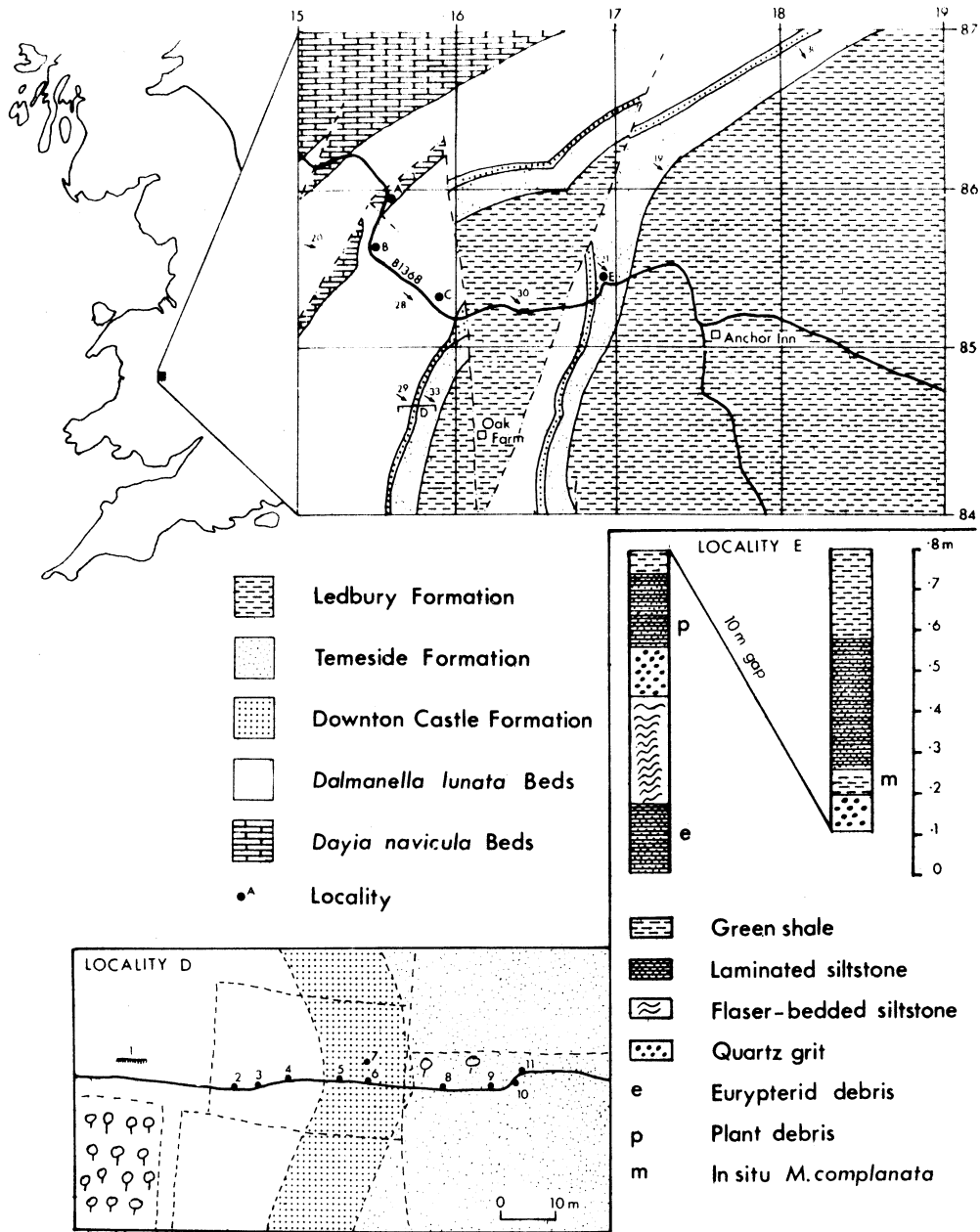
The region studied and sample localities are indicated in text-fig. 10. The sediments observed have been mapped by Earp (1938) and may be described as follows:

##### 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<sup>2</sup> bedding plane surface area: 10 m<sup>2</sup> examined), alternating with well laminated grey clay/silt rhythmites containing no fauna (6 m<sup>2</sup> 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?).

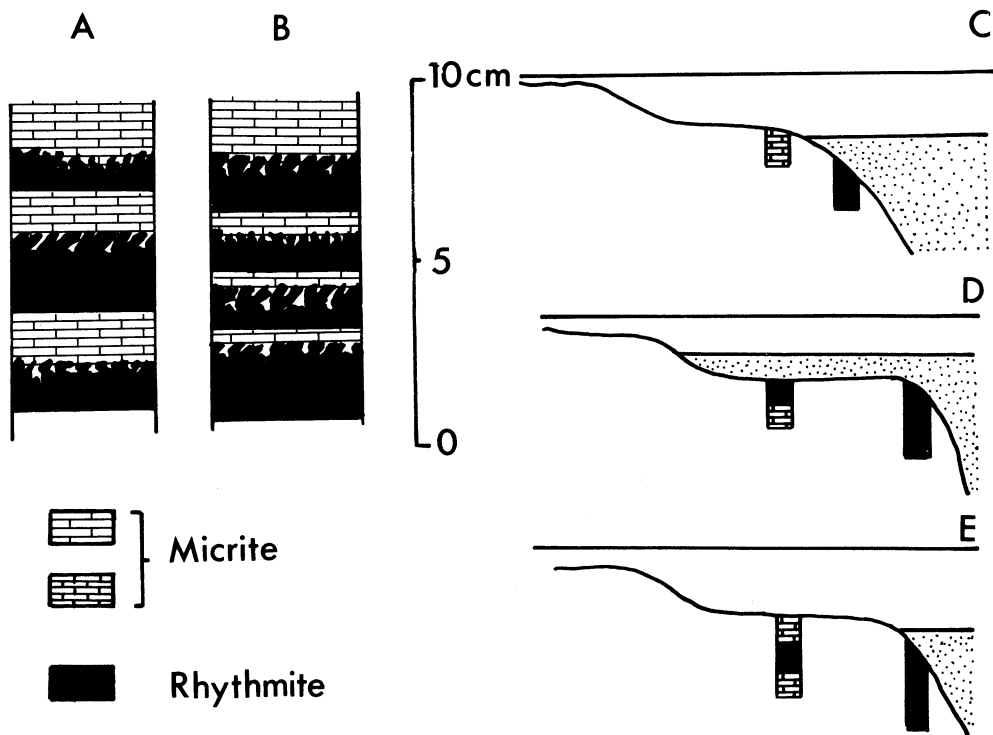
At the present time similar sediment structures are produced as a direct result of an oscillating thermohaline stratification of the water body (Degens & Stoffers, 1976; Degens *et al.*, 1978). It is known that the Ludlovian basin (Holland & Lawson, 1963) in which Kerry is situated, had a stratified 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<sub>3</sub> 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).



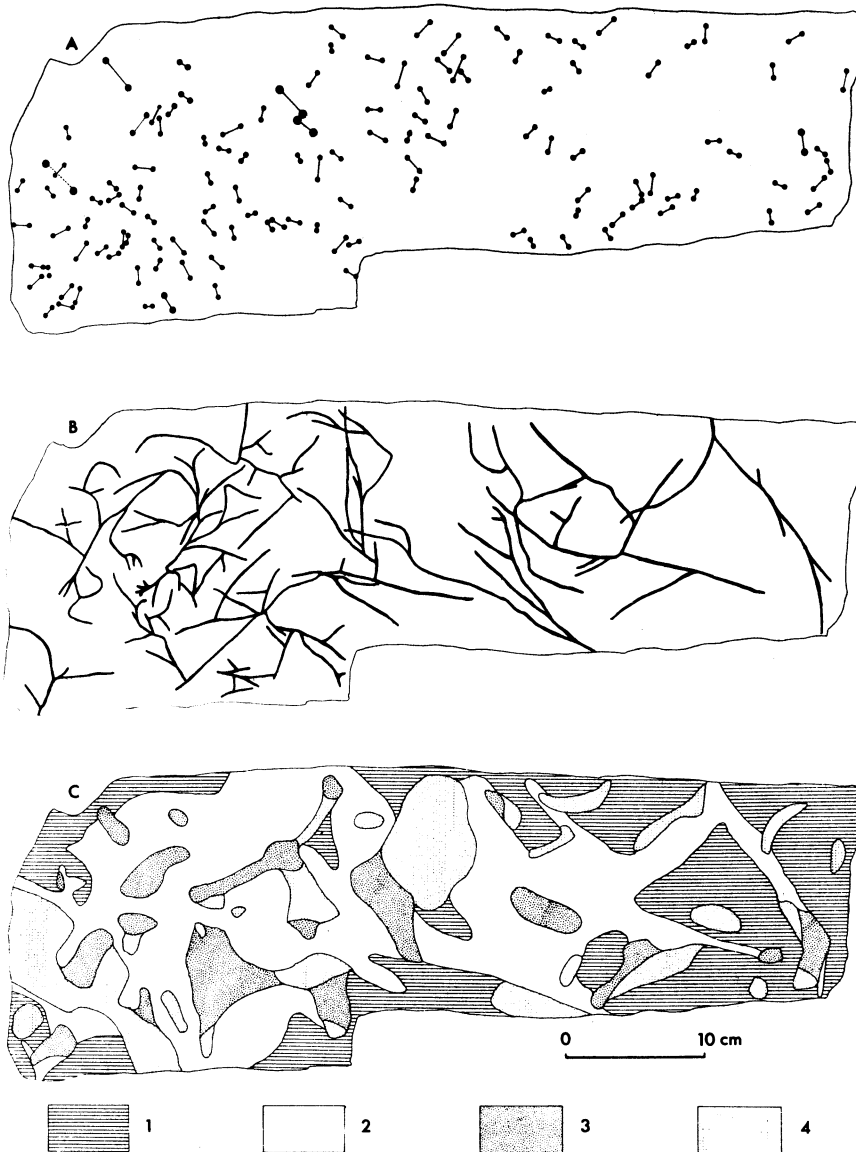
Text-fig. 10. Geological map of the Kerry district with insets of (1) minor localities within Locality D and (2) the sediment section at Locality E.





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 pycnocline 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

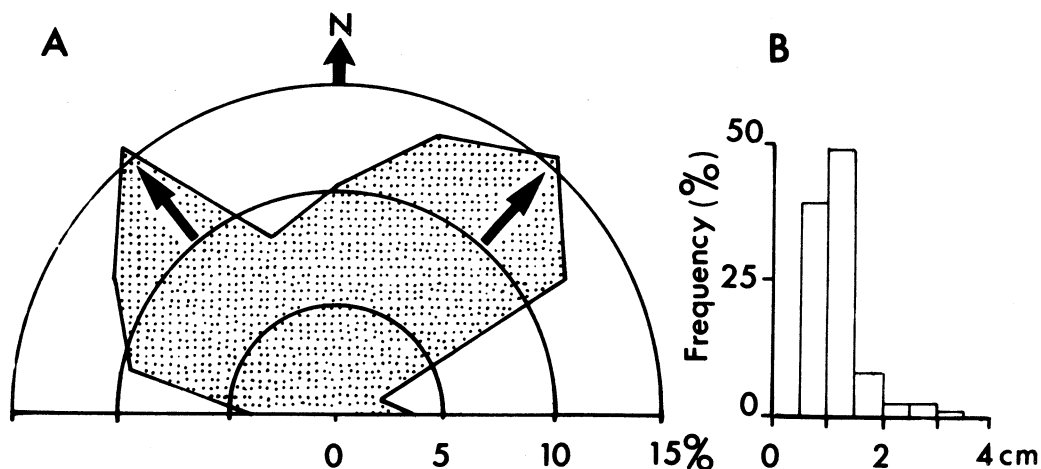
## 2. The *Dalmanella lunata* Beds

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<sup>2</sup> 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

Species	1	2	3	4	5	6	7	8	9	10	11
<b>Brachiopods</b>											
<i>Craniops implicatus</i> (J. de C. Sowerby)	7.5	5.8	-	-	-	-	-	-	-	-	-
<i>Lingula cornea</i>	-	-	12.5	-	-	0.4	-	-	0.4	-	3.3
<i>Microsphaeridiorhynchus mucula</i>											
(J. de C. Sowerby)	-	-	-	5.0	-	-	-	-	-	-	-
<i>Orbiculoidea rugata</i> (J. de C. Sowerby)	-	5.8	-	-	-	-	-	-	-	-	-
<i>Protochonetes ludloviensis</i> Muir Wood	25.0	23.5	-	65.0	-	-	-	-	-	-	-
<i>Salopina lunata</i> (J. de C. Sowerby)	65.0	52.9	-	15.0	-	-	-	-	-	-	-
<b>Molluscs</b>											
<i>Bucanopsis expansus</i> (J. de C. Sowerby)	2.5	-	-	5.0	-	-	-	-	-	-	-
<i>Leodispsis barrowsi</i>	-	5.8	12.8	-	0.0	3.0	62.1	-	77.0	-	6.6
<i>Modiolopsis complanata</i> J. de C. Sowerby	-	-	-	-	57.3	14.1	7.3	14.0	8.3	66.6	86.6
<i>Solenamya</i> sp.	-	-	-	-	-	-	6.3	-	-	-	-
<i>Turbocheilus helicitus</i> (J. de C. Sowerby)	-	-	-	-	-	67.8	-	-	-	-	-
<b>Ostracods</b>											
<i>Cytherellina siliqua</i> Jones	-	-	5.1	10.0	-	-	1.0	-	-	-	-
<i>Frostiella groenvalliana</i>	-	-	-	-	-	-	-	0.7	-	-	-
<i>Hermannia marginata</i>	-	5.8	53.8	-	3.7	6.4	14.7	3.7	3.1	33.3	-
<i>Hermannia phaseola</i> (Jones)	-	-	-	-	-	1.7	5.2	5.9	5.9	-	-
<i>Londinia kiesowi</i>	-	-	2.5	-	38.8	1.2	-	71.1	1.5	-	3.3
<i>Lophoctonella</i> sp.	-	-	-	-	-	-	1.0	-	-	-	-
<b>Other fossils</b>											
Eurypterid fragments	-	-	2.5	-	-	2.5	-	-	-	-	-
Fish skin ( <i>T. parvidens</i> )	-	-	-	-	-	-	-	-	0.4	-	-
<i>Gomphonchus murchisoni</i> (Ag.)	-	-	10.2	-	-	-	-	-	0.4	-	-
<i>Logania ludlowiensis</i>	-	-	-	-	-	2.5	2.1	-	5.5	-	-
<i>Thelodus parvidens</i>	-	-	-	-	-	-	-	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 Built 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.

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

## 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. Chonetes 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)

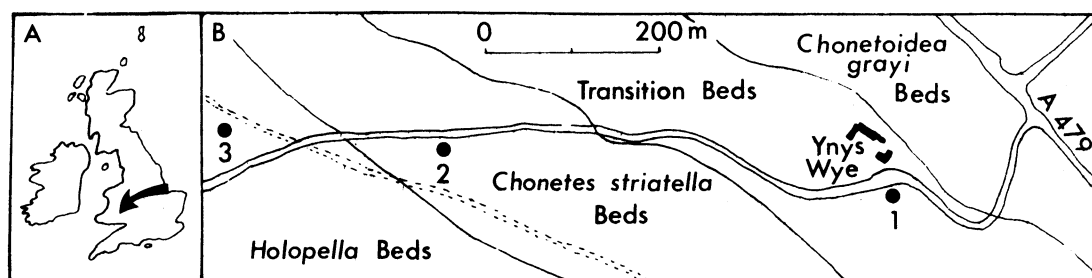
These sediments are exposed in a quarry 500 m south of Wallop Hall (S.J. 311 307) and consist of irregularly bedded, shaley - massive, muddy siltstones with a poorly developed rhythmite type carbonate sedimentation, similar to the basinal Ludfordian sediments (*Chonetes striatella* Beds) of Kerry. The 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.

Species	Sample Positions				
	0.3m	1.1m	1.6m	2.2m	3.0m
<b>Brachiopods</b>					
<i>Lingula cornea</i>	15.62	-	0.39	5.76	5.88
<b>Bivalves</b>					
<i>Leodispis barrowsi</i>	15.62	5.55	74.71	56.73	21.58
<i>Modiolopsis complanata</i>	-	72.22	8.04	5.76	-
<i>Solenamya</i> sp.	-	-	-	3.84	-
<b>Ostracods</b>					
<i>Cytherellina siliqua</i>	6.25	-	-	0.96	-
<i>Hermannia marginata</i>	-	-	5.74	5.76	11.76
<i>Hermannia phaseola</i>	43.75	19.44	3.06	12.50	25.49
<i>Londinia kiesowi</i>	3.12	2.77	1.53	-	5.88
<i>Lophoctonella</i> sp.	-	-	-	1.92	-
<b>Other fossils</b>					
<b>Eurypterids</b>					
<i>Gomphonchus murchisoni</i>	-	-	-	-	11.76
<i>Logania ludlowiensis</i>	12.50	-	0.39	-	5.88
<i>Nosteolepis</i> sp. (Fish skin)	-	-	5.36	6.73	11.76
<i>Thelodus parvidens</i>	3.12	-	0.39	-	-
<i>Thelodus parvidens</i>	-	-	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 lepiditid 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.

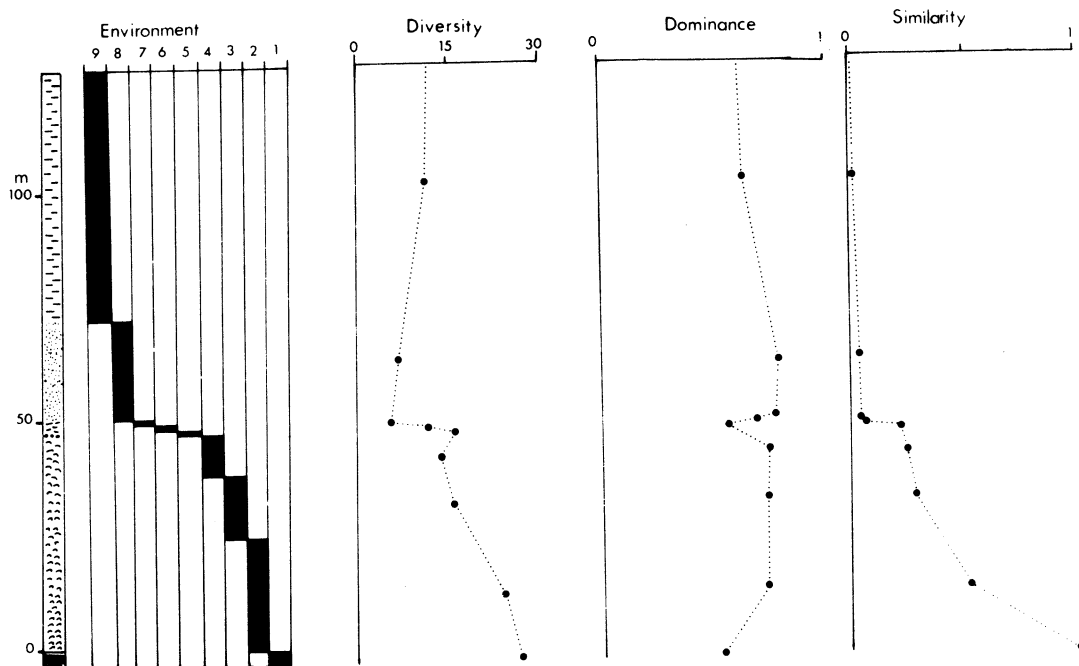
### Summary of environmental change at Ludlow

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. 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<sup>+</sup> 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.

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

Table 9 (Contd.)

<b>Cephalopods</b>											
<i>Kionoceras angulatum</i>	25	21	-	-	-	-	-	-	-	2	1 - 2
' <i>Orthoceras</i> ' sp.	23	6	9	-	-	-	-	-	-	2	1 - 3
<i>Paraphragmites ibex</i>	40	25	22	-	-	-	-	-	-	3	1 - 3
<b>Other molluscs</b>											
<i>Bucanopsis expansus</i>	-	27	-	19	-	-	-	-	-	4	2 - 4
<i>Hyolithes forbesi</i>	35	22	15	14	-	-	-	-	-	4	1 - 4
<b>Trilobites</b>											
<i>Calymene</i> sp.	10	-	-	-	-	-	-	-	-	1	1
<i>Encrinurus</i> sp.	16	44	-	-	-	-	-	-	-	1	1 - 2
<b>Annelids</b>											
<i>Arabellites</i> sp.	35	35	10	-	-	-	-	-	-	3	1 - 3
<i>Keilorites</i> sp.	-	-	4	-	-	-	-	-	-	3	3
' <i>Serpulites</i> ' <i>longissimus</i>	13	11	7	-	-	-	-	-	-	3	1 - 3
<i>Spirorbis lewisii</i>	-	39	-	-	-	-	-	-	-	2	2
<b>Ostracods</b>											
<i>Amygdalina</i> sp.	50	-	-	-	-	-	-	-	-	1	1
<i>Aparchites sinuatus</i>	-	-	-	-	-	-	-	-	1	9	9
<i>Aechmina</i> sp.	-	-	-	-	-	-	-	-	6	9	9
' <i>Beyrichia</i> ' sp.	20	16	-	-	-	-	-	-	-	2	1 - 2
<i>Calcaribeyrichia tegula</i>	-	14	-	-	-	-	-	-	-	2	2
<i>Calcaribeyrichia torosa</i>	-	-	22	-	13	-	-	-	-	5	3 - 5
<i>Cavellina</i> sp.	29	-	-	-	-	-	-	-	-	1	1
<i>Cavellina</i> cf. <i>plana</i>	-	-	-	-	-	-	-	-	4	9	9
<i>Cavellina primaria</i>	32	51	-	-	-	-	-	-	-	1	1 - 2
<i>Cytherellina siliqua</i>	8	30	12	16	5	7	5	3	-	8	1 - 8
? <i>Gottlandella</i> sp.	-	-	-	-	-	-	-	-	6	9	9
<i>Hebellum tetragonum</i>	4	13	-	-	17	9	9	-	-	1	1 - 7
<i>Hebellum triviale</i>	29	-	-	-	-	-	-	-	-	1	1
<i>Hermannia</i> cf. <i>marginata</i>	-	-	-	-	19	-	-	-	6	9	5 - 9
<i>Frostiella groenvalliana</i>	-	-	-	-	2	1	1	1	-	6 - 8	5 - 8
<i>Kuresaaria circulata</i>	11	48	22	-	15	12	-	12	6	9	1 - 9
<i>Londinia kiesowi</i>	-	-	-	-	3	4	3	5	-	5,7	5 - 8
<i>Lophoconella</i> sp.	-	-	-	-	25	-	-	-	-	5	5
<i>Neobeyrichia lauensis</i>	19	-	-	-	-	-	-	-	-	1	1
<i>Neobeyrichia sissica</i>	32	-	-	-	-	-	-	-	-	1	1
<i>Nodibeyrichia verrucosa</i>	-	-	-	9	16	-	-	-	-	4	4 - 5
<i>Nynamella</i> sp.	29	50	-	-	12	9	9	-	-	6 - 7	1 - 7
<i>Primitia mundula</i>	-	-	-	-	-	14	-	-	-	6	6
<i>Scaldianella simplex</i>	3	8	-	-	-	-	-	-	-	1	1 - 2
<b>Other fossils</b>											
Calcareous tubes	-	-	-	-	-	10	7	7	-	7 - 8	6 - 8
Coral colonies	-	32	-	-	-	-	-	-	-	2	2
<i>Cornulites</i> sp.	25	-	-	23	23	-	-	-	-	4 - 5	1 - 5
Crinoid columnals	-	44	21	-	-	-	-	-	-	3	2 - 3
<i>Hypermania</i> sp.	-	-	-	-	-	-	-	-	2	9	9
<i>Ozarkodina</i> 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  $i = 1 \dots s$ ,  
 $N$  = 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 rhythmic 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; Cherno, 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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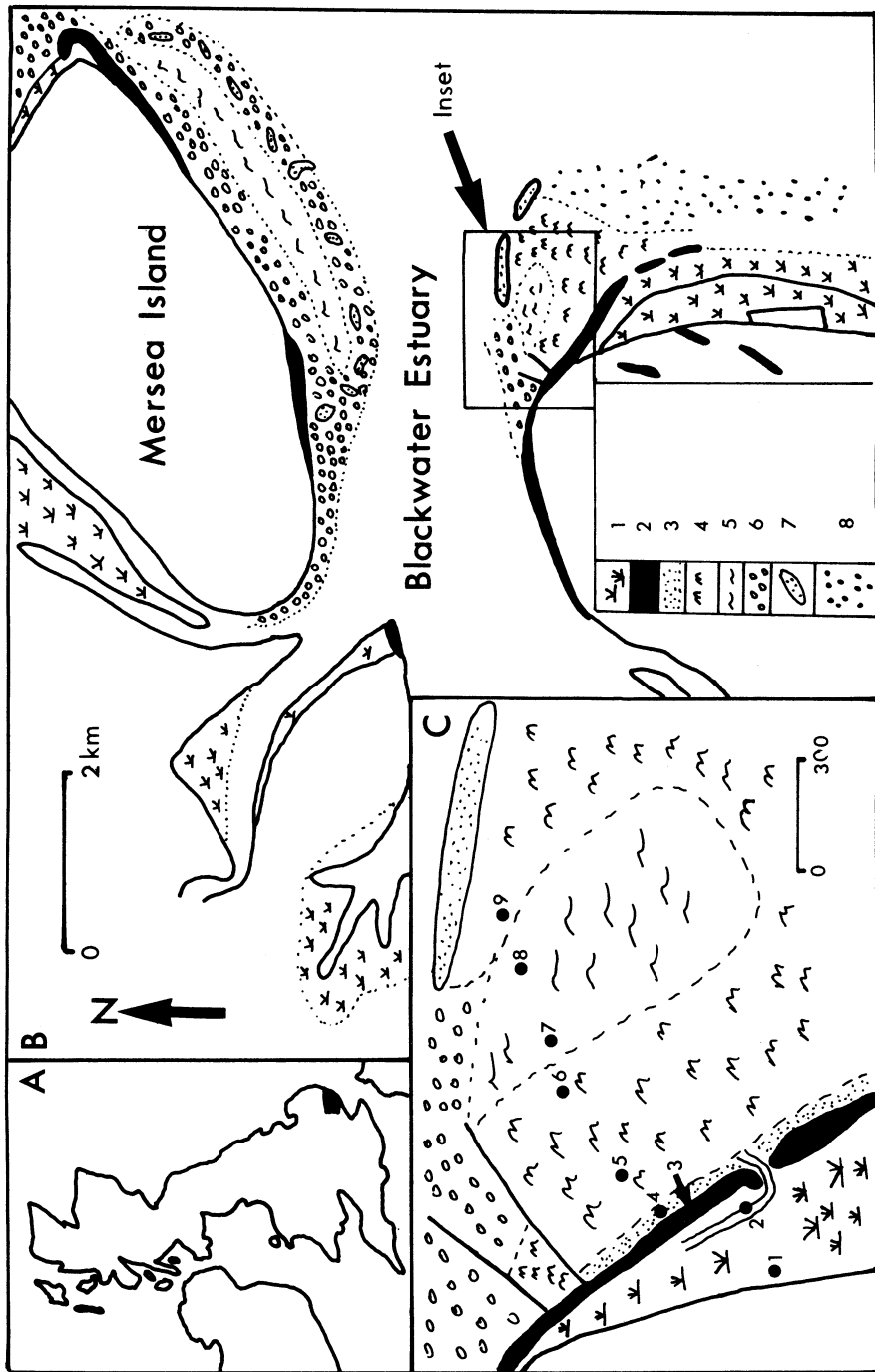
#### Appendix 1

##### 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.

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		<i>Carinocythere</i> cf. <i>carinata</i>	<i>Cythere lutea</i>	<i>Pontocythere elongate</i>	<i>Heterocythereis</i> cf. <i>albomaculata</i>	<i>Leptocythere pellucida</i>	<i>Loxochoncha rhomboidea</i>	<i>Urocythere</i> 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<sup>2</sup> 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)	<i>Cythere lutea</i>														
	% valves	1	2	2R	3	4	5	Locality		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)	<i>Carinocythere cf. carinata</i>														
	% 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)	<i>Pontocythere elongata</i>														
	% 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)	<i>Loxochoncha rhomboidea</i>														
	% 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)	<i>Leptocythere pellucida</i>														
	% 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)	<i>Heterocythereis cf. albomaculata</i>														
	% 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)	<i>Urocythere sp.</i>														
	% 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 micro-habitats 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

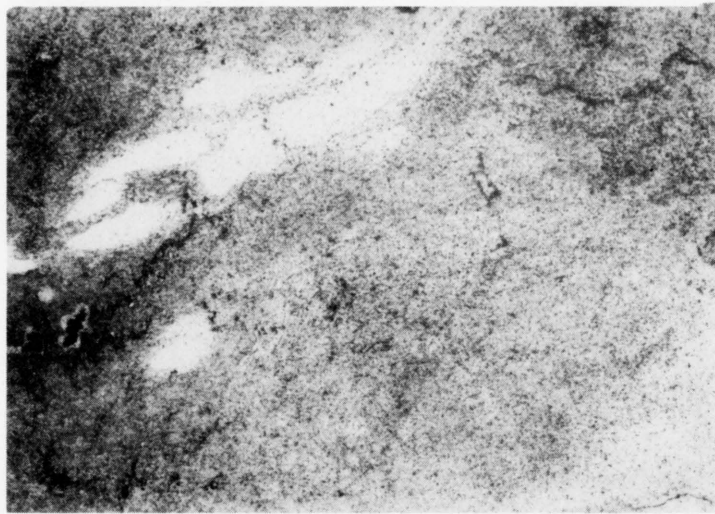
The ostracod species *F.* cf. *bicristata*, *F. groenvalliana*, *L. kiesowi* and *H.* cf. *marginata* prove (see Appendix 1) a Downtonian (Pridiolian) age for the Cennan Beds (cf. Elles & Slater, 1906; Martinsson, 1967; Siveter, 1978; Shaw, 1969, 1971).

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.

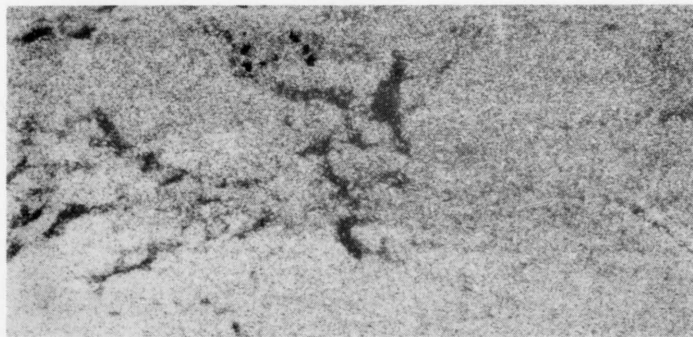




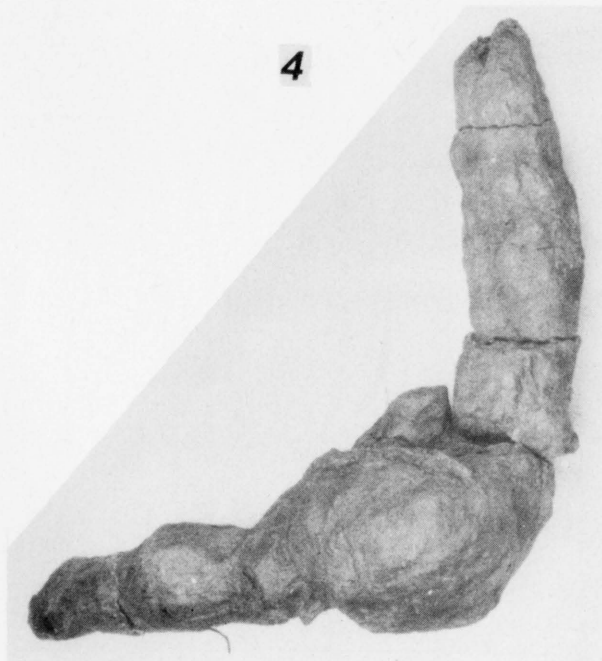
1.



2.



3.



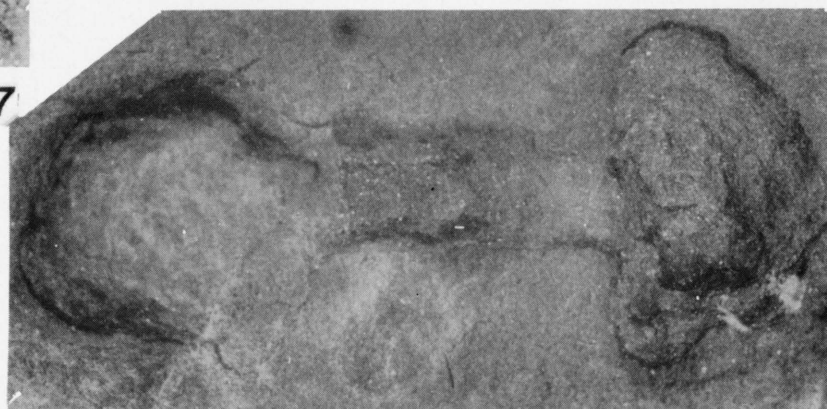
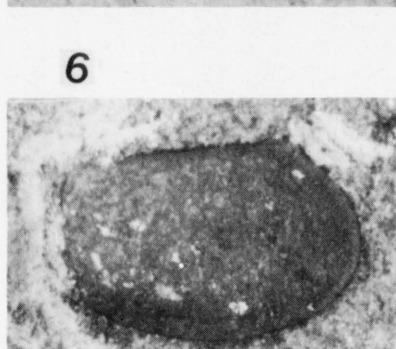
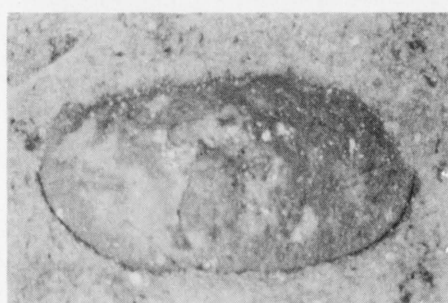
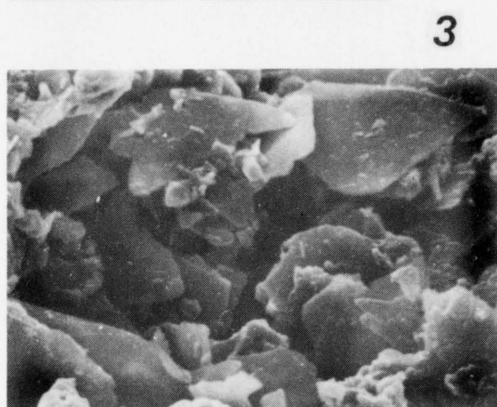
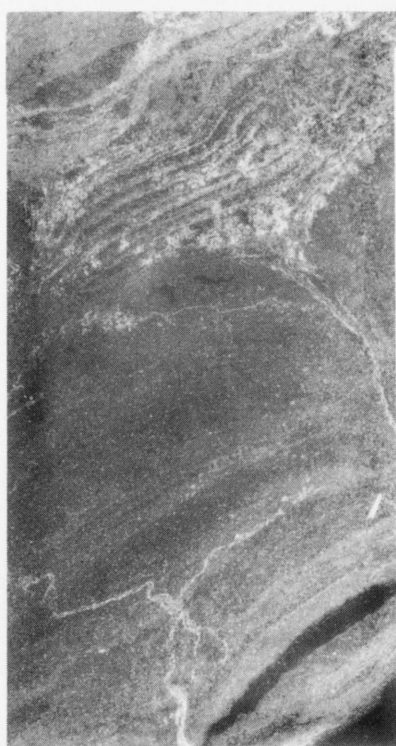
4.



5.

Antia - Temeside Bone-Bed.  
Explanation opposite.





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



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David D.J. Antia  
 Exploration Department  
 BP Petroleum Development Ltd.  
 Kirklington Road  
 Eakring  
 Nottinghamshire



THE PROBLEM OF DISCORDANT DRAINAGE IN CHARNWOOD FOREST,

LEICESTERSHIRE

by

J. F. D. Bridger<sup>1</sup>

Summary

In the light of the recent recognition that Charnwood Forest was glaciated during the Pleistocene, the origin of its discordant drainage is reconsidered. It is concluded that, whilst Watts' notion of superimposition as the process responsible for the discordant phenomenon is still valid, the present stream network has a Quaternary genesis and was not, as previously thought, inherited from a drainage pattern which had evolved on a former cover of Mesozoic rocks.

Introduction

The problem of Charnwood Forest's drainage has attracted the attention of earth scientists since the turn of the century. For many years it was accepted that the direct inheritance of a network which had developed on a former cover of Mesozoic rocks could satisfactorily explain the anomalous features. However, recent work on the Quaternary history of the area has shown that Charnwood Forest was completely glaciated during the Pleistocene and the purpose of this paper is to reconsider the evolution of the drainage in the light of this new understanding.

Geology

The basic geological structure of Charnwood Forest is a breached south-easterly plunging anticline of Precambrian age with igneous intrusions. These ancient rocks are overlain by the remnants of a one-time more extensive cover of Upper Triassic strata resting unconformably on the Precambrian structure. Quaternary deposits comprise head and glacial drift (Bridger 1972 and 1975), the widespread distribution of the latter implying that, following the final melting of the ice during the Wolstonian glaciation, a thick Pleistocene mantle almost certainly masked the preglacial landscape to give Charnwood Forest the broad topographical form of an inverted saucer.

<sup>1</sup>Faculty of Humanities,  
Hull College of Higher Education,  
Inglemire Avenue, HULL, HU6 7LJ

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pp. 217-223, 3 text-figs.

## The Drainage Pattern

Although Charnwood Forest's drainage (text-fig. 1) has an ill defined watershed aligned north-east to south-west, its pattern is essentially radial at altitudes higher than 122 m. O.D. Above this datum, stream erosion has been unexceptional, producing open valleys in both Triassic and Pleistocene deposits. However, around 122 m. O.D. and occasionally well below it many streams, particularly those in the eastern and northern areas, change their direction to flow discordantly over outcrops of ancient rock where varying degrees of gorge development have been accomplished. The term discordant is applied here to streams wherever they flow over ancient rocks irrespective of the relationship of the direction of drainage flow to the structure of the strata. It should not be overlooked that, whilst the larger discordant sections are associated with stream deflection, the angle of turn may be very small, e.g. Blackbrook (SK 470170) and also that minor discordancies have developed without any perceptible change in stream direction, e.g. Lady Hay Wood (SK 515083). Furthermore, gorge formation is not restricted to localities where ancient rocks crop out and it may occur in Keuper sandstone, as at Whitwick (SK 433163) where Charnian rocks are exposed only in part of the gorge.

To a greater or lesser extent, all of the major discordancies have been modified by man, the most notable example being around the reservoir dam at Blackbrook. The one discordant section which could with any confidence be considered as displaying basically unmodified morphology is that at Grace Dieu Wood (SK 432175) near Thringston.

## Previous views

Watts (1903, 1905 and 1947) argued that the crucial event in the evolution of Charnwood Forest's drainage was the burial of the area by Keuper sediments which obscured a drainage network of Triassic wadis together with elements of earlier Palaeozoic drainage history. He envisaged that the cover of Keuper and possibly other Mesozoic rocks provided a surface for the development of a new drainage system; the subsequent superimposition of this stream pattern being the process responsible for the present discordant phenomena.

The gorges were thought by Watts to have two possible modes of formation. Some were believed to be exhumed Triassic wadis cleared by streams guided onto them by factors concerning differences in the resistance between the ancient rocks and the Keuper Marl. Other gorges were seen as the work of streams turned aside from the lines of sub-Triassic valleys to pass "unconsciously" over buried ridges of ancient rock onto which they were later superimposed through Keuper deposits.

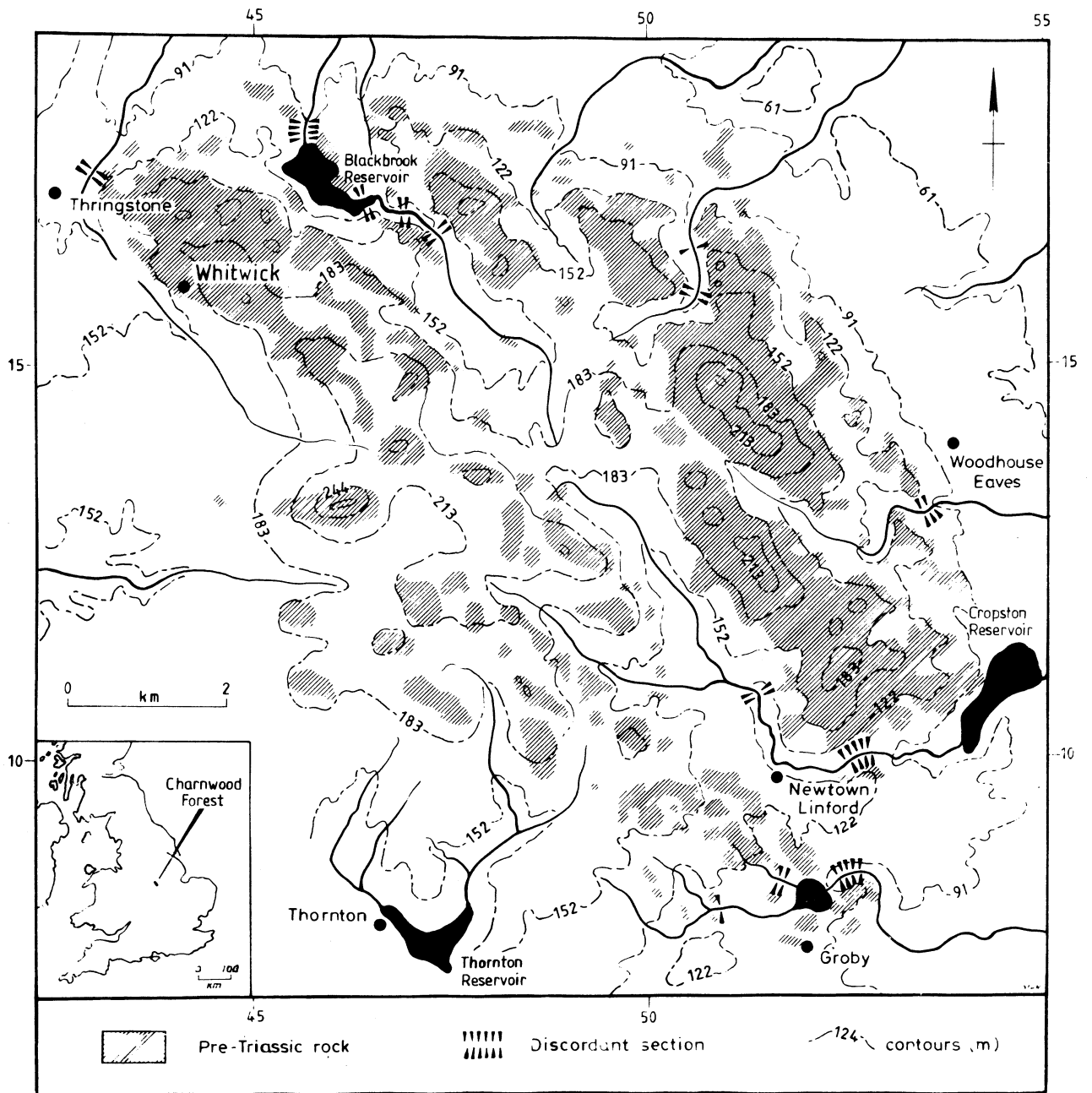
His interpretation received considerable support, particularly by Bennett (1929) who advocated superimposition through Triassic rock to account for the discordancy at Ulverscroft Mill (SK 514108).

In a reappraisal of drainage history in the Ulverscroft valley, Bridger (1968) considered his remapping of drift boundaries in the locality indicated that the formation of the Ulverscroft Mill discordancy had also involved stream superimposition through glacial deposits.

Ford (1968) stated that gorge formation was attributable to superimposition from till, but did not present detailed evidence to sustain his conclusion.

## Recent field findings

Fieldwork by the author has included the topographical survey of the localities with discordant drainage as well as the mapping of them geologically. The latter activity has revealed neither Pleistocene nor Triassic rock within the gorges, but both types of deposit have been recorded in contiguous areas.



Text-fig. 1: Discordant drainage in Charnwood Forest, Leicestershire.

Three of the gorges have been levelled to Ordnance Survey bench marks, Bradgate Park (SK 526100), the Brand (SK 536131) and Grace Dieu Wood (SK 432175) and their cross-profiles together with that of Blackbrook (SK 458178), plotted from survey data kindly provided by Loughborough Corporation, are shown in text-figs. 2 and 3. The long-profile also illustrated in text-fig. 3 extends over the whole length of the discordancy at Grace Dieu Wood but it will be noted that only part of it is occupied by the gorge.

The cross-profiles exhibit a wide range of forms with considerable differences in both scale and shape and reasonably reflect the diversity of morphologies displayed by the group of Charnwood Forest gorges as a whole.

### Discussion

As a basis for understanding drainage evolution in pre-Quaternary times Watts' hypothesis is, in general, acceptable. That there was at least a measure of discordant drainage before the onset of the Wolstonian glaciation may be supported by the evidence of a small, drift-filled ravine, lying a few hundred metres to the west of the present stream discordancy, at Ulvercroft Mill. Nevertheless the absence of other records of this type suggests that such features are less common than might be anticipated.

The Pleistocene, the period totally neglected by Watts, is a vitally important stage in the history of Charnwood Forest's drainage for, apart from the actual impact of glaciation, the ice left behind a thick deposit of drift to obscure the preglacial relief. Accordingly, Watts' view, that the present drainage has an exclusively Mesozoic and Tertiary ancestry, is no longer tenable for it is clear that any satisfactory account of the drainage should take into consideration Quaternary events.

There are several instances in other glaciated regions of Britain where abnormal drainage has been attributed to the activity of meltwater. For example, gorge formation has been discussed by Price (1960) Derbyshire (1961), Sissons (1963) and Clapperton (1968), who, without exception, support a late Pleistocene glacial genesis. Clapperton believes that discordancies may be formed by the superimposition of glacial streams and that in certain circumstances meltwater routes may be influenced by crevasses.

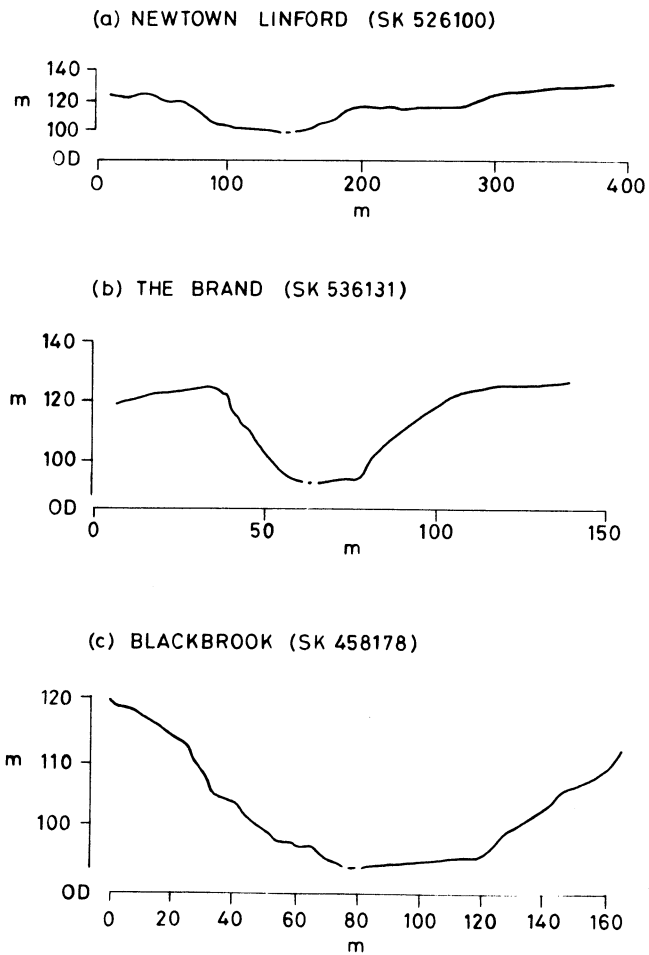
In Charnwood Forest, which lies outside the limit of Devensian ice, but well within the Wolstonian boundary, depositional evidence for a glacial meltwater origin of the gorges has not been found. Apart from Grace Dieu, where the long profile does not show any humping, disturbance has largely removed the possibility of detecting diagnostic bedrock profiles (Peel, 1956).

Notwithstanding the absence of unequivocal evidence, it is reasonable to assume that meltwater would play a fundamental role in the genesis of the pattern which emerged after the melting of Charnwood Forest's ice cover and the radial element in the present network is considered to be the imprint of the more important drainage routes followed at the time of deglaciation.

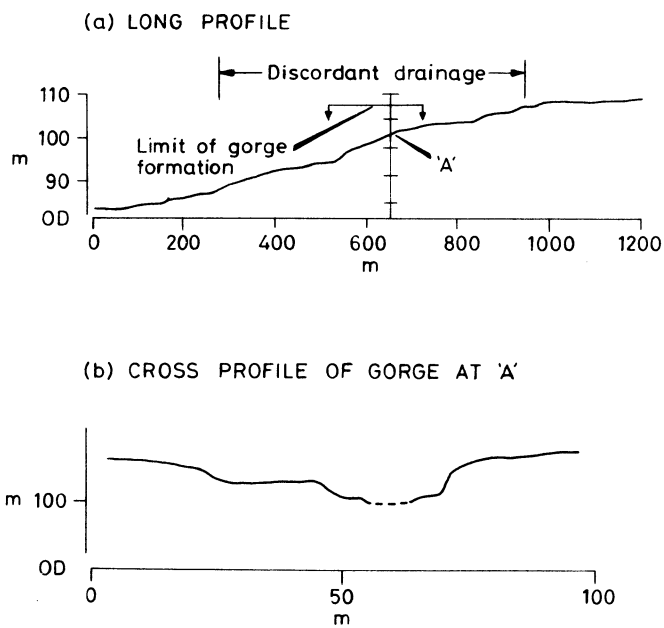
An explanation for the variety of turns in the courses of the streams is also presented by the setting of deglaciation for it would allow the possibility of meltwater routes being determined by a wide range of glaciological factors including the direction of crevasses. During the period of ice cover, the major-crevassed zones in Charnwood Forest would be close to its margins where gradients are steepest. Although the trends of the crevasses would not necessarily follow the isograds of the ice-bedrock interface, they would rarely be coincident with the dip. Thus glacial streams guided by crevasse systems would probably be deflected from radial routes and where these detours became particularly well established they could become permanent features of the network.

Additionally an environment of deglaciation offers conditions allowing epigenesis of drainage by down cutting through ice and it is possible that some gorges in Charnwood Forest were





Text-fig. 2: Surveyed cross-profile of gorges in Charnwood Forest



Text-fig. 3: Surveyed profiles of the Grace Dieu discordancy Thringston (SK432175)

initiated in this way. However, the thick and widespread distribution of drift suggests that the mechanism of superimposition could equally have operated on glacial deposits alone. A Quaternary interpretation does not necessarily exclude the possibility of a stream cutting progressively downwards from ice and/or drift into Keuper Marl before coming in contact with older rocks and the stratigraphy of certain areas, as for example, in the Ulverscroft valley, lends support to the view that such a sequence of events may have occurred.

There remains the problem of the concentration of the discordancies in the northern and eastern parts of the area and here it is necessary to take into account the contrasting Upper Pleistocene histories proposed for the valleys of the Proto-Trent and the Proto-Soar lying respectively to the north and south of Charnwood Forest.

It has been suggested by Straw (1963) that following the withdrawal of the Wolstonian ice the Trent, in its middle reaches reoccupied the valley of the Proto-Trent. The fluvio-glacial interpretation of the Hilton Terrace by Posnansky (1960), implies that in the vicinity of Willington, Derbyshire (SK 295285), the Trent had eroded its valley to below 61 m. O.D., before the ice had finally retreated from the region. To the south of Charnwood Forest, however, it seems that a reversal of drainage direction may have followed the glaciation (Shotton 1953), the Proto-Soar's extensive valley remaining largely buried under drift. This situation would give streams flowing to the Trent from Charnwood Forest the erosional advantage of lower local base levels. Consequently, streams in the Trent's catchment would have a faster rate of downcutting and so increase their chances of forming discordant sections by superimposition.

#### Conclusion

It has been argued that most of the anomalies of Charnwood Forest's drainage may be explained in a Quaternary context and that it is unnecessary to postulate inheritance from preglacial periods. Watts' notion of superimposition as the process responsible for discordant drainage is still valid, but his understanding of the environments in which it operated is unsatisfactory in so far as it overlooks the area's glaciation. A revised interpretation of the history of Charnwood Forest's drainage, which takes into account Pleistocene events, is summarised in Table 1.

<p>1. Palaeozoic</p> <p style="padding-left: 40px;">Drainage adjusted to the Precambrian structure ?</p>
<p>2. Mesozoic</p> <p style="padding-left: 40px;">Triassic wadi system developed. Keuper and possibly later Mesozoic rocks bury features of earlier drainage episodes.</p>
<p>3. Tertiary</p> <p style="padding-left: 40px;">New drainage pattern evolves on Mesozoic cover. Some superimposition onto pre-Triassic rock.</p>
<p>4. Quaternary</p> <p style="padding-left: 40px;">i. Tertiary drainage network buried under cover of drift.</p> <p style="padding-left: 40px;">ii. Glacial meltwater forms radial pattern with localised stream deflection by glaciological factors.</p> <p style="padding-left: 40px;">iii. Superimposition, first through ice and later drift, forms discordancies and gorges.</p> <p style="padding-left: 40px;">iv. Dominance of Trent drainage leads to concentration of discordancies in northern and eastern parts of Charnwood Forest.</p>

Table 1. Drainage history of Charnwood Forest.

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A BOREHOLE PROVING DOLOMITE BENEATH THE DINANTIAN LIMESTONES  
NEAR MATLOCK, DERBYSHIRE

by

J.I. Chisholm and N.J.D. Butcher

Summary

A recent borehole in the Via Gellia valley has proved the thickness of the Griffe Grange Bed to be 105 m. An underlying suite of darker-coloured quartzose dolomites with subordinate limestones was proved, 51 m of these being penetrated without reaching the pre-Carboniferous basement.

Introduction

A borehole put down in 1979 in search of water at Ryder Point, Derbyshire, started near the base of the exposed Carboniferous Limestone sequence and encountered dolomite, the existence of which was previously unknown. The limestone succession in the area has been described by Smith, Rhys and Eden (1967, pp. 8-11) as follows:

Hoptonwood Group:	pale grey coarse to medium-grained granular limestones .....	77 m
Griffe Grange Bed:	pale grey porcellanous limestone with granular bands .....	36 m+

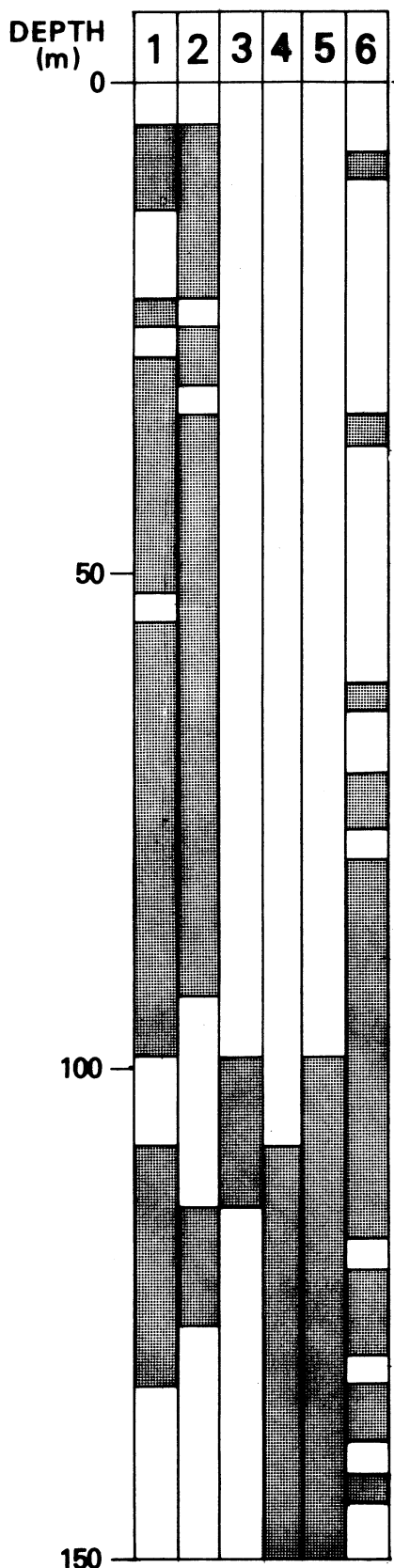
The top of the Griffe Grange Bed was drawn by these authors at the top of the highest porcellanous bed exposed in a roadside crag [SK 2617 5644] close to the borehole site and about 6 m above it. The borehole therefore started about 6 m below the top of the Griffe Grange Bed. The strata at the borehole site are almost horizontal, so that depth measurements in the borehole can be regarded as stratigraphical thicknesses.

Details of Ryder Point No. 3 water bore

Location: SK 2620 5642      Depth: 150 m      Surface Level: about 178 m O.D.

Chipping samples were recovered during the drilling at approximately three-metre intervals. Representative material from each sample was etched in hydrochloric acid and examined with a binocular microscope. Thin sections were prepared from a few of the

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1981, pp. 225-228, 1 text-fig.



**RYDER POINT NO. 3 WATER BOREHOLE**

Shaded areas indicate presence of lithology or component as follows:

Columns 1-4: main lithologies present in chipping samples.

1. Pale granular limestone
2. Pale porcellanous limestone
3. Medium-grey limestone
4. Medium-grey dolomite

Columns 5-6: accessory components.

5. Quartz present in carbonate chippings
6. Greenish mudstone and/or pyrite present

**GRIFFE  
GRANGE  
BED**

Text-fig. 1: Summary of data on chipping samples

chippings. Data on the samples are summarized in text-figure 1. In interpreting the data, more importance is attached to the first appearance of a particular lithology than to its persistence in depth.

The pale porcellanous and granular limestones of the Griffe Grange Bed persist with little change to 93 m, but below this depth the porcellanous lithology dies out, and between 93 and 105 m the colour of the limestone chippings becomes gradually darker. The change to medium-grey takes place at 99 m. Below this depth, several new lithologies appear, notably a medium-grey fine-grained limestone with a pale argillaceous residue and dispersed detrital quartz grains at 111 m and a medium-grey quartzose oolite at 114 m. A dolomitized equivalent of the fine-grained lithology is also present in the 111 m sample. Quartzose dolomites dominate the samples from 117 m to the bottom of the borehole. Most are fine-grained like that just described but coarser-grained dolomites are also found below 132 m.

The quartz first appears as sparsely scattered sand-sized grains in a pale grey limestone at 102 m and continues as an accessory constituent (10% or less) in the underlying dolomites. In the basal sample, at 150 m, half the chippings consist of dolomite with between 30 and 50% of quartz sand. A thin section of this material shows that the majority of grains are sub-angular unstrained quartz, with a few of strained quartz and some lithic grains of polycrystalline quartz.

Greenish-grey generally pyritic mudstone, present as whole chippings and as wisps in chippings of other lithologies, is taken to be a product of contemporaneous volcanic activity (Walkden 1972). The occasional chippings of green clay in samples from the uppermost 64 m of the borehole probably reflect the presence of a small number of discrete clay wayboards interbedded with the limestones. Below 70 m, however, greenish mudstone and pyrite are more generally distributed as patches and wisps in the limestones and dolomites, although everywhere as minor constituents.

Pale limestone chippings that form a significant proportion of the samples between 111 m and 132 m are thought to represent contamination from higher levels in the hole.

## Discussion

### Griffe Grange Bed

The base of the unit is drawn at a depth of 99 m in the borehole, because below this level the limestones are medium-grey rather than pale. The full thickness of the Griffe Grange Bed, including the 6 m exposed at surface above the bore site, is thus 105 m. Most of this thickness was proved in a recent IGS borehole sited [SK 2619 5645] a short distance from the present hole, and a detailed account of the lithological sequence has been published (Cox and Harrison 1980).

### Ryder Point dolomites

The downward passage to quartzose dolomite is gradational, for although quartz first appears in the 102 m sample, dolomite does not appear until 111 m. No formal name is proposed for the strata below the Griffe Grange Bed, in view of the fact that chipping samples provide only a generalized record of the sequence. However, both the Griffe Grange Bed and the underlying strata can be classified in terms of the current IGS nomenclature for the Derbyshire shelf limestone province (Aitkenhead and Chisholm, in preparation) as members of the Woo Dale Limestones Formation.

The age of the strata at the bottom of the borehole is not known with certainty. The only faunal evidence is that recorded at outcrop from the top part of the Griffe Grange Bed (Ramsbottom *in* Smith, Rhys and Eden 1967, p. 47), where there are sparse brachiopods and corals thought to be indicative of the S<sub>2</sub> Zone ( $\approx$  Holkerian). On this basis the dolomites are of Holkerian age or older. The existence of dolomites in the lower part of the Carboniferous





## TEMPORARY EXPOSURES IN THE LATE PRECAMBRIAN ROCKS OF

### WART HILL, NEAR CRAVEN ARMS, SOUTH SHROPSHIRE

by

J. B. Moseley

#### Summary

A description is given of the rock types encountered at a series of temporary exposures at Wart Hill, South Shropshire. A tentative correlation is made with known exposures. Fault gouging has been observed which confirms the presence of a major NNE - SSW faulted boundary to the eastern flank of Wart Hill and a fault breccia on the western flank of the hill suggests a faulted boundary here also. Evidence at a further locality could be interpreted as indicative of sequence inversion.

#### Introduction

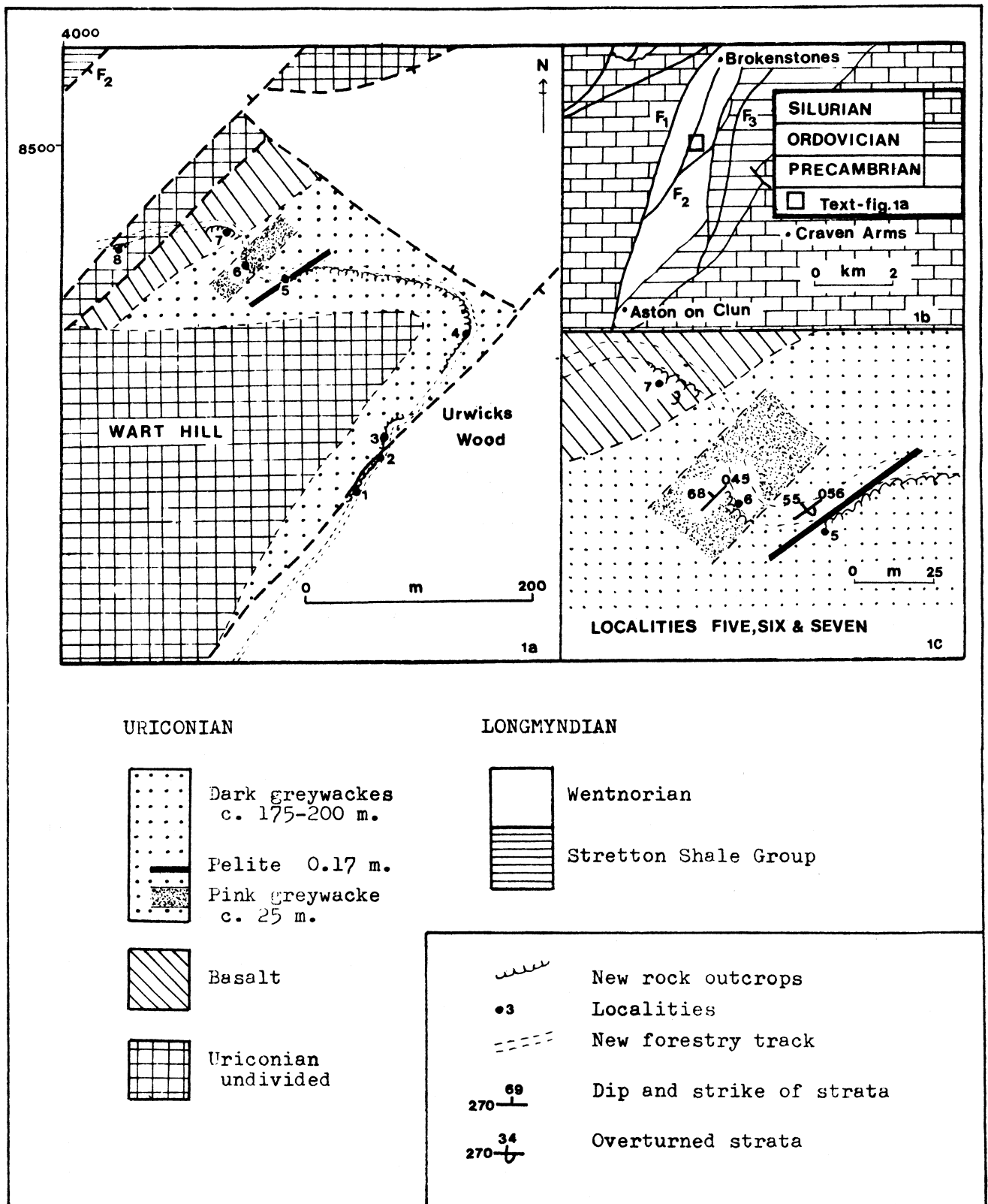
Excavation for a track for forestry purposes around the eastern and northern flanks of Wart Hill (401848) 4 km north-west of Craven Arms, Shropshire, has presented new sections in the local Precambrian rocks. The sections demonstrate the structural complexity that is expected, but so rarely exposed, in Precambrian inliers within the Church Stretton Fault Complex.

Longmyndian and Uriconian rocks form a lozenge-shaped outcrop (text-fig. 1b) within the Church Stretton Fault Complex between Brokenstones (419881) and Aston on Clun (393817). Wart Hill lies between the F2 and F3 components of the complex, but is not bounded by them (text-fig. 1b). Brecciation of rocks now exposed along the eastern flank of Wart Hill (text-fig. 1a, localities 1, 2, 3 and 4) indicates major NNE - SSW faulting; this has been inferred previously (Greig, Wright, Hains & Mitchell, 1968), and locally marks the contact between the Wentnorian and Uriconian. Sedimentary rocks, mainly greywackes (Pettijohn, Potter & Siever, 1973), pelites and conglomerates, are affected by the faulting.

#### Description of localities

The following vertical sections which are 1-2 m high were first examined during April 1980; and by mid-December 1980 their condition, particularly at localities 1, 2, 3, 5 and 7, had considerably deteriorated due to soil creep and rain wash.

Mercian Geologist, Vol. 8, No. 3, 1981  
pp. 229-232, 1 text-fig.



Text-fig. 1: Geological sketch map of part of Wart Hill (1a and 1b adapted from Greig *et al.*, 1968)

### Locality 1

Here the cutting provides a section 11 m long exposing dark, weathered, brecciated conglomeratic greywackes with a buff fault gouge at the northern end. Fresh, unbrecciated fragments of rhyolite found on the track were not *in situ*. Rhyolites have been recorded from several localities around Wart Hill (Greig *et al.*, 1968).

### Locality 2

This section, which is 20 m long, is 10 m north of locality 1, and before soil creep showed the following sequence of brecciated strata:

Fault breccia; composed of angular clasts of dark greywacke	39 cm
Pale grey fault gouge .....	15 cm
Purple fault gouge; containing rotten fragments up to 3 cm long of purple, very coarse-grained greywacke .....	7 cm
Purple, very coarse-grained, conglomeratic greywacke; only weakly brecciated .....	40 cm

### Locality 3

The zonation of brecciated, dark greywackes, pale grey fault gouge and gritty purple fault gouge at locality 2 is exposed again around 24 m of a bend in the track (text-fig. 1a).

### Locality 4

Dark greywackes with subordinate dark grey pelites crop out along 40 m of the track. There is no trace of bedding and these greywackes are not so intensely brecciated as those at localities 1, 2 and 3.

Similar very coarse- to medium-grained greywackes containing pelitic clasts up to 5 mm long and subordinate finer-grained pink and green greywackes crop out intermittently along 190 m of the track between localities 4 and 5. There is no evidence of brecciation in these massive, jointed rocks.

### Locality 5

Here, the following, presumably inverted, sequence (see Conclusions) is inclined at 55°/326°:

Red pelite; with eroded lower surface .....	17 cm
Shale-pebble breccia; contains angular clasts of red pelite in a greywacke matrix .....	1-5 cm
Dark, coarse-grained greywacke with red pelite clasts up to 1 cm long .....	120 cm

### Locality 6

There are several very small outcrops of finely bedded pink-stained greywackes with thin pelitic partings, dipping at 68°/315° and 63°/309°. The lateral extent of these greywackes (text-fig. 1a and 1c) is uncertain, as they could not be traced to the north-east or south-west of this locality.

### Locality 7

Amygdaloidal basalts which show some internal zones of intense shearing and deformation (text-fig. 1c) crop out 37 m to the north-west of the pink-stained greywackes, and are exposed along 34 m of the track.

### Locality 8

A very small outcrop of fault breccia. Fragments collected from this were mainly of a dark, weathered trachytic rock.

### Conclusions

Stratigraphical relations are not easily established in this area as exposures are small and scattered, and most contacts are faulted ones. However,  $\frac{1}{2}$  km north of Wart Hill fossiliferous Ordovician sandstones (Hoar Edge Grit) rest unconformably on the purple Longmyndian greywackes (Wentnorian) which form much of the fault bounded Precambrian block including Wart Hill and the new exposures. Conglomeratic greywackes on Wart Hill (401848) and basalts  $\frac{1}{2}$  km north of Wart Hill near Upper Carwood (406852) are generally accepted as being of Uriconian age (Greig *et al.*, 1968). These rocks are similar in hand specimen to those exposed in the new sections which, until further evidence becomes available, are tentatively placed in the Uriconian. The brecciation of greywackes at localities 1, 2, 3 and 4 suggests major N.N.E.-S.S.W. faulting along the south-eastern side of Wart Hill, and fault breccias at locality 8 (text-fig. 1a) support the supposition that the hill is also fault-bounded on the north-western side (Greig *et al.*, 1968). The purple fault gouge and breccia at locality 2 is probably derived from purple conglomeratic greywackes of the type that occur in the Wentnorian succession, locally, (Urwick's Wood, 405848) and 10 km to the north around Bridges (394964) and Wentnor (384927). This speculation is based on the colour and lithological similarity of fault breccia fragments from locality 2 and typical coarse-grained Wentnorian greywackes, although no detailed petrographic comparison has yet been made. By extrapolation of the few dip values available, it is thought that there are approximately 200 m of sedimentary rocks, mainly greywackes with some tuffs, pelites and conglomeratic horizons intermittently exposed in these new sections. A local overturning of the strata may be suggested by the lower eroded surface of a red pelite which immediately overlies a shale-pebble breccia and greywackes with angular red pelite clasts (locality 5). No other evidence has been found to indicate overturning of the strata and a possible sedimentary sequence is shown in the key to text-fig. 1. The association of greywacke (Pettijohn *et al.*, 1973) and amygdaloidal basalt (text-fig. 1a and 1c) is unusual, but here these rocks are not necessarily contemporaneous and their contact, which is not exposed, could be, like many in the Uriconian, a faulted one.

The writer is currently researching this area and hopes that a more detailed stratigraphical, structural and petrographic description will be possible, particularly if imminent forestry work reveals fresh exposures.

### Acknowledgements

I am grateful to Drs. A.M. Evans and B. Windley for reading a preliminary copy of the manuscript. Text-fig. 1a is adapted from part of Geological Sheet SO48 (Craven Arms) by kind permission of the Institute of Geological Sciences.

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J. B. Moseley  
35, Cotterell Street,  
Whitecross  
Hereford, HR4 0HH

## BOOK REVIEWS

AGER, D.V. *The Geology of Europe*, McGraw-Hill, 1980, i-xix, + 1-535 pp. illustrated with text-figs. and tables. Bound in boards, £16.00

Not many people are prepared to write a synthesis of large regions so that initial thanks must be given to the author for providing an up to date account of the European Region for those of us unable or unwilling so to do. The book is divided into four unequal parts based on orogenic criteria, or rather, the subsequent lack of it.

Eu-europa is geographically largely the Fenno-Scandian Shield, Hebridean Province and the East European Platform. Whilst mainly concerned with Precambrian rocks details of the younger unfolded 'cover' rocks will be found in this section.

Palaeo-europa consists of the Caledonides and the Danish triangle consisting of the Baltic Plain, the North Sea basin and the central British block. It includes those areas not greatly affected by major orogenies at the end of the early Palaeozoic. Meso-europa are the various Variscide areas and the Urals. Neo-europa is made up of the most recently active areas, those involved in the Alpine earth movements, making up the outer arcs of the continent.

Thus the synthesis is not based on political divisions and if one is interested in the geology of a particular country it might be easier to turn to a compilation from, say, the resident Geological Survey, Institute or Society, but the book reviewed here is written in English.

However, if one can accept the author's intentions and restriction of contents, then one can certainly follow him from the obscure beginnings of Europe and its apparent simplicity (lack of knowledge?) to the complexity of the latest orogeny (lots of information, not necessarily completely understood?).

The book is well written and edited. So far I have only found one print error (p.53). Not everyone will appreciate Ager's style of prose; the comments and asides get a bit tedious after only 53 pages - "Permian is for the most part hidden by Quaternary rubbish..." Not rubbish for the Quaternary Geologist. "...volume of Russian literature thankfully small for those of us that concentrate of (sic) the Lias." Parochialism is also evident, despite the claim to the contrary (p.xiv) with references to the University College of Swansea (p.5) or to S. Johnson (p.11).

In conclusion, I must say that comments apart, I have enjoyed reading this book and have learnt a lot from it. What other recommendations does one need to go ahead and purchase it?

D.H. RAYNER, *The stratigraphy of the British Isles*, Cambridge University Press, 1981, 460pp., 84 figs., appendix, bibliography, index. Hard cover edition at £32.50; paper back edition, £12.50. *2nd Edition*.

In contrast to Ager's, *Geology of Europe*, reviewed above, your reviewer now turns to the description of the geology of a much more restricted area, the British Isles. The first edition of this book was reviewed in the *Mercian Geologist*, Vol.3, No.1, pp.104-105.

Dr. Rayner states in the introduction to the second edition that extensive revision has been possible with greater reference to countries away from the British Isles, inclusion of the wealth of information being made available from the study of the surrounding seas, with incorporation of plate tectonic theory and by the intensive study of British stratigraphy sponsored by the Geological Society of London and published in their Special Report Series. Such is the amount of material now available that nothing less than a new edition was possible.

Reading the new edition it is quite clear that much new information has been included and errors in the first edition corrected. However I must remark upon initial disappointment. The book looks essentially the same as the 1st edition, with 460 pages (453) 84 figs. (80) and the format of the print, tables and figs. Was this strait-jacket imposed by the publisher? Closer examination lifts the gloom, for the early text and figs. do include reference to plate tectonic theory. But must the outline of the British Isles still be so dominant? The early Iapetus Ocean or Sea crossing Great Britain is restricted to a small paragraph on p.44. The later Tethys Ocean or Sea (but older concept) although well outside the British Isles area gets much more prominent treatment. I could find no reference to Pangea, and the relevance of the British Isles area within this supercontinent. What influence does the land area, west of the British Isles have on the geography of the area before the formation of the Atlantic Ocean? What was the latitude and longitude position of the British Isles prior to the Mesozoic? None of these questions are really touched upon and yet are essential for the understanding of the sedimentology of the British Isles area at various times. As with the first edition, fauna of the time is relegated strictly to its stratigraphical possibilities and is not used for palaeogeographical reconstructions. Certainly there is the outline of a new edition here but there is still much that could be revised.

Whilst most of the text figures are clear and self explanatory, I find some very difficult to interpret, usually because of the amount of information on them, their size or a combination of both. The three figures comprising fig. 1, the geology of the British Isles, should include some colour. Fig. 55, Permian palaeogeography of much of the British Isles, in two parts, is reduced to such an extent that both figs. occupy less than a quarter page. In comparison fig. 56 has extra large lettering and open spaces.

Considerable attention has been paid in modernising terminology. The Special Reports of the Geological Society of London are the most recent summaries and are listed in Dr. Rayner's bibliography. How far was Dr. Rayner able to incorporate the new terms under the constraints of a new edition? For the Trias only the three major group terms are used - Penarth, Mercia Mudstones and Sherwood Sandstone Groups, - and then only in one table (36). The terms are used here alongside Rhaetic, Keuper & Bunter. This is precisely what the authors of the Trias Special Report wished people to avoid. The latter terms are to be suppressed as far as British stratigraphy is concerned. Can future text-book writers please try to follow the recommendations? As for Dr. Rayner's book, the new terms appear to be used merely as an after-thought. The speed with which new changes takes place these days is also beyond the efforts of writers and publishers. If we accept the advice of Holland *et al.* (1980) the terms listed for the Upper part of the Silurian are already out of date.

In 1967 I thought the book was a little over priced at £3.10s. (£3.50). The price of the 2nd edition is £32.50p. and for this one would have the right to expect a completely modern format, new presentation and content.

F. M. Taylor

## Secretary's Report for 1979

In this its 16th year, the Society seemed to remain on an even keel with a membership of just under 500; the programme of meetings and excursions being well supported, and leaders and speakers congratulating us on the enthusiasm of our members.

Fourteen meetings were held during the year, 8 of which were indoor - 6 were lectures, the others being the Annual General Meeting and lecture and the Foundation Lecture. The Annual Dinner was also held. The 6 meetings in the field consisted of 4 day, one week-end and one week excursions.

The Annual General Meeting on 3 March was attended by about 60 members. Professor the Lord Energlyn had retired the previous year and the Society was able to welcome Professor P.E. Baker as the new Head of Department, as his lecture followed the meeting. He, along with the University, had continued to allow many of our activities to take place in the Department. This facility is of great benefit as no charge has been made for the use of the rooms, so allowing all our funds to be used in other directions.

On the election of Officers, according to the Constitution, Dr. W.A. Cummins, having served 3 years as President, retired and became Vice-President. Following the national trend Council chose Mrs. D.M. Morrow as the new President. She had already done much for the Society as unofficial and official Secretary through much of its existence, and Council meetings were held in her home for many years. The Presidency would enable her to become involved again but without too much onerous work, and to enjoy a well earned rest. Mr. E.H. Marriott had also given sterling service throughout his 6 years as Treasurer, and Mr. H.G. Fryer was chosen to replace him. As no other nominations had been received for the Secretary and Editor, these four officers were duly elected. A vote of thanks was proposed to the retiring President, Treasurer and Members of Council for the valuable work done during their term with Council. Five Members of Council were due to retire and one had resigned, 6 new Members were elected to replace them. Professor Baker then gave his lecture to a packed hall, describing the dramatic changes in views on the origin of oceanic islands and illustrated his talk with some awe-inspiring slides.

The 17 March was a day the President, Secretary and the speaker, Dr. D.J. Fettes of the Institute of Geological Sciences, Edinburgh, will remember only too well. Blizzard conditions had delayed Dr. Fettes' journey from Edinburgh and he had arrived by train 2 hours later than planned. The lecture, starting only 10 minutes late but to a rather smaller audience than usual, described his work in the Outer Hebrides. During his stay in Nottingham the outline for the week's excursion in July was planned.

The April meeting was given by Mr. J.M. Hodgson of the Soil Survey of England and Wales, and his subject "Soil Survey and Quaternary Geology". His work was mainly for agricultural use, but it did have some interesting geological 'spin-off' for the understanding of superficial deposits.

In mid-May about 40 members attended the week-end excursion based at Whitby. Dr. P.J. Hill and Mr. P.F. Jones led the party to Jurassic and some Quaternary locations in the Whitby, Robin Hood's Bay and Flamborough area.

The first day excursion was held in the Stoke-on-Trent area in June. Mr. D.B. Thompson met the coach at Parkhall Country Park which had been most successfully landscaped to provide an amenity for the general public and geologists alike. A day was happily spent amongst the Bunter Pebble Beds of the area.

Dr. R. J. Aldridge of the University of Nottingham led some 30 members to Wren's Nest, Dudley in early July. Unfortunately, over the years, the whole area has been so abused by collectors, that specimens must only be removed if required for serious work. Nevertheless still a very worthwhile visit and one enjoyed by all who attended.

At the end of July, 20 members travelled to the Notre Dame College of Education, Bearsden, Glasgow, HQ. for the week's excursion. Dr. Fettes had organised the different day's excursions, and after a problem of contacting him, due to out-of-order pay-phones at the college, it was arranged that he meet the party at Aberfoyle on Sunday to examine the Dalradian Grits and slates, then on to Balmaha, to retrace some of the ground covered in 1978 and to see Loch Lomond in sunshine, not torrential rain. On Monday Mr. W. Henderson covered the Kilcreggan Coast section, Mr. I. Patterson led from Largs to Gourrock on Tuesday. During the afternoon rocks of Lower Carboniferous age were traversed, intruded by a volcanic vent, into which the President intruded herself, resulting in a chipped wrist bone and her arm in a sling for the rest of the week. The free day on Wednesday was used by most people to visit the Fossil Grove and various museums in Glasgow. Loch Fyne and Arrochar were visited on Thursday, led by Dr. G. Smith and the party returned to the college via the Hunter's Quay to Gourrock ferry. The last day's excursion was led by Dr. J. McDonald to the Campsie Fells, complete with microscope to enable the rocks to be examined in thin section at the appropriate location. A most interesting week and enabling the party to renew its acquaintance with Dr. Fettes, Mr. Henderson and Dr. Smith, and to meet for the first time Mr. Patterson and Dr. McDonald. We owe them our sincere thanks, especially Dr. Fettes for making it all possible. Dr. Fettes, Dr. Smith, Mr. Henderson and Mr. Patterson are all from the Institute of Geological Sciences, Edinburgh. Dr. McDonald is at the Adult Education Department, University of Glasgow.

In September we made one of the shortest journeys to the first location in the Society's history. Dr. F.M. Taylor stopped the coach half a mile away at Nottingham Castle Rock before continuing an excursion in the Nottingham area. The final excursion of 1979 was to Wirksworth and Crich when Dr. P.H. Bridges of Derby Lonsdale College of Higher Education led the party to the Lower Carboniferous Limestone of the area. He had prepared polished specimens and photographs of thin sections of the different rocks encountered.

Dr. B.F. Windley, University of Leicester, discussed in his lecture in November, the apparently more vigorous growth of the Earth's crust during the Precambrian period. In December the Society welcomed Dr. A.J. Charig, Natural History Museum, when he delighted the full Lecture Hall with his talk on whether Dinosaurs were warm blooded or not - it remained unresolved. Metalliferous Mining in the North Pennines was the subject for January, Mr. D.G. Elford talked of his work with the British Steel Corporation and brought along some most interesting books logging the daily work of miners during the 19th Century.

The Fifteenth Annual Dinner was attended by only 17 members, but in spite of the low numbers, a very pleasant evening spent at the George Hotel, Nottingham.

It was envisaged when the Society was in its infancy, that a President may one day be elected who was unable to give the annual Presidential Address on a geological subject; the Foundation Lecture was provided as a substitute. Mrs. Morrow asked Professor Janet Watson, Imperial College London, to give the Foundation Lecture in February. Professor Watson kindly agreed to this request and spoke to a packed hall on "Flaws in the Continental Crust". She was besieged with questions right up until the time she was prised away from her enthusiastic audience.

So the year ended with a lecture which appealed to a wide group of members and finished a very successful season of lectures and field excursions. Our sincere thanks are due to the leaders: Dr. P.J. Hill, Mr. P.F. Jones, Mr. D.B. Thompson, Dr. R.J. Aldridge, Dr. D.J. Fettes, Mr. W. Henderson, Mr. I. Patterson, Dr. G. Smith, Dr. J. McDonald, Dr. F.M. Taylor and Dr. P.H. Bridges, and to the speakers: Professor P.E. Baker, Dr. D.J. Fettes, Mr. J.M. Hodgson, Dr. B.F. Windley, Dr. A.J. Charig, Mr. D.G. Elford and Professor Janet Watson.



There were eleven monthly circulars publicising the meetings and excursions of the Society, also information received from other bodies who wish to reach a wider public. The postage had increased twice during the year making this an even more expensive item. The Society is as usual most grateful to those members who hand deliver circulars in their own area.

Council met 6 times during the year discussing the Society's affairs and arranging meetings and excursions, some from ideas submitted by members which are always very welcome.

The membership seems to be remaining steady, and we now had:

Honorary	Ordinary	Joint	Junior	Institutional	Total
2	239	106	8	115	470

One of the Honorary Members, Professor L.J. Wills had died in December 1979, his obituary being published in the last Journal, Vol. 8, No. 2.

There had been 2 issues of the Mercian Geologist during 1979, Vol. 7, No. 2, containing a long article which had received considerable attention and resulted in a number of enquiries regarding membership of the Society. New machinery at the printers had also made it possible and economical to return to the use of glossy art paper for the plates. For the first time in Vol. 7, No. 3, several papers had been processed by the Associate Editors, Dr. P.G. Baker, Dr. P.H. Bridges and Mr. P.F. Jones all of Derby Lonsdale College of Higher Education. It must be stressed that without the voluntary labour involved in collating, packing and distributing, the Journal would cost considerably more to produce, and the Society is most appreciative of the help given so willingly by members on these occasions.

The Society Exhibit had been on display at the Natural History Museum at Wollaton Park, the University of Nottingham and the recently opened headquarters of the Institute of Geological Sciences at Keyworth, where it had resulted in several new members joining the Society. We are grateful to Mr. B.R.P. Playle for arranging the various locations and its transport to them.

I wish again to express our thanks to both the University of Nottingham and Professor Baker for allowing us to use the Lecture Hall and Swinnerton Laboratory for our meetings, and the use of one of the teaching laboratories for collating week-ends. With these facilities readily available and the hard work of many of the members, we are now a thriving and very successful Society.

In conclusion, my own personal thanks to everyone who has helped me throughout the year and made the task of Secretary that much easier.

W.M. Wright

CLUES

Across

Down

1. Blend Common Market into ring of close relatives (7)
5. Leapt gaily about the old city (7)
8. Tuff from Fujiyama's hillside (3)
9. A spot of bother (5)
10. Ten enter girl for sensory attachment (7)
12. Coins a new word, it's heard (5)
13. Determined character-singing cowboy? (4)
15. Not all right on the drilling platform (3)
16. Folded softly, 50, 99, 26 folded (7)
18. Locality of the type with standard spaces (3)
20. Participates in a diabolic hash (6)
21. Weakness in the face leads to usual & face stir (6, 7)
23. Survey headless boars (1. 1. 1.)
25. Discover a state in the Pyrenees, or make Arran do instead? (7)
26. Break and hold in 19 or 34 (3)
27. Team heard to breathe heavily (4)
30. 36 body bits for the April rainers (5)
32. Brown man on the fringe of the circle (7)
33. Current 31s (5)
34. Run-around container (3)
35. See 21.
36. As a doctor, no dunderhead, but useless (7)

1. Collector found hoarding *Raymondella*? (4)
2. Return in honour (5)
3. Lacking all the rest, the journal is incomplete (8)
4. Slaughter the horse in wild race (7)
5. Quiet chaos, quiet chaos (7)
6. Halt chaos - in good shape (4)
7. Change of shape involves us all (10)
11. Paid a vendor in return (7)
14. It's here! It's modal, man! I tested it! (10)
17. Pointless Canadian mess in the Cambrian (7)
19. Gum up container (3)
22. Bring to account a vast, disordered article (8)
23. I upset a worried old ocean (7)
24. Gravity in sanity insanity (7)
28. Are communities controlled by department hot-head? (5)
29. Rare exotic pygidium (4)
31. Hit a six straight down the middle (4)

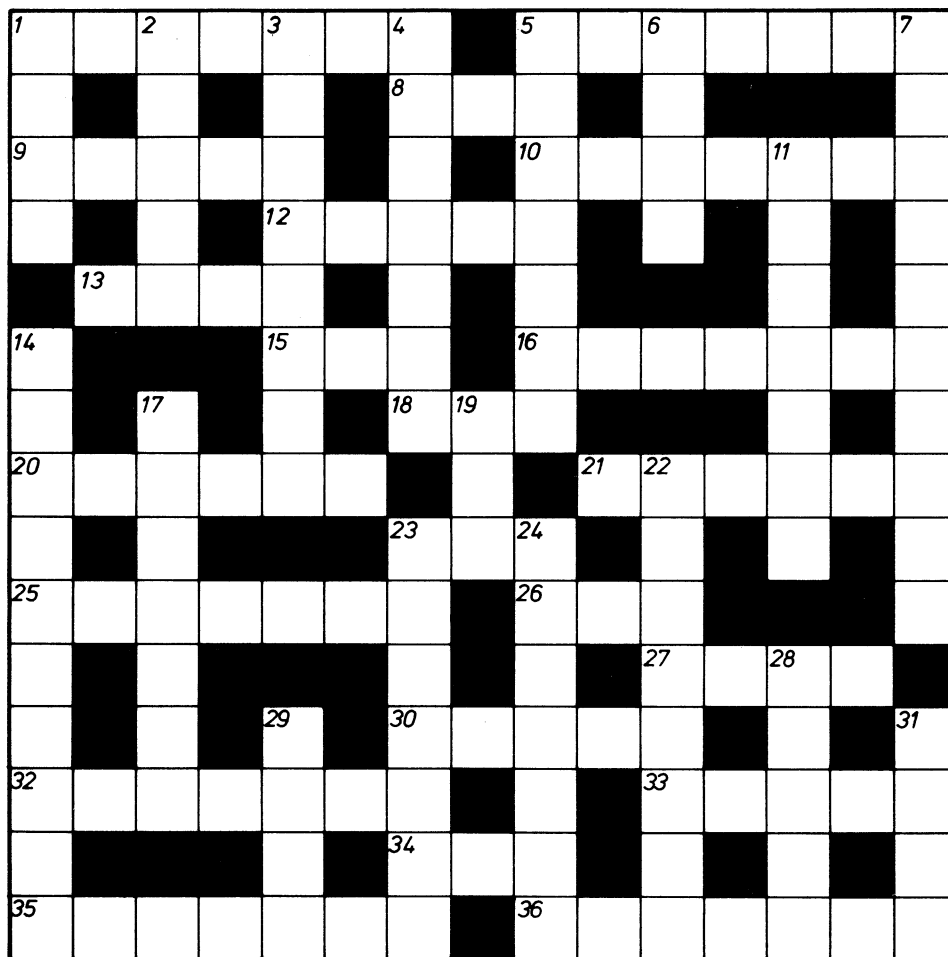
R. J. Aldridge  
Department of Geology  
University of Nottingham

A. W. Rushton  
Institute of Geological Sciences,  
Exhibition Road,  
London, S. W. 7

Solution to be printed in Vol. 8, No. 4

Geological Crossword Puzzle No.1

This crossword is thematic. 13 of the clues contain no definition part and lead to members of a single group. The remainder of the clues are normal; several of the solutions relate directly or indirectly to the theme. 1 across gives some indication of the relationship between the theme words.



R.J.A. / A.W.A.R.





## THE MERCIAN GEOLOGIST

### Journal of the East Midlands Geological Society

The journal first appeared in December 1964 and since that time 30 parts, comprising 8 volumes have been issued; the last, Vol.8, No.2, in March 1981. The Mercian Geologist publishes articles especially on the geology of the Midlands of England, but other articles have been published which are of current interest to geology generally. Contents include original papers, review articles, biography, bibliographies, excursion reports, book reviews and the Secretary's report on Society activities.

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Authors intending to submit manuscripts of papers for publication in the Mercian Geologist are asked to follow the format of papers included in a recent number of the journal, and if possible to provide two copies. As the journal is read by Members with a wide spectrum of geological interest and ability, authors are asked to ensure adequate introductions for their papers, particularly, if the subject has not been reviewed in the journal over the last few years. The paper should be complete in itself, without the need of the reader to refer to specialist journals not easily available to the average Member of this Society. It follows that the length of the paper may be greater than that published by some other journals but authors are asked to be as lucid and concise as possible and to avoid repetition.

Text-figs. normally occupy a full page of the journal, but part diagrams can be fitted into the typed page. Double page diagrams have been published with a single fold but each printed page has to be folded by hand. The standard reduction by our present printing process is approximately  $\times 0.75$ . Thus the optimum size for the original diagram, including space for caption, index and explanation if required on the diagram, should be 285 x 190 mm. (285 x 380 mm with a single fold). Greater reduction is possible but care must be taken with the original to ensure that at the final reduced size (230 x 155 mm; or 230 x 310 mm) the smallest letters are no smaller than 1 mm and that there is a similar minimum spacing between letters and lines. Bar scales (metric) should be provided as the exact reduction cannot be guaranteed.

Half-tone plates are reproduced at the original size, and should not exceed 230 x 155 mm. The quality of the published photograph depends initially on the quality of the original and it follows that the photographs submitted should be exactly as the author would wish them to appear in the journal - good contrast, in focus, adequate magnification and without distortion.

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1982

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Institutional Members	£6.00		

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