MICROPALAEONTOLOGY
(CONODONTA, OSTRACODA) ACROSS
THE LUDLOW / PRÍDOLÍ SERIES
BOUNDARY (SILURIAN) OF WALES AND
THE WELSH BORDERLAND

A thesis
submitted for the degree of
Doctor of Philosophy
in the
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by
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LUDFORD CORNER

This is the world-famous type locality for the Ludlow Bone Bed in which the fragmented remains of primitive fish are abundant. It marks the beginning of a change in this region about 400 million years ago from open seas to extensive land areas with large rivers.

Sir Roderick Murchison in 1839 placed the Fish Bed near the upper limit of his Silurian System.
This thesis is dedicated to my parents whose unconditional support throughout my education has been so important to me.

_The stone that the builders rejected as worthless turned out to be the most valuable of all._

PSALM 118: 22
The ostracod and conodont micropalaeontology of the Silurian Ludlow/Pridolf series boundary is documented from 88 localities across Wales and the Welsh Borderland. Fourteen multielement conodont species (two in open nomenclature), eight unassigned *Ozarkodina* elements and ten ostracod species (four in open nomenclature) are described from the Upper Whitcliffe and Downton Castle Sandstone formations and their lateral equivalents in Wales and the Welsh Borderland. A septimembrate prionodontid conodont apparatus *Coryssognathus dubius* (Rhodes, 1953) is reconstructed from discrete elements. Original calcareous valves of the ostracod *Frostiella groenvalliana* and moulds of open and partially open ostracod carapaces are described for the first time from the Welsh Basin.

The Upper Whitcliffe Formation and its lateral equivalents are characterised by the ostracod *Calcaribeyrichia torosa* and the conodonts *Ozarkodina confluens, Ozarkodina excavata, Panderodus serratus* and *Coryssognathus dubius*. The Downton Castle Sandstone Formation and its lateral equivalents are characterised by the ostracods *F. groenvalliana, Londinia arisaigensis, Londinia fissurata* and *Nodibeyrichia verrucosa*.

Conodont trends across the shelf area of the Welsh Borderland reflect an increasingly turbulent environment towards the top of the Ludlow Series. The sudden ostracod faunal change at the base of the Downton Castle Sandstone at Ludlow (shelf) contrasts with a gradual change at Long Mountain (basin) and parallels shelf-basin palynofacies changes. Variations in ostracod frequency, faunal composition and carapace preservation in the Downton Castle Sandstone Formation at Ludlow coincide with minor lithofacies variations. Local variations in the frequency of ostracods and land plant spores may be related to proximal channels delivering sediment off an irregularly prograding shoreline.

Ostracod faunas correlate the base of the Downton Castle Sandstone across the Welsh Borderland to localities in E central Wales where bone beds are absent. Combined conodont and ostracod evidence suggests that the base of the Pridolf Series is concurrent with the base of the Downton Castle Sandstone Formation in Britain.
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CHAPTER 1

INTRODUCTION

GEOLOGICAL SETTING

Historical significance of the Ludlow Bone Bed

"So brilliantly black are many of the organic fragments, that when discovered, this bed conveyed the impression that it enclosed a triturated heap of black beetles cemented in a rusty ferruginous paste" (Murchison 1839, p. 198). This is the first description of the bed which was first mentioned by Murchison (1834), later described in detail (Murchison 1852) and named the Ludlow Bone Bed (Murchison 1854). Murchison (1839, pp. 198, 199) also noted that, "this bone bed is not merely local, since fragments having the same structure, but of greater thickness than any of Ludford, have been found near Richard's Castle; and there is every reason to believe that it extends through various parts of the Ludlow promontory."

The Ludlow Bone Bed, which consists essentially of acanthodian remains and thelodont dermal denticles, is the lowest of several bone beds in the Ludlow Bone Bed Member at Ludford Corner, Ludlow (Holland et al. 1963; Antia 1979a, 1980a). For the purpose of the present study, other bone beds, either higher in the section at Ludlow or at any other locality in the Welsh Borderland, will be referred to simply as a bone bed, thus implying no correlative significance with the Ludlow Bone Bed itself.

Murchison never stated that the Ludlow Bone Bed defined the upper limit of the Silurian System. French workers (Dorlodot 1912; Barrois et al. 1918) mis-translated Murchison (1842, p. 648) and considered the Ludlow Bone Bed as the Siluro-Devonian boundary (White 1950). The Ludlow Bone Bed was then accepted (Stump 1920, 1923; and subsequent workers) as the base of the Devonian System.

The suggestion that the Siluro-Devonian boundary be raised to be coincident with the base of the Monograptus uniformis Zone (Holland 1965), led to abandonment of the Welsh Borderland as a standard for the Siluro-Devonian boundary (McLaren 1977). The Siluro-Devonian boundary is now defined at a level coincident with the base of the Monograptus
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uniformis Biozone, within Bed 20 at Klonk in Czechoslovakia (Chlupác 1972; McLaren 1977). This is stratigraphically higher than the Ludlow Bone Bed. To accommodate the strata between these two stratigraphical markers a fourth Series to the Silurian after the Llandovery, Wenlock and Ludlow Series had to be established (Text-fig. 1.1). The base of the Downton Group at Ludlow (the base of the Ludlow Bone Bed) was a prime contender for the basal stratotype for the fourth series (Bassett et al. 1982), as was the base of the Skala Series, Podolia and the Prídolf Series of the Barrandian area (Prague Basin). There was little support for the Skala section as "at this level cyclic dolomites dominate the sequence and correlation with the base of the corresponding Downton and Prídolf sequences could be achieved only with the use of limited ostracodal evidence" (Holland 1989, p. 18). Even though the base of the Downton Group could be correlated with graptolitic facies via a complex chain of correlation (Bassett et al. 1982), the marine Prídolf succession was eventually confirmed as the fourth series of the Silurian (Bassett 1985). The basal boundary stratotype was designated at Pozáry near Prague with the base at a level coincident with the base of the Monograptus parultimus Biozone (Kříž et al. 1986; Kříž 1989, 1992).

In the Welsh Basin the lithostratigraphical boundary between the Upper Whitcliffe Formation and the Downton Castle Sandstone Formation, corresponds to the base of the Ludlow Bone Bed (Text-fig. 1.1) at Ludford Corner, Ludlow, Shropshire (Text-fig. 1.2). Ostracods approximately correlate the base of the Downton Castle Sandstone Formation, via Baltic marine sequences, with the base of the Prídolf Series at the stratotype in Czechoslovakia (Siveter 1978, 1989; Bassett et al. 1982; Hansch et al. 1990). Conodont evidence has suggested that the base of the Prídolf may be slightly higher than the base of the Downton Castle Sandstone Formation at Ludlow (Schönlaub 1986; Aldridge & Schönlaub 1989).
TEXT-FIG. 1.1. Chronostratigraphy of the Silurian (radiometric dates after Harland et al. 1989) and lithostratigraphy of the Upper Whitcliffe and Downton Castle Sandstone formations (after Bassett et al. 1982) at the type locality for the Ludlow Bone Bed Member at Ludford Corner, Ludlow, Shropshire (loc. 18).
TEXT-FIG. 1.2. Map of study area showing outcrop of the Downton Group and Ludlow formations in Wales and the Welsh Borderland (after Bassett et al. 1982) and areas covered by each chapter.
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RESEARCH AIMS

1. To document the detailed distribution of ostracods and conodonts across the base of the Downton Castle Sandstone Formation at Ludlow and its lateral equivalents (Text-fig. 1.3), throughout the Welsh Basin.

2. To use conodont and ostracod faunas to test the correlation of the base of the Downton Castle Sandstone Formation across the Welsh Basin.

3. To integrate the results with recently published palynofacies (Richardson and Rasul 1990) and sedimentological studies at coeval sections.

4. To investigate the correlation of the base of the Pródolf Series, as defined at Pozár in the Barrandian Basin, Czechoslovakia, with the base of the Downton Castle Sandstone Formation within the Welsh Basin.

STRUCTURE OF THESIS

Chapter 1 provides a background to the thesis, including details of techniques which would not normally be published in full. Other chapters are written as a series of individual papers in the style of the *Journal of Micropalaeontology* (Chapters 2 and 3) and *Palaeontology* (Chapters 4-7).

Chapter 2 (conodont taxonomy) and Chapter 3 (ostracod taxonomy) have separate reference lists to allow for the abbreviated style of references accepted by the *Journal of Micropalaeontology*. At the time of submission of this thesis, a joint paper with Dr R. J. Aldridge entitled "The taxonomy and apparatus structure of the Silurian distomodontid conodont Coryssognathus Link & Druce, 1972" had been submitted to the *Journal of Micropalaeontology*, including part of the text from Chapter 2. Some of the material collected for this thesis was used for a study (Hansch et al. 1990) of the ostracod species Frostiella groenvalliana Martinsson, 1963 (see Appendix 3).

Chapters 4-7 document the conodont and ostracod distribution across the Ludlow/Pródolf series boundary on a shelf to basin transect through Wales and the Welsh Borderland (Text-fig. 1.2). Unless stated, the lithostratigraphy outlined by Cocks et al. (1992) is followed (Text-fig. 1.3). The localities and horizons studied in each area are given at the start of each chapter. A complete list of localities, which includes more detailed information such as British
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Geological Survey (BGS) specimen numbers and the current state of the exposure, is given in Appendix 1. A lithological key for all of the sections logged is given in Text-figure 1.4.

PREVIOUS RESEARCH

Correlation of the Downton Castle Sandstone Formation across the Welsh Borderland

The sedimentology and facies variations across the base of the Downton Castle Sandstone Formation have been summarised by Bassett et al. (1982), Allen (1985) and Smith and Ainsworth (1989). For the present study, the Welsh Basin has been considered in three areas (Text-fig. 1.2) which correspond to the subdivision of the Welsh Basin by Bassett et al. (1982, fig. 2).

The Ludlow Anticline and surrounding area. The Silurian exposures east of the Church Stretton Fault are normally referred to as the shelf area of the Welsh Borderland (Holland 1962). Chapters 4 and 5 describe the northern part of the shelf (Text-fig. 1.2), which includes the classic reference sections for the Ludlow Series exposed around Ludlow, Shropshire (Chapter 4). Bone beds are exposed at Much Wenlock (Robertson 1927; White and Coppock 1978), Corve Dale (Shergold and Shirley 1968), Downton (Whitalcer 1962), Kington (Holland and Williams 1985) and Netherton (Stamp 1923; Ball 1951) and have been assumed by these authors to be the lateral equivalent of the Ludlow Bone Bed. These bone beds mark a change from the subtidal coquinaoid siltstone facies of the Upper Whitcliffe Formation (Watkins 1979) to the intertidal shelf facies with a proximal prograding shoreline of the lowest Downton Castle Sandstone Formation (Bassett et al. 1982).

Inliers of the southern Welsh Borderland. The inliers of the southern Welsh Borderland (Text-fig. 1.2; Chapter 6) were assigned to southern part of the shelf area (Holland 1962). Bone beds are developed in the Malvern Hills (Phipps and Reeve 1967), at Woolhope (Squirrel and Tucker 1967), Usk (Walmley 1959) and Tite's Point (Cave and White 1971), with a phosphatic pebble bed occurring in the May Hill inlier (Lawson 1954, 1955). All of these deposits have been taken by previous authors to be the lateral equivalents of the Ludlow Bone Bed. At Gorsley near May Hill, the Ludlow Series succession is condensed and represented by
SEDIMENTS AND
SEDIMENTARY STRUCTURES

Orange/brown micaceous fine sandstone
Conglomerate (phosphatic and siltstone clasts in mudstone matrix) with micaceous sandstone interbeds
Cross laminated units with sharp erosive bases and internal low angle cross laminations
Wavy bedform with parallel to low angle cross laminations
Streaky to parallel laminations
Thelodont rich phosphatic coarse sandstone (bone beds)
Bioturbated siltstone
Convolute bedded siltstone
Parallel laminated siltstone with mudstone beds and impersistent limestone lenses/ beds
Dolomite

GRAIN SIZE ABBREVIATIONS

m mudstone
s siltstone
vf very fine sandstone
f fine sandstone
c coarse sandstone
l limestone

FLORAS AND FAUNAS

Ostracod rich horizons
Gastropods
Bivalves
Inarticulate brachiopods
Plant and other organic fragments
Eurypterid fragments
Brachiopod rich coquinas

TEXT-FIG. 1.4. Key to sections logged for the present study.
only 12.5 ft (3.80m) of strata (Lawson 1954). The sedimentological and macro-faunal change across the base of the Downton Castle Sandstone Formation in the southern Welsh Borderland is similar to that of the shelf localities around Ludlow (Bassett et al. 1982).

**E central Wales.** The area to the W of the Church Stretton Fault (Text-fig. 1.2, Chapter 7), approximates to the presumed deeper, basin area of the Silurian of the Welsh Borderland (Holland 1962, fig.1). With the exception of a thin and sporadic bone bed at Wallop Hall in the Long Mountain area (Palmer 1973), bone beds are not developed at the local equivalent of the base of the Downton Castle Sandstone Formation. Localities in the basin are much less fossiliferous and are characterised by much greater thicknesses of Ludlow strata than on the shelf (Holland 1960). Bone beds are not developed in the Clun (Stamp 1919, Earp 1940), Kerry (Earp 1938) or Knighton (Holland 1959) outcrops, and "deposition seems to have been continuous from Ludlow into Downton times only in the heart of the Welsh Basin" (Allen 1985, p. 90). Although the basal *P. helicites* Beds of the Knighton area often have a similar lithology to typical uppermost Ludlow strata, the boundary can still be identified on the basis of a change from typical Ludlow shelf faunas dominated by articulate brachiopods, to typical lowest Downton gastropod, bivalve and inarticulate brachiopod faunas (Holland 1962).

**SW Wales.** Localities in SW Wales (Text-fig. 1.2) are described briefly in Chapter 7. The base of the Downton Group is represented by an unconformity which progressively oversteps older and more deformed rocks to the west until, west of Llandeilo, it overlies Ordovician strata (Potter and Price 1965, Squirrell and White 1978). "Much of this south western area therefore may briefly have been land towards the end of the Ludlow and in early Downtonian" (Allen 1985, p. 90). Early Próidol times (Text-fig. 1.5) saw alluvial plains in Pembrokeshire and possible deltaic conditions near Llandovery (Potter and Price 1965).
TEXT-FIG. 1.5. Palaeogeography of southern Britain in the early Pridolf (Little Missenden Borehole=late Pridolf) (after Siveter et al. 1989, fig. 11; Bassett et al. 1992).
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METHODS AND TECHNIQUES OF STUDY

Fieldwork

Detailed bed by bed sampling and sedimentary logging was undertaken at a number of localities throughout the Welsh Borderland to give coverage of both the shelf and basin areas (Text-fig. 1.2). Localities were chosen that had been reported in the literature, or in British Geological Survey (BGS) records, to span the base of the Downton Castle Sandstone Formation and its supposed correlatives (Text-fig. 1.3). Localities that exposed strata either just above or just below this level were also sampled.

Calcareous or slightly calcareous lithologies, often present in discontinuous lenses, were sampled for conodonts; sample size varying from 300gm to three kg depending on ease of sampling. Each individual bed was split in the field and examined for macrofauna and for decalcified ostracod moulds, which are one to three millimetres long and therefore visible to the naked eye. Beds yielding either macrofauna or ostracods were sampled to fill a 20 x 30cm plastic bag and later split in the laboratory for ostracods.

Sample size was dependent on the stability of overhanging strata or the presence of two-dimensional “cliff” exposures. In general sampling was restricted to detailed collecting over 2-3m of exposure, although at some localities, for example the foreshore of the Severn Estuary at Tite’s Point (loc. 31b), over 20m of sediment was sampled. Sampling intervals were dependent on the presence of calcareous beds, or ostracod moulds. The smallest possible bed thicknesses (2-10cm) were collected.

Additional material has been obtained from a number of sources: British Geological Survey (BGS), Dr Richard J. Aldridge (RJA), and Dr David J. Siveter (DJS). Dr Aldridge’s samples are suffixed by an asterisk and the original locality numbers retained as they have been used in a previous publication (Aldridge 1985) and are to be published in a monograph on British Silurian conodonts.

Laboratory Processing

Conodonts. Calcareous lithologies were scrubbed, crushed into approximately 5cm³ pieces using a jaw crusher and then examined for macrofauna and ostracod moulds. Less calcareous samples were crushed into smaller, approximately 2cm³ pieces to increase the surface area
available for acid attack. Samples were dry weighed and digested in warm 10% acetic acid with approximately 10g of calcium carbonate added to the first treatment to produce a calcium acetate buffer which prevents fresh acid from reacting with any phosphates present.

After 5-7 days, some of the spent acid was retained to act as a buffer for the next treatment and the remaining acid and undigested rock sieved at 2mm and 75μm. Particles greater than 2mm were reprocessed and the 75μm fraction dried and retained for separation.

After the second treatment the fraction finer than 75μm was retained, washed, dried and stored for possible palynological preparation. Slightly calcareous samples not broken down by acid were washed, dried then weighed. These were then soaked and wet crushed in the fly-press and the residue kept separate. Wet crushing was shown to have little or no fragmentation effect on conodont elements.

An aqueous solution of the inert heavy liquid sodium polytungstate (manufactured by Somettu, Berlin), at a specific gravity (S.G) of 2.80, was used to separate the 75μm residue into heavy and light fractions. Samples were stirred every half hour in a 250cm³ separating funnel containing the heavy liquid. If more than a centimetre of heavy fraction accumulated at the bottom of the funnel before the first stirring, the heavies were tapped off between stirrings to prevent funnel blockage. After all the heavy residue had settled out it was tapped off and washed in de-ionised water. The soluble polytungstate was reclaimed by evaporation in a water bath. The light fraction was similarly washed and retained.

Heavy fractions were picked for conodont elements using a sable brush. Only elements with their basal cavities preserved were picked, counted and mounted using gum tragacanth on black background faunal slides. For prolific faunas, representative fractions of heavy residues were picked. Any other phosphatic fragments such as acanthodians or thelodonts were also selectively picked out but are not included in counts.

Light fractions were scanned for ostracod internal moulds, scolecodonts and foraminifera, with a representative fraction picked if any of these groups were present.

**Ostracod mould faunas.** Each individual bed containing at least one ostracod mould or macrofossil visible in the field was bulk sampled and split in the laboratory using a chisel. A black marker pen was used in the field to show the way-up orientation of each bed. Part and
counterpart moulds were kept together whenever possible. Seemingly barren fragments were further split up until the rock pieces became too small to split any further. Samples yielding a good microfauna were further divided to obtain a representative portion for identification. Barren fragments were retained.

Faunal slabs were labelled and each ostracod ringed with fine black indelible marker pen. The ostracods were identified and their preservation (internal and/or external moulds) noted. Single internal or single external moulds and specimens with both part and counterpart moulds preserved were recorded as one valve. Numbers of disarticulated valves and carapaces (with both valves still attached) were recorded.

The surface area of each faunal slab was recorded and the total surface area of barren fragments also measured, so that ostracod frequency based on the number of ostracods per unit of surface area studied (cm$^2$) could be calculated.

Well preserved external moulds were cast by the method described by Siveter (1982). Moulds were first cleaned out with a sable brush to remove any loose matrix. Specimens in soft lithologies were hardened by impregnating with Butvar B98 (propan-2-ol) and left overnight to dry. Silicone rubber (manufactured by Ambersil Ltd. Basingstoke), darkened with carbon black, was gently introduced into the mould with an old brush to ensure an even coating and to prevent air bubbles forming in the mould. Fine detail, up to 5$\mu$m in diameter, has been replicated using this technique (Pl. 12, fig. 1). The moulds and their casts have been labelled clearly with the same scanning electron microscope (S.E.M) stub number to aid curation and future reference.

Illustration of material. A Hitachi S520 S.E.M was used to obtain stereo-micrographs. Ostracod specimens were cut from the rubber casting medium using a scalpel and glued to flat, one centimetre diameter stubs using the acetone-soluble adhesive 'Durofix'. Conodonts and other phosphatic and organic microfossils were mounted using gum tragacanth. Ostracod internal moulds have also been prepared by cutting round the specimen with a rock saw and mounting the fragment with 'Durofix' onto a one centimetre stub. Electro dag (conductive silver paint) was then applied to the contact of the specimen with the stub to reduce the effects of charging. All specimens were coated with gold using a Bio-Rad E5200 sputter coater.
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Conodont white matter drawings have been made using a Wild Leitz microscope with camera lucida attachment.

REPOSITORIES

Illustrated material with the prefix PM is deposited in the Natural History Museum, London. Material with the prefix BGS is deposited at the British Geological Survey (Keyworth), and with the prefix SGWG at the Sektion Geologische Wissenschaften der E.-M.-Arndt-Universität, Greifswald, Germany. Material with the prefix GM or LEIUNG is kept in the Department of Geology, University of Leicester, where a representative suite of specimens collected for this thesis is held.
CHAPTER TWO

Conodonts from the Upper Whitcliffe and Downton Castle Sandstone formations (Silurian) of Wales and the Welsh Borderland

ABSTRACT

14 multielement species (two in open nomenclature) and eight individual unassigned Ozarkodina elements are described from the Upper Whitcliffe and Downton Castle Sandstone formations (and their lateral equivalents) of Wales and the Welsh Borderland. The boundary between the two formations can be shown to correlate to the Ludlow/Prídolf Series boundary within the Upper Silurian of the Welsh Basin. Most of the specimens have been obtained from calcareous lenses within the Upper Whitcliffe Formation, with a few rare and abraded specimens recovered from bone beds within the basal Downton Castle Sandstone Formation. Ozarkodina crispa, Dapsilodus obliquicostatus and Walliserodus cf. sancticlairei are described for the first time from the Upper Silurian of the Welsh Borderland. O. crispa and O. snajdri are shown to have co-existed towards end of deposition of the Upper Whitcliffe Formation; O. crispa is probably a phylogenetic descendant of O. snajdri. The Pa element Pelekysgnathus dubius and the elements previously described as Distomodus (?) dubius are synonymised as Coryssognathus dubius and a septimembrate prionodontid apparatus reconstructed. A new subspecies, O. remseheidensis baccata is described from the Upper Whitcliffe Formation.
INTRODUCTION

The lithostratigraphical boundary between the Upper Whitcliffe and Downton Castle Sandstone formations in the Welsh Borderland is defined at the base of the lowest bone bed in the sequence at Ludford Corner, Ludlow, Shropshire (Fig. 1.1) and correlates with the chronostratigraphical boundary between the Ludlow and Prfdolf Series (see Chapter 4). The conodont faunas for this study were collected by the author during a detailed micropalaeontological investigation of the Upper Whitcliffe and Downton Castle Sandstone formations, and their lateral equivalents (Fig. 1.3) across Wales and the Welsh Borderland. A total of 65 samples were taken, 11 of which were barren and 17 additional samples from the collection of Dr R.J. Aldridge have also been used (see Appendix 2 for processing details). Details of localities sampled are also given (Fig. 2.1, Appendix 1).

A thorough review of conodont studies on the British Silurian can be found in Aldridge (1985, pp. 68, 69) and will not be dealt with in detail here. Upper Whitcliffe and Downton Castle Sandstone formation conodont faunas were first reported by Harley (1861) who figured a few conodont specimens from the Ludlow Bone Bed Member at Ludlow under a new crustacean genus Astacoderma. Pioneering work by Branson & Mehl (1933) and Branson & Branson (1947) on the Silurian of N. America attempted to classify many of the species which have subsequently been found in the upper Silurian of the Welsh Borderland. It was not until 1953 that Rhodes published a similar study on Ordovician and Silurian conodonts of England and Wales. Although Rhodes did not sample from the Upper Whitcliffe or Downton Castle Sandstone formations his work included several common species. Subsequently Walliser (1966), Collinson & Druce (1966) and Druce (1967) have reported conodonts from the Upper Whitcliffe Formation and the distribution of conodonts throughout the British Silurian outlined (Aldridge 1975, 1985) and compared on a global scale (Aldridge & Schönlaub 1989).

TERMINOLOGY, MEASUREMENTS AND TECHNIQUES

The terminology for systematic descriptions has been outlined in the Treatise of Invertebrate Paleontology on conodonts (Clark et al. 1981, pp. 5-16) and used throughout this text unless otherwise stated. The taxonomic classification of Sweet (1988) has been followed from Order level with the Class Conodonta Pander, 1856 used rather than the Phylum Conodonta (Sweet 1988). The chordate assignment of the conodonts (Briggs et al. 1983; Aldridge et al. 1986,
Fig. 2.1. Outcrop of the Downton Group and Ludlow formations in Wales and the Welsh Borderland (after Bassett et al. 1982) showing sampled localities yielding conodonts.
Dzik 1986) is accepted here and supported by the recent discovery of vertebrate hard tissues in conodonts (Sanson et al. 1992).

The descriptive terms; length, height, width and breadth are used as shown in Figure 2.2. Measurements have been made only for the new subspecies O. remscheidensis baccata, on which maximum length and maximum height of the elements have been recorded (Fig. 2.2).

The majority of the specimens were extracted from limestones or slightly calcareous rocks of the Upper Whitcliffe Formation using 10% acetic acid (for details see Chapter 1). Often samples did not dissolve effectively, particularly bone bed samples from the Downton Castle Sandstone Formation (or lateral equivalents), and were wet crushed in a fly-press. Residues were dried and sieved to 75µm and the heavy fraction (including conodonts) separated using an aqueous solution of the inert heavy liquid sodium polytungstate (manufactured by Sometu, Berlin) at a specific gravity of 2.80.
ABBREVIATIONS

- $b =$ breadth (referring to denticles)
- $bm =$ basal margin
- $h =$ height
- $l =$ length
- $lb =$ length of base
- $lc =$ length of cusp
- $lbm =$ lower basal margin
- $ubm =$ upper basal margin
- $w =$ width

Fig. 2.2. Measurement and descriptive terms used in systematic descriptions of conodonts.
SYSTEMATIC PALAEONTOLOGY

Phylum: Chordata Bateson, 1886
Class: Conodonta Pander, 1856
Order: Belodellida Sweet, 1988
Family: Belodellidae Khodalevich & Tschernich, 1973
Genus: Walliserodus Serpagli, 1967

Walliserodus cf. sancticlairi Cooper, 1976
(Pl. 1, figs 1, 2)

1978 Walliserodus curvatus (Branson & Branson); Rexroad et al.: 12, pl. 1, fig. 2.

Material. One element.

Locality and horizon. 2m below top of Whitecliff Formation (20/1b), old tramway cutting, Netherton, West Midlands (loc. 20).

Description. Slightly asymmetrical non geniculate element with cusp reclined, triangular in section towards base, becoming lenticular with distal curvature. Posterior margin sharp; anterior margin flat at anterobasal corner, becoming more rounded distally. Each lateral face with prominent ridge close to anterior margin; ridge fading to low costa distally, fading out at point of maximum curvature. Non-costate lateral face with well developed sharp ridge running entire length of element close to posterior margin. Costate lateral face with costa originating just above base, fading just before element becomes curved. Base extends to half length of preserved element, triangular in section, with straight upper and lower margins. Basal margin straight, though possibly broken on the one available specimen. Element has deep basal excavation.

Remarks. The curvature of the element and the two ridges parallel and close to the anterior margin are distinctive of the genus Walliserodus. The specimen differs only slightly from Walliserodus sancticlairi (Cooper 1976) as it possesses a costa on one lateral face. The specimen is also similar to elements figured under the genus Dvorakia (Klapper & Barrick 1983); however it is symmetrical and triangular in section, probably a Sa element. Klapper & Barrick (1983, p. 1227) remark that symmetrical elements are absens from the symmetry transition series of the apparatus of Dvorakia.
Family: Dapsilodontidae Sweet, 1988
Genus: Dapsilodus Cooper, 1976

*Dapsilodus obliquicostatus* (Branson & Mehl, 1933)

(Pl. 1, figs 3, 4)

1933 *Distacodus obliquicostatus* Branson & Mehl: 41, pl. 3, fig. 2.

1976 *Dapsilodus obliquicostatus* (Branson & Mehl); Cooper: 212, pl. 2, figs 10-13, 18-20, (with synonymy to 1976).

1977 *Dapsilodus obliquicostatus* (Branson & Mehl); Barrick: 50-52, pl. 2, figs 6, 10, 13.

1978 *Distacodus obliquicostatus* Branson & Mehl; Miller: pl. 1, fig. 18.

1978 *Dapsilodus obliquicostatus* (Branson & Mehl); Rexroad et al.: 4, pl. 1, fig. 9.

**Diagnosis.** See Cooper (1976, p. 211-212).

**Holotype.** University of Missouri, No. C152-5. Figured by Branson & Mehl, 1933, pl. 3, fig. 2, from the Bainbridge (middle Silurian) at Lithium, Missouri, U.S.A.

**Material.** One element.

**Locality and horizon.** Whitcliffe Formation (10), quarry in Siefton Batch, Corve Dale, Shropshire (loc. 10).

**Description.** Flat symmetrical element with erect cusp flattened and distally decreasing gradually in height. Posterior margin with deep, broad, v-shaped furrow along entire length; anterior margin sharp. Both lateral faces slope to anterior, striated oblique to anterior margin, with slight indentation just above base parallel to anterior margin. Base flat, broad and triangular in lateral outline, with straight upper and lower margins. Basal margin straight with elongate conical cavity close to posterior margin, extending to point of maximum curvature of element.
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Order: Panderodontida Sweet, 1988
Family: Panderodontidae Lindström, 1970
Genus: Panderodus Ethington, 1959

Type species. University of Missouri, No. C153-3. Figured by Branson & Mehl, 1933, pl. 3, fig. 3 from the Bainbridge (middle Silurian) at Lithium, Missouri, U.S.A.

Remarks. Panderodus apparatuses described here are based on the reconstructions of Cooper (1975) for P. unicostatus and Barrick (1977), for P. recurvatus. However, the genus Panderodus is currently under revision and shall not be dealt with in great detail in this study. Historically a number of schemes for locational nomenclature have been used to describe Panderodus elements. For a summary and discussion of these notational schemes refer to Smith et al. (1987, p. 93-95). Descriptions here are based on the terminology of Sweet (1979) who used the terms falciform, arcuatiform, tortiform, similiform and asimiliform. The additional terms “hooked” and “symmetrical” have also been used to describe additional elements which have been shown to belong to the apparatus (Jeppsson 1983).

Panderodus recurvatus (Rhodes, 1953)

(Pl. 1, figs 5-20)
1953 Paltodus recurvatus Rhodes: 297, pl. 23, figs 219-220 (similiform/ asimiliform).
1957 Paltodus cf. recurvatus Rhodes; Walliser: 42, pl. 2, figs 2-4 (asimiliform?, similiform, arcuatiform).
1957 Paltodus compressus Branson & Mehl; Walliser: 42, pl. 2, figs 5, 6 (tortiform?, falciform).
1966 Panderodus sp. a Spasov & Filipovic: 46, pl. 2, fig. 1 (falciform).
1966 Panderodus sp. b Spasov & Filipovic: 46-47, pl. 2, fig. 2 (arcuatiform).
1967 Acodus sp. C. Igo & Koike: 15, pl. 1, fig. 3, text-fig. 4J (falciform).
1967 Acodus similaris Rhodes; Igo & Koike: 13-14, pl. 1, fig. 18 (similiform).
1971 Panderodus recurvatus Rhodes; Rexroad & Craig: 696-697, pl. 81, figs 23-25 (falciform, similiform, tortiform).
1972 Panderodus panderi Stauffer; Link & Druce: 74, pl. 7, figs 17, 18, 25, pl. 8, fig. 1 (asimiliform, falciform).
1973 *Panderodus recurvatus* Rhodes; Pollock & Rexroad: 83, pl. 1, figs 7, 8 (?arcuatifom, falciform).

1974 *Panderodus panderi* Stauffer; Drygant: pl. 1, figs 5, 6 (falciform).

1975 *Panderodus recurvatus* Rhodes; Telford: 37-38, pl. 3, figs 4-7 (falciform).

1976 *Panderodus recurvatus* Rhodes; De Deckker: fig. 3.1 (falciform).

1976 *Panderodus panderi* Stauffer; De Deckker: figs 3.8, 3.9 (arcuatifom).

1977 *Panderodus recurvatus* Rhodes; Barrick: 54-55, pl. 3, figs 3, 4, 7-12 (asimiliform, falciform, tortiform?, similiform) with synonymy to 1977.

1977 *Panderodus recurvatus* Rhodes; Liebe & Rexroad: pl. 2, fig. 22 (asimiliform).

1978 *Panderodus recurvatus* Rhodes; Miller: pl. 1, fig. 6 (similiform).

1978 *Panderodus* sp. Helfrich: pl. 2, fig. 13 (falciform).

1984 *Panderodus recurvatus densistriatus* Kozur: 156, pl. 2, fig. 3 (falciform).

1984 *Panderodus recurvatus recurvatus* (Rhodes); Kozur: pi. 4, figs 1, 3 (similiform).

1984 *Panderodus recurvatus densistriatus* Kozur; Balogh & Kozur: pl. 1, fig. 3 (falciform).

1984 *Panderodus recurvatus recurvatus* (Rhodes); Balogh & Kozur: pl. 2, fig. 4 (similiform).

**Diagnosis.** (After Barrick 1977, p. 54) Robust elements, sharply recurved and strongly flattened near mid-height. Base extended postero-basally with groove on posterior shoulder of pronounced longitudinal depression.

**Holotype.** Department of Geology, University of Birmingham, Great Britain, No. CIID 1a. Paratype specimen No. CIID 1c, figured by Rhodes, 1953, pl. 23, figs 219, 220.

**Material.** 30 elements (9 falciform, 7 arcuatifom, 3 tortiform, 2 asimiliform and 9 similiform).

**Localities and horizons.** (Fig. 2.3) Whitcliffe Formation, Corve Dale (10), Netherton (20/1a, 20/1b, 115/1*), Tite's Point (31b/6); Upper Perton Beds, Perton (23b/2), Prior's Frome (24a/2a, 24a/4); Rushall Beds, Prior's Frome (24b/2).

**Description.** *Falciform element* recurved, robust and asymmetrical. Cusp lenticular, decreasing only gradually in width during curvature, sharp anterior and posterior margins, with anterior margin attenuated slightly at point of maximum curvature. Furrow on furrowed lateral face originates at mid-line of basal margin and migrates rapidly towards posterior margin, distally parallel to posterior margin from point of maximum curvature. Striations well developed just to anterior of entire length of furrow. Unfurrowed lateral face slightly less...
Fig. 2.3. Frequency of *Dapsilodus obliquicostatus*, *Walliserodus cf. sancticlairi* and *Panderodus recurvatus* elements from the Upper Whitcliffe and Downton Castle Sandstone formations (and their lateral equivalents) of Wales and the Welsh Borderland.

<table>
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<th>Arcuniform</th>
<th>Tortiform</th>
<th>Similiform</th>
<th>Asimiliform</th>
<th><em>Dapsilodus obliquicostatus</em></th>
<th><em>Walliserodus cf. sancticlairi</em></th>
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convex and striated near to posterior margin at recurved part of cusp. Base striated parallel to straight basal margin, straight and converging upper and lower margins, sharp antero-basal margin and rounded postero-basal margin. White matter is confined to tip of cusp for all elements in the apparatus.

*Arcuatiform element* with robust cusp, lenticular in section, recurved through 90°, and remaining almost constant height for preserved part of element. Posterior margin sharp at base, rounded during curvature and sharp again towards tip. Anterior margin rounded at base, becoming gradually sharper towards tip. Unfurrowed face with short costa mid-way between anterior and posterior margins, originating at point where element starts to curve and fading out at point of maximum curvature, this face striated close to posterior margin during curvature. Entire length of opposite face furrowed, originating at mid-length of basal margin, migrating rapidly towards posterior margin, becoming parallel to posterior margin at point of maximum curvature. Base broad at basal margin, decreasing in height gradually until element starts to curve, straight upper and lower margins. Element drawn out postero-basally into a keel. Striated band circles entire element close to basal margin.

*Similiform element* symmetrical with recurved, lenticular cusp maintaining relatively constant height through recurvature. Both anterior and posterior margins rounded at base becoming sharper distally. Both lateral faces with small longitudinal costa mid-face originating from point where element begins to curve to point of maximum curvature. Furrowed lateral face furrowed from mid-length of basal margin, rapidly migrating to posterior margin, becoming parallel to posterior margin at start of curvature; this face striated just to anterior of furrow, unfurrowed face striated to posterior of costa. Base with straight upper and lower margins, and both lateral faces striated in a band parallel to straight basal margin.

*Asimiliform element* asymmetrical with slightly twisted, robust cusp of lenticular section, decreasing only slightly in height through curvature. Posterior margin sharp; anterior margin rounded at base, both becoming sharper distally. Furrowed lateral face with costa just to posterior of furrow during curvature of element; striated to anterior of furrow. Unfurrowed face striated close to posterior margin during curvature. Base with straight upper and lower margins, distally decreases more rapidly in height than cusp; both lateral faces with striated band parallel to basal margin. Basal margin extended slightly postero-basally; basal notch on furrowed face.
CHAPTER 2

Tortiform element with long, slender, twisted cusp reclined through approximately 70°. Element tall at base, becoming rapidly shorter, decreasing only gradually in height through recurvature. Posterior margin rounded at base, becoming sharp distally after recurvature; anterior margin rounded at base, becoming sharp just above base. Furrowed lateral face with furrow originating half way along basal margin and migrating rapidly towards posterior, becoming parallel to posterior margin at point where element begins to curve. Unfurrowed lateral face much flatter with ridge originating just above basal margin and fading out at point of maximum curvature. Base with straight lower margin, weakly concave upper margin; basal margin entirely excavated and extended into postero-basal heel.

Remarks. Reconstruction is based on elements figured by Barrick (1977). The notation system used by Barrick shows inconsistencies with the scheme used by Sweet (1979). For example, the element figured (Barrick, 1977, pl. 3, fig. 6) as an M element of \textit{P. unicostatus} is the equivalent of a falciform of Sweet (1979). The element figured as an Sc element of \textit{P. recurvatus} (Barrick 1977, pl. 3, fig. 4) is also considered a falciform using Sweet's notation. One tortiform element (Pl. 1, figs 19, 20) is much more slender than other elements in the apparatus, but shows a similar recurvature and is twisted like a tortiform element.

\textit{Panderodus serratus} (Rexroad, 1967)

(Pl. 2, figs 1-23)

1967 \textit{Panderodus unicostatus serratus} Rexroad; 47, pl. 4, figs 3, 4 (arcuatiform).
1967 \textit{Panderodus cf. P. unicostatus} (Branson & Mehl); Rexroad: 46, pl. 4, figs 1, 2 (hooked).
1967 \textit{Panderodus simplex} (Branson & Mehl); Rexroad: 45, pl. 4, figs 7, 8 (falciform).
1969 \textit{Panderodus denticulatus} Schwab: 521-524, text-figs 1, 2 (arcuatiform).
1972 \textit{Panderodus unicostatus serratus} Rexroad; Link & Druce: 76-77, pl. 8, figs 2-4 (arcuatiform).
1972 \textit{Panderodus simplex} (Branson & Mehl); Link & Druce: 75-76, pl. 7, figs 13-16, 21, 22 (falciform).
1974 \textit{Panderodus serratus} Rexroad; Drygant: pl. 1, fig. 4 (arcuatiform).
1974 \textit{Panderodus compressus} (Branson & Mehl); Drygant: pl. 1, figs 9-11 (falciform).
1974 \textit{Panderodus simplex} (Branson & Mehl); Drygant: pl. 1, figs 13, 14 (falciform).
1974 *Panderodus gracilis* (Branson & Mehl); Drygant: pl. 1, figs 15-20 (asiniform, similiform).

1974 *Panderodus unicosatus* (Branson & Mehl); Drygant: pl. 1, figs 22-25 (similiform, asiniform).

1975 *Panderodus serratus* (Rexroad); Cooper: 993-994, pl. 1, figs 3-5, 7-9, 13, 14, 23 (arcuatifonn, similiform, asiniform, falciform).

1978 *Panderodus serratus* (Rexroad); Miller: pl. 1, figs 1-5, 7, 8 (tortiform, arcuatifonn, falciform, asiniform, similiform, falciform).

1980 *Panderodus serratus* (Rexroad); Helfrich: pl. 2, figs 12-14 (asiniform?, falciform, arcuatifonn).

Diagnosis. (After Rexroad, 1967, p. 47) Apparatus with arcuatifonn element with serrate posterior margin caused by development of germ denticles along approximately two thirds of the length of cone starting near base.

Holotype. Indiana University / Indiana Geological Survey collections, No. 10063 (3-10). Figured by Rexroad, 1967, pl. 4, figs 3,4, from the Brassfield (Silurian), of the Cincinnati Arch area, Indiana, U.S.A.

Material. 2,971 elements (915 falciform, 496 arcuatifonn, 131 tortiform, 1298 similiforms & asiniforms, 119 hooked, 7 symmetrical and 5 indeterminable fragments).

Localities and horizons. Characteristic species of Upper Whitcliffe Formation and its lateral equivalents across Wales and Welsh Borderland (Figs 2.1, 2.4).

Description. *Falciform element* flat with cusp of lenticular section, almost bilaterally symmetrical, curved steadily, decreasing in height gradually towards tip. Posterior edge sharp, anterior edge rounded at basal margin, sharper towards mid-element, becoming rounded distally. On furrowed face, narrow furrow runs entire length, originating from basal margin, one third of distance from postero-basal margin, migrating to posterior as element thins distally. Keel-like postero-lateral face extensive near base, decreasing in width distally. Keel striated from base to two thirds of length of element on furrowed face and striated only at base on unfurrowed face. Basal margin straight and wrinkled (striated), with small basal notch on furrowed lateral face. White matter confined to tip of element, extending further down posterior than anterior margin.
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**Total**: 915 496 131 1298 119 7 5

Fig. 2.4. Frequencies of *P. serratus* elements from the Upper Whitcliffe Formation and its lateral equivalents of Wales and the Welsh Borderland.
CHAPTER 2

Arcuatiform element  asymmetrical bowed and recurved, decreasing in height rapidly from base, gradually decreasing in height from point where element begins to curve markedly. Sharp posterior margin appears serrate to non-serrate under light microscope (X50), but S.E.M. studies show that margins that appear non-serrate are slightly serrate (Pl. 2, fig. 6). Basal and distal anterior margin smooth and rounded, with middle third slightly sharper. Unfurrowed lateral face, costate close and parallel to anterior margin starting just above basal margin, fading out at point of maximum curvature; this face flat from costa to posterior margin with a broad shallow depression distally extending one third length of element from a point midway along basal margin. Furrowed lateral face with furrow extending entire length of element within broad depression slightly to posterior of mid-line and striations either side of furrow. Entire basal margin wrinkled and excavated with postero-basal heel and pronounced notch on furrowed lateral face where furrow meets basal margin.

Tortiform element  relatively small, asymmetrical, slightly bowed and twisted, decreasing in width till point of maximum curvature, tapering gradually to tip. Anterior and posterior margins sharp. Unfurrowed lateral face with shallow depression at base becoming flat at mid-length then convex distally; this face striated at point of maximum curvature. Furrowed lateral face more strongly convex with furrow extending entire length close to posterior margin, migrating towards, and becoming parallel to posterior margin at point of maximum curvature; striations either side of furrow from basal margin to mid-length of element. Basal margin straight to slightly extended in postero-basal direction, with notch on lateral side where furrow meets basal margin. Both lateral faces weakly striated towards basal edge.

Similiform element  variable, symmetrical bi-costate, long, slender, straight almost entire length then reclined and circular in section towards tip. Posterior margin sharp near base, becoming more rounded distally at point of maximum curvature. Entire anterior margin smoothly rounded. Costa on each lateral face extends parallel to anterior margin from point just above base, to point of maximum curvature. Wide based form extended in postero-basal direction and slightly more recurved than slender narrow based form, which also has straighter basal margin. One lateral face furrowed close to posterior margin, migrating towards posterior distally. Basal margin always has basal notch and can be either straight or drawn out in a postero-basal direction.
CHAPTER 2

Asimiliform elements similar to similiforms but with the costae on either lateral face slightly asymmetrically arranged. Asimiliform elements are generally slightly smaller than similiforms and may be more recurved.

Hooked element relatively small, asymmetrical, recurved through 90°, decreasing in height rapidly from basal margin until mid-length recurvature, decreasing only gradually in height distally. Posterior margin sharp, anterior margin smooth and rounded. Unfurrowed lateral face virtually flat with costa close to anterior margin extending from a point just above base, to point where element begins to straighten after curvature. Furrowed lateral face has a similar costa which is further from anterior margin and a furrow extending entire length of element close to posterior margin, producing a notch at basal margin. Basal margin may be straight or extended slightly in a postero-basal direction. Both lateral faces striated near to basal margin.

Symmetrical elements distinct from similiform elements as they are smaller and both lateral faces are furrowed. Element erect, distally tapering evenly. Sharp posterior and rounded anterior margins. Both lateral faces furrowed just to posterior of mid-face, extending from basal margin, terminating at point where cusp starts to curve inwards; cusp becoming lenticular in section at this point. Both lateral faces costate close to anterior margin on distal two thirds of element. Basal margin straight with cavity extending under entire element.

Remarks. The specimens have been referred to the species serratus because of the serrate nature of the arcuatiform element. Many specimens which appear non-serrate are in fact slightly serrate when viewed under the S.E.M. (Pl. 2, fig. 6). Lack of evident serration is possibly enhanced by abrasion which can remove the serrations on the arcuatiform elements. It is also possible that there are two closely related species present: P. serratus and P. unicostatus, as previously suggested by Cooper (1975). The other elements in the apparatus however, do not show sufficient variation to be able to distinguish between the two. Often elements from the apparatus, other than the arcuatiform element have been figured and therefore cannot be included in synonymy, so it is possible that P. serratus is more common than the literature suggests. The majority of arcuatiform specimens from the Upper Whitchcliffe Formation of the Welsh Borderland appear to be serrate, therefore the species name serratus has been given here. Similiforms and asimiliforms have been counted together for this study. Dzik & Drygant (1986) have been able to distinguish two forms of each, which is consistent with the fact that
asimilis similiforms are always most abundant in samples from the Welsh Borderland (Fig. 2.4). From work on *Panderodus* clusters (Jeppsson 1983, Smith et al. 1987), the relatively small size of the tortiform, hooked and symmetrical elements relates not only to ontogeny but also to position of the elements within the apparatus.

**Order:** Prioniodinida Sweet, 1988  
**Family:** Prioniodinidae Bassler, 1925  
**Genus:** *Oulodus* Branson & Mehl, 1933

*Oulodus* sp.  
(Pl. 3, figs 1-9)

**Material.** 17 identifiable elements (3Pb, 6M, 1Sa, 6Sb, 1Sc) and 21 indeterminable fragments.

**Localities and horizons.** (Fig. 2.5) Upper Longhope Beds, Longhope bypass (168/5*); Whitcliffe Formation, Tite's Point (31b/2, 3, 4, 6, 8); Upper Llangibby Beds, Usk (33/2); Upper Perton and Rushall Beds, Prior's Frome, Woolhope (162/2*, 24a/3, 24b/2); Downton Castle Sandstone Formation, Linley, Much Wenlock (3b/1), Downton Estate (14b/3, 14c).

**Description.**  

**Pb element** with broad, flat cusp, lenticular in section and curved to posterior. Preserved part of anterior process has two broken denticles, curved towards posterior; posterior and anterior processes lenticular in section with thickened bar parallel to upper margin just below base of denticles. Posterior process not as tall as anterior, two subequal denticles of lenticular section in same orientation as cusp. Basal body present, extending beneath entire length of element.

**M element** cusp circular in section with anterior and posterior costae, although cusp of best preserved specimen almost entirely broken off. Posterior process taller and longer than anterior, curved to posterior, with distal denticles increasingly inclined to posterior. Anterior process straighter than posterior, five crowded denticles becoming smaller, narrower and more crowded distally. Cavity appears to extend under entire length of element, although obscured by basal body, lips on inner side pinched and inclined to posterior.

**Sa element** symmetrical, cusp of circular section, broken in only specimen. Identical lateral processes form angle of approximately 100° to each other, inclined downwards and slightly to posterior, becoming slightly less tall distally, with peg-like denticles of circular cross-
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Fig. 2.5. Frequencies of *Oulodus* sp. elements from the Upper Whitcliffe and lowermost Downton Castle Sandstone formations (and their lateral equivalents) of Wales and the Welsh Borderland.
section (Pl. 3, fig. 4) increasing in breadth to third denticle from cusp then decreasing in breadth distally. Six denticles preserved on one lateral process and four on the other process which is broken. Cavity pinched posteriorly, extending under entire length of processes. Most of element composed of white matter except lips of cavity; basal body present.

Sb element with slender, bicostate cusp curved and twisted to posterior. Anterior process short with two slender denticles curved inwards slightly towards cusp. On one specimen (Pl. 3, fig. 8) these denticles are well developed and larger than any denticles on posterior process. On another specimen (Pl. 3, fig. 6) these are smaller than all of denticles on the posterior process. Downwardly curved posterior process with three or four denticles; proximal denticle after cusp always minor and slightly backward of more distal denticles, second denticle from cusp always largest, size then decreasing distally. Short extension to process after terminal denticle. Cavity pinched and inclined to posterior reflecting curvature of cusp, extending under entire length of both processes.

Sc element bipennate with bicostate cusp of circular section, distally decreasing gradually in breadth, and inclined to posterior. Only anterior process completely preserved on figured specimen; three isolate denticles of ovoidal section, distally decreasing in size. Posterior process taller than anterior, with one denticle obscured by matrix although process incompletely preserved. Cavity extends under entire element; basal body present.

Remarks. The elements described here are similar to those described from the apparatus of Oulodus by Sweet and Schönlau (1975) as they possess stout peg-like denticles separated from adjacent denticles by U-shaped spaces (Pl. 3, fig. 4). The generic name Oulodus has been used rather than Ligonodina (see Jeppsson 1969, 1972, 1974) as the apparatus of Oulodus has been described and reconstructed from the Ordovician (Sweet & Schönlau 1975) whereas the apparatus of Ligonodina, first described from the Devonian (Bassler 1925), is at present unclear. The Sb elements described are similar to specimens figured by Jeppsson (1972) as L. confluens (pl. 2, figs 15, 16) and L. confluens confluens (pl. 2, figs 1, 7, 8), but differ in that proximal denticle on the posterior process is always slightly backward of the proceeding denticles. Only 17 identifiable elements have been recovered, and are not well enough preserved to be assigned to a specific apparatus and have therefore been described under Oulodus sp.
CHAPTER 2

Order: Prionodontida Dzik, 1976
Family: Distomodontidae Klapper, 1981
Genus: Coryssognathus Link & Druce, 1972
Coryssognathus dubius (Rhodes, 1953)

(Pls 4–7; text-figs 2.7 - 2.12)

1861 Astacoderina spinosum Harley: pl. 27, fig. 16a, b (Sc?).
1953 Distomodus suberectus Rhodes: 290, pl. 23, fgs 207, 208 (Pb/Pc), 210, 211 (M).
1953 Distomodus curvatus Rhodes: 290, pl. 23, fgs 209, 226-228 (Pb/Pc).
1953 Distomodus curvatus var. dentatus Rhodes: 291, pl. 23, fgs 217, 218, 229, 230 (Pb/Pc).
1953 Cordylodus? dubius Rhodes: 299, pl. 23, fgs 221-224 (Sc).
1972 Distomodus dabis (Rhodes); Jeppsson: 56–58, pl. 1, fgs 1 (M), 2-4 (Sc), 5 (Sa/Sb), 6 (Pb?), 7–9 (Pc), 10–13 (coniform).
1972 Coryssognathus dentatus Link & Druce: 31-32, pl. 2, fgs 13-19, text-fig. 13 (Pa).
1972 Cordylodus? dubius Rhodes; Link & Druce: 30-31, pl. 2, fgs 11, 12, text-fig. 12 (Sc).
1972 Distomodus curvatus Rhodes; Link & Druce: 33-34, pl. 2, fgs 20, 21 (Pc), 22, 25, text-fig. 15 (Pb).
1974 Distomodus dabis (Rhodes); Jeppsson: 18, pl. 1, fgs 1 (Pb/Pc?), 2 (coniform), 3 (Sc), 4 (Sa/Sb), 5, 6 (Sc), pl. 2, fig. 1 (M).
1974 Pelelysgnathus dubius Jeppsson; Jeppsson: pl. 2, fgs 2a-c (Pa).
1975 Distomodus dabis (Rhodes); Aldridge: pl. 1, fgs 10 (Sc), 11 (M), 12 (Sb), 13 (Pb), 14 (Sa/Sb).
1975 Pelelysgnathus dubius Jeppsson; Aldridge: pl. 1, fgs 5-7 (Pa).
1978 Distomodus dabis (Rhodes); Pickett: pl. 1, fgs 10, 13 (Pb/Pc), 11, 12 (M), 14 (?Sa/Sb), 15-17 (Sc).
1979 Distomodus dabis (Rhodes); Jeppsson: fig. 1A (coniform), 4A (Sa/Sb).
?1980 Dentacodina dubia (Rhodes); Wang: 370, pl. 2, fgs 1, 2 (Sa/Sb).
1985 Distomodus? dubius (Rhodes); Aldridge: pl. 3, 4, figs 10 (Pb/Pc), 11 (M), 12 (Sc), 13 (Sa/Sb), 14 (Sb).

1985 Pelecygnathus dubius Jeppsson; Aldridge: pl. 3, fig. 16 (Pa).

?1989 Dentacodina trilinearis Wang; Walliser & Wang: pl. 2, figs 17 (Sc), 18 (Sa/Sb), 26 (Sa/Sb), 27, 28 (Sc).

1990 Coryssognathus dentatus Link & Druce; van den Boogaard: pl. 1, figs 1-7, pl. 2, figs 1, 2 (Pa).

1990 Coryssognathus dubius (Jeppsson); van den Boogaard: pl. 3, figs 3, 4, pl. 7, figs 2, 3 (Pa).

1990 Distomodus dubius (Rhodes); van den Boogaard: pl. 3, figs 1, 2 (M), 5 (Pb/Pc?), pl. 4, figs 1, 2 (Pc), 3, 4 (Sc), 5, 6 (Sa/Sb), 7 (M), 8, 9 (Sa/Sb), 10 (Pb), 11 (Pb/Pc?), pl. 4, figs 1 (M), 2 (Pb/Pc), pl. 7, fig. 1 (Pc).

**Diagnosis.** Pa element with erect triangular cusp, denticulate inner lateral process well developed in mature specimens. Pb and Pc elements with triangular bases. Sa/Sb and Sb elements with strongly curved cusps and weakly developed peg-like denticles on posterior process. Sc element with up to four denticles on posterior process.

**Holotype.** Department of Geology, University of Birmingham, Great Britain, No. CIIE2a. Figured by Rhodes, 1953, pl. 23, figs 221-223, from the Aymestry Limestone of Shropshire.

**Material.** (Fig. 2.6) 5,868 elements (269 Pa, 1045 Pb/Pc, 726 M, 565 Sa/Sb, 362 Sb, 1009 Sc, 1323 coniform elements and 358 non-identifiable elements).

**Localities and horizons.** Characteristic species of Upper Whitcliffe Formation and lowermost Downton Castle Sandstone Formation (and their lateral equivalents) of Wales and the Welsh Borderland (Fig. 2.6).

**Description.** Pa element (Fig. 2.7 and Pl. 4, figs 1-14) broadly triangular with cusp at anterior and always highest point of inflation of element, although denticles next to cusp is sometimes fused to cusp making cusp less pronounced (Pl. 4, fig. 9). Posterior process denticles inclined to posterior, triangular in specimens where they are less fused, elongate in specimens with more fused denticles; denticle furthest posteriorly from cusp often most pronounced. All denticles lenticular in cross section, those closest to cusp smooth, posteriormost denticles in mature specimens often with small longitudinal ridge on inner and outer lateral faces (Pl. 4, figs 13, 14). Anterior process adenticulate, weakly developed extension to ridge
Fig. 2.6. Frequencies of elements from the apparatus of Coryssognathus dubius, simple coniform elements and non-identifiable coniform elements from the Upper Whitcliffe Formation and lowest Downton Castle Sandstone Formation (and their lateral equivalents) of Wales and the Welsh Borderland.

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Fig. 2.7. Pa elements of *C. dubius* showing ontogenetic changes in morphology. The Pa element became more denticulate by successively incorporating denticles during ontogeny.
on anterior side of cusp. Lateral process of juvenile specimens present only as a fold on inner lateral surface, mature specimens with well-developed posteriorly curved process with one to three denticles (Fig. 2.7); denticles similar to those on the posterior process. Basal cavity deepest at junction of posterior and lateral processes; thick layer of spongelike basal body matter up to 80μm thick always present. Cavity extends under entire element. White matter clearly defines denticles and characteristically extends down anterior blade almost to termination of anterior process (Fig. 2.7).

**Pb and Pc elements** (Fig. 2.8 and Pl. 5, figs 1-15) were first described by Rhodes (1953), and later by Jeppsson (1972). The morphological terminology of Jeppsson (1972, p. 57) is used in this description. Both elements with similar pointed cusp, sharp posterior lateral and inner anterior lateral edges, proximal inner face between two sharp lateral edges falcoid to weakly biconcave and outer face strongly convex. Cusp twisted and becoming lenticular distally, so that posterior lateral edge becomes the lateral edge. Processes of Pc element more strongly developed than Pb element, although both have been counted together (Fig. 2.6) as elements are very difficult to distinguish if they have been abraded. Brown base with distinct transition to white denticles when present. Brown blends into amber hyaline area at start of cusp which distally blends into white matter of cusp.

**Pb element** (Pl. 5, figs 1-6) with three weakly developed, simple processes; inner anterior lateral process often bearing single triangular denticle sometimes showing distinct suture at base and occasionally barely attached to the element (Pl. 5, figs 3, 4). Posterior lateral process rarely develops small stubby denticle fused to inner base of cusp. Outer anterior lateral process adenticulate and only visible proximally, blending into strongly convex outer face distally.

**Pc element** (Pl. 5, figs 7-15) inner anterior lateral process better developed than outer anterior and posterior lateral processes with no denticles or up to three denticles of lenticular cross section and circular bases; denticle furthest from cusp usually best developed. Stubby triangular denticle on posterior lateral process blends into inner side of the cusp. Outer anterior process minor and adenticulate. Basal cavity triangular, margins when complete are convex between outer anterior and posterior lateral processes and concave either side of outer anterior lateral process. Within basal cavity, each denticle has own basal pit with later lamellae enclosing each denticle (Pl. 5, figs 9, 11); cavity often contains basal body or sediment.
Fig. 2.8. Pb, Pc, M and Sc elements of C. dubius. P=posterior, PL=posterior lateral edge, IAL=inner anterior lateral edge.
CHAPTER 2

*M element* (Fig. 2.8 and Pl. 5, figs 16-18) with flat cusp, lenticular in section, curved both posteriorly and inwards and with sharp lateral edges. Proximal cusp, inner lateral face more strongly convex than outer which is almost flat in some cases with cusp becoming more lenticular towards apex (Fig. 2.8). Inner lateral posterior face striated. Two processes with posterior process strongly developed and sometimes bearing small blade-like denticle. Anterior process rarely denticulate (Pl. 5, fig. 18) with denticle developed from proximal anterior margin. Shallow lenticular basal cavity, angular to plane of cusp with inner lateral lip slightly pinched and outer lateral margin weakly convex (Fig. 2.8). Thickened area above cavity brown with a distinct transition to white matter of cusp and denticles.

*Sa/Sb element* (Fig. 2.9 and Pl. 6, figs 1-8) showing a wide range of symmetry. Morphotype A is symmetrical and morphotypes B and C become increasingly asymmetrical, with intermediate forms between morphotypes common (Fig. 2.9).

*Morphotype A* (Fig. 2.9 and Pl. 6, figs 1, 2) symmetrical with well developed costae extending from proximal cusp to approximately half way up cusp. Cusp tricostate proximally, becoming lenticular towards tip with posterior and anterior faces flattened; single costa on posterior face. Costae on the lateral margins of the cusp blend into two lenticular lateral denticles either side of cavity extending to cavity margin. Lateral margins extend into two downwardly directed posterior processes, which may be taphonomically accentuated by breakage of part of cavity lips. Posterior process at base of cusp, short with peg-like denticle extending axially from costa on the posterior face of the cusp. Base brown with denticles, costae and posterior process composed of distinct white matter.

*Morphotype B* (Fig. 2.9 and Pl. 6, figs 3-5) with cusp slightly twisted and denticles sub-symmetrically arranged either side of cavity. Well developed costa on posterior face of cusp extends from base to tip and sometimes twisted sinistrally or dextrally. Cusp triangular at base becoming lenticular towards tip with convex lateral faces. Small posterior process with peg-like denticle developed at junction between base and cusp coincident with the end of costa on posterior face and slight thickening at start of cusp. Striae on junction between base and cusp diverge either side of posterior process. One or two lateral denticles on either side of cavity; lenticular to rounded in cross section. Deep triangular cavity ranging from equilateral to inequilateral with shortest edge to anterior. Brown area of base extends into proximal cusp at
Fig. 2.9. Symmetry transition in Sa/Sb and Sb elements of *C. dubius*. All elements drawn from the posterior and cross sections of the elements are drawn with the posterior facing the top of the page.
posterior but to a lesser extent on the anterior margin. White matter in lateral denticles, posterior process and entire length of cusp.

*Morphotype C* (Fig. 2.9 and Pl. 6, figs 6-8) asymmetrical, similar to morphotype B but with cusp inclined laterally and denticles arranged asymmetrically either side of cavity. Costa extends entire length of posterior face of cusp to posterior process. Cusp proximally inequilateral triangular to circular with costae occasionally developed; cross section lenticular towards tip, often with one lateral face less convex than the other. Posterior process with single peg-like denticle inclined slightly inwards, tip rounded if preserved entire. Two lateral denticles on outer margin much more closely spaced than those on inner margin. Denticles lenticular and bicostate in cross section and more strongly developed towards cavity margin. Cavity deep and triangular in cross section. White matter distribution similar to morphotype B.

*Sb element* (Fig. 2.9 and Pl. 6, figs 9-12) distinctly asymmetrical with inner side of the cavity and cusp flattened and drawn out into a downwardly directed process. Cusp twisted slightly inwards, almost ovoidal at base, becoming lenticular towards apex, inner margin flattened or weakly convex, with lateral margins weakly to strongly convex. Mono-, bi- and tricostate forms occur, with costa on posterior face always present. Posterior process with peg-like denticle curved slightly inwards, extends from costa which runs entire length of posterior face of cusp. Single denticle, often fused with a costa, developed near the termination of downwardly directed process. Two to three sharp denticles developed on outer margin further from cavity margin than denticle on downwardly directed process. Cavity deep and ovoidal in cross section with inner margin weakly convex, flattened or sometimes slightly concave. White matter distribution similar to Sa/Sb elements.

*Sc element* (Fig. 2.8, and Pl. 7, figs 1-5) with cusp strongly curved to posterior, proximally flattened on one side and weakly concave near anterior margin, distally becoming lenticular towards tip, bicostate; costa running entire length of anterior and posterior margins. Row of up to four peg-like denticles on upper margin of base, with denticle closest to cavity usually most strongly developed, although all denticles may be of equal proportion. Denticles bi-costate and lenticular in section, occasionally showing attachment sutures (Pl. 7, fig. 2). Series of three tiny angular denticles sometimes developed on lower margin of base (Pl. 7, figs 2, 3). Cavity deep, lenticular with margin flattened on one side. Area below denticles dark brown, grading into distinctive triangular amber, hyaline area at the base of the cusp (Fig. 2.8).
White matter extends almost entire length of anterior margin but terminates at junction of cusp with base on the posterior margin producing a distinctive line cross cutting base (Fig. 2.8).

Coniform elements (Pl. 7, figs 6-15) commonly occur in collections from the Upper Whitcliffe Formation. Coniforms are lenticular in section, often slender, but occasionally stubby and triangular. Cusp can be proclined or erect with basal cavity circular to lenticular commonly containing basal body and sometimes displaying lamellar edges of crown tissue. Rarely occur as pairs, fused at base (Pl. 7, fig.6).

Remarks. Clark et al. (1981) and Jeppsson (1972) have considered Pelekysgnathus dubius and Coryssognathus dentatus to be conspecific, while Klapper and Murphy (1974) considered the two as congeneric. Van den Boogaard (1990) assigned them both to the genus Coryssognathus but considered P. dubius to be a different species from C. dentatus as it has a marginal fold which is rarely denticulated whereas mature specimens of C. dentatus have a denticulate lateral process. Specimens of the Pa element from the Upper Whitcliffe Formation in the Welsh Borderland show a wide range of morphologies associated with intraspecific variation and an ontogenetic series (Fig. 2.7). Mature specimens may have up to three denticles on the lateral process. Van den Boogaard (1990) figured a specimen of C. dentatus which possesses two to three denticles while the Australian specimens from the Yass Basin figured by Link & Druce (1972) have no more than one. Link & Druce (1972) collected only nine specimens of C. dentatus so it is perhaps possible that these are juveniles, and more mature specimens would possess up to three denticles on the lateral process. A specimen (Pl. 5, fig. 11) from the Whitcliffe Formation at Aston Munslow in the Welsh Borderland (sample 39/1*) is almost identical though slightly more mature than the holotype of C. dentatus figured by Link & Druce (1972, pl. 2, figs 15, 18, 19). The specimen is part of a population that contains typical 'P.' dubius forms. The size and shape of the denticles on the posterior blade, the position of the cusp and the inward and posteriorly facing lateral process suggest 'P.' dubius is conspecific with C. dentatus. One specimen figured by Link & Druce (1972, pl. 2, figs 13 &14) is unusual in that it possesses a denticle to the anterior of the cusp, a feature not seen on any specimens from the Welsh Borderland.

Pa elements of C. dubius grew by successively incorporating neighbouring denticles in a manner similar to that demonstrated by van den Boogaard (1990) for the specimens he referred to C. dentatus. A specimen (van den Boogaard, 1990, pl. 1, fig. 4) shows lamellae
inside the cavity, but these have not been observed on specimens of *C. dubius* from the Welsh Borderland because the deep basal cavity is always filled with a basal body or sediment. However, Jeppsson (1972, fig. 5) showed that each dентicle has its own basal cavity tip so it is likely that the Pa elements formerly referred to *P. dubius* and *C. dentatus* grew in the same way. Van den Boogaard (1990) observed that the *Pelekysgnathus* Pa element described from the Upper Devonian (Thomas 1949) has a posterior cusp and only the one dентicle to the posterior of the cusp has a basal pit. As all the denticles of the Pa element of *C. dubius* have their own basal pits, *C. dubius* should be assigned to the genus *Coryssognathus* rather than *Pelekygnathus*.

The suite of elements assigned by Jeppsson (1972) to *Distomodus dubius* does not include a Pa element. The Pa elements formerly identified as *Coryssognathus dentatus* and *Pelekygnathus dubius* have been suggested by van den Bogaard (1990) and Aldridge (1975), respectively, as possible Pa elements for this apparatus. Collections from the Upper Whitcliffe Formation from the Welsh Borderland (Fig. 2.6) support this contention as the Pa element commonly occurs associated with the *D. dubius* suite but never without. Based on all the evidence including that from the Welsh Borderland, *D. dubius* and *C. dubius* are considered to be from a single apparatus, and thus are synonymous.

It is common in conodont faunas for the Pa element to be over-represented (van den Boogaard 1990). However, the Pa of *C. dubius* is always under-represented in Upper Whitcliffe faunas (Fig. 2.6). *C. dubius* has not been reported without associated *D. dubius* elements, although Jeppsson (1979) noted that in Sklinia, *C. dubius* is restricted to a much shorter interval than *D. dubius* and, when present, is under-represented and of a much more juvenile growth stage. Merrill & Powell (1980) recovered conodont faunas from the Pennsylvanian Drum Limestone from the Kansas City area which showed a similar minimum representation of Pa elements and suggested that juvenile Pa elements could be less well developed during early stages of ontogeny. A similar pattern has been observed by Aldridge (1975, p. 615) through the Upper Bringewood to Upper Whitcliffe formations, where rare earlier specimens are "small, fragile and commonly only have a single dентicle in addition to the cusp". Van den Boogaard (1990) suggested that this could be because the simple coniform elements had not yet fused into multi-denticulate elements or the fragile juveniles had been broken sometime post-mortality. From my experience of handling juvenile *C. dubius* Pa
elements, they are easily broken. Faunas from the Welsh Borderland with most simple coniform elements are also under-represented by Pa elements (Fig. 2.6). These large collections of coniforms include some elements morphologically similar to juvenile Pa elements of *C. dubius* (Fig. 2.7). Juvenile Pa elements were therefore broken during deposition or laboratory processing and their dissociated denticles have been counted as simple coniforms.

For a more detailed analysis of the apparatus composition of *C. dubius*, nine samples have been selected which yielded a large, well preserved collection of over 100 elements, with a wide size distribution. These samples are the least likely to have been affected by sorting and abrasion, although all samples will have been transported to some degree in the subtidal storm depositional environment of the Upper Whitcliffe Formation. The samples show a roughly constant proportion of Pa elements to other elements and a similar relative proportion of individual elements (Fig. 2.10). Totals from all samples (Fig. 2.6) also show similar relative proportions between elements.

Figures 2.6 and 2.10 show a dominance of Pb/Pc elements and Sc elements for each sample. This abundance suggests a double set of Pb/Pc elements, a Pb and accompanying morphologically more complex Pc element. This group of three P elements (Pa, Pb, and Pc) is a similar arrangement to the apparatuses of *Pterosphathodus amorphognathoides*, *Pranognathus tenuis* (see Männik & Aldridge 1989) and *Promissum pulchrum* (Theron et al. 1990). The low abundance of A, B and C morphotypes of the Sa/Sb element (Fig. 2.6) suggests that they should be grouped together as one morphologically plastic Sa/Sb element varying from nearly symmetrical to twisted and somewhat asymmetrical, and a separate distinctly asymmetrical Sb element. This is again similar to the *Pterospathodus* apparatus. The consistently high abundance of Sc elements (Figs 2.6, 2.10) suggests the apparatus contains a double set of identical Sc elements. In the absence of bedding plane assemblages or clusters, the reconstructed apparatus of *C. dubius* is illustrated in Figure 2.11. For this reconstruction the M elements (associated with the ramiforms in an *Ozarkodina* type apparatus) have been placed with the Pb/Pc elements as this is a similar arrangement to the morphologically similar apparatus of *Promissum pulchrum* (Theron et al. 1990).

Coniform elements vary greatly in frequency (Fig. 2.6). It was suggested by Jeppsson (1972) and later shown by van den Boogaard (1990) that elements of the apparatus incorporated these cones during ontogeny to become increasingly more denticulate. This could
Fig. 2.10. Relative proportions of *C. dubius* elements in 9 selected samples.
Fig. 2.11. Schematic reconstruction of the apparatus plan of *C. dubius* (not to scale).
explain morphological variations in Pc and Sc elements in particular, and also the differing proportions of coniform elements present in each sample. Pc elements show separate denticles each with their own basal pit, incorporated by later lamellae (Pl. 5, figs 9, 11) and some Sc elements show the suture between the cone and the base of the cusp (Pl. 7, fig. 2) suggesting that they were incorporated at a later stage of growth. The cones are neither too large nor too small to have been part of a multidenticulate element of the apparatus. The discrete cones were therefore either broken off after incorporation into multidenticulate elements or represent simple cones not yet incorporated into a multidenticulate element.

The Sc element of Coryssognathus dubius was originally figured by Rhodes (1953) as Cordyodus? dubius. The apparatus of Cordyodus however, is bimembrate and the genus confined to the Lower Ordovician (Sweet 1988). The genera Distomodus Branson & Branson 1947, Rotundacodina Carls & Gandl, 1969, Dentacodina Wang, 1980, and Pelekygnathus Thomas, 1949, all include elements similar to those in the apparatus of C. dubius. As discussed earlier, Pelekygnathus can be discounted. For similar reasons Distomodus can also be discounted as the Pa element cannot be shown to have grown by successive incorporation of coniform elements, although there are similarities in the apparatus, particularly in the Sa/Sb and Sc elements. The genera Rotundacodina Carls & Gandl, 1969 and Dentacodina Wang, 1980 appear to be defined on the basis of an Sc element and could both therefore, be part of Pelekygnathus apparatuses. The senior subjective synonym Astacoderma spinosum has been suppressed (Jeppsson & Aldridge 1988), so the correct binomen is Coryssognathus dubius (Rhodes 1953).

Similar elements have been found by: Mabillard and Aldridge (1983) from the Coralliferous Group (Llandovery-Wenlock) of Marloes Bay, S.W Wales, Klapper & Murphy (1974) from the Upper Silurian-Lower Devonian of the Roberts Mountains, Central Nevada, Nicoll (1982) from the Upper Devonian of the Canning Basin, W. Australia, and Savage (1973) from the Lower Devonian of New South Wales. The apparatus described by Mabillard & Aldridge (1983) as Rotundacodina aff. R. dubia is very similar to C. dubius. These elements are possibly part of an early prioniodontid type apparatus, although a Pa element has not been recognised. It is possible that the seximembrate apparatuses of Icriodus as described by Nicoll (1982) and Serpagli (1983) are direct phylogenetic descendants from Coryssognathus as there are obvious similarities in the morphology of the Sc elements and the symmetry transition series.
proposed by Serpagli (1983, fig. 6). Similarly, the genus *Pelekysgnathus*, particularly the species *P. index* (Klapper & Murphy 1974, pl. 12, figs 1-3), shows similar elements to Pb/Pc elements of *C. dubius* and is a possible descendant.

Family: *Spathognathodontidae* Hass, 1959
Genus: *Ozarkodina* Branson & Mehl, 1933

*Ozarkodina confluens* (Branson & Mehl, 1933)
(Pl. 8, figs 1-11; text-fig. 2.12)

1861 *Astacoderma serratum* Harley: 546, 550, pl. 17, fig. 15 (Pa).
1933 *Prioniodus bicurvatus* Branson & Mehl: 44, pl. 3, figs 9-12 (M).
1933 *Hindeodella confluens* Branson & Mehl: 45, pl. 3, figs 22, 23 (Sc).
1933 *Spathodus primus* Branson & Mehl: 46, pl. 3, figs 25-30 (Pa).
1933 *Plectospathodus flexuosus* Branson & Mehl: 47, pl. 3, figs 31, 32 (Sb).
1933 *Trichognathus symmetrica* Branson & Mehl: 50, pl. 3, 33, 34 (Sa).
1933 *Ozarkodina typica* Branson & Mehl: 51, pl. 3, 43-45 (Pb).
1953 *Plectospathodus contrarius* Rhodes: 322, pl. 23, 225, 247, 249, 250 (Sc).
1953 *Plectospathodus elegans* Rhodes: 323, pl. 23, figs 255, 263, 264 (Sb).
1969 *Hindeodella confluens* Branson & Mehl; Jeppsson: 15-18, figs 1A-F, 2 (whole apparatus).

For more complete pre-1974 synonymy see Jeppsson (1974, p. 31-32) and include;
1971 *Ozarkodina typica* Branson & Mehl; Saladzius: pl. 1, figs 5a, b (Pb).
1971 *Spathognathodus primus* (Branson & Mehl); Saladzius: pl. 1, figs 6-7 (Pa)
1971 *Trichonodella excavata* Branson & Mehl; Barnett: pl. 37, fig. 15 (Sa).
1971 *Ozarkodina media* Walliser; Spasov: pl. 1, fig. 8 (Pb).
1971 *Trichonodella symmetrica* (Branson & Mehl); Spasov: pl. 2, fig. 5 (Sa).
1971 *Trichonodella sp. n.* Spasov: pl. 2, fig. 6 (Sa).
1971 *Spathognathodus primus* (Branson & Mehl); Spasov: pl. 2, figs 16-18 (Pa).
1974 *Spathognathodus primus* (Branson & Mehl); Feist & Schönlaub: pl. 7, fig. 1 (Pa).
1974 *Ozarkodina confluens* (Branson & Mehl); Klapper & Murphy: 30-33, pl. 3; pl. 4, figs 1-9, 11-27 (whole apparatus).
1975 *Ozarkodina confluens* (Branson & Mehl); Aldridge: pl. 2, figs 1-6 (whole apparatus).

1975 *Spathognathodus primus primus* (Branson & Mehl); Helfrich: pl. 2, figs 2, 5, 8, 9; pl. 3, figs 1-12; pl. 11, fig. 11 (Pa).

1975 *Ozarkodina typica typica* (Branson & Mehl); Helfrich: pl. 4, figs 6, 7, 13, 14, 17, 18; pl. 7, figs 30, 31, but not 32 (Pb).

1975 *Hindeodella confluens* (Branson & Mehl); Telford: 36, pl. 11, fig. 13 (Pb).

1975 *Trichonodella symmetrica* (Branson & Mehl); Mehrtens & Barnett: pl. 1, fig. 6 (Sa).

1977 *Ozarkodina confluens* (Branson & Mehl); Pickett: pi. 1, figs 1-9 (whole apparatus).

1978 *Ozarkodina confluens* (Branson & Mehl); Helfrich: pl. 1, fig. 3 (Pa).

1978 *Ozarkodina confluens* (Branson & Mehl); Rexroad et al.: 7, pl. 1, figs 11-16 (whole apparatus).

1980 *Ozarkodina typica* Branson & Mehl; Wang: 372-373, pl. 1, fig. 26 (Pb).

1980 *Ozarkodina confluens* (Branson & Mehl); Uyeno: 40, pl. 1, figs 1-18, 31, 32 (whole apparatus).

1982 *Ozarkodina confluens* (Branson & Mehl); Viira: pl. 10, figs 13, 14, 16, 17, 19 (Pa, Pb, M, Sb, Sc).
1983 *Ozarkodina confluens* (Branson & Mehl); Barrick: fig. 18.H (Pa).

1983 *Ozarkodina confluens* (Branson & Mehl); Harris *et al.*: pl. 1, fig. A (Pa).

1983 *Spathognathodus primus* (Branson & Mehl); Viira: 51, pl. 1, figs 1, 2 (Pa).

1983 *Spathognathodus primus cornidentatus* Viira: 55-58, pl. 3, figs 1-10, pl. 4, figs 1-6, 8, text-figs 9, 10 (Pa).

1983 *Ozarkodina typica* Branson & Mehl; Viira: pi. 5, figs 5-8 (Pa).

1984 *Ozarkodina confluens* (Branson & Mehl); Kozur: pi. 5, fig. 7 (Pa).

1984 *Ozarkodina confluens* (Branson & Mehl); Balogh & Kozur: pi. 3, fig. 1 (Pa).

1985 *Ozarkodina confluens* (Branson & Mehl); Aldridge: pl. 3.4, fig. 1 (Pa).

1989 *Ozarkodina confluens* (Branson & Mehl); Jeppsson: 27, fig. 1 (Pa).

1989 *Ozarkodina confluens* (Branson & Mehl); Siveter *et al.*: pl. 3, fig. 16 (Pa).

1990 *Ozarkodina confluens* Branson & Mehl; van den Boogaard: 11, pl. 6, fig. 1 (Pa).

**Diagnosis.** Jeppsson 1974, p. 34.

**Lectotype.** University of Missouri, No. UMC C157-3 (Sc element). Originally figured by Branson & Mehl, 1933, pl. 3, fig. 23, selected and refigured by Rexroad & Craig, 1971, pl. 79, fig. 22.

**Material.** (Fig. 2.12) 3,336 elements (1,571 Pa, 503 Pb, 370 M, 146 Sa, 432 Sb and 314 Sc).

**Locality and horizon.** Cosmopolitan species characteristic of Upper Whitcliffe Formation (and lateral equivalents), occasionally found in lowermost Downton Castle Sandstone Formation of the Welsh Borderland (Fig. 2.12).

**Discussion.** The apparatus of *O. confluens* is well known and has been fully described by Walliser (1964) and Jeppsson (1969, 1974). Welsh Borderland material from the Upper Whitcliffe Formation shows similarly variable Pa and most notably variable Sb elements, but subspecies determinations have been impossible using variations in denticle fusion and morphology of the high anterior end of Pa elements, as suggested by Jeppsson (1974, p. 34).

It is possible that these conodonts belonged to a distinct and little varying population that was confined to the Welsh Basin during deposition of the Upper Whitcliffe Formation.
**Ozarkodina confluens**

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<td>503</td>
<td>377</td>
<td>146</td>
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<td>316</td>
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Fig. 2.12. Frequencies of *O. confluens* elements from the Upper Whitchiffe and lowermost Downton Castle Sandstone formations (and their lateral equivalents) of Wales and the Welsh Borderland.
stratigraphic range of *O. confluens* in Great Britain has also been shown to extend as low as the Scheinwoodian Stage of the Wenlock Series (Aldridge 1985).

**Ozarkodina crispa** (Walliser, 1964)

(Pl. 9, figs 1-6; text-figs 2.13 - 2.15)

1964 *Spathognathodus crispus* Walliser: 74-75, pl. 21, figs 7-13 (Pa).

1969 *Spathognathodus crispus* Walliser; Fähnle: pl. 2, figs 13, 14 (Pa).

1971 *Spathognathodus crispus* Walliser; Bultynck & Peltane: pl. 1, figs 19, 20 (Pa).

1974 *Spathognathodus crispus* Walliser; Feist & Schönlaub: pl. 7, figs 8, 9, 11, 12, 14, 15 (Pa).

1974 *Ozarkodina crispa* (Walliser); Klapper & Murphy: 33, pl. 8, fig. 10 (Pa).

1975 *Spathognathodus crispus* Walliser; Helfrich: pl. 14, figs 1-4, 9, 14, 19 (Pa).

1976 *Spathognathodus crispus* Walliser; De Deckker: figs 4.11, 4.13 (Pa).

1977 *Ozarkodina crispa* (Walliser); Cooper: 188, pl. 16, figs 16, 17 (Pa).


1980 *Ozarkodina crispa* (Walliser); Schönlaub: pl. 17, figs 11, 12, 14, 15; pl. 25, figs 12-15, text-fig. 4 (Pa).

1984 *Ozarkodina crispa* (Walliser); Kozur: pl. 4, fig. 4 (Pa).

1984 *Ozarkodina crispa* (Walliser); Balogh & Kozur: pl. 3, fig. 3 (Pa).

1989 *Ozarkodina crispa* (Walliser); Walliser & Wang: 114-116, pl. 1, figs 1-16, text-fig. 1 (Pa).

**Diagnosis.** (After emended diagnosis of Walliser & Wang 1989, p. 114) Pa element with asymmetrical, broadly expanded basal cavity, oral margin of blade straight over entire length, or higher at anterior, with or without middle furrow above cavity, which extends either to posterior of distinctly curved margin, or just to anterior of posterior margin.

**Holotype.** Geologisch-Paläontologische Institut, Phillips-Universität, Marburg/Lahn, FRG., No. Wa 785/3. Figured by Walliser, 1964, pl. 21, fig. 12.

**Material.** 7 Pa elements (2 *O. crispa* and 5 *O. cf. crispa*).
<table>
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<tr>
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<td>M</td>
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<tr>
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<td>M</td>
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<td>G. r. sp.</td>
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Fig. 2.33. Frequencies of elements from the O. melitensis genome library: the nonessential plasmid and from the apparatus of O. melitensis virulence. A = Fig. 2.33a (p. 34, fig. 10). Specimens in brackets were recovered by reverse plating of impressions.
Fig. 2.14. Stratigraphic distribution and frequency of Pa elements of *O. snajdri* and *O. crispa* from the Upper Whitclifffe Formation and its lateral equivalents in the Welsh Borderland. Approximate stratigraphic position is measured from the top of the Upper Whitclifffe Formation which is marked by the base of the Ludlow Bone Bed at Ludlow and approximately equivalent bone beds at other localities.

<table>
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<tr>
<th>Sample</th>
<th>Approximate stratigraphical position (m) below top of Upper Whitclifffe Fm.</th>
<th><em>O. snajdri</em></th>
<th><em>O. crispa</em></th>
<th><em>O. cf. snajdri</em></th>
<th><em>O. cf. crispa</em></th>
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Fig. 2.15. Camera lucida drawings of Pa elements of *O. snajdri* and *O. crispa* showing the similarity in morphology and possible intermediate forms in the *snajdri-crispa* lineage.
Localities and horizons. Upper Perton Beds (162/2*), Perton (loc. 24a); Whitcliffe Formation (31b/7), Tite's Point (loc. 31b). See Figures 2.13 and 2.14 for stratigraphic ranges including material identified as *O. cf. crispa*.

Description. Pa element (Fig. 2.15) with no cusp and distinctive concave termination to posterior margin. Thin furrow present towards posterior termination, denticles fused at posterior above cavity, becoming less fused towards anterior with process either ending abruptly or curving away suddenly as final three denticles decrease rapidly in size. Cavity extends to posterior margin and is more widely flared in circular shape on one side of blade than other (Pl. 9, figs 2, 4, 6). On less flared side, main area of cavity extends further to anterior and tapers off much less abruptly with cavity finally terminating half way along free blade. White matter present as individual bars beneath denticles on free blade extending to posterior margin becoming thickest over widest part of cavity.

Remarks. The two elements figured as *O. crispa* (Pl. 9, figs 1-6) correspond to the alpha-morphotype of Walliser & Wang (1989). Some elements show similar morphologies to *O. crispa* and have been described as *O. cf. crispa* (Pl. 9, figs 7-13, 16). These include elements with a row of denticles instead of a furrow or ridge at the posterior margin, and elements with no distinctive curved posterior termination (Fig. 2.15) These are likely to be intermediates between *O. snajdri* and *O. crispa*. It has been suggested (Aldridge & Schonlaub 1989) that *O. crispa* is a direct phylogenetic descendant of *O. snajdri* as it follows *O. snajdri* stratigraphically. The distribution of the two species in the Welsh Borderland (Fig. 2.14) suggests that *O. crispa* is descended from *O. snajdri*, which ranges through the entire Ludfordian and just into the Gorstian of the British Isles (Aldridge 1985). There is not a simple stratigraphic replacement of *O. snajdri* by *O. crispa* (Fig. 2.14), as the two species probably co-existed for some time in the Welsh Basin along with a number of intermediate forms on the same phylogenetic lineage. There is no gradual transition from *O. snajdri* to *O. crispa* as intermediate forms occur stratigraphically higher than the first occurrence of *O. crispa* (Fig. 2.14).
Ozarkodina excavata  Branson & Mehl, 1933
(Pl. 8, figs 12-24; text-figs 2.16, 2.17)

1933 Prionodus excavatus  Branson & Mehl: 45, pl. 3, figs 7, 8 (M).
1933 Trichognathus excavata  Branson & Mehl: 51, pl. 3, figs 35, 36 (Sa).
1933 Ozarkodina simplex  Branson & Mehl: 52, pl. 3, figs 46, 47 (Pb).
1953 Hindeodella equidentata  Rhodes: 303, pl. 23, 248, 252-254 (Sc).
1953 Trichonodella aboraflexa  Rhodes: 312, pl. 23, figs 231, 241, 242 (Sa).
1953 Plectospathodus extensus  Rhodes: 323, pl. 23, 236-240 (Sb).
1953 Ozarkodina sp. Rhodes: pl. 23, fig. 244 (Pb).
1969 Hindeodella excavata  (Branson & Mehl); Jeppsson: 18-20, figs 1G-L, 2 (whole apparatus).

For more complete synonymy see Jeppsson (1974, p. 25-26) and include:
1968 Trichonodella excavata  (Branson & Mehl); Nicoll & Rexroad: 63, pl. 4, fig. 2 (Sa).
1969 Plectospathodus sp.; Hill et al.: s16, pl. 8, fig. 2 (Sc).
1969 Neoprionodon sp. cf. latidentatus  Walliser; Hill et al.: s16, pl. 8, fig. 5 (M).
1971 Neoprioniodus excavata  (Branson & Mehl); Spasov: pl. 1, figs 5, 6 (M).
1971 Hindeodella sequidentata  Rhodes; Spasov: pl. 1, fig. 13 (Sc).
1971 Ozarkodina media  Walliser; Spasov: pl. 1, fig. 19 (Pb).
1971 Trichonodella excavata  (Branson & Mehl); Spasov: pl. 2, figs 8, 9 (Sa).
1971 Spathognathodus inclinatus inclinatus  (Rhodes); Spasov: pl. 3, figs 13, 14 (Pa).
1971 Plectospathodus extensus  (Branson & Mehl); Spasov: pl. 2, figs 12, 15 (Sb).
1972 Ozarkodina media  Walliser; Link & Druce: 65, pl. 6, figs 14, 15 (Pb), but not figs 11, 12.
1974 Hindeodella excavata  (Branson & Mehl); Jeppsson: pl. 4 (whole apparatus).
1975 Ozarkodina excavata  (Branson & Mehl); Aldridge: pl. 2, figs 9-14 (whole apparatus).
1975 Plectospathodus extensus  Rhodes; Helfrich: pl. 7, figs 4, 7, 9, 10, 14, 16, 20, 27 (Sb).
1975 Trichonodella excavata  (Branson & Mehl); Helfrich: pl. 8, figs 1, 4, 5, 7, 9, 10, 14, 17, 23-25, 27, 28, 30, 31 (Sa).
1975 *Hindeodella equidentata* Rhodes; Helfrich: pl. 10, figs 16, 22 (Sc).
1975 *Ozarkodina sinuosa* Helfrich: pl. 16, figs 22, 25, 28 (Pb).
1975 *Trichonodella excavata* (Branson & Mehl); 75, pl. 16, figs 1-3 (Sa).
1976 *Ozarkodina excavata excavata* (Branson & Mehl); Barrick & Klapper; 78-79, pl. 3, figs 14-19, 21, 22, 26 (Pb, M, Sa, Sb, Sc).
1976 *Spathognathodus inclinatus inclinatus* Rhodes; De Deckker: figs 4.1-4.8 (Pa).
1976 *Hindeodella priscilla* Stauffer; De Deckker: fig. 4.17 (Sc).
1976 *Ozarkodina media* Walliser; De Deckker: fig. 4.18 (Pb).
1976 *Hindeodella equidentata* Rhodes; De Deckker: fig. 4.19, not fig. 4.16 (Sc).
1977 *Ozarkodina excavata* (Branson & Mehl); Mehtens & Barnett: 497, pl. 1, figs 11, 12, 14, 18, 21 (Sb, Sa, Pa, Sa, Pb).
1977 *Ozarkodina excavata* (Branson & Mehl); Cooper: 188, pl. 16, figs 8-15 (whole apparatus).
1978 *Ozarkodina excavata* (Branson & Mehl); Helfrich: pl. 2, figs 1-7 (Sa, Sb, M, Sc).
1978 *Ozarkodina excavata excavata* (Branson & Mehl); Rexroad *et al.*: 9-10, pl. 1, figs 17-22 (whole apparatus).
1979 *Hindeodella excavata* (Branson & Mehl); Jeppson: fig. 10A (Pa).
1980 *Ozarkodina excavata excavata* (Branson & Mehl); Uyeno: 41, pl. 2, figs 6-13, 17 (whole apparatus).
1982 *Hindeodella equidentata* Branson & Mehl; Degardin & Lethiers: 336-338, pl. 1, fig. 1 (Sc).
1982 *Neoprioniodus excavatus* (Branson & Mehl); Degardin & Lethiers: 339, 342, pl. 1, fig. 4 (M).
1982 *Neoprioniodus multiformis* Walliser; Degardin & Lethiers: 342, pl. 1, fig. 5 (M).
1982 *Ozarkodina media* Walliser; Degardin & Lethiers: 342-343, pl. 1, fig. 6 (Pb).
1982 *Plectospathodus extensus* Rhodes; Degardin & Lethiers: 344-345, pl. 1, fig. 9 (Sb).
1982 *Ozarkodina excavata* (Branson & Mehl); Viira: pl. 10, figs 10-12, 15, 18 (M, Sa, Pb, Sb).
1983 *Ozarkodina excavata* (Branson & Mehl); Mabillard & Aldridge: pl. 3, figs 1-6 (whole apparatus).
1985 *Ozarkodina excavata excavata* (Branson & Mehl); Wang: 155, pl. 1, figs 10, 11, 15 (M, Sc, Sb); pl. 2, figs 24, 25 (Sc, Pb).

1986 *Hindeodella priscilla* Stauffer; Wang & Li: 423, pi. 2, fig. 1 (Sc).

1989 *Hindeodella excavata* (Branson & Mehl); Walliser & Wang: pl. 1, figs 19-24 (whole apparatus).

1989 *Hindeodella equidentata* Rhodes; Walliser & Wang: pl. 2, figs 6, 9 (Sc).

1989 *Ozarkodina excavata* (Branson & Mehl); Walliser & Wang: pl. 2, figs 32-37 (whole apparatus).

1989 *Ozarkodina excavata* (Branson & Mehl); Jeppsson: 27, pi. 3, figs 6-8 (Pa, Sb, M).

**Neotype.** Indiana University/Indiana Geological Survey, No. 13151 (M element). Collected, assigned and figured by Rexroad & Craig, 1971, pi. 80, fig. 7.

**Diagnosis.** Jeppsson 1974, p. 29.

**Material.** (Fig. 2.16) 9,880 elements (1,832 Pa, 1,218 Pb, 1,669 M, 838 Sa, 1,772 Sb and 2,551 Sc elements).

**Localities and horizons.** Cosmopolitan species characteristic of Upper Whitcliffe Formation (and lateral equivalents) of Wales and the Welsh Borderland (Fig. 2.16). Platyschisma Shale Member, Downton Castle Sandstone Formation, Downton (14b/3, 14c); Rushall Beds (24b/2), Prior’s Frome (loc. 24b); Long Quarry Formation (241/1*), Llandovery (loc. 43).

**Remarks.** Pa elements of *O. excavata* recovered from the Upper Whitcliffe of the Welsh Borderland show a wide range of morphologies (Fig. 2.17). Variables include degree to which cavity lips are developed, regularity/irregularity in denticle size and development of white matter bars beneath denticles. Generally the Pa elements have short processes, slender cavities (occasional well developed lips), even denticulation, and slightly arched aboral margin, but never well developed ledges parallel with the base of the denticles. The other elements in the apparatus show very little variation. Jeppsson (1974, p. 29) recognised a subspecies, *O. excavata excavata* based on elements with "short processes, without regularly alternating denticles, Pa elements with a small basal cavity and small basal cavity lips." This is a similar morphology to the Welsh Borderland material (Fig. 2.17), but denticulation is occasionally uneven, and the basal cavity lips are developed to a variable extent. The apparatus of *O. excavata* from the Welsh Borderland is distinct from specimens figured as *O. excavata excavata*.
<table>
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<td>1218</td>
<td>1669</td>
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Fig. 2.16. Frequencies of *O. excavata* elements from the Upper Whitcliffe and lowermost Downton Castle Sandstone formations (and their lateral equivalents) of Wales and the Welsh Borderland.
Fig. 2.17. Camera lucida drawings showing variation of the Pa element of *Ozarkodina excavata* from the Upper Whitcliffe Formation and its lateral equivalents across the Welsh Borderland.
by Klapper & Murphy (1974, pl. 6), Barrick & Klapper (1976), Bischoff (1986, pl. 26), and Sorentino (1989, pl. 1), which have much more crowded and slender denticles, longer processes and a prominent step parallel to the base of the denticles. The subspecies O. excavata hamata (Walliser 1964), O. e. inflata (Walliser 1964) and O. e. wurmi (Bischoff & Sannemann 1958), are also distinct as they possess longer processes and a step like ridge parallel to the base of the denticles. O. e. wurmi has characteristically long processes, often reaching 2mm in length (Jeppsson 1974). Similar to O. confluens from the Upper Whitcliffe Formation of the Welsh Borderland, it is possible that O. excavata belongs to an isolated, restricted and slightly variable population that existed during Upper Whitcliffe times.

Ozarkodina remscheidensis baccata ssp. nov.

(Pl. 10, figs 1-6; text-fig. 2.18)

1985 Ozarkodina remscheidensis subsp. nov. Aldridge: 90, pl. 3.4, fig. 17 (Pa).

Derivation of name. Subspecies named baccata (Latin=yew tree) as first specimens were collected from an exposure in the car park of the Yew Tree Inn Prior’s Frome, near Hereford (loc. 24).

Diagnosis. "Pa element with straight compact blade bearing irregular mostly broad denticles; cusp inconspicuous, cavity at midlength with broadly flared lips " (Aldridge 1985, p. 90).

Holotype. Natural History Museum, No. PM X 1156 (Pa). Holotype figured in Pl. 10, figs 1, 4. Original Pa element figured by Aldridge (1985, pl. 3.4, fig. 17), now lost.

Material. (Fig. 2.13) 27 elements (15 Pa elements of O. r. baccata and 12 Pa elements of O. r. cf. baccata).

Localities and horizons. Holotype 2m below top of Whitcliffe Formation (39/1*), Aston Munslow, Corve Dale (loc. 7a); Upper Whitcliffe Formation (sample 15c/2), Whitcliffe Quarry, Ludlow (loc. 15c); Upper Perton Beds (162/2*), Prior’s Frome (loc. 24a).

Description. Pa element (Fig. 2.18) with cusp inconspicuous and just to posterior of cavity. Posterior process with four or five denticles; first two denticles posterior of cusp, similar shape and size to cusp, although one specimen has tiny accessory denticle fused to first denticle posterior to cusp. Third, fourth (and fifth) denticles, when present, become increasingly smaller as process diminishes to three quarters original height, finally terminating with a small step like extension beyond last denticle. Posterior aboral surface slightly concave. Anterior
Ozarkodina remseheidensis baccata
ssp. nov. Pa element

Fig. 2.18. Camera lucida drawings of Pa elements of *O. remseheidensis baccata* ssp. nov. and *O. remseheidensis remseheidensis*. A=Anterior, P=Posterior.
process same length as posterior; four denticles in juvenile specimens and up to six denticles in more mature specimens, denticles of uneven size, crowded close to cusp, becoming slightly more isolate distally. Terminal denticle slightly lower than previous denticle, with anterior margin sloping slightly to anterior and rounded aborally. Anterior process with straight aboral margin and decreases gradually in height. Main area of cavity at mid-length has rounded asymmetrical lips and is markedly flared on one side of element. Shallow cavity extends entire length of element. Pinched aboral extension beneath cusp extends half way to base of cusp. Beneath each denticle white matter bar slopes inwards towards cusp.

### Dimensions.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Length (µm)</th>
<th>Maximum height (µm)</th>
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<tr>
<td>Aldridge (1985, pl. 3.4, fig. 17)</td>
<td>938</td>
<td>375</td>
</tr>
<tr>
<td>PM X 1156 (holotype)</td>
<td>812</td>
<td>334</td>
</tr>
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<td>PM X 1157</td>
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<td>406</td>
</tr>
<tr>
<td>PM X 1258</td>
<td>800</td>
<td>310</td>
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</table>

**Remarks.** *O. r. baccata* is distinct from *O. r. eosteinhornensis* and *O. r. remscheidensis* as it has an asymmetrically flared cavity and broad denticles of relatively even height and breadth. The apparatus of *O. r. baccata* as yet is unknown. It is possible that the associated Pb element is very similar to the Pb element of *O. r. eosteinhornensis*, as this is over-represented with respect to the number of Pa elements of *O. r. eosteinhornensis* (Fig. 2.13). Aldridge (1985, p. 90) suggested that the Pa element "is associated with ramiform elements bearing crowded denticles of alternating size." The M element (Pl. 10, fig. 14) is possibly from the apparatus of *O. r. baccata*.

Until 1974, subspecies similar to *baccata*, for example *eosteinhornensis*, had been treated as subspecies of the form species *Ozarkodina steinhornensis* (Ziegler, 1956). Klapper & Murphy (1974, pp. 39, 40) argued that the appropriate species name should be *remscheidensis* rather than *steinhornensis*. On the basis of the reconstruction of the apparatus of *O. steinhornensis* using bedding plane assemblages (Mashkova 1972), Klapper & Murphy (1974, p. 40) argued that the Sa element in Mashkova’s reconstruction is closer to the apparatus of *O. remscheidensis* (Ziegler, 1960) than the nominate subspecies of *O. steinhornensis*. 

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Ozarkodina renscheidensis eosteinhornensis (Walliser, 1964)

(Pl. 10, figs 7-12)

1964 Spathognathodus steinhornensis eosteinhornensis Walliser: 85-86, 19-25, pl. 20, figs 7-16 (Pa).

1964 Ozarkodina typica denckmanni Ziegler; Walliser: 61, pl. 9, fig. 14; pl. 26, figs 3-11 (Pb). See Walliser (1964, p. 61) for further synonymy of Pb element.

1968 Spathognathodus steinhornensis eosteinhornensis Walliser; Legault: 17-18, pl. 1, figs 1-3 (Pa).

1968 Ozarkodina typica denckmanni Ziegler; Legault: 15-16, pl. 1, figs 5, 6 (Pb).

1969 Spathognathodus inclinatus inclinatus Rhodes; Wolska: 585-586, pl. 2, fig. 15 (Pa).


1969 Spathognathodus steinhornensis eosteinhornensis Walliser; Fähræus: pl. 1, figs 9-11 (Pa).

1971 Spathognathodus eosteinhornensis (Walliser); Saladzis: pl. 1, figs 8, 9, but not 10 (Pa).

1971 Spathognathodus steinhornensis eosteinhornensis Walliser; Bultynck & Pelhate: 195, pl. 1, figs 1-3, 21 (Pa).

1971 Ozarkodina typica denckmanni Ziegler; Bultynck & Pelhate: 194, pl. 1, fig. 8 (Pb).

1971 Spathognathodus eosteinhornensis (Walliser); Rexroad & Craig: 700, pl. 82, figs 18, 19 (Pa).

1971 Ozarkodina typica denckmanni Ziegler; Spasov: pl. 1, fig. 15 (Pb).

1971 Spathognathodus steinhornensis eosteinhornensis Walliser; Spasov: pl. 1, figs 18, 20, 21 (Pa).

1972 Ozarkodina steinhornensis eosteinhornensis Walliser; Mashkova: 83, pl. 2, figs 25-30 (whole apparatus) with synonymy to 1972.

1972 Ozarkodina denckmanni Walliser; Link & Druce: 62-63, pl. 6, figs 4, 9, text-fig. 36 (Pb) with synonymy to 1972.

1973 Ozarkodina typica denckmanni Ziegler; Savage: 322-323, pl. 33, figs 1, 7-10, text-fig. 17 (Pb).
1974 *Spathognathodus steinhornensis eosteinhornensis* Walliser; Feist & Schönlaub: pl. 7, fig. 5 (Pa).

1974 *Ozarkodina remscheidensis eosteinhornensis* (Walliser); Klapper & Murphy: 41-43, pl. 7, figs 12, 13, 16-19, 23, 24 (Pa).

1975 *Ozarkodina steinhornensis eosteinhornensis* (Walliser); Aldridge: pl. 2, figs 23, 24 (Pa, Pb).

1975 *Spathognathodus steinhornensis eosteinhornensis* Walliser; Helfrich: pl. 11, figs 1-10, 12-16 (Pa).

1975 *Ozarkodina denckmanni* Ziegler; Telford: pl. 11, figs 5-9 (Pb).

1976 *Spathognathodus eosteinhornensis* (Walliser); Telford: 56, 58, pl. 12, figs 9-11 (Pa).

1976 *Spathognathodus steinhornensis eosteinhornensis* Walliser; Ebner: 292, pl. 4, 5-10; pl. 5, figs 1, 2 (Pa).

1977 *Spathognathodus steinhornensis eosteinhornensis* Walliser; Mehrten & Barnett: 497, pl. 1, figs 13, 16 (Pa).

1976 *Ozarkodina typica typica* Ziegler; Ebner: 289, pl. 4, fig. 11 (Pb).

1978 *Ozarkodina steinhornensis eosteinhornensis* (Walliser); Helfrich: pl. 1, figs 4-38 (Pa).

1980 *Ozarkodina remscheidensis eosteinhornensis* (Walliser); Schönlaub: pl. 17, figs 16-19; pl. 25, figs 16-18 (Pa).

1982 *Ozarkodina typica denckmanni* Ziegler; Degardin & Lethiers: 343-344, pl. 1, fig. 7 (Pb).

1982 *Spathodus steinhornensis eosteinhornensis* (Walliser); Degardin & Lethiers: 346-347, pl. 1, fig. 12 (Pa).

1983 *Ozarkodina remscheidensis eosteinhornensis* (Walliser); Harris *et al.*: pl. 1, figs B, C, J-P (Pa, Pb), pl. 2, figs J, K (Pa).

1984 *Spathognathodus steinhornensis eosteinhornensis* Walliser; Wang & Li: 425, pl. 2, figs 2,3 (Pa).

1985 *Ozarkodina remscheidensis eosteinhornensis* (Walliser); Aldridge: 90, pl. 3, fig. 20 (Pa).

1986 *Ozarkodina remscheidensis eosteinhornensis* (Walliser); Bultynck: 202, pl. 37, figs 12, 19-21 (Pa).

1989 *Ozarkodina steinhornensis eosteinhornensis* Walliser; Jeppsson: 28, pl. 2, fig. 4 (Pa).

Diagnosis. Aldridge, 1985, p. 90.

Material. 34 elements (3 Pa, 25 Pb O. r. eosteinhornensis and 6 Pa elements of O. r. cf. eosteinhornensis).

Localities and horizons. Whitcliffe Formation (8/1), Diddlebury, Corve Dale (loc. 8); Upper Whitcliffe Formation (18/1), Ludford Corner, Ludlow (loc. 18); Ludlow Bone Bed Member, Downton Castle Sandstone Formation, Ludford Corner, Ludlow (Walliser 1966); Platyschisma Shale Member, Downton Castle Sandstone Formation (14c), Downton (loc. 14c).

Description. Pa element of uneven denticulation with cavity and indistinct cusp slightly to posterior of mid-length. Cusp triangular, posterior edge sloping at 60-70°, anterior edge at 45°. Both processes lenticular in section with distinct thickened area extending entire length of element, parallel with oral margin, at a level confluent with the uppermost extension of the cavity. Posterior process decreases slightly in height distally, either the second or third denticle from cusp dominant, terminal two denticles more isolate than previous denticles, slightly concave oral margin. Anterior process of constant height, longer than posterior, five fused denticles of roughly similar proportion, just to anterior of cusp, terminal two denticles larger, broader and more isolate. Termination of anterior process inclined slightly to anterior, rounded postero-oral, straight oral margin. Cavity circular under cusp, drawn out under entire length of both processes, lips pinched and inclined slightly to posterior. White matter bar below each denticle, extending to top of thickened bar, parallel with oral margin. Two denticles either side of cusp have accessory white matter bars between them.

Pb element with cusp strongly inclined to posterior. Angle between processes 150-160°. Anterior process taller than posterior with proximal denticles strongly fused to cusp, denticles becoming more isolate and more erect, distally, with final three denticles rapidly decreasing in size. Posterior process much less tall than anterior, decreasing in height distally, discrete denticles all similar in size and inclination to posterior. Cavity elongate, narrow, tapering distally, extending entire length of both processes. Posteriorly inclined distinct white matter bars beneath each denticle decrease in size distally on anterior process, extending almost to the cavity for entire length of posterior process.
Remarks. Elements similar to *O. denckmanni* have been found in abundance associated with *O. crispa*, *O. snajdri* and *O. r. eosteinhornensis* (Fig. 2.13). It is probable that this Pb element belongs with the apparatus of *O. r. eosteinhornensis* (see Mashkova 1972, pl. 2, fig. 25) rather than *O. crispa* or *O. snajdri*, as *O. denckmanni* is well represented in the *eosteinhornensis* zone and has been recorded in the Emsian (Clark & Ethington 1966), much later than the final occurrences of *O. snajdri* and *O. crispa* which are confined to the Ludlow Series (Aldridge & Schönlaub 1989). Pb elements are over-represented with respect to Pa elements (Fig. 2.13), which probably reflects the fact that Pb elements of conodonts from the *remscheidensis* plexus are morphologically very similar (see Mashkova 1972, pl. 2). With small numbers and poor preservation of material from the Upper Whitcliffe Formation of the Welsh Borderland, these Pb elements are hard to distinguish into subspecies. Jeppsson (1989, pl. 2, figs 1-3) figures Pa elements with lateral processes which have not been found on specimens from the Welsh Borderland. Mashkova (1972) figures elements with alternating denticulation, based on a bedding plane assemblage of *O. steinhornensis* (Ziegler). Only a single well preserved Sb element with alternating denticulation has been recovered from the Whitcliffe Formation, Diddlebury, Corve Dale (loc. 8). This element (described later) is distinct from the Sb element figured by Mashkova (1972, pl. 2, fig. 28) as it has a downwardly directed posterior process.

*Ozarkodina remscheidensis remscheidensis* (Ziegler, 1960)

(Pl. 10, figs 13, 16; text-fig. 2.18)

1960 *Spathognathodus remscheidensis* Ziegler: 194-196, pl. 13, figs 1, 2, 4, 5, 7, 8, 10, 14 (Pa).
1964 *Spathognathodus steinhornensis* ssp. indet. Walliser: pl. 21, figs 3-6 (Pa).
1969 *Spathognathodus inclinatus inclinatus* Rhodes; Wolska: 585-586, pl. 3, figs 6, 7, 12 (Pa).
1969 *Spathognathodus steinhornensis remscheidensis* Ziegler; Fähræus: text-fig. 1 (Pa).
1971 *Spathognathodus remscheidensis* Ziegler; Barnett: pl. 35, fig. 11 (Pa).
1972 *Spathognathodus remscheidensis* Ziegler; Barnett: text-figs 1, 2, 5, 6, 7, 11 (Pa).
1973 *Spathognathodus remscheidensis* Ziegler; Savage: 329, pl. 34, figs 22, 33-36, 39-42, text-fig. 28 (Pa).
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1974 *Spathognathodus steinhornensis remscheidensis* (Walliser); Feist & Schönlaub: pl. 8, fig. 10 (Pa).

1980 *Ozarkodina remscheidensis remscheidensis* (Ziegler); Jaeger & Schönlaub: pl. 4, figs 2-3/16, 8-9/17, 10/20, 13/24 (Pa).

1980 *Ozarkodina remscheidensis remscheidensis* (Ziegler); Uyeno: 41-42, pl. 3, fig. 4 (Pa).

1980 *Ozarkodina remscheidensis remscheidensis* (Ziegler); Schönlaub: pl. 19, fig. 7 (Pa).

1985 *Ozarkodina remscheidensis remscheidensis* (Ziegler); Wang: 155-156, pl. 2, fig. 26 (Pa).

Diagnosis. Ziegler, 1960, p. 64.


Material. 2 Pa elements.

Locality and horizon. Whitcliffe Formation (31b/3), Tite's Point (loc. 31b); Upper Perton Beds (161/1*), Perton (loc. 23b).

Description. Pa element with indistinct cusp, slightly to anterior of cavity. Processes inlined inwards towards cavity and both with uneven denticulation. Proximal denticle on posterior process large and similar to cusp with following three denticles decreasing rapidly in size. Process decreases in height distally, although termination broken in one of specimens available. Posterior and anterior processes thickened parallel to oral margin at level half way between aboral margin and base of denticles. Anterior process longer than posterior, constant height, with first two denticles after cusp, small, followed by a tiny fused denticle with no free blade. Fourth, fifth and sixth denticles larger, more isolate and of roughly similar size and triangular shape. Terminal denticle small, extending to three quarters height of rest of blade. Cavity asymmetrical, more laterally flared on one side and slightly obliquely pinched either side of blade. In lateral view, cavity lips parallel to inclination of posterior aboral margin. Cavity tapers, extending under entire length of anterior process and unbroken part of posterior process. White matter bar beneath each denticle mirrors inward inclination of processes towards cavity. Accessory white matter bars between cusp, first and second denticles on both sides of cusp (Fig. 2.18).
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Remarks. Indistinct cusp, pinched and flared cavity, and uneven denticulation are typical of species from the *O. remscheidensis* plexus. Denticulation and inclination of processes inwards towards the cusp is distinctive of the sub-species *O. r. remscheidensis* (Ziegler 1960).

*O. remscheidensis* ssp.
M element morphotype A

(Pl. 10, fig. 14)

1974 *Hindeodella steinhornensis* ssp. 1. Jeppsson: 43-44, pl. 11, fig. 50.

Material. 3 specimens.

Localities and horizons. Whitcliffe Formation (8/1), Diddlebury, Corve Dale (loc. 8); Upper Perton Beds (160/1*), Perton (loc. 23a).

Description. Short cusp with rounded inner face, flatter outer face, sharp anterior and posterior edges. Anterior process as downward extension of cusp with three strongly fused denticles. Posterior process increases in height distally, denticles nearest cusp, small, pointed, strongly fused, becoming wider and more isolate distally. Specimen broken after sixth denticle on posterior process. Cavity most extensive beneath cusp, tapering gradually to termination of anterior process and present as thin groove under entire preserved part of posterior process.

Remarks. Figured as a subspecies of *O. steinhornensis* by Jeppsson (1974) although alternating denticulation typical of the *remscheidensis* (*steinhornensis*) plexus is absent.

M element morphotype B

(Pl. 10, figs 15, 17)


Material. 14 elements.

Localities and horizons. Whitcliffe Formation, Aston Munslow, Corve Dale (39/1*), Tite's Point (31b/4); Upper Whitcliffe Formation, Whitcliffe Quarry, Ludlow (15c/2), Ludford Lane (77/2*), Ludford Corner (18/1); Upper Perton Beds, Perton Lane (160/1*), Prior's Frome (162/2*).

Description. Cusp lenticular in section with sharp anterior and posterior edges. Anterior process as well developed downwards extension of cusp with two or three denticles strongly fused to base of cusp; angle of 45° between anterior and aboral margins. Posterior process
markedly curved posteriorly, proximal denticles upright and fused, distally becoming more isolated and posteriorly directed. Cavity lips slightly flared below cusp, extending as groove along entire postero-aboral margin, but only to first denticle on anterior process.

Remarks. M element morphotype B occurs commonly associated with *remscheidensis* Pa elements and *O. snajdri* in the Welsh Borderland (Fig. 2.13) but is probably part of a *remscheidensis* type apparatus as a similar element has been figured as part of the apparatus of *Hindeodella steinhornensis scanica* by Jeppsson (1974).

**Sb element.**

(Pl. 10, fig. 18)

Material. Two elements.

Localities and horizon. Whitcliffe Formation, Aston Munslow (39/1*) and Diddlebury (8), Corve Dale.

Description. Cusp lenticular in section, inclined to posterior, posterior edge rounded and anterior edge sharp. Anterior process curved slightly inwards with alternating denticulation; first denticle after cusp with small denticle fused to anterior margin. Similar style of alternating denticulation distally, denticles increasing in size until break in specimen after fourth large denticle. Posterior process curved downwards, increasing in height distally with first denticle, small and fused to base of cusp, followed by two larger denticles. Similar style of denticulation until largest denticle in third group of denticles is almost cusp sized. Element is curved downwards through an angle of approximately 45° at this point. Final two denticles on posterior process half as broad as previous denticles and process terminates at this point with perpendicular postero-oral margin. Cavity inclined to anterior and reflecting cusp cross section; lips flared to a greater extent on inner margin.

Remarks. The element possesses alternating denticulation which is a characteristic of the *remscheidensis* plexus. The element possibly belongs to the apparatus of *O. remscheidensis eosteinhornensis*. However, its posterior process is curved downwards through 45° and is unlike the Sb element figured from the apparatus of *O. r. eosteinhornensis* (Mashkova 1972, pl. 2, fig. 28).
**Ozarkodina snajdri** (Walliser, 1964)

(Pl. 9, figs 14, 15, 17-22; text-figs 2.14, 2.15)

1964 *Spathognathodus snajdri* Walliser; 84, pl. 21, figs 14, 15; pl. 22, figs 1-4 (Pa).

1971 *Spathognathodus snajdri* Walliser; Rexroad & Craig: 700, pl. 82, figs 16, 17 (Pa).


1975 *Spathognathodus crispus* Walliser; Helfrich: pl. 14, figs 21, 24, 27 (Pa).

1976 *Spathognathodus snajdri* Walliser; Ebner: 292, pl. 4, figs 1, 2 (Pa).


1977 *Spathognathodus snajdri* Walliser; Mehrten & Barnett: 497-498, pl. 1, figs 19, 22 (Pa).

1985 *Ozarkodina snajdri* (Walliser); Aldridge: pl. 3.4, fig. 18 (Pa).

1989 *Ozarkodina snajdri* (Walliser); Siveter et al.: pl. 3, fig. 11 (Pa).

**Diagnosis.** Aldridge, 1985, p. 90.

**Holotype.** Geologisch-Palaeontologische Institut, Phillips-Universität, Marburg/Lahn, FRG., No. Wa 868/2 (Pa element). Figured by Walliser 1964, pl. 9, fig. 22, from the Carnic Alps.

**Material.** *O. snajdri* (38 Pa elements), *O. cf. snajdri* (33 Pa elements)

**Localities and Horizons.** Recovered from samples throughout the Upper Whitcliffe Formation (and lateral equivalents) across the Welsh Borderland (Figs 2.13, 2.14).

**Description.** Pa element (Fig. 2.15) with no cusp and discrete upright denticles on anterior blade which become more fused towards posterior. Perpendicular or steeply curved termination of anterior blade with last three denticles on anterior process decreasing rapidly in size, until terminal denticle is approximately half way up blade. Similar curved termination to posterior process. Cavity elongate, extending from posterior margin to approximately two thirds length of element, widening gradually from posterior, reaching maximum width at point on blade where denticles become more discrete, then suddenly tapering off. Cavity asymmetrical, slightly more flared on one lateral side. Anteriormost denticles lack white matter, with best formed denticles on anterior process having well formed white matter bars. White matter most extensive above widest point of cavity in a bar which extends under fused denticles and tapers to posterior.

**Remarks.** *O. snajdri* is thought to be the phylogenetic precursor of *O. crispus* (see discussion for *O. crispus*). Many of the elements recorded in Figure 2.13 as *O. cf. snajdri* are indistinct as
they are incomplete. Unassigned Ozarkodina M element morphotype B is possibly part of the apparatus of *O. snajdri* which has not been reconstructed.

**Ozarkodina wimani** (Jeppsson, 1974)

(Pl. 11, figs 1-12; text-fig. 2.19)

1974 *Ozarkodina* sp. nov. E. Klapper & Murphy: 44-45, pl. 7, figs 6, 9, 10 (Pa).
1974 *Ozarkodina confluens* (Branson & Mehl); Klapper & Murphy: 30-33, pl. 3, fig. 10 (Pa).
1974 *Hindeodella wimani* Jeppsson: 45-46, pl. 12, figs 2-4 (Pa).
1974 *Hindeodella* cf. *wimani* Jeppsson: 46, pl. 12, fig. 1 (Sa).
1985 *Ozarkodina wimani* Jeppsson; Aldridge: 90, pl. 3.4, fig. 19 (Pa).

Diagnosis. Species of *Ozarkodina* in which innermost part of posterior process of Pa element is very low (after Jeppsson 1974, p. 45).

**Holotype.** Department of Historical Geology and Palaeontology, University of Lund, Sweden, No. Lo 4854 (Pa element). Figured by Jeppsson, 1974, pl. 12, fig. 3.

**Material.** (Fig. 2.13) 15 elements (5Pa, 3Sa, and 7 fragments of Pa elements).

**Localities and horizons.** Upper Whitcliffe Formation, Whitcliffe Quarry, Ludlow (74/1*);
Upper Perton Beds, Perton (160/1*, 161/1*), Prior's Frome (162/2*).

**Description.** Pa element with dominant central cusp, posterior edge near vertical, anterior edge sloping approximately 45° towards anterior. Area immediately posterior of cusp low, with small denticle (often broken off in specimens from the Welsh Borderland). Four isolated denticles on posterior process all parallel and inclined to posterior, increasing in size till third denticle is most pronounced. Posterior process increases in height until third denticle from cusp, then decreases in height; termination roughly parallel with inclination of fourth denticle. Anterior process taller than posterior, six to seven denticles more fused with first two denticles small and strongly fused to base of cusp. Process increases slightly in height to fourth denticle which is always broadest of either process with final two denticles near vertical and final denticle often half way down posterior margin which can be either straight or slightly convex. Cavity below cusp, round, shallow, symmetrical, with lateral folds above margin extending half way to base of cusp. Cavity tapers and extends under entire length of both posterior and anterior blades. White matter on both processes slopes gently down to base of cusp where it is
Fig. 2.19. Camera lucida drawings of Pa and Sa elements of *Ozarkodina wimani*. 
most extensive. White matter bars beneath denticles become less extensive distally, often absent beneath the final denticle on the posterior process.

*Sa* element tertiopeate with striated cusp, pointed and curved slightly to posterior, triangular in section with sharp posterior edge extending to posterior process and two sharp lateral edges extending to lateral processes. Posterior process of constant height, discrete alternating denticulation with first denticle fused to base of cusp. Angle between basal margins of straight lateral processes approximately 90°. First denticle on each lateral process small and fused to base of cusp, succeeding denticles increase in size until fifth denticle is largest, with two terminal denticles on each process becoming much smaller. Cavity shallow and triangular at meeting point of three processes but extends entire length of each process. Cusp and each denticle composed of white matter, posterior process containing no white matter in more complete juvenile specimen. Posterior process of fragmentary, more mature specimen has white matter bars beneath each denticle which are all inclined to posterior (Fig. 2.19).

**Remarks.** *Pa* elements of *O. wimani* from the Upper Whitecliff Formation of Welsh Borderland differ from material collected from Gotland and Scania by Jeppsson (1974) in that their aboral margins are straight rather than sloping inwards towards the cavity. The holotype does have a straight aboral margin, unlike the other two specimens figured by Jeppsson (1974, pl. 12, figs 2, 4). In all but one of the Welsh Borderland specimens, their cavities extend under the whole of the element rather than fading "away below the highest points of the processes" (Jeppsson 1974, p. 46). These differences are here taken to be intra-specific. The tertiopeate *Sa* element described above, with a pronounced posterior process, is very similar to Jeppsson (1974, pl. 12, fig. 1).

**Unassigned *Ozarkodina* elements**

*(Pl. 11, figs 13-18)*

**Material.** 8 elements (3 Pb, and 5 M elements).

**Remarks.** These elements occur in very small numbers and are distinct from elements in the apparatus of *O. confluens* or *O. excavata*. They are not sufficiently abundant to test an association with any of the rarer *Pa* elements described here, but probably belong to the apparatus of either *O. crispa*, *O. snajdri*, or *O. wimani*. None of the elements possess alternating denticulation which is a common feature of elements from *remscheidensis* plexus.
apparatuses. However, alternating denticulation is not an essential feature and the elements could also be part of the apparatus of *O. remscheidensis baccata* or a similar *remscheidensis* apparatus.

Pb element morph A

(Pl. 11, fig. 13)

**Material.** Two elements

**Localities and horizons.** Whitcliffe Formation (8), Corve Dale (loc. 8); Upper Whitcliffe Formation (74/1*), Whitcliffe Quarry, Ludlow (loc. 15c).

**Description.** Pb element (Pl. 11, fig. 13) similar to Pb element of *O. confluens* but with a well developed cavity which bridges posterior and anterior processes. Denticles on anterior process all inclined to posterior unlike Pb element of *O. confluens* which has last three denticles inclined slightly to anterior.

Pb element morph B

(Pl. 11, fig. 16)

**Material.** One element.

**Locality and horizon.** Upper Perton Beds (161/1*), Perton Lane (loc. 23b).

**Description.** Element similar to Pb element of *O. confluens*, but with lateral process at inner base of cusp. Weakly developed lateral process extends from ridge which runs along inner lateral face of cusp. Two lateral denticles fused to base of cusp at a level slightly lower than first denticles on anterior and posterior processes. Main part of cavity appears circular, extending a short way below all three processes, although single specimen available is broken and is obscured by basal body. White matter similar to *O. confluens* but including lateral process made entirely from white matter.

**Remarks.** This element occurs in a sample with Pa elements of *O. wimani* and is possibly from the same apparatus which known to contain an Sa element with a well developed posterior process. Klapper & Murphy (1974) figure a similar Pb element belonging to the apparatus of *Ozarkodina* sp. nov. E. The Pa element of *O. sp. nov E* differs from the Pa element of *O. wimani* as its posterior process denticles are more slender and less posteriorly inclined. Jeppsson (1974, p. 46) describes an associated Pb element that might belong to *O. wimani*, but
CHAPTER 2

does not possess a lateral process. It is most likely that this Pb element (morph B) is an aberrant form of a Pb element of O. confluens.

M element morphotype A

(Pl. 11, fig. 17)

Material. Three elements.

Localities and horizons. Upper Perton Beds (161/1*, 24a/2a), Perton Lane (loc. 23b) and Prior's Frome (loc. 24a).

Description. Cusp lenticular in section, rounded on the inner face, flatter on the outer face, only partly preserved in specimens available. Anterior process well developed with four fused denticles decreasing in size as process tapers distally. Posterior process ovoidal in section, pointed and more isolate denticles than anterior process; denticles increase in size distally although specimen broken after fourth denticle. Cavity lips inclined slightly to posterior, tapering off under entire length of anterior process, but twice as wide under portion of posterior process preserved.

M element morphotype B

(Pl. 11, figs 14)

Material. One element.

Locality and horizon. Upper Perton Beds (24a/2a), Prior's Frome (loc. 24a).

Description. Similar to M element of O. confluens but with anterior process with two denticles and a posterior process which increases markedly in height distally.

M element morphotype C

(Pl. 11, figs 15, 18)

Material. One element.

Locality and horizon. Upper Perton Beds (162/2*), Prior's Frome (loc. 24a).

Description. Minor rounded cusp extending just above level of anterior process. Posterior process proximally thin and round in cross section with a row of fused denticles; at level of cavity lips, process becomes flat, increasing in height distally and supporting increasingly taller and broader denticles. Anterior process with one large (broken) denticle followed by smaller denticle. Lateral bulbous extension just below cusp. Circular cavity extending along entire
posterior and anterior processes; basal body below anterior and lateral processes. White matter bars below two denticles on anterior process and lateral bulge below cusp. Initial fused denticles on posterior process have no white matter but later discrete denticles have distinct white matter bars inclined to posterior, similar to an M element of *O. confluens*.

Remarks. Probably an aberrant specimen which at one time had its cusp broken off and later regenerated.

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CHAPTER 2


Explanation of Plate 1

Both lateral faces of all specimens illustrated with upper basal margin horizontal.

Figs 1, 2. *Walliserodus* cf. *sanciclairei* (Cooper, 1976), symmetrical element, PM X 1223; Upper Whitcliffe Formation, sample 20/1b, old tramway cutting, Netherton, W Midlands (loc. 20), X100.

Figs 3, 4. *Dapsilodus obliquicostatus* (Branson & Mehl, 1933), symmetrical element, PM X 1172; Whitcliffe Formation, sample 10/1, quarry in Siefon Batch, Corve Dale, Shropshire (loc. 10), X100.


Figs 5, 6. Falciform element, PM X 1170; sample and locality as for fig. 3, X110.

Figs 7, 8. Arcuatiform element, PM X 1197; sample and locality as for fig. 1, X75.

Figs 9, 10. Arcuatiform element, PM X 1237; Upper Perton Beds, sample 23b/2, Perton Lane, Perton, near Hereford, Hereford and Worcester (loc. 23b), X85.

Figs 11, 12. Similiform element, PM X 1214; Whitcliffe Formation, sample 20/1a, locality as for fig. 1, X85.

Figs 13, 14. Asimiliform element, PM X 1220; Whitcliffe Formation, sample 115/1*, locality as for fig. 1, X75.

Figs 15, 16. Asimiliform element, PM X 1171; sample and locality as for fig. 3, X55.

Figs 17, 18. Tortiform element, PM X 1173; sample and locality as for fig. 3, X50.

Figs 19, 20. Tortiform element, PM X 1273; Rushall Beds, sample 24b/2, exposure opposite Yew Tree Inn, Prior's Frome near Hereford, Hereford and Worcester (loc. 24b), X40.
**Explanation of Plate 2**

Figs 1-23. *Panderodus serratus* (Rexroad, 1967), both lateral faces illustrated unless stated.

Figs 1, 2. Falciform element, PM X 1199; Whitcliffe Formation, sample 20/1b, old tramway cutting, Netherton, W Midlands (loc. 20), X50.

Figs 3, 4. Arcuatiform element, PM X 1269; Upper Perton Beds, sample 24a/4, opposite the Yew Tree Inn, Prior's Frome near Hereford, Hereford and Worcester (loc. 24a), X70.

Figs 5-7. Arcuatiform element, PM X 1200; sample and locality as for fig. 1. Fig. 5, Furrowed lateral face, X55; Fig. 6, Detail of serrations on posterior margin and furrow/striations on furrowed lateral face, X300; Fig. 7, Unfurrowed lateral face, X55.

Figs 8, 9. Tortiform element, PM X 1216; sample and locality as for fig. 1, X90.

Figs 10, 11. Tortiform element, PM X 1215; sample and locality as for fig. 1, X80.

Figs 12, 13. Similiform element, PM X 1198; sample and locality as for fig. 1, X60.

Figs 14, 15. Similiform element, PM X 1219; sample 115/1*, locality as for fig. 1, X70.

Figs 16, 17. Asimiliform element, PM X 1196; sample and locality as for fig. 1, X110.

Figs 18, 19. Asimiliform element, PM X 1218; sample and locality as for fig. 1, X70.

Figs 20, 21. Hooked element, PM X 1217; sample and locality as for fig. 1, X100.

Figs 22, 23. Symmetrical element, PM X 1270; sample and locality as for fig. 3, X120.
Explanation of Plate 3

Figs 1-9. *Oulodus* sp.

Fig. 1. Pb element, lateral stereo-pair, PM X 1280; Whitcliffe Formation, sample 31b/3, foreshore of Severn Estuary, Tite’s Point, Gloucestershire (loc. 31b), X30.

Fig. 2. Pb element, lateral stereo pair, PM X 1275; Upper Longhope Beds, sample 168/5*, road cutting on Longhope by-pass, Longhope, Gloucestershire (loc. 30b), X60.

Fig. 3. M element, lateral stereo-pair, PM X 1286; Whitcliffe Formation, sample 31b/2, locality as for fig. 1, X60.

Figs 4, 7. Sa element, PM X 1278; sample and locality as for fig. 1. Fig. 4, Detail of denticles on left lateral process, X110; Fig. 7, Posterior stereo-pair, X50.

Figs 5, 8. Sb element, PM X 1266; Upper Perton Beds, sample 162/2*, opposite the Yew Tree Inn, Prior’s Frome near Hereford, Hereford and Worcester (loc. 24a). Fig. 5, Detail of basal body, X100; Fig. 8, Lateral stereo-pair, X45.

Fig. 6. Sb element, lateral, PM X 1279; sample and locality as for fig. 1, X40.

Fig. 9. Sc element, lateral stereo-pair, PM X 1274; sample and locality as for fig. 2, X35.
Explanation of Plate 4


Figs 1, 2. PM X 1210; Whitcliffe Formation, sample 115/1*, old tramway cutting, Netherton, W Midlands (loc. 20), X50. **Fig. 1**, Stereo-pair of oral view; **Fig. 2**, Lateral.

Figs 3, 4. PM X 1285; Whitcliffe Formation, sample 31b/3, foreshore of Severn Estuary, Tite's Point, Gloucestershire (loc. 31b), X38. **Fig. 3**, Stereo-pair of oral view; **Fig. 4**, Lateral.

Figs 5, 6. PM X 1209; sample and locality as for fig. 1, X58. **Fig. 5**, Stereo-pair of oral view; **Fig. 6**, Lateral.

Figs 7, 8. PM X 1232; Upper Perton Beds, sample 160/1*, Perton Lane, Perton, Hereford and Worcester (loc. 23a), X34. **Fig. 7**, Stereo-pair of oral view; **Fig. 8**, Lateral.

Figs 9, 10. PM X 1161; Whitcliffe Formation, sample 7a/4, exposure opposite the Swan Inn, Aston Munslow, Corve Dale, Shropshire (loc. 7a), X34. **Fig. 9**, Lateral; **Fig. 10**, Stereo-pair of oral view.

Figs 11, 12. PM X 1162; Whitcliffe Formation, sample 39/1*, locality as for fig. 9, X34. **Fig. 11**, Lateral; **Fig. 12**, Stereo-pair of oral view.

Figs 13, 14. PM X 1159; sample and locality as for fig. 9, X34. **Fig. 13**, Stereo-pair of oral view; **Fig. 14**, Lateral.
Explanation of Plate 5

Figs 1-18. Coryssognathus dubius (Rhodes, 1953), Pb, Pc and M elements.

Figs 1, 2. Pb element, PM X 1243; Upper Perton Beds, sample 24a/2a, exposure opposite the Yew Tree Inn, Prior's Frome near Hereford, Hereford and Worcester (loc. 24a). Fig. 1, Lateral, X 60; Fig. 2, Detail of base, X180.

Figs 3, 4. Pb element, PM X 1203; Whitecliff Formation, sample 115/1*, old tramway cutting, Netherton, W Midlands (loc. 20). Fig. 3, Lateral stereo-pair, X 70; Fig. 4, Detail of denticle on inner anterior lateral process, X525.

Figs 5, 6. Pb element, PM X 1283; Whitecliff Formation, sample 31b/4, foreshore of Severn Estuary, Tite's Point, Gloucestershire (loc. 31b). Fig. 5, Basal view showing basal body, X90; Fig. 6, Lateral, X45.

Figs 7-9. Pc element, PM X 1205; sample and locality as for fig. 3. Fig. 7, Lateral stereo-pair, X130; Fig. 8, Oblique view of basal cavity showing lamellar edges of crown tissue, X150; Fig. 9, Detail of cavity under outer anterior process showing concentric lamellae surrounding basal pit of denticle, X320.

Figs 10, 11. Pc element, PM X 1204; sample and locality as for fig. 3. Fig. 10, Lateral, X100; Fig. 11, Cavity showing basal body, X190.

Figs 12-14. Pc element, PM X 1282; sample and locality as for fig. 5. Fig. 12, Lateral, X42; Fig. 13, Detail of junction of denticle with basal body on inner anterior lateral process, X700; Fig. 14, Denticles on inner anterior lateral process, X100.

Fig. 15. Pc element, lateral, PM X 1202; sample and locality as for fig. 3, X80.

Fig. 16. M element, inner lateral, PM X 1242; sample and locality as for fig. 1, X62.

Fig. 17. M element, inner lateral, PM X 1250; sample and locality as for fig. 1, X75.

Fig. 18. M element, inner lateral, PM X 1208; sample and locality as for fig. 3, X100.
Explanation of Plate 6

Figs 1-12. Coryssognathus dubius (Rhodes, 1953), symmetry transition series. All specimens illustrated from the posterior.

Fig. 1. Sa/Sb element, morphotype A, PM X 1255; Upper Perton Beds, sample 24a/2a, exposure opposite the Yew Tree Inn, Prior's Frome near Hereford, Hereford and Worcester (loc. 24a), X100.

Fig. 2. Sa/Sb element, morphotype A, stereo-pair, PM X 1179; Upper Whitcliffe Formation, sample 15c/1, Whitcliffe Quarry, Ludlow, Shropshire (loc. 15c), X60.

Fig. 3. Sa/Sb element, morphotype B, PM X 1201; Whitcliffe Formation, sample 115/1*, old tramway cutting, Netherton, W Midlands (loc. 20), X60.

Fig. 4. Sa/Sb element, morphotype B, PM X 1251; sample and locality as for fig. 1, X55.

Fig. 5. Sa/Sb element, morphotype B, stereo-pair, PM X 1239; sample and locality as for fig. 1, X70.

Fig. 6. Sa/Sb element, morphotype C, stereo-pair, PM X 1207; sample and locality as for fig. 3, X60.

Fig. 7. Sa/Sb element, morphotype C, PM X 1230; Upper Ludlow Formation, sample 22/1, Brockhill Quarry, near Malvern Wells, Hereford and Worcester (loc. 22), X70.

Fig. 8. Sa/Sb element, morphotype C, PM X 1281; Whitcliffe Formation, sample 31b/3, foreshore of Severn Estuary, Tite's Point, Gloucestershire (loc. 31b), X120.

Fig. 9. Sb element, PM X 1228; sample and locality as for fig. 7, X60.

Fig. 10. Sb element, PM X 1271; sample and locality as for fig. 1, X45.

Fig. 11. Sb element, PM X 1254; sample and locality as for fig. 1, X60.

Fig. 12. Sb element, stereo-pair, PM X 1252; sample and locality as for fig. 1, X60.
Explanation of Plate 7


**Figs 1-3.** Sc element, PM X 1245; Upper Perton Beds, sample 24a/2a, exposure opposite the Yew Tree Inn, Prior’s Frome near Hereford, Hereford and Worcester (loc. 24a). **Fig. 1,** Lateral stereo-pair, X55; **Fig. 2,** Detail of base showing denticles on upper and lower basal margins, X220; **Fig. 3,** Detail of denticles on lower basal margin, X250.

**Fig. 4.** Sc element, lateral, PM X 1249; sample and locality as for fig. 1, X60.

**Fig. 5.** Sc element, lateral, PM X 1240; sample and locality as for fig. 1, X65.

**Fig. 6.** Fused coniform elements, lateral, PM X 1206; Whitcliffe Formation, sample 115/1*; old tramway cutting, Netherton, W Midlands, X190.

**Figs 7, 8.** Coniform element, PM X 1241; sample and locality as for fig. 1. **Fig. 7,** Lateral, X110; **Fig. 8,** Oblique view of opposite lateral face showing basal body in part of cavity, X220.

**Fig. 9.** Coniform element, lateral, PM X 1227; Upper Ludlow Formation, sample 22/1, Brockhill Quarry, near Malvern Wells, Hereford and Worcester (loc. 22), X180.

**Figs 10, 11.** Coniform element, PM X 1165; Whitcliffe Formation, sample 8/1, Diddlebury, Corve Dale, Shropshire (loc. 8). **Fig. 10,** Detail of basal cavity showing lamellar edges of crown tissue, X130; **Fig. 11,** Lateral, X75.

**Figs 12, 13.** Coniform element, PM X 1226; sample and locality as for fig. 9: **Fig. 12,** Lateral, X130; **Fig. 13,** Detail of cavity showing lamellar edges of crown tissue and basal body, X300.

**Fig. 14.** Coniform element, lateral, PM X 1257; sample and locality as for fig. 1, X100.

**Figs 15, 16.** Coniform element, PM X 1231; sample and locality as for fig. 9. **Fig. 15,** Basal cavity, X250; **Fig. 16,** Lateral, X110.
Fig. 20. Sa element, posterior, PM X 1287; Upper Llangibby Beds, sample 33/3, exposure next to Cwm-ffrwd Brook, Brook House near Usk, Gwent (loc. 33).

Fig. 21. Sb element, lateral, PM X 1222; sample and locality as for fig. 12.

Fig. 22. Sb element, lateral, PM X 1181; Upper Whitcliffe Formation, sample 15c/1, Whitcliffe Quarry, Ludlow, Shropshire (loc. 15c).

Fig. 23. Sc element, lateral, PM X 1182; sample and locality as for fig. 22.

Fig. 24. Sc element, lateral, PM X 1155; Whitcliffe Formation, sample 5c/2*, old quarry behind Brockton School, Corve Dale, Shropshire (loc. 5c).
Explanation of Plate 8

Figs 1-11. *Ozarkodina confluens* (Branson & Mehl, 1933), all X30 unless stated.

Fig. 1. Pa element, lateral, PM X 1191; Upper Whitcliffe Formation, sample 20/1a, old tramway cutting, Netherton, W Midlands (loc. 20).

Fig. 2. Pb element, lateral, PM X 1264; Upper Perton Beds, sample 162/2*, opposite the Yew Tree Inn, Prior's Frome near Hereford, Hereford and Worcester (loc. 24a).

Fig. 3. M element, lateral, PM X 1261; Upper Perton Beds, sample 24a/2a, locality as for fig. 2.

Fig. 4. M element, lateral, PM X 1213; Whitcliffe Formation, sample 20/1b, locality as for fig. 1.

Fig. 5. M element, lateral, GM 8189 (226/7); sample and locality as for fig. 4, X60.

Fig. 6. Sa element, anterior, PM X 1260; sample and locality as for fig. 3.

Fig. 7. Sa element, anterior, PM X 1262; sample and locality as for fig. 3.

Fig. 8. Sb element, lateral, PM X 1163; Whitcliffe Formation, sample 38/1*, cross roads 120m NW of the Swan Inn, Aston Munslow, Corve Dale, Shropshire (loc. 7b).

Fig. 9. Sb element, lateral, PM X 1211; sample and locality as for fig. 1.

Fig. 10. Sc element, outer lateral, PM X 1246; sample and locality as for fig. 3.

Fig. 11. Sc element, inner lateral, PM X 1192; sample and locality as for fig. 1.

Figs 12-24. *Ozarkodina excavata* (Branson & Mehl, 1933), all specimens X40.

Fig. 12. Pa element, lateral, PM X 1221; Whitcliffe Formation, sample 115/1*, locality as for fig. 1.

Fig. 13. Pa element, lateral, PM X 1193; sample and locality as for fig. 1.

Fig. 14. Pa element, lateral, PM X 1212; sample and locality as for fig. 1.

Fig. 15. Pa element, lateral, PM X 1174; Upper Whitcliffe Formation, sample 15a/2, Whitcliffe Quarry, Ludlow, Shropshire (loc. 15a).

Fig. 16. Pb element, lateral, PM X 1175; sample and locality as for fig. 15.

Fig. 17. M element, lateral, PM X 1195; sample and locality as for fig. 1.

Fig. 18. Pb element, lateral, PM X 1194; sample and locality as for fig. 1.

Fig. 19. M element, lateral, PM X 1185; Upper Whitcliffe Formation, sample 15d/1, Whitcliffe Quarry, Ludlow, Shropshire (loc. 15d).
Explanation of Plate 9


Figs 1, 2, 4, 5. Pa element, PM X 1276; Whitcliffe Formation, sample 31b/7, foreshore of Severn Estuary, Tite’s Point, Gloucestershire (loc. 31b). Fig. 1, Lateral stereo-pair, X60; Fig. 2, Aboral, X60; Fig. 4, Oral, X60; Fig. 5, Detail of cavity showing lamellar edges of crown tissue, X130.

Figs 3, 6. Pa element, PM X 1263; Upper Perton Beds, sample 162/2*, exposure opposite the Yew Tree Inn, Prior’s Frome near Hereford, Hereford and Worcester (loc. 24a), X45. Fig. 3, Lateral stereo-pair; Fig. 6, Oral.


Figs 7, 10. Pa element, PM X 1244; Upper Perton Beds, sample 24a/2a, locality as for fig. 3, X50. Fig. 7, Lateral; Fig. 10, Aboral.

Figs 8, 11. Pa element, PM X 1189; Upper Whitcliffe Formation, sample 18/1, Ludford Corner, Ludlow, Shropshire (loc. 18), X40. Fig. 8, Lateral; Fig. 11, Oral.

Figs 9, 12. Pa element, PM X 1160; Whitcliffe Formation, sample 7a/4, exposure opposite the Swan Inn, Aston Munslow, Corve Dale, Shropshire (loc. 7a), X40. Fig. 9, Lateral; Fig. 12, Oral.

Figs 13, 16. Fragment showing cavity and posterior termination of Pa element, PM X 1187; Upper Whitcliffe Formation, sample 77/2*, Ludford Lane, Ludlow, Shropshire (loc. 17a), X120. Fig. 13, Lateral; Fig. 16, Oral.


Figs 14, 17. Pa element, PM X 1158; Whitcliffe Formation, sample 39/1*, locality as for fig. 9, X45. Fig. 14, Lateral; Fig. 17, Oral.

Figs 15, 18. Pa element, GM 8141 (125/3); sample and locality as for fig. 7, X50. Fig. 15, Lateral; Fig. 18, Oral.

Fig. 19. Pa element, lateral, PM X 1166; Whitcliffe Formation, sample 8/1, Diddlebury, Corve Dale, Shropshire (loc. 8), X55.

Figs 20-22. Pa element, GM 8141 (125/8); sample and locality as for fig. 7. Fig. 20, Aboral view showing basal body, X250; Fig. 21, Lateral, X65; Fig. 22, Oral, X65.
Explanation of Plate 10

Figs 1-6. Ozarkodina remscheidensis baccata ssp. nov.
Figs 1, 4. Pa element holotype, PM X 1156; Whitcliffe Formation, sample 78/1*, exposure opposite the Swan Inn, Aston Munslow, Corve Dale, Shropshire (loc. 7a), X45. Fig. 1, Lateral stereo-pair; Fig. 4, Oral.
Figs 2, 5. Pa element, PM X 1157; sample and locality as for fig. 1, X40. Fig. 2, Lateral stereo-pair; Fig. 5, Oral.
Figs 3, 6. Pa element, PM X 1258; Upper Perton Beds, sample 24a/2a, exposure opposite the Yew Tree Inn, Prior’s Frome, near Hereford, Hereford and Worcester (loc. 24a), X45. Fig. 3, Lateral stereo-pair; Fig. 6, Oral.

Figs 7, 10. Pa element, PM X 1164; Whitcliffe Formation, sample 8/1, Diddlebury, Corve Dale, Shropshire (loc. 8), X30. Fig. 7, Lateral; Fig. 10, Oral.
Figs 8, 11. Fragment showing cavity and posterior process of Pa element, PM X 1190; Upper Whitcliffe Formation, sample 18/1, Ludford Corner, Ludlow, Shropshire (loc. 18), X50. Fig. 8, Lateral; Fig. 11, Oral.
Figs 9, 12. Pb element, lateral, GM 8145 (143/7); sample and locality as for fig. 3, X50.

Figs 13, 16. Ozarkodina remscheidensis remscheidensis (Ziegler, 1960), Pa element, PM X 1277; Whitcliffe Formation, sample 31b/3, foreshore of Severn Estuary, Tite’s Point, Gloucestershire (loc. 31b), X45. Fig. 13, Lateral stereo pair; Fig. 16, Oral.

Figs 14-18. Ozarkodina remscheidensis ssp.
Fig. 14. M element morphotype A, lateral, PM X 1169; sample and locality as for fig. 7, X50.
Fig. 15. M element morphotype B, lateral, PM X 1265; Upper Perton Beds, sample 162/2*, locality as for fig. 3, X70.
Fig. 17. M element morphotype B, lateral, PM X 1180; Upper Whitcliffe Formation, sample 15c/1, Whitcliffe Quarry, Ludlow, Shropshire (loc. 15c), X50.
Fig. 18. Sb element, lateral, PM X 1168; sample and locality as for fig. 7, X70.
Explanation of Plate 11

Figs 1-12. *Ozarkodina wimani* (Jeppsson, 1974).

Figs 1, 4. Pa element, PM X 1184; Upper Whitcliffe Formation, sample 74/1*, Whitcliffe Quarry, Ludlow, Shropshire (loc. 15c), X85. **Fig. 1**, Lateral stereo-pair; **Fig. 4**, Oral.

Figs 2, 5. Pa element, PM X 1233; sample 160/1*, Perton Lane, Perton near Hereford, Hereford and Worcester (loc. 23a), X90. **Fig. 2**, Lateral stereo pair; **Fig. 5**, Oral.

Figs 3, 6. Pa element, PM X 1272; Upper Perton Beds, sample 162/1*, exposure opposite the Yew Tree Inn, Prior's Frome, near Hereford, Hereford and Worcester (loc. 24a), X70. **Fig. 3**, Lateral stereo-pair; **Fig. 6**, Oral.

**Fig. 7.** Fragment of Pa element showing cavity and cusp, PM X 1234; Upper Perton Beds, sample 161/1*, Cliff section to E of Perton Lane, Perton near Hereford, Hereford and Worcester (loc. 23b), X110.

Figs 8-10, 12. Sa element, PM X 1236; sample and locality as for fig. 7, X90. **Fig. 8**, Posterior; **Fig. 9**, Oblique posterior; **Fig. 10**, Basal; **Fig. 12**, Oblique lateral showing posterior process.

**Fig. 11.** Sa element, posterolateral view showing denticles on posterior process, PM X 1268; sample and locality as for fig. 3, X120.


**Fig. 13.** Pb element morphotype A, lateral, PM X 1167; Whitcliffe Formation, sample 8/1*, Diddlebury, Corve Dale, Shropshire (loc. 8), X45.

**Fig. 14.** M element morphotype B, lateral, PM X 1238; Upper Perton Beds, sample 24a/2a, locality as for fig. 3, X85.

Figs 15, 18. M element morphotype C, PM X 1267; Upper Perton Beds, sample 162/2*, locality as for fig. 3, X40. **Fig. 15**, Lateral; **Fig. 18**, Oblique oral.

**Fig. 16.** Pb element morphotype B, lateral, PM X 1235; sample and locality as for fig. 7, X40.

**Fig. 17.** M element morphotype A, lateral, PM X 1247; Upper Perton Beds, sample 24a/2a, locality as for fig. 3, X100.
CHAPTER THREE

Ostracoda from the Upper Whitcliffe and Downton Castle Sandstone formations (Silurian) of Wales and the Welsh Borderland

ABSTRACT

10 species (four in open nomenclature) are described from the Upper Whitcliffe and Downton Castle Sandstone formations of the Welsh Borderland. On the basis of ostracod faunas the boundary between the two formations can be shown to correlate to the Ludlow /Pròdol series boundary within the Upper Silurian of the Welsh Basin. Ostracods are most commonly preserved as internal and external moulds of disarticulated valves, occasionally as carapaces with both valves still cojoined but open and mostly in the 'butterfly' position. Moulds of damaged (flattened) valves, pyritised internal moulds and original calcareous valves are rare. The Upper Whitcliffe Formation ostracod fauna is dominated by Calcaribeyrichia torosa, with Hemsiella cf. maccoyiana and Lophoctenella cf. scanensis, although all three species occur 0-2cm above the correlated base of the Downton Castle Sandstone Formation at Long Mountain. The ostracod Frostiella groenvalliana associated with Londinia arisaigensis, L. fissurata, L. kiesowi and N. verrucosa, is present at the base of the Downton Group. The latter, restricted to the lowermost 2.7m of the Downton Group, is considered synonymous with N. jurassica, index species for the late Pròdol of the East Baltic. Large leperditid and non-palaeocope Ostracoda occur almost exclusively in the restricted near shore environment of the uppermost Downton Castle Sandstone Formation and latter parts of the Downton Group.
INTRODUCTION

The lithostratigraphical boundary between the Upper Whitcliffe and Downton Castle Sandstone formations in the Welsh Borderland is defined at the base of the lowest bone bed in the sequence at Ludford Corner, Ludlow, Shropshire (Fig. 1.1) and correlates with the chronostatigraphical boundary between the Ludlow and Prídlöf series (see Chapter 4).

The ostracod faunas for this study were collected during a detailed micropalaeontological investigation of the Upper Whitcliffe and Downton Castle Sandstone formations and their lateral equivalents (Fig. 1.3) across Wales and the Welsh Borderland. Details of localities sampled for ostracods are given (Fig. 3.1 and Appendix 1).

A thorough review of previous research into British Silurian beyrichiacean ostracods was given by Siveter (1980, pp. 1, 2); Shaw (1969, p. 52) reviewed past research on Downtonian (Downton Group) ostracods. Previously, detailed taxonomic work on mould fauna ostracods has been hampered by poor preservation and problems with illustration of material. Martinsson (1963, fig. 18) illustrated four internal moulds of Frostiella cf. groenvalliana from Ludford Lane, Ludlow (loc. 17) referring to the material with a confer as no original shell material was preserved. Shaw (1969, 1971) used a latex casting technique which enabled light photographs to be taken of casts of external moulds. Shaw (1969) worked on loose material from the Downton Group at Ludford Lane (loc. 17) and at Onibury (loc. 12b).

David J. Siveter (1974) in his PhD thesis was the first worker to employ a silicone rubber casting technique, scanning electron microscopy and stereo-photography for illustration (Siveter 1982). The first half of Siveter's monograph has been published (Siveter 1980), however the second half, which includes descriptions of most of the species covered in this paper, is yet to be published. The present study has involved much more detailed collecting across a much more restricted stratigraphic horizon than in either the studies of Shaw (1969) or Siveter (1974, 1978). Descriptions herein have been made from collections made by the author and Dr David J. Siveter, augmented by material from BGS (Keyworth) collections.
Fig. 3.1. Outcrop of the Downton Group and Ludlow formations in Wales and the Welsh Borderland (after Bassett et al. 1982) showing sampled localities yielding ostracods.

1-4, Much Wenlock; 1, Callaughton Mill. 2, Willey. 3, Dean Brook. 4, Linley Brook. 5-9, Corve Dale; 5, Brockton. 6, Shipton. 7, Aston Munslow. 9, Corfton. 11, Culmington. 12, Onibury. 13, Clungunford. 14, Downton. 15-18, Ludlow; 15, Whitcliffe Quarry. 16, Charlton Arms Car Park. 17, Ludford Lane. 18, Ludford Corner. 20, Netherton. 21, Abberley. 23 & 24, Woolhope; 23, Personton. 24, Prior's Frome. 33, Brook House, Usk. 36, Long Mountain. 37, Nantyrhynau Quarry, Clun. 38, Felindre. 39, Clun. 40, Knighton. 43, Capel Horeb, Llandovery. 45, Cennen Valley.
PRESERVATION

Disarticulated valves

The majority of specimens figured are silicone rubber casts, taken from external moulds of well preserved individual disarticulated valves. Typically moulds are incomplete, obscured by sediment, or broken during sample splitting (Fig. 3.2). Only the best representatives of the total number of external moulds collected have been cast. Preservation of fine morphological detail is dependant on the depositional environment and grain size of the surrounding sediment; occasionally this technique replicates fine detail up to 5 μm in diameter (Pl. 12, fig. 1).

Carapaces

Approximately 1% of the total number of individual ostracod specimens collected are preserved with both valves still co-joined (Pl. 12, fig. 2). Carapaces are usually preserved in 'butterfly position', with valves fully open so that both valves would have rested flat on the bottom sediment (Pl. 12, fig. 2). Only two examples have been found where the valves are partially open and protrude into the sediment at an angle (Pl. 12, figs 3-6).

Flattened valves

Occasionally valves are preserved which have been flattened by sediment weight, obscuring original lobal and cruminal features. One such example (Pl. 12, fig. 7) shows a 'carapace' of Calcaribeyrichia torosa with both valves still completely closed, with only the velar spines of the lower (right) valve visible.

Pyrised internal moulds

Three pyritised internal moulds of Hemiella cf. maccrojiana (Pl. 12, fig. 8) have been found in (acetic acid) conodont preparations on a limestone from the Upper Llangibby Beds (Upper Whitcliffe Formation) of the Usk inlier (loc. 33).

Original calcareous valves

One calcareous fine sandstone bed from the Downton Castle Sandstone Formation at Linley Brook, near Much Wenlock (loc. 3c) has produced an original calcareous valve of a heteromorph of Frostiella groenvalliana (Pl. 12, fig. 9). This is the first example of original valve material of F. groenvalliana from the Silurian of the Britain. Calcareous valve material of the upper Prfdolf species Kloedenia wilckensiana and Nodibeyrichia pustulosa has been figured from the Little Missendon Borehole, Buckinghamshire (Siveter 1978, pl. 9, figs 1-4).
Fig. 3.2. Ostracod moulds (sample 17b/28), Platyschisma Shale Member, Downton Castle Sandstone Formation, Ludford Lane, Ludlow, Shropshire (loc. 17b), X8.
CHAPTER 3

TERMINOLOGY TECHNIQUES AND MEASUREMENTS

Martinsson's (1962, 1963) descriptive terminology for the beyrichiacean carapace has been used throughout this text. The additional term 'supravelar groove' has also been used to describe the linear depression between the lobes and the adventral structures (velum) in tecnomorphic valves, for example some specimens of *Londinia fissurata* (see Pl. 17, fig. 15)

The abbreviations used for tables and plate descriptions are as follows:
RV, Right valve; LV, Left valve; H, Heteromorph; T, Tecnomorph.

Well preserved external moulds were cast using the silicone rubber casting technique described by Siveter (1982); see Chapter 1 for a description of this method. Internal moulds and a single original calcareous valve were excavated using a vibrotool and some pyritised internal moulds picked from the heavy fraction of (acetic acid) conodont preparations. A Hitachi S520 S.E.M. was used to obtain stereo-micrographs of gold-coated specimens. Specimens too large to photograph under the S.E.M. were illustrated by the method described by Derek J. Siveter (1989); such specimens were coated with opaque and then a thin layer of aluminium chloride sublimate and photographed using a Leitz 'Aristophot' camera. Both stereo pairs and single prints are used in illustrating the fauna.

Measurements given in systematic descriptions (when preservation allows) are for the hinge length and maximum height measured perpendicular to the hinge line.
CHAPTER 3

SYSTEMATIC PALAEOONTOLOGY

Subclass: Ostracoda Latreille, 1806
Order: Palaeocopida Henningsmoen, 1953
Superfamily: Beyrichiacea Matthew, 1886
Family: Beyrichidae Matthew, 1886
Subfamily: Amphitoxodontinae Martinsson, 1962
Genus: Henssella Martinsson, 1962

*Henssella cf. maccoyiana* (Jones, 1855)

(PI. 12, fig. 8, PI. 13, figs 1-10)

**Material.** 21 specimens, equal proportions of tecnomorphs and heteromorphs; mostly internal and external moulds of individual valves, with some pyritised internal moulds of valves from (acetic acid) conodont preparations.

**Localities and horizons.** Whitcliffe Formation, Much Wenlock area (loc. 4b); Upper Whitcliffe Formation, Ludlow Anticline and surrounding area (locs 12a, 13b, 14b, 18); Kington (loc. 19a); Upper Perton Beds, Woolhope inlier (loc. 23a); Upper Llangibby Beds, Usk inlier (loc. 33); Causey Mountain Formation, Long Mountain (loc. 36a); Cefn Einion Formation, Clun Forest (locs 37 and 38c).

**Description.** Valve preplete with slender crescentic anterior lobe, less well developed in heteromorphs than tecnomorphs. Pre-adductoral node flat and ovoidal, extending from mid point of valve, protruding to point just above dorsal margin. Syllobium weakly cuspidate, dorsally to posterodorsally less inflated in right valves and slightly less inflated to smooth in left valves. Syllobium extends to ventral of preadductorial node and terminates at an anteroventral depression in tecnomorphic valves. Curved anteroventral termination of syllobium substituted by posteriorly flattened edge to crumina in heteromorphic valves. Adductorial sulcus straighter and deeper than posteriorly curved preadductorial sulcus, confluent to ventral of preadductorial node in both tecnomorphs and heteromorphs. Smooth velum well developed anteroventrally (Pl. 13, fig. 7) and in lateral view subvelar field protrudes beyond anterior margin in tecnomorphs. Subvelar field with a marginal ridge running parallel with valve ventral margin and a shorter toric ridge diverging from marginal ridge, and ending at about the position marked laterally by the anteroventral depression (Pl. 13, fig. 8). Crumina depressed parallel to weakly developed velar structure and striate/ granulostriate on lateral face dorsal of depression (Pl. 13,
fig. 3). Lobes punctate to reticulate (Pl. 13, figs 9, 10) or unornamented (possibly a taphonomic effect).

Dimensions. Hinge length - height of complete figured specimens: HLV (PM OS 14093), 1250μm-958μm; TRV (PM OS 14146), 1250μm-958μm.

Remarks. A well developed velum, cruminal depression and a dorsally depressed syllobium are typical of the genus *Hemsiella*. The genus contains a number of closely related species whose morphological variations often overlap (see Siveter & Hansch 1990). Hansch has personally examined the Welsh Borderland specimens from the present study and supports the view that they are closer to *H. macc oyiana* than to *H. loensis* Martinsson, 1962. For synonomy and diagnosis for *H. macc oyiana* see Siveter & Hansch (1990). The well preserved Welsh Borderland tecnomorph figured here (Pl. 13, figs 7-9) differs only slightly from *H. macc oyiana* of Siveter & Hansch (1990, pl. 17,56, figs 3, 5; pl. 17,60, fig. 1) in that it lacks anteroventral undulations on the velum. With only a few well preserved specimens (most are rather poorly preserved) from the Welsh Borderland available, they are assigned to *H. macc oyiana* with a confer. The Welsh Borderland material does show the left-right valve asymmetry typical of *H. macc oyiana*. The well preserved left valves available have only weakly depressed syllobia; however, there is not sufficient material to show that the anterior lobe is better developed in left valves as is typical of *H. macc oyiana* (see Siveter & Hansch 1990).

**Genus: Lophoctenella** Martinsson, 1962

*Lophoctenella cf. scanensis* (Kolmodin, 1869)

(Pl. 13, figs 11-16)

1971 *Lophoctenella cf. scanensis* Kolmodin; Shaw: 599-600, pl. 110, figs 1-6.

1974 *Lophoctenella cf. scanensis* (Kolmodin); Shaw: 599, pl. 110, figs 1-6.

1978 *Lophoctenella cf. L. scanensis* Kolmodin; Siveter: 82, pl. 7, figs 9, 10.


For type-species and description see Siveter (1980, pp. 52, 53).

**Material.** 14 internal and external moulds of individual valves; mostly heteromorphic right valves, no complete tecnomorphs.
**Locality and horizons.** Whitcliffe Formation, Much Wenlock area (loc. 4b); Causemountain Formation, Long Mountain (loc. 36a).

**Description.** Anterior lobe of tecnomorph, elongate, straight and minor, extending half-way to ventral margin from a point just above dorsal margin. Preadductorial lobe similar length to anterior lobe but slightly broader, more elevated and has a cristal loop. Preadductorial node connected to syllobium via a low ventromedial ridge. Syllobium very slightly cuspidate and inclined slightly to anterior at dorsal end, curving gently to anterior parallel with curvature of posteroventral margin. Continuous crista encircles raised area of syllobium (Pl. 13, fig. 15). Adductorial sulcus deeper and extends further ventrally than prenodal sulcus, which extends to median level then stops abruptly at pronounced anteroventral depression. Inwardly sloping marginal flange well developed posteriorly and anteriorly extending to anteroventral velum, although this is not well preserved on the one specimen available. Subvelar field pronounced at anterior margin but obscured by sediment along rest of margin.

Heteromorph with well developed crumina, outline ovoidal, rounded in relief with flattened posteroventral face. Anterior lobe and preadductorinal node more rounded than on tecnomorph, lack cristae and are truncated anteromedially by extensive crumina (Pl. 13, figs 11-14). Syllobium flatter, more rounded than in tecnomorph, with pronounced posterodorsal depression. Flattened posterior area tapers and dissappears at point where syllobium meets crumina.

**Dimensions.** Hinge length - height for complete figured specimens: HRV (BGS RT 336), 1458μm-1290μm; HRV (PM OS 14136), 1267μm-1100μm. Hinge length of incomplete TLV (BGS RT 336), 1140μm.

**Discussion.** Material recovered from the Upper Whitcliffe Formation and lowermost Downton Castle Sandstone Formation is identical to figured material from the Upper Leintwardine Formation (Siveter 1980, pl. 14, figs 10-16, 19). Due to the nature of the type material of *Lophoctenella*, it is uncertain whether *L. scanensis* occurs outside Scania, and the genus as a whole, is in need of thorough taxonomic revision. For these reasons, Siveter (1980) used a *confer* with respect to *L. scanensis*. Only a few specimens have been recovered in this present study, from the Upper Whitcliffe Formation of the Welsh Borderland, most of which are very poorly preserved. Only a few specimens have therefore been recorded as *L. cf. scanensis* and the remainder recorded as *Lophoctenella* sp.
Subfamily: Beyrichinae Matthew, 1886
Genus: Nodibeyrichia Henningsmoen, 1954

Nodibeyrichia verrucosa Shaw, 1969

(Pl. 14, figs 1-16)

1968 Nodibeyrichia jurassica (Gailite); Sarv: 47, pl. 17, figs 5-9.
1969 Nodibeyrichia verrucosa Shaw: 63-65, text-fig. 7.


Figured by Shaw, 1969, figs 7a, b, from the Platyschisma bed, Downton Castle Sandstone Formation, Forge Bridge, Downton, Shropshire (SO 4540 7510). Type locality no longer exposed (September 1991).

Material. 63 internal and external moulds of individual valves; tecnomorphs greatly outnumbering heteromorphs.

Localities and horizons. Ludlow Bone Bed Member and Platyschisma Shale Member, Downton Castle Sandstone Formation, Much Wenlock area (loc.3b), Ludlow (locs 17, 18); Causemountain Formation, Long Mountain (loc. 36a); Platyschisma helicites Beds, Knighton (loc. 40b).

Description. Preplete outline with flat and weakly developed anterior lobe, ventrally developed into a node. Smooth preadductor node rounded and knob-like, sometimes elongate and always (ventrally) inclined slightly to posterior, extending from mid-valve to almost dorsal margin. Syllobium bicuspat, wide and flat at dorsal margin, becoming narrower and more laterally elevated posterovertrally. Variably developed callus and groove angularly dissect syllobium (Pl. 14, figs 4, 6). Syllobium ends abruptly at crumina in heteromorphs, but in tecnomorphs continues a short way along ventral margin beneath preadductor node, terminating at shallow anteroventral depression. Preadductor sulcus more pronounced than shallow, often absent, prenodal sulcus, with both connected ventral of preadductor node. Marginal ridge entire in tecnomorphs, rarely microspinose anteriorly (Pl. 14, fig. 13). Syllobium, anterior lobe and crumina (when present) have weak granulose, occasionally tuberculate ornament (Pl. 14, fig. 12).
CHAPTER 3

Dimensions.

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<th>Sample number</th>
<th>Hinge length (µm)</th>
<th>Height (µm)</th>
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<td>BGS SH 3685</td>
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</table>

Remarks. In the Welsh Borderland *N. verrucosa* is confined to the lowermost Downton Castle Sandstone Formation (Ludlow Bone Bed Member and Platschisma Shale Member) and has a limited geographical distribution, being found only in the Ludlow, Downton, Much Wenlock Long Mountain and Knighton areas (see above). In addition poorly preserved specimens identified as *Nodibeyrichia*. sp. have been found at Knighton (loc. 40c) and in the Woolhope inlier (loc. 23a), and Aff. *Nodibeyrichia* occurs in the Ludlow Anticline (loc. 14b). The highest occurrence of *N. verrucosa* in the Welsh Borderland is from a bed approximately 0.70m above a bone bed assumed to correlate with the Ludlow Bone Bed, in the Long Mountain area (loc. 36a).

The stratigraphical range of *N. verrucosa* is more extensive than previously thought. Due to the tuberculate crumina, undissected nature of the syllobium, and the relatively incipient development of the anteroventral lobule, the taxon is regarded as conspecific with *N. jurassica* (Gailite), index species for the late Prfdolf of Estonia (Hansch & Siveter, in press). It is possible that the environment in the Welsh basin after the early Downton Castle Sandstone Formation times was not favourable for *N. verrucosa* or any other ostracods other than leperditids. Further research is needed to find British beyrichiacean ostracod faunas above the assumed early Prfdolf occurrences in Britain.
Genus: *Calcaribeyrichia* Martinsson, 1962

*Calcaribeyrichia torosa* (Jones, 1855)

(Pl. 15, figs 1-17)

1855 *Beyrichia kloedeni* var. *torosa* Jones: 167, pi. 6, figs 10-12.

1971 *Neobeyrichia torosa* (Jones); Shaw: 602, pl. 111, figs 7, 8.

1978 *Calcaribeyrichia torosa* (Jones); Siveter: 84, pl. 8, figs 5, 6, tab. 2.

1989 *Calcaribeyrichia torosa* (Jones); Siveter: text-fig. 167.

**Diagnosis.** (After Siveter 1978, p. 84). *Calcaribeyrichia* with faceted, elongate preadductorial node and faceted lobules in cuspidal area which are each capped by small spine. Syllobium slender and ridge-like, mostly lacking distinct postero-dorsal region. Curved ridge, ventrally on crumina, and calcarine spines may occur.

**Lectotype.** British Museum (Natural History), BM GSM 36863 (H external mould). Figured by Jones, 1885, pl. 6, fig. 18, from the "Upper Ludlow" at Frith Quarry, Welsh Borderland.

**Material.** Approximately 50 internal and external moulds of individual valves with equal proportions of teichomorphs and heteromorphs.

**Localities and horizons.** Whitcliffe Formation, Corve Dale (locs 5b, 6a, 7a, 7b); Upper Whitcliffe Formation, Onibury area (locs 12a, 13a, b), Ludlow Anticline (locs 14b, 15b, 15c, 17a, 17c, 18); Upper Ludlow Formation, Abberley (locs 21a-d); Causemountain Formation, Long Mountain (locs 36a, b); Cefn Einion Formation, Clun area (locs 37, 38c, 39c, 39d). One figured specimen (Pl. 15, fig. 11) from a bed 0-2cm below the top of the Upper Leintwardine Formation at Sunnyhill Quarry, Mortimer Forest, Shropshire (SO 4974 7244; Siveter et al. 1989, loc. 3.6d). Ludlow Bone Bed Member, Downton Castle Sandstone Formation, Ludford Lane, Ludlow (loc. 17a) (Bassett et al. 1982).

**Description.** Anterior lobe crescentic with coarsely tuberculate ornament; raised anterodorsal area faceted and sometimes with small dorsally directed spine (Pl. 15, fig. 16). Heteromorphs have only faceted part of lobe. Preadductorial node rounded to elongate in a ventrodorsal direction with top usually faceted, but sometimes smoothly rounded. Syllobium with similar, but slightly less ventrally extensive, raised, faceted dorsal area as anterior lobe, and also bears dorsally directed spine. Syllobium crescentic, with coarsely tuberculate ornament and small calcarine spine sometimes preserved posteroventrally (Pl. 15, fig. 8). Adductorial and prenodal sulcus broad and U-shaped in section, joining to ventral of, and completely surrounding...
preadductorial node. Base of sulci at a higher level than well developed anteroventral depression and supravelar groove. Velum bears spines or small stumps when these have been broken off, and if preservation allows, a microgranular ornament (Pl. 12, fig. 1; Pl. 15, fig. 17). Crumina occasionally bears three prominent spines (Pl. 15, fig. 10), has similar ornament to syllobium/ anterior lobe, and is usually laterally slightly pointed, although it can also be rounded.

**Dimensions.**

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**Remarks.** The stratigraphic range of *C. torosa* in the Welsh Borderland appears to be from uppermost Upper Leintwardine Formation to basal Downton Castle Sandstone Formation. The species, however, shows a certain degree of intraspecific variation which follows a stratigraphic pattern. Although this study is concerned mainly with faunas from the Upper Whitcliffe Formation, *Calcaribeyrichia* faunas have also been collected from the Upper Leintwardine Formation and material is available from the Lower Whitcliffe Formation (Dr. David J. Siveter collection). The characteristic Upper Whitcliffe Formation morphotype, collected from just below the top of the formation, possesses faceted lobules on the anterior lobe, syllobium and preadductorial node, with heteromorphs commonly having a slightly rounded rather than pointed crumina (Pl. 15, fig. 1). Although the morphology of the crumina does not appear to show an even change from rounded to pointed, the lobules typical of Upper Whitcliffe specimens are faceted and become increasingly smaller and more rounded (Pl. 15, fig. 11) in specimens down through the Lower Whitcliffe Formation into the Upper Leintwardine Formation. More material is needed, particularly heteromorphs from the Lower Whitcliffe Formation, to test this hypothesis; however, this could show the transition from a
distinct *Calcaribeyrichia* species common to the uppermost Upper Leinwardine Formation to a true *C. torosa*, common to the Upper Whitcliffe Formation. The true *C. torosa* would not therefore range into the Upper Leinwardine Formation. *Beyrichia cuspidata* (Grønwall, 1867), characteristic of the upper Ludlow of Scania, although in need of taxonomic revision, has been noted as a possible synonym for *C. torosa* (Siveter 1989), thus the species may have biostratigraphical/correlative potential outside Britain.

Subfamily: *Kloeedeniinae* Ulrich & Bassler, 1923

Genus: *Londinia* Martinsson, 1963

*Londinia arisaigensis* Copeland, 1964

(Pl. 16, figs 1-16)


1969 *Londinia arisaigensis* Copeland; Shaw: 61, text-fig. 6.

1989 *Londinia arisaigensis* Copeland; Siveter *et al.*: pl. 3, fig. 13.

1989 *Londinia arisaigensis* Copeland; Siveter: pl. 168, fig. 1.

Diagnosis. See Siveter 1978, p. 86.


Material. Approximately 150 internal and external moulds of individual valves of dominantly heteromorphic specimens and three specimens, part and counterpart, of carapaces with both valves still co-joined.

Localities and horizons. Downton Castle Sandstone Formation, Much Wenlock area (locs 2, 3a, 4a, b), Onibury (loc. 11), Ludlow Anticline (locs 14a, 14b, 17a, 17b, 18); Rushall Beds, Woolhope inlier (loc. 23a); Clun Forest and Cefn Einion formations, Clun area (locs 37, 38c, 39b); *P. helicites* Beds, Knighton area (locs 40a-c); Causemountain Formation, Long Mountain (loc. 36a).

Description. Tectomorphic valves widest at mid-line. Anterior lobe weakly cuspidate and ridge-like ridge parallel to anterior margin and less obtrusive than preadductorial lobe and syllobium. Preadductorial node narrow at dorsal margin, becoming broader ventrally, terminating suddenly mid-valve in heteromorphs and connected with syllobium by broad
ventral swelling in tecnomorphs. Both preadductorial node and syllobium usually faceted dorsally (Pl. 16, fig. 5), although in some cases they are smooth (Pl. 16, fig. 3). Anterior part of syllobium similar shape and forward inclination as preadductorial node, but slightly broader and more ventrally extensive. Ventral part of syllobium with reticulate ornament when preservation allows (Pl. 16, fig. 8). Posterior syllobial lobule usually present as weak ridge parallel to posterior margin, sometimes develops cusp; terminates just short of posteroventral part of syllobium, or weakly connected to syllobium. Tecnomorphs have well developed supravelar groove. Prominent prenodal sulcus inclined slightly away from vertical and is deep at dorsal margin, shallowing ventrally. Adductorial sulcus and sulcus between syllobium and posterior syllobial lobule weak. Crumina smooth, elongate and ovoidal (Pl. 16, fig. 1).

### Dimensions

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### Remarks

Apart from a few minor intraspecific variations, the Welsh material, particularly heteromorphic specimens, appear identical to the Canadian type material (Copeland 1964). Tecnomorphic Welsh material shows variation in morphology of the prenodal sulcus and connecting lobe between the preadductorial node and the syllobium. The prenodal sulcus is always dominant, but occasionally inclined at a greater angle than the Canadian material (Pl. 16, fig. 7). Occasionally the lobes are more rounded rather than faceted and in these cases the prenodal sulcus extends further ventrally, cross-cutting the ventrally swelled area, almost
reaching the ventral margin. In the Canadian tecnomorphic material the sulcus extends just to ventral of mid-line and terminates abruptly.

*Londinia fissurata* Shaw, 1969

(Pl. 17, figs 5-16)

1969 *Londinia fissurata* Shaw: 58-59, text-fig. 4.

1978 *Londinia fissurata* Shaw; White & Coppack: 30, pl. 1, figs 5-9.

1978 *Londinia fissurata* Shaw; Siveter: 86, pl. 9, fig. 6.

Diagnosis. See Siveter 1978, p. 86.

Holotype. British Museum (Natural History) London, No. GSM 103242, (internal mould of right and left co-joined tecnomorphic valves). Figured by Shaw, 1969, fig. 4f, g, from the Temeside Bone Bed, Temeside Shales Formation, Norton Lane, Onibury, Shropshire (loc. 12b). Type locality no longer exposed (September 1991).

Material. Approximately 150 internal and external moulds of individual valves; mostly tecnomorphs. Three part and counterpart carapace specimens with both valves still co-joined.

Localities and horizons. Downton Castle Sandstone Formation, Much Wenlock area (locs 2, 3a-c, 4b), Corve Dale (loc. 9), Onibury area (locs 12b, c), the Ludlow Anticline (locs 14b, 17a, b, 18); Rushall Beds, Woolhope inlier (loc. 23a); Causemountain Formation, Long Mountain (loc. 36a); Clun Forest Formation, Clun area (locs 37, 39b); *Platyschisma helicites* Beds, Knighton (locs 40a, c), Temeside Shales Formation, the formation stratigraphically above the Downton Castle Sandstone Formation (Shaw 1969).

Description. Tecnomorphic valve symmetrical with greatest height at mid-line. Preadductorial lobe slightly more slender than posterior syllobial lobule; both are dorsally rounded and do not protrude beyond dorsal margin. Lobes can be slightly faceted dorsally (Pl. 17, figs 12, 13) and are connected laterally in tecnomorphs by lateroventral lobe which is sometimes well developed (Pl. 17, fig. 7) but occasionally valve slopes regularly to ventral margin from termination of adductor sulcus (Pl. 17, figs 13, 14). Anterior face of preadductorial lobe occasionally shows reticulostriate ornament (Pl. 17, figs 8, 16). Supravelar groove well developed. Adductor sulcus dominant, bisecting valve, generally broad and extending to two thirds distance to ventral margin, although can be thinner and extend just over half way to margin (Pl.
17, fig. 12). Crumina elongate, ovoidal and truncated at point where it meets syllobium (Pl. 17, fig. 9).

### Dimensions.

<table>
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**Remarks.** *L. fissurata* occurs in common association with *L. arisaigensis* but unlike the latter has not been recovered from the Cefn Einion Formation. *L. fissurata* differs from *L. arisaigensis* in that the former has a straighter and mostly shorter adductor sulcus, less faceting on the lobes and a slender, posteroventrally truncated crumina. *L. kiesowi* is most closely related to *L. fissurata*, rather than to *L. arisaigensis* (cf. Martinsson 1967), but is distinguished by its cruminal morphology and the extent of its adductor sulcus, which never extends beyond valve mid-height for *L. kiesowi* (Hansch & Siveter 1990, p. 47) but commonly extends two-thirds of the way to the venter in *L. fissurata*. Some variants that have been described herein as *L. fissurata* are very similar to *L. kiesowi*, particularly forms which laterally slope gently to the ventral margin rather than possessing a pronounced latero-ventral lobar connection (Pl. 17, fig. 13). These forms also have pronounced vela close to ventral margin which are not present on the specimens of *L. kiesowi* figured by Hansch & Siveter (1990, pl. 17,48, fig. 1; pl. 17,50, fig. 1). These forms have been recorded herein as intra-specific variants of *L. fissurata*, but they are possibly intermediates between these two closely related species (see discussion on *L. kiesowi*).
1891 Kloedenia kiesowi Krause: 506-507, 518-519, pl. 32, figs 12, 13.

1990 Londinia kiesowi (Krause); Hansch & Siveter; 45-52, 4 pls.

For further synonymy, diagnosis and holotype see Hansch & Siveter (1990).

Material. Decalcified external moulds of one TRV and one HLV.

Localities and horizons. Tectomorph, Causemountain Formation, Wallop Hall, Long Mountain (loc. 36a); heteromorph, Downton Castle Sandstone Formation, Linley Brook, near Much Wenlock (loc. 3b).

Description. Similar to L. fissurata but tectomorph with adductorial sulcus which extends only to valve mid-height; cuspidal facets and flattened mid-ventral area (Pl. 6, fig. 3).

Heteromorph has broad, flat, ovoidal crumina (Pl. 6, fig. 1).

Dimensions. Hinge length - valve height of: HLV (BGS SH 3685), 1833μm-1333μm; TRV (GM8029), 1899μm-1444μm.

Remarks. L. kiesowi is rare (2 specimens only) in the lowermost Downton Castle Sandstone Formation of the Welsh Borderland and is confined to just two localities. Hansch & Siveter (1990, p. 51) suggested that British material figured under Londinia by Shaw (1969) could hide conspecific material. As discussed above, L. fissurata and L. kiesowi are considered two distinct species; however, the nature of the British mould fauna, (the majority of the specimens are only poorly preserved) allows only identification to generic level for most Londinia specimens. It is therefore possible that more specimens of L. kiesowi are present amongst the Londinia material. Distinction between Londinia species is easier when well preserved tectomorphic specimens are available. Martinsson (1963) mentioned that the typical features of tectomorphic specimens of Londinia reticulifera Martinsson, 1963, the type-species of Londinia, become obvious only at the last adult growth stage. It is possible that tectomorphs of L. kiesowi and L. fissurata are difficult to distinguish in early growth stages. Unfortunately the material of L. fissurata and L. kiesowi collected for this study consists almost exclusively of tectomorphs, whereas specimens of L. arisaigensis are almost exclusively heteromorphs. More specimens are needed to thoroughly investigate the occurrence of L. kiesowi in the Welsh Borderland and to pick up features such as sub-cuminal striae and lobal reticulation which will enable identification to greater certainty.
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Genus: *Frostiella* Martinsson, 1963

*Frostiella groenvalliana* Martinsson, 1963

(Pl. 18, figs 1-15)

1963 *Frostiella groenvalliana* Martinsson: 29-33, figs 7c, 8, 14, 15a, 15b, 16a, 16b, 17a-f.
1991 *Frostiella groenvalliana* Martinsson; Hansch et al.: 125-134, pl. 18,126; pl. 18,128; pl. 18,130; pl. 18,132 and for synonymy to 1991 (see Appendix 3).

**Diagnosis.** (After Hansch et al. 1991, p. 133) *Frostiella* species with well developed lobation and prominent cusps on anterior lobe and anterior lobule of syllobium. In adults cristal loop on preadductorial lobe complete, drawn out in sagittodorsal direction or nearly rounded. Valve surface smooth except for striate criminal field and ornament (reticulostriation/striation/punctation) on lateral facet of pre-adductorial lobe.


**Material.** Approximately 1000 internal and external moulds mostly tecnomorphs. 19 moulds of carapaces with both valves still co-joined. One heteromorphic specimen (Pl. 12, fig. 9) with original calcareous valve recovered from locality 3a.

**Localities and horizons.** Downton Castle Sandstone Formation, Much Wenlock area (Iocs 3a-c), Onibury (loc. 11), Ludlow Anticline (locs 14a, b, 17a, b, 18); Rushall Beds, Woolhope inlier (loc. 23a); Causemountain Formation, Long Mountain (loc. 36a); Green Downton Formation, Clun (loc. 39b); *Platyschisma helicites* Beds, Knighton (loc. 40a); Long Quarry Formation, Llandovery area (loc. 43); Cennen Formation (?uppermost Ludlow), Cennen Valley, Dyfed (loc. 45) (see Bassett et al. 1982, Siveter 1989).

**Description.** Preplete valve with cusps on anterior lobe and anterior syllobial lobule. Preadductor lobe strongly developed forms highest point of elevation of valve; in lateral view crest can be either circular in shape (Pl. 18, fig. 3) or elongate and curved in a dorsoventral direction (Pl. 18, fig. 15). In adult specimens a cristal loop surrounds entire preadductoral lobe, one specimen of tecnomorphic left valve showing hint of reticular ornament on cuspidal part of lobe (Pl. 18, fig. 8). Syllobium has anterior cusp at mid-dorsal margin, lobe increases in width ventrally and is connected to anterior lobe by mid-ventrally tumid connecting lobe. In heteromorphs the crumina is well developed and shows subcriminal striations (Pl. 18, figs 10, 12). Posterior syllobial lobule present as small ridge parallel to posterior margin, fading out.
posteroventrally before reaching posteroventral margin of syllobium. Adductorial sulcus strongly developed, extending to approximately mid height in tecnomorph and heteromorph.

**Dimensions.**

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**Remarks.** For discussion and global distribution of *F. groenvalliana* see Siveter (1989), Hansch *et al.* (1991). The Welsh Borderland mould material has a less ventrally drooping lateral profile to the lateroventral lobal connection (tecnomorphs) and crumina (heteromorphs) than does the Scanian (shell) material (Hansch *et al.* 1991, p. 133). The calcareous valve recovered (Pl. 12, fig. 9) is the first occurrence of original shell material for this species in Britain. Apart from one or two rare cases (Pl. 18, figs 8, 10, 12), coarse sediment does not normally allow features such as sub-cruminal striae and striations on the cuspidal part of the preadductorial lobe to be preserved.

The main intraspecific variation is in the morphology of the preadductorial lobe. Martinsson (1977) synonymised *F. groenvalliana*, characterised by an elongate and curved preadductorial lobe (Pl. 18, fig. 15), and *F. 'lebiensis* ' Martinsson, 1964, characterised by a more rounded preadductorial lobe (Pl. 18, fig. 3). Welsh Borderland material shows similar morphological variations, but often, due to poor preservation, it is not possible to make detailed quantitative observations of these two morphotypes. In the reasonably well preserved samples from ostracod-rich lag deposits of the Platyschisma Shale Member, Downton Castle Sandstone Formation, at Ludford Lane Ludlow (Loc. 17), the two morphotypes co-exist in approximately 50:50 proportions, although in most samples across the Welsh Borderland the *groenvalliana* type is much more common than the *'lebiensis* ' type. In the Baltic area such variations appear to equate with ecological changes, with the *groenvalliana* type confined to shallow water facies.
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and 'lebiensis' being normally associated with deeper, basinal, outer shelf facies (Hansch et al. 1991). The dominance of the *groenvalliana* type in the "shelf" area of the Welsh Borderland at this time, would agree with variations seen in the Baltic material. *F. groenvalliana* is very rare in localities further out into the "basin" area, in west central Wales. However, in this respect it should be noted that preservation is poor and does not allow quantitative comparison of the two morphotypes. Generally, the shelf-associated palaeogeographical distribution and greater number of *groenvalliana* type specimens identified in the present study indicates that the *groenvalliana* type is dominant over the 'lebiensis' type in the Welsh Borderland.

*Frostiella cf. groenvalliana* has been collected from the Cennen Beds (?upper Ludlow) of the Cennen Valley (loc. 45), (Squirrel & White 1978, Bassett et al. 1982, Siveter 1989). The material (BGS collections, Keyworth) has been identified by the author and by Dr David J. Siveter, as *F. cf. groenvalliana*. The sediment of the Cennen Beds is very coarse, preservation of features is poor only allowing an identification of *F. cf. groenvalliana*. *Frostiella cf. groenvalliana* also occurs in the basal Downton Castle Sandstone Formation at Netherton (loc. 20) and Corve Dale (loc. 7a); *Frostiella* sp. has been identified from the Downton Castle Sandstone Formation, Corve Dale (locs 5b, 7a), the Clun Forest Formation, Clun (loc. 37) and the *Platyschisma helicites* Beds, Knighton (loc. 40c).

**Order:** Leperditicopida Scott, 1961  
**Family:** Leperditidae Jones, 1856  
**Genus:** *Leperditia* Jones, 1856  
*Leperditia* sp.  
(Pl. 18, fig. 17) 113515/2

**Material.** Approximately 50 internal and external moulds of individual valves.

**Localities and horizons.** Green Downton Formation, Clun (loc. 39b); erratic boulder, Vale of Wigmore, with *F. groenvalliana* indicating a Downton Group age.

**Description.** Large preplete ostracods with straight hinge line. Internal moulds sometimes show slight mid-anterior indentation.

**Dimensions.** Length - height of figured specimen: (LEIUG 113515/2), 1.00cm-0.55cm.

**Remarks.** Leperditid ostracods have not previously been figured from the Pridolf of the Welsh Basin. The erratic boulder from the Vale of Wigmore contains a few specimens of *F.*
groenvalliana and is therefore of Downton Group age. The boulder contains abundant inarticulate brachiopods and leperditid ostracods, is thus distinct from the Downton Castle Sandstone Formation as exposed at Ludlow and probably derived from a Pridolf exposure younger than the Downton Castle Sandstone Formation.

Non-palaecope Ostracoda

(Pl. 18, fig. 16)

Material. Approximately 800 specimens of internal and external moulds. 

Localities and horizons. Upper Whitcliffe Formation, Clungunford (loc. 13a); Downton Castle Sandstone Formation, Much Wenlock area (locs 2, 3a-c, 4a, 4b, 11), the Ludlow Anticline (locs 14a, 14b, 17a, 17b, 18); Clun Forest Formation, Clun (loc. 39b); Platschisma helicites Beds, Knighton (locs 40b, c); Upper Perton and Rushall beds, Woolhope inlier (loc. 23a); Causemountain Formation, Long Mountain (loc. 36a). 

Description. Smooth unornamented ostracods with no lobation. 

Dimensions. Maximum length - height of figured specimen: (PM OS 14120), 1100μm-525μm. 

Remarks. Generally the non palaecope fauna is too badly preserved to enable detailed taxonomic research. Individuals have been treated as a single 'group' for the purpose of this study. Historically non-palaecopes at this level have been assigned to Cytherellina siliqua. Due to their simple nature, it is probable that non palaecope ostracodes have not been widely recognised in the field and are more common than previously reported in the literature.
REFERENCES


CHAPTER 3


85
Explanation of Plate 12

Figs 1, 7. *Calcaribeyrichia torosa* (Jones, 1855).

Fig. 1, TRV, silicone rubber cast of external mould, detail of velar spine and granular ornament on anteroventral margin of Pl. 15, fig. 13, PM OS 14150; Cefn Einion Formation, Radnor Wood, Clun, Shropshire (loc. 39d), X130; Fig. 7, Stereo-pair of T carapace, silicone rubber cast of external mould, closed carapace, only velar spines of (lower) RV visible, PM OS 14147; loose material, Cefn Einion Formation, Within Wood, Clun, Shropshire (loc. 39a), X21.


Fig. 2. T carapace, internal mould, lateral, carapace open in 'butterfly position,' PM OS 14098; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17a/5s, Ludford Lane, Ludlow, Shropshire (loc. 17a), X20.

Figs 3, 5. Stereo-pair of T carapace, silicone rubber cast of external mould, valves partially open, PM OS 14131; Rushall Beds, sample 23a/Y1, Perton Lane, Hereford and Worcester (loc. 23a), X30. Fig. 3, Oblique lateral/ dorsal; Fig. 5, Anterior.


Figs 4, 6. Stereo-pair of T carapace, silicone rubber cast of external mould, valves partially open, PM OS 14121; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17b/22a, Ludford Lane, Ludlow, Shropshire (loc. 17b), X29. Fig. 4, Oblique lateral/ dorsal; Fig. 6, Oblique posterior.

Fig. 9, HLV, original calcareous valve, lateral, BGS SH 3587; Downton Castle Sandstone Formation, Linley Brook, near Much Wenlock, Shropshire (loc. 3c), X15.

Fig. 8. *Hemsiella* cf. *maccoyiana*. Stereo-pair HRV, pyritised internal mould, lateral, PM OS 14133; Upper Llangibby Beds, sample 33/2, exposure next to Cwm-frwd Brook, Brook House, Usk, Gwent (loc. 33), X35.
Explanation Plate 13

All specimens are illustrated as stereo-pairs of silicone rubber casts of external moulds.

**Figs 1-10. Hemiisella cf. maccayiana.**

**Figs 1-4.** HLV, PM OS 14093; Upper Whitcliffe Formation, sample 14b/1, Weir Quarry, Downton, Shropshire (loc. 14b). **Fig. 1,** Lateral, X22; **Fig. 2,** Ventral, X22; **Fig. 3,** Detail of cruminal striaions, X38; **Fig. 4,** Dorsal, X22.

**Figs 5, 6, 10.** HLV, BGS JD 1251; Upper Whitcliffe Formation, Onibury, Shropshire (loc. 12a). **Fig. 5,** Lateral, X22; **Fig. 6,** Ventral, X22; **Fig. 10,** Detail of ornament on crumina, X130.

**Figs 7-9.** TRV, PM OS 14146; Cefn Einion Formation (loose material), Hendre Farm, Felindre, Powys (loc. 38c). **Fig. 7,** Lateral, X19; **Fig. 8,** Oblique ventral, X19; **Fig. 9,** Detail of ornament on preadductor and anterior lobes, X47.

**Figs 11-16. Lophoctenella cf. scanensis.**

**Figs 11, 12.** HRV, BGS RT 336; Whitcliffe Formation, Dean Brook, near Much Wenlock, Shropshire (loc. 4b). **Fig. 11,** Lateral, X18; **Fig. 12,** Dorsal, X18.

**Figs 13, 14.** HRV, PM OS 14136; Cauesmountain Formation, sample 36a/K1, Wallop Hall, Long Mountain (loc. 36a). **Fig. 13,** Lateral, X18; **Fig. 14,** Dorsal, X18.

**Figs 15, 16.** TLV, BGS RT 336; sample and locality as for fig. 11: **Fig. 15,** Lateral, X24; **Fig. 16,** Dorsal, X24.
Explanation of Plate 14

All specimens are illustrated as stereo-pairs of silicone rubber casts taken from external moulds.


Figs 1, 2. HLV, PM OS 14138; Causemountain Formation, sample 36a/M2, Wallop Hall Long Mountain, Powys (loc. 36a). **Fig. 1**, Lateral, X23; **Fig. 2**, Ventral, X22.

Figs 3, 4. HLV, BGS SH 3685; Downton Castle Sandstone Formation, Linley Brook, near Much Wenlock, Shropshire (loc. 3b). **Fig. 3**, Lateral, X14; **Fig. 4**, Detail of syllobium showing very weakly developed syllobial groove, X26.

Fig. 5. TLV, lateral, PM OS 6606; collected by Dr. David J. Siveter, Ludlow Bone Bed Member, Downton Castle Sandstone Formation, Ludford Lane, Ludlow (loc. 17a), X23.

Fig. 6. TLV, detail of syllobial callosum and groove, PM OS 14119; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17b/3a, Ludford Lane Ludlow, Shropshire (loc. 17b), X35.

Figs 7, 8. TLV, PM OS 14104; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17a/5r, Ludford Lane, Ludlow, Shropshire (loc. 17a). **Fig. 7**, Lateral, X17; **Fig. 8**, Ventral, X17.

Fig. 9. HRV, lateral, PM OS 14095; collected by Dr David J. Siveter, sample and locality as for fig. 5, X18.

Fig. 10. TRV, oblique ventral, PM OS 14101; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17a/5g, locality as for fig. 7, X14.

Fig. 11. TRV, lateral, PM OS 6609; collected by Dr David J. Siveter, sample and locality as for fig. 5, X15.

Fig. 12. TLV, detail of granulate/ tuberculate ornament on ventral part of syllobium and anterior lobe, PM OS 14099; Ludlow Bone Bed Member, Downton Castle Sandstone Formation sample 17a/5c, locality as for fig. 7, X28.

Figs 13, 15. TRV, PM OS 14123; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 18/2, Ludford Corner, Ludlow, Shropshire (loc. 18). **Fig. 13**, Detail of anterior margin showing velar spine, X65; **Fig. 15**, Lateral, X17.

Fig. 14. TRV, lateral, BGS SH 3685; sample and locality as for fig. 3, X17.

Fig. 16. TRV, ventral, PM OS 14100; sample and locality as for fig. 10, X16.
Explanation for Plate 15

All specimens are illustrated as stereo pairs of silicone rubber casts of external moulds, unless otherwise stated.

Figs 1-17. *Calcaribeyrichia torosa* (Jones, 1855).

Figs 1, 2. HLV, PM OS 14094; Upper Whitcliffe Formation (15c/3a), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15b). Fig. 1, Lateral, X11; Fig. 2, Posterior, X14.

Fig. 3. HLV, lateral, PM OS 6584; collected by Dr David J. Siveter, Cefn Einion Formation, Five Turnings outlier, Clun, Shropshire (loc. 39e), X11.

Fig. 4. TLV, dorsal, GM 8161; Cefn Einion Formation, Radnor Wood, Clun, Shropshire (loc. 39d), X16.

Figs 5, 6, 8. TLV, BGS DEY 3653, Upper Whitcliffe Formation, Ludford Lane, Ludlow, Shropshire (loc. 17a). Fig. 5, Lateral, X12; Fig. 6, Oblique ventral, X12; Fig. 8, Detail of syllobium showing coarsely tuberculate ornament and base to calcarine spine, X17.

Fig. 7. TLV, lateral, PM OS 6587; collected by Dr David J Siveter, sample and locality as for fig. 3, X13.

Figs 9, 10. HRV, GM 8022; sample and locality as for fig. 4. Fig. 9, Lateral, X11; Fig. 10, Oblique ventral, X11.

Fig. 11. HRV, lateral, PM OS 14151; Upper Leintwardine Formation, Sunnyhill Quarry, Ludlow, Shropshire (loc. 3.6d of Siveter et al. 1989), X11.

Fig. 12. HRV, lateral, PM OS 14092; Whitcliffe Formation, Aston Munslow, Corve Dale, Shropshire (loc. 7b), X15.

Figs 13, 16, 17. TRV, PM OS 14150; sample and locality as for fig. 4. Fig. 13, Lateral, X20; Fig. 16, Single shot showing detail of cuspidal part of preadductorial lobe, X27; Fig. 17, single shot of velar spines and granular ornament on anterior margin, X36.

Fig. 14. TRV, internal mould (counterpart to external mould cast and illustrated in fig. 13), lateral, PM OS 14149; sample and locality as for fig. 4, X20.

Fig. 15. TRV, lateral, PM OS 14091; Whitcliffe Formation, sample 7a/6, Aston Munslow, Corve Dale, Shropshire (loc. 7a), X13.
Explanation of Plate 16

All specimens are illustrated as stereo-pairs of silicone rubber casts of external moulds.

**Figs 1-16. Londinia arisaigensis** Copeland, 1964

**Fig. 1.** HLV, lateral, PM OS 14128; Downton Castle Sandstone Formation from loose material dumped after the excavation of Ludford Corner, Ludlow, Shropshire (loc. 18), X12.

**Fig. 2.** HLV, lateral, PM OS 14108; collected by Dr David J. Siveter, Platyschisma Shale Member, Downton Castle Sandstone Formation, Ludford Lane, Ludlow, Shropshire (loc. 17), X15.

**Fig. 3.** HLV, lateral, PM OS 14126; loose material from Platyschisma Shale Member, Downton Castle Sandstone Formation, Ludford Lane, Ludlow, Shropshire (loc. 17), X15.

**Fig. 4.** HLV, lateral, GPM OS 14134; Causemountain Formation, sample 36a/L, Wallop Hall, Long Mountain, Powys (loc. 36a), X13.

**Fig. 5.** TLV, lateral, PM OS 14140; Causemountain Formation, sample 36a/top2, locality as for fig. 4, X13.

**Figs 6-8.** TLV, PM OS 14130, Rushall Beds, sample 23a/P, Perton Lane, Perton, Hereford and Worcester (loc. 23a). **Fig. 6,** Oblique ventral, X19; **Fig. 7,** Lateral, X19; **Fig. 8,** Detail of ornament on ventral part of syllobium, X95.

**Fig. 9.** HRV, lateral, PM OS 14109; collected by Dr David J. Siveter, sample and locality as for fig. 2, X15.

**Fig. 10.** HRV, lateral, PM OS 14110; collected by Dr David J. Siveter, sample and locality as for fig. 2, X16.

**Figs 11, 12.** TRV, PM OS 14125; sample and locality as for fig. 1. **Fig. 11,** Lateral, X13; **Fig. 12,** Ventral, X13.

**Fig. 13.** TRV, lateral, GM 8131; Causemountain Formation, sample 36a/top5, locality as for fig. 4, X13.

**Fig. 14.** TRV, lateral, PM OS 14129; collected by Dr David J. Siveter, Rushall Beds, locality as for fig. 6, X25.

**Fig. 15.** TRV, lateral, PM OS 14122; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17b/23b, Ludford Lane, Ludlow, Shropshire (loc. 17b), X19.

**Fig. 16.** TRV, lateral, PM OS 14118; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17b/2b, locality as for fig. 15, X19.
All specimens illustrated as stereo-pairs of silicone rubber casts of external moulds.

Figs 1-4. *Londinia kiesowi* (Krause, 1891).

**Figs 1, 2.** HLV, BGS SH 3685; Downton Castle Sandstone Formation, Linley Brook, near Much Wenlock, Shropshire (loc. 3b). Fig. 1, Lateral, X15; Fig. 2, Dorsal, X15.

**Figs 3, 4.** TRV, PM OS 14135, Causemountain Formation, sample 36a/L, Wallop Hall, Long Mountain, Powys (loc. 36a). Fig. 3, Lateral, X15; Fig. 4, Ventral, X15.


**Fig. 5.** TLV, lateral, PM OS 14148; Green Downton Formation, sample 39b/4d, Clun Forest, Shropshire (loc. 39b), X19.

**Fig. 6.** TLV, lateral, BGS SH 3685; sample and locality as for fig. 1, X15.

**Figs 7, 8.** TRV, PM OS 14103; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17a/Sq, Ludford Lane, Ludlow, Shropshire (loc. 17a). Fig. 7, Lateral, X22; Fig. 8, Anterior view of preadductorial lobe showing reticulostriate ornament, X40.

**Figs 9, 10.** HRV, PM OS 14112; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17a/12d, locality as for fig. 7. Fig. 9, Lateral, X15; Fig. 10, Dorsal, X15.

**Fig. 11.** HRV, lateral, PM OS 14102; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17a/5p, locality as for fig. 7, X16.

**Fig. 12.** TRV, lateral, PM OS 14139; Causemountain Formation, sample 36a/M2, locality as for fig. 3, X17.

**Figs 13, 14.** TRV, PM OS 14132; Rushall Beds, sample 23a/X1, Perton Lane, Perton, Hereford and Worcester (loc. 23a). Fig. 13, Lateral, X27, Fig. 14, Ventral, X27.

**Figs 15, 16.** TRV, PM OS 14117; Ludlow Bone Bed Member, Downton Castle Sandstone Formation, sample 17b/2a, Ludford Lane, Ludlow, Shropshire (loc. 17b). Fig. 15, Lateral, X16; Fig. 16, Anterior view of preadductorial lobe showing reticulostriate ornament, X62.
Fig. 15. TLV, detail of preadductor lobe showing cristal loop and elongate/ twisted 'groenvalliana' type outline, PM OS 14116; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17a/29c, locality as for fig. 3, X30.

Fig. 16. Non-palaeocene ostracod, lateral, PM OS 14120; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17b/12a, locality as for fig. 9, X27.

Fig. 17. Leperditia sp. Lateral, LEIUG 113515/2; from erratic boulder of Downton Group age, Vale of Wigmore, X3.
Explanation for Plate 18

Specimens illustrated as stereo-pairs of silicone rubber casts from external moulds, unless otherwise stated.


**Figs 1, 2.** HLV, PM OS 14124; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 18/13a, Ludford Corner, Ludlow, Shropshire (loc. 18). **Fig. 1,** Lateral, X16; **Fig. 2,** Ventral, X16.

**Fig. 3.** HLV, detail of preadductorial lobe showing cristal loop and rounded 'lebiensis' style outline, PM OS 14114; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17a/26d, Ludford Lane, Ludlow, Shropshire (loc. 17a), X30.

**Fig. 4.** TLV, lateral, PM OS 14113; sample 17a/26a, locality as for fig. 3, X13.

**Fig. 5.** TLV, lateral, PM OS 13922; Downton Castle Sandstone Formation from loose material dumped after the excavation of Ludford Corner (loc. 18), X17.

**Fig. 6.** HRV, detail of striations on cuspidal part of preadductorial lobe, SGWG 90/2; from erratic boulder no. BEY B20, Graal-Muritz, near Rostock, Germany, X100. (Hansch et al. 1991, pl. 18.128, figs 4a, b, see Appendix 3 for further details).

**Figs 7, 8.** TLV, PM OS 14115; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17a/28b, locality as for fig. 3. **Fig. 7,** Lateral, X16; **Fig. 8,** Detail of cuspidal part of preadductorial lobe showing remains of striate ornament, X85.

**Figs 9, 10.** HRV, GM 8156; Platyschisma Shale Member, Downton Castle Sandstone Formation, sample 17b/28d, Ludford Lane, Ludlow, Shropshire (loc. 17b). **Fig. 9,** Lateral, X14; **Fig. 10,** Ventral, X14.

**Fig. 11.** T carapace, lateral, PM OS 14111; Platyschisma Shale Member, Downton Castle Sandstone Formation (17a/14a), locality as for fig. 3, X9.

**Fig. 12.** HRV, oblique ventral showing subcristal striations, BM OS 6621; collected by Dr David J. Siveter, Ludlow Bone Bed Member, Downton Castle Sandstone Formation, locality as for fig. 3, X13.

**Figs 13, 14.** TRV, PM OS 14127; sample and locality as for fig. 5. **Fig. 13,** Lateral, X17; **Fig. 14,** Dorsal, X17.
CHAPTER 4

OSTRACOD AND CONODONT DISTRIBUTION ACROSS THE LUDLOW/ PŘÍDOLÍ SERIES BOUNDARY (SILURIAN) AT LUDLOW, SHROPSHIRE

ABSTRACT. Conodont and ostracod faunas have been recovered from the Upper Silurian, Upper and Lower Whitcliffe formations and in detail across the basal boundary stratotype for the Downton Castle Sandstone Formation at Ludlow. The Upper Whitcliffe Formation is characterised by the ostracod Calcaribeyrichia torosa with the conodont O. cf. crispa ranging 15-30cm below the top of the formation.

The sudden change at the base of the Downton Castle Sandstone Formation to an ostracod fauna characterised by Frostiella groenvalliana is unlikely to be entirely facies related, although variations in ostracod abundance, faunal composition and carapace preservation coincide with palynofacies and minor lithofacies variations and may be related phenomena.

F. groenvalliana allows correlation of the base of the Downton Castle Sandstone Formation across the Welsh Borderland and by indirect and approximate correlation, to the base of the Prfdolf Series defined in Czechoslovakia. Direct and more precise conodont correlations suggest that the base of the Prfdolf Series is at least as high as the base of the Downton Castle Sandstone Formation and possibly at a low level within the formation. Combined ostracod and conodont correlations suggest that the base of the Prfdolf Series in Britain is concurrent with the base of the Downton Castle Sandstone Formation.
CHAPTER 4

INTRODUCTION

The Silurian System has four series and seven stages (Text-fig. 1.1). The bases of the Llandovery, Wenlock and Ludlow series are defined within the British Isles (Cocks 1985; Holland 1980). The base of the Předolí Series is defined at a level coincident with the base of the Monograptus parultimus Biozone (Bassett 1985) at Pozdy near Prague, Czechoslovakia.

In the Welsh Basin the lithostratigraphical boundary between the Upper Whitcliffe Formation and the Downton Castle Sandstone Formation (Text-fig. 1.1) is defined at the base of the Ludlow Bone Bed (Holland et al. 1963). The historical significance of the Ludlow Bone Bed has already been discussed (Chapter 1).

Previous work on ostracods has shown that the base of the Downton Castle Sandstone Formation correlates approximately with the base of the Předolí Series via a chain of correlation through Baltic marine successions (Siveter 1978, 1989; Bassett et al. 1982). Published conodont evidence suggests that the base of the Předolí may be slightly higher than the base of the Downton Castle Sandstone Formation (Schönlaub 1986; Aldridge and Schönlaub 1989; Miller 1992).

The aims of the present study are:

1. To document the distribution of conodonts and ostracods through the Upper Whitcliffe Formation and in detail across the boundary between the Upper Whitcliffe and Downton Castle Sandstone formations at Ludlow (Text-fig. 4.1).
2. To compare variations in the ostracod and conodont faunas with coeval variations in lithofacies and palynofacies.
3. To investigate the correlation of the base of the Ludlow Bone Bed Member across the Welsh Borderland and within the stratotype section for the base of the Předolí Series in Czechoslovakia.
CHAPTER 4

PREVIOUS RESEARCH

Much of the early research in the Ludlow area was stimulated by the work of Murchison (1839, 1842, 1852, 1854). Elles and Slater (1906), who described the geology of the Ludlow district, reviewed much of the early literature on the area, but considered at that time that the Ludlow Bone Bed was already too well known to require description.

The Silurian stratigraphy of the Ludlow area is based on the fundamental study of Holland et al. (1963). Details of the exposures of Silurian rocks around Ludlow can be found in chapter 2 of 'Silurian Field Excursions' (Siveter et al. 1989), published as a field guide to the Murchison Symposium, a meeting held to commemorate the 150th anniversary of the first edition of Murchison's book "The Silurian System" (1839).

The sedimentology of the Upper Whitcliffe and Downton Castle Sandstone formations at Ludford Corner and Ludford Lane (locs 17 and 18) has been interpreted by a number of authors (Allen and Tarlo 1963; Allen 1974; Antia 1980; Bassett et al. 1982; Smith and Ainsworth 1989). The macrofaunal communities of the Ludlow Series have been described (Calef and Hancock 1974; Watkins 1979), and an excellent summary of the macrofaunal and ostracod faunal changes across the base of the Downton Castle Sandstone Formation at Ludlow given by Bassett et al. (1982). The fish faunas from the Ludlow Bone Bed have been documented and interpreted by Turner (1973), Antia (1979a) and Antia and Whitaker (1979). Richardson and Lister (1969) and Richardson and Rasul (1990) have presented palynological data from the Upper Whitcliffe and Downton Castle Sandstone formations at Ludford Lane. Jeram et al. (1990) have documented trigonotarbid arachnids from the Ludlow Bone Bed Member at Ludford Corner (loc. 18), which are the earliest reported land animals. An iridium anomaly has been described in bone bed sediments from the Ludlow Bone Bed Member at Ludlow (Schmitz 1992).

Ostracods from the Downton Castle Sandstone Formation at Ludford Lane (loc. 17) have been studied by Shaw (1969), who used loose hand specimens as the basis of his work. Siveter (1974, 1978, 1989) and Hansch et al. (1991) have also described ostracod mould material from Ludford Lane. Conodont faunas from the Upper Whitcliffe Formation and from the Ludlow Bone Bed Member of the Downton Castle Sandstone Formation at Ludlow have been reported (Harley 1861; Walliser 1966; Aldridge et al. 1980; Aldridge 1985; Aldridge and Smith 1985; Schönlaub 1986; Aldridge and Schönlaub 1989).
CHAPTER 4

LOCALITIES AND HORIZONS

15a. WHITCLIFFE QUARRY. GR SO 5098 7414 (Siveter et al. 1989, loc. 3.1f). Upper and Lower Whitcliffe formations (boundary stratotype).

15b. WHITCLIFFE QUARRY. GR SO 5096 7414. Strata exposed as for loc. 15a.

15c. WHITCLIFFE QUARRY. GR SO 5092 7415. Possible boundary between Lower and Upper Whitcliffe formations.

15d. WHITCLIFFE QUARRY. GR SO 5089 7416. Strata exposed as for 15c.

16. CHARLTON ARMS HOTEL CAR PARK. GR SO 5116 7416. Upper Whitcliffe Formation.

17a. LUDFORD LANE 90m W of junction with A49. GR SO 5116 7413 (Siveter et al. 1989, loc. 3.2b). Upper Whitcliffe Formation, Ludlow Bone Bed Member and Platyschisma Shale Member of Downton Castle Sandstone Formation.

17b. LUDFORD LANE 80m W of junction with A49. GR SO 5117 7413. Strata exposed as for loc. 17a.

17c. LUDFORD LANE 70m W of junction with A49. GR SO 5118 7413. Strata exposed as for locals 17a and b. Only Upper Whitcliffe Formation sampled.

18. LUDFORD CORNER. GR SO 5124 7413. Upper Whitcliffe Formation§, Ludlow Bone Bed Member§, Platyschisma Shale Member and Sandstone Member of Downton Castle Sandstone Formation. Only units suffixed by § and the lowermost 7cm of the Platyschisma Shale Member sampled.

METHODS OF STUDY

Sampling

Slightly calcareous lithologies, bone beds and horizons with decalcified macrofauna or ostracod moulds were sampled from localities 15, 16, 17 and 18 (Text-fig. 4.1) covering the Lower and Upper Whitcliffe formations and the base of the Downton Castle Sandstone Formation (Text-fig. 4.2). Inaccessible cliff exposures at Whitcliffe Quarry (locals 15a-c) allowed only the lower part of the Upper Whitcliffe Formation to be sampled (Text-fig. 4.3) and only a single spot sample was taken at locality 16 because of access problems. Detailed sampling at Ludford Lane (loc. 17) was with permission from the Whitcliffe Commoners Association. A small number of samples were taken from the Upper Whitcliffe Formation and Ludlow Bone Bed Member of the
TEXT-FIG. 4.2. Approximate stratigraphic position of sections (thick black lines) and horizons sampled for phosphatic microfossils through the Lower Whitcliffe and Upper Whitcliffe formations on the Whitcliffe at Ludlow, Shropshire. Total thickness approximately 32m (Siveter et al. 1989, fig. 30). Sample numbers in bold (bed thicknesses given in brackets if known). For detailed sedimentary logs see Text-figs 4.3 and 4.4.
TEXT-FIG. 4.3. Measured logs across the boundary between the Lower Whitcliffe and Upper Whitcliffe formations at Whitcliffe Quarry, Ludlow (locs 15a, b, c) showing sampled horizons. Log at locality 15a after Holland et al. (1963, fig. 6).
CHAPTER 4

Downton Castle Sandstone Formation at Ludford Corner (loc. 18) in conjunction with Dr P. Selden and his co-workers (University of Manchester) who had obtained special permission to sample for land arthropods.

Detailed sedimentary logs were taken on a 'bed by bed' basis at localities 17 and 18, spanning the base of the Downton Castle Sandstone Formation (Text-fig. 4.4). The sampling interval was dictated by the presence of calcareous horizons or ostracod moulds. For each sample the minimum practical thickness of strata was collected (1-10 cm). Where possible, enough rock was sampled to fill a 20cm x 30cm sample bag, the equivalent of approximately 2kg of sample. However, sample size was often dictated by the presence of unstable overhanging strata or vertical cliff exposures.

Acid preparation

To recover conodonts and other phosphatic microfossils, slightly calcareous lithologies and bone beds were disaggregated in 10% acetic acid and, if the acid had little or no effect, crushed in a fly press (see Chapter 1 for more detailed description of laboratory processing techniques). All residues were sieved at 75μm and separated into heavy and light fractions using an aqueous solution of sodium polytungstate (manufactured by Sometru, Berlin) at a specific gravity of 2.80. Each heavy residue was picked completely for conodonts. The dry weight of each sample was taken initially and after treatment, to enable numbers of conodont elements per gram to be calculated.

Ostracod mould fauna preparation

Samples containing ostracod moulds were split in the laboratory, with care taken to keep part and counterpart together. An approximate calculation of ostracod abundance for each bed was obtained by dividing the total number of ostracod valves and carapaces for each bed by the total surface area viewed. Ostracods with well preserved external moulds were prepared and cast using silicone rubber (manufactured by Ambersil Ltd., Basingstoke) by the method described by Siveter (1982).
TEXT-FIG. 4.4. Sedimentary logs across the boundary between the Upper Whitcliffe and Downton Castle Sandstone formations at Ludford Corner and Ludford Lane (locs 17 and 18), showing horizons sampled for ostracods (bracketed and numbered).
CHAPTER 4

UPPER WHITCLIFFE FORMATION

Description and localities

The Upper Whitcliffe Formation consists of olive to blue-grey bioturbated siltstones and very fine sandstones with calcareous lenses and coquinoioid horizons. The coquinas are rich in disarticulated brachiopod valves with occasional orthoconic nautiloids and bivalves. The distinctive brachiopod and other calcareous fauna, which includes *Protochonetes ludloviensis*, *Salopina lunata* and *Microsphaeridiorhynchus nucula*, is often concentrated in decalcified, brown, rottenstone 'gingerbread' bands. Bedding is irregular, hard to trace laterally and towards the base is convoluted.

The base of the Upper Whitcliffe Formation is defined (Elles & Slater 1906; Holland et al. 1963, p. 123) at the base of the bed above the convoluted horizon at the disused 'Whitcliffe Quarry' (loc. 15a, Text-fig. 4.3). The two shaly beds beneath the convoluted bed are traceable from localities 15a to 15b, but there is a small fault in the section at locality 15c which makes it difficult to trace the convoluted horizon to localities 15c and 15d. Convoluted bedding is well developed at the 'dog-leg' of the exposure at 15c and for the purposes of this study has been taken as the topmost bed of the Lower Whitcliffe Formation, although the convoluted bed is considerably thicker at 15c than at 15a (Text-fig. 4.3). The precise stratigraphic position of samples from localities 15c and 15d is consequently uncertain. A single spot sample was taken 50cm above the base of the exposure at 15d and has been estimated as 3m below the base of the Upper Whitcliffe Formation. The top of the Upper Whitcliffe Formation is at the base of the Ludlow Bone Bed Member (i.e. the base of The Ludlow Bone Bed) at loc. 18, and the formation is approximately 32m thick at Ludlow (Siveter et al. 1989, fig. 30).

There are no continuous exposures through the Upper Whitcliffe Formation at Ludlow. Localities 15-18 are mostly cliff exposures and give an almost complete coverage of the formation (Text-fig. 4.2). At localities 15 and 16 the upper parts of the sections are inaccessible. The sampling interval throughout the formation is, therefore, irregular and ranges from 5cm to approximately 10m. If the convoluted horizon at 15c is the topmost bed of the Lower Whitcliffe Formation then samples 15c/1, 74/1* and 15d/1 are all from the upper part of the Lower Whitcliffe Formation (Text-figs 4.2, 4.3). The sample taken at locality 16 is estimated as approximately 10m below the Ludlow Bone Bed, and samples from localities 17 and 18 cover the top 50cm of the formation (Text-fig. 4.2).
CHAPTER 4

Microfossil distribution

Conodonts. Conodonts were recovered from calcareous to slightly calcareous lithologies which occur sporadically throughout the Upper Whitcliffe Formation. Elements are well preserved and pale amber in colour although some specimens are fragmentary, particularly those from slightly calcareous lithologies which required crushing to extract the fauna. More than 1,800 specimens belonging to 9 multielement species (Text-figs 4.5, 4.6) were extracted and examined from localities 15 to 18. Conodont bearing samples contain from 20 to 1,056 conodont elements per kilogram (Text-fig. 4.7).

Conodont faunas from the topmost Lower Whitcliffe Formation and lowermost 5m of the Upper Whitcliffe Formation (Text-fig. 4.7) consist dominantly of Ozarkodina excavata and Coryssognathus dubius elements with minor numbers of Panderodus serratus and O. confiuens. Other less common species include O. remcheidensis eosteinhornensis, O. r. baccata, O. snajdri and O. wimani (only sample 74/1*). At the top of the Upper Whitcliffe Formation these less common species become more frequent and the fauna becomes dominated by C. dubius and O. snajdri with minor numbers of remcheiagensis subspecies (notably O. r. eosteinhornensis) and O. cf. crisps, which occurs only in strata 15-30cm below the top of the formation. In the topmost 30cm of the Upper Whitcliffe Formation O. excavata is much less abundant, O. confiuens becomes more abundant and P. serratus is no longer present.

Relative proportions of the individual elements from the apparatus of O. excavata, calculated for samples from the uppermost Lower Whitcliffe Formation and the lowermost 5m of the Upper Whitcliffe Formation that contain more than 50 elements of O. excavata, show insignificant variation in relative percentages of elements (Text-fig. 4.8).

Ostracods. So far it has been practical to recover the faunas, the Upper Whitcliffe Formation has a virtually monospecific ostracod fauna of Calcaribeyrichia torosa (Text-figs 4.9 a, b). This species has been found throughout the Upper Whitcliffe Formation (loc. 17a and in samples 15b/2, 15c/3, 17c/1, 18/1) and is mostly confined to decalcified brachiopod coquinas. At localities 17 a-c and 18, where the uppermost 50cm of the Upper Whitcliffe Formation has been sampled 'bed by bed,' only a few isolated specimens of C. torosa have been recovered (samples 17c/1, 18/1 and specimen BGS DEY 3653). C. torosa has been reported from both
TEXT-FIG. 4.5. Conodonts from the Upper Whitcliffe and Downton Castle Sandstone formations at Ludlow, Shropshire. a, Panderodus serratus (Rexroad, 1967), unfurrowed lateral face, arcuiform element, Upper Whitcliffe Formation (sample 15a/2), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15a), PM X 1178, x80. b, Coryssognathus dubius (Rhodes, 1953), lateral, Pa element, Upper Whitcliffe Formation (sample 15a/2), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15a), PM X 1177, x45. c, d, Ozarkodina confluens (Branson & Mehl, 1933): c, lateral, Pa element, Upper Whitcliffe Formation (sample 74/1*), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15c), PM X 1183, x22; d, lateral, Pa element fragment, Ludlow Bone Bed Member, Downton Castle Sandstone Formation (sample 17a/5), Ludford Lane, Ludlow, Shropshire (loc. 17a), PM X 1188, x22. e, O. excavata (Branson & Mehl, 1933), lateral, Pa element, Upper Whitcliffe Formation (sample 15a/2), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15a), PM X 1174, x36. f, h, i, O. cf. crispa (Walliser, 1964): f, i, lateral and upper views, Pa element with broken posterior termination, Upper Whitcliffe Formation (sample 18/1), Ludford Corner, Ludlow, Shropshire (loc. 18), PM X 1189, x40; h, lateral, posterior termination of Pa element, Upper Whitcliffe Formation (sample 77/2*), Ludford Lane, Ludlow, Shropshire (loc. 17a), PM X 1187, x100. g, O. snajdri (Walliser, 1964), lateral, Pa element, Upper Whitcliffe Formation (sample 15a/2), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15a), PM X 1176, x40. j, O. remscheidensis eosteinhornensis (Walliser, 1964), lateral, fragment of Pa element with broken anterior process, Upper Whitcliffe Formation (sample 18/1), Ludford Corner, Ludlow, Shropshire (loc. 18), PM X 1190, x50. k, O. r. baccata ssp. nov., lateral, fragment of a Pa element with broken posterior process, Upper Whitcliffe Formation (sample 77/2*), Ludford Lane, Ludlow, Shropshire (loc. 17a), PM X 1186, x50. l, O. wimanii Jeppson, 1974, lateral, Pa element, Upper Whitcliffe Formation (sample 74/1*), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15c), PM X 1184, x85. All specimens are deposited in the Natural History Museum, London.
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TEXT-FIG. 4.6. Conodont faunas from the Upper Whitchcliffe and Downton Castle Sandstone formations (locs 15-18) at Ludlow (Text-fig. 4.1).
TEXT-FIG. 4.7. Conodont ranges and compositions of conodont faunas from the Lower Whitcliffe, Upper Whitcliffe and Downton Castle Sandstone formations at Ludlow, Shropshire (locs 15-18). Positions marked on the lithostratigraphical column are given to the centre of the bed sampled. Details of bed thicknesses are given in Text-figures 4.2 - 4.4.
TEXT-FIG. 4.8. Relative proportions of *O. excavata* elements from the Lower Whitcliffe and Upper Whitcliffe formations at Whitcliffe Quarry, Ludlow, Shropshire (loc. 15). Samples are arranged in stratigraphic order with oldest at the base. Sample positions are shown in Text-figures 4.2 and 4.3.
TEXT-FIG. 4.9. Ostracods from the Upper Whitcliffe and Downton Castle Sandstone formations at Ludlow, Shropshire. Unless stated, all specimens illustrated are lateral views of silicone rubber casts from external moulds. a, b, Calcaribeyrichia torosa (Jones, 1855): a, heteromorphic left valve, Upper Whitcliffe Formation (sample 15c/3a), Whitcliffe Quarry, Ludlow, Shropshire (loc. 15c), PM OS 14094, x11; b, tecnomorphic left valve, Upper Whitcliffe Formation, Ludford Lane, Ludlow, Shropshire (loc. 17a), BGS DEY 3653, x12. c, d, Frostiella groenvalliana Martinsson, 1963: c, heteromorphic right valve, Platyschisma Shale Member, Downton Castle Sandstone Formation (sample 17b/28d), Ludford Lane, Ludlow, Shropshire (loc. 17b), GM 8156, x14; d, tecnomorphic left valve, Downton Castle Sandstone Formation from loose material dumped after clearing Ludford Corner (loc. 18) in 1988, BM OS 13922, x17. e, f, Londinia arisaigensis Copeland, 1960: e, heteromorphic left valve, Downton Castle Sandstone Formation from loose material dumped after clearing Ludford Corner (loc. 18) in 1988, PM OS 14128, x12; f, tecnomorphic right valve, Downton Castle Sandstone Formation from loose material dumped after clearing Ludford Corner (loc. 18) in 1988, PM OS 14125, x13. g, h, Londinia fissurata Shaw, 1969: g, heteromorphic right valve, Platyschisma Shale Member, Downton Castle Sandstone Formation (sample 17a/12d), Ludford Lane, Ludlow, Shropshire (loc. 17a), PM OS 14112, x15; h, tecnomorphic right valve, Ludlow Bone Bed Member, Downton Castle Sandstone Formation (sample 17b/2a), Ludford Lane, Ludlow, Shropshire (loc. 17b), PM OS 14117, x16. i, j, Nodibeyrichia verrucosa Shaw, 1969: i, heteromorphic right valve, Ludlow Bone Bed Member, Downton Castle Sandstone Formation (collected by Dr David J. Siveter), PM OS 14095, x15; j, tecnomorphic left valve, Ludlow Bone Bed Member, Downton Castle Sandstone Formation (sample 17b/3a), Ludford Lane, Ludlow, Shropshire (loc. 17b), PM OS 14119, x17. k, non-palaeocope ostracod, Platyschisma Shale Member, Downton Castle Sandstone Formation (sample 17b/12a), Ludford Lane, Ludlow, Shropshire (loc. 17b), PM OS 14120, x27. l, Londinia fissurata Shaw, 1969, internal mould of tecnomorphic carapace with valves fully open in 'butterfly position,' Ludlow Bone Bed Member, Downton Castle Sandstone Formation (sample 17a/5s), Ludford Lane, Ludlow, Shropshire (loc. 17a), PM OS 14098, x15. All figured specimens are deposited in the Natural History Museum, London with the exception of Text-figure 4.10b, which is kept at the British Geological Survey (Keyworth).
CHAPTER 4

the Lower Whitcliffe and Upper Whitcliffe formations (Siveter 1974) and also in the lowest part of the Ludlow Bone Bed Member of the Downton Castle Sandstone Formation at Ludford Lane (loc. 17a) (Bassett et al. 1982, fig. 6). An internal mould of Hemiella cf. maccyiana has been recovered from 15cm below the top of the Upper Whitcliffe Formation at Ludford Corner (loc. 18) (Text-fig. 4.10).

DOWNTON CASTLE SANDSTONE FORMATION

Description and localities

The base of the Downton Castle Sandstone Formation is defined at locality 18, Ludford Corner (Holland et al. 1963). Samples have been taken from the Upper Whitcliffe Formation, Ludlow Bone Bed Member and lowermost 7cm of the Platyschisma Shale Member at that locality. Text-figure 4.4 shows sample positions and the extensive sampling carried out at localities 17a and b on Ludford Lane, which also expose the boundary between the Upper Whitcliffe and Downton Castle Sandstone formations.

The Downton Castle Sandstone Formation has three members (Text-fig. 1.1). The lowest member, the Ludlow Bone Bed Member, described in detail by Bassett et al. (1982, pp. 6, 14), consists of parallel to lenticular laminated muddy siltstones with several discontinuous vertebrate sand lamina tions which are occasionally ripple laminated (Text-fig. 4.4). The vertebrate sands consist essentially of thelodont dermal denticles with Thelodus parvidens and Logania ludloviensis dominant (Turner 1973). Acanthodian and phosphatised shell fragments, minor quartz grains and rare conodont fragments also occur (Text-fig. 4.5d). The base of the member is defined at the base of the Ludlow Bone Bed (Holland et al. 1963). The upper limit of the member is defined at the top of a sequence of three closely spaced millimetre scale bone beds 21cm above the base of the member (Bassett et al. 1982, p. 14). In practice, bone beds in the Ludlow Bone Bed Member are discontinuous and the top of the member has not been accurately located at Ludford Lane (locs 17a & b), and only a single bone bed has been located at that level at Ludford Corner (loc. 18) (Text-fig. 4.4).

The Platyschisma Shale Member consists of up to 2m of siltstones to very fine sandstones. The lower metre consists of bioturbated laminated siltstones fining upwards to thin mudstone caps. Bedding is gently undulose with near parallel laminations to low angle cross laminations and synaeresis cracks (Text-fig. 4.4; Smith and Ainsworth 1989). In the metre
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**TEXT-FIG. 4.10.** Frequencies of ostracod valves and carapaces from the Upper Whitcliffe and Downton Castle Sandstone formations at Ludford Corner (loc. 18). Numbers after decimal points refer to numbers of carapaces. Positions of samples are given in Text-fig. 4.4.
above, bioturbated siltstones are gradually replaced by very fine sandstones with sharp erosive bases and internal low angle cross laminations; gastropods (*Turbocheilus helicites, Loxonema* sp.), bivalves (*Modiolopsis* sp.) and ostracods are accumulated in lags at the bases of beds.

The Sandstone Member consists of 15m of gradually coarsening upwards, hummocky cross stratified, very fine to fine sandstones (Smith and Ainsworth 1989), but these have not been sampled for the present study.

**Microfossil distribution**

*Conodonts.* Conodonts are very rare in the Downton Castle Sandstone Formation. Conodont bearing samples contain 6-105 conodont elements per kg, but generally less than 20 per kg (Text-fig. 4.7). Conodont elements have been obtained from bone beds within the Ludlow Bone Bed Member, but the bone beds are hard to process, contain abundant phosphatic material and conodont elements are extremely fragmentary and abraded thus making identification difficult. Only fragments of Pa elements of *O. confluens* (Text-fig. 4.5d) and Sa/Sb elements of *C. dubius* have been identified with any certainty in this study. Harley (1861) figures a similar fauna, Aldridge and Smith (1985) have also reported fragments of *O. excavata* and WALLISER (1966) has recorded *O. r. eosteinhornensis* from the Ludlow Bone Bed Member at Ludlow.

*Ostracods.* 2145 individual ostracod valves and 23 specimens of carapaces with co-joined valves have been recovered from the Downton Castle Sandstone Formation at localities 17 and 18 (Text-figs 4.10-4.12). Individual (mould) specimens are often incomplete or obscured and therefore identifiable only to generic level. Relative generic proportions for each bed containing more than 10 specimens have been plotted (Text-fig. 4.13), with ostracod frequency and % of carapaces against valves plotted for every bed in the section (Text-fig. 4.14).

The ostracod fauna shows a similar trend in the two parallel sections 10m apart on Ludford Lane (locs 17a, b) and also at Ludford Corner (loc. 18). The lowest bed in the Ludlow Bone Bed Member at all three sections contains *Frostiella groenvalliana, Londinia arisaigenys, L. fissurata*, and *Nodibeyrichia verrucosa*. The relative generic proportions from these three beds are relatively similar with *Londinia* (44-62%), *Frostiella* (24%), *Nodibeyrichia* (12-17%) and non-palaeocope ostracods (0-14%). The percentage of *Frostiella* increases upwards through the Ludlow Bone Bed Member until it becomes the dominant genus with a
| Sample number | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Area (cm²)    | 1456| 595| 274| 231| 118| 15 | 814| 841| 90 | 1194| 136| 121| 12 | 80 | 684| 844| 260| 410| 376| 36 | 672| 486| 810| 274|
| n valves      | 128 | 52 | 46 | 21 | 7  | 2  | 49 | 30 | 9  | 57 | 11 | 7  | 2  | 4  | 17 | 35 | 4  | 79 | 47 | 6  | 54 | 56 | 85 | 88 | 30 |
| n carapaces   | 5   | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| *Froestiella* | 12.3| 7  | 26 | 10.1| 3  | 1  | 35.1| 11 | 6.1| 29.1| 3  | 4  | 3  | 5  | 14.1| 2  | 37 | 13 | 3  | 32 | 38 | 34 | 57 | 14 |
| *F. cf.*     |     |    | 3  | 1  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *groenvalli* | 6   | 5  | 2  | 4  | 8  | 1  | 2  | 2  | 2  | 3  | 14 | 3  | 7  | 5  | 10 | 10 | 4  |    |    |    |    |    |    |    |
| *Londinia*   | 13.1| 2  | 1  | 5  | 1  | 1  | 1  | 2  | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *A. o. artu* |     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *L. cf. artu*|     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *Londinia*   | 10.1| 2  | 3  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *L. cf. artu*| 18  | 6  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *Nobilerychia*| 13 | 3  | 3  | 3  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| *N. terric*  | 1   | 1  | 2  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| *N. terric*  | 3   | 1  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| *on-palaeocytes*| 13 | 3  | 2  | 5  | 1  | 2  | 2  | 2  | 2  | 2  | 3  | 1  | 4  | 11 | 1  | 16 | 17 | 1  | 9  | 8  | 8  | 6  | 9  |
| *Unidentifiable*| 39 | 22 | 8  | 2  | 3  | 4  | 2  | 16 | 3  | 3  | 5  | 12 | 14 | 2  | 5  | 5  | 11 | 9  | 2  |

**TEXT-FIG. 4.11.** Frequencies of ostracod valves and carapaces from the Downton Castle Sandstone Formation at Ludford Lane (loc. 17a). Numbers after decimal points refer to numbers of carapaces. Positions of samples are given in Text-figure 4.4.
<table>
<thead>
<tr>
<th>Sample number</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8.1</th>
<th>8.2</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (cm²)</td>
<td>370</td>
<td>227</td>
<td>126</td>
<td>367</td>
<td>20</td>
<td>360</td>
<td>148</td>
<td>366</td>
<td>132</td>
<td>181</td>
<td>101</td>
<td>228</td>
<td>329</td>
<td>352</td>
<td>759</td>
<td>221</td>
<td>469</td>
</tr>
<tr>
<td>n valves</td>
<td>48</td>
<td>41</td>
<td>17</td>
<td>53</td>
<td>5</td>
<td>37</td>
<td>15</td>
<td>39</td>
<td>11</td>
<td>35</td>
<td>2</td>
<td>16</td>
<td>18</td>
<td>31</td>
<td>53</td>
<td>18</td>
<td>26</td>
</tr>
<tr>
<td>n carapaces</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Frostiella</em></td>
<td>6</td>
<td>12</td>
<td>9</td>
<td>33.1</td>
<td>2</td>
<td>11</td>
<td>13</td>
<td>20.1</td>
<td>6</td>
<td>11.2</td>
<td>6</td>
<td>6</td>
<td>13.1</td>
<td>27</td>
<td>5</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td><em>greenvalliara</em></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>1</td>
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<td>4</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><em>Londinia</em></td>
<td>3</td>
<td>5</td>
<td>0.1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>13</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><em>ariaigenisis</em></td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>L. cf. flavuata</em></td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>4</td>
<td>10</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td><em>Nodobryrichia</em></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>13</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><em>vernicosa</em></td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td><em>Nodobryrichia</em></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>13</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><em>nano-valvescles</em></td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Unidentifiable</td>
<td>15</td>
<td>8</td>
<td>3</td>
<td>10</td>
<td>14</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>18</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**TEXT-FIG 4.12.** Frequencies of ostracod valves and carapaces from the Downton Castle Sandstone Formation at Ludford Lane (loc. 17b). Numbers after decimal points refer to numbers of carapaces. Positions of samples are given in Text-figure 4.5.
TEXT-FIG. 4.13. Ostracod faunal composition from the Downton Castle Sandstone Formation at Ludford Lane and Ludford Corner (locs 17a, b and 18). The height of each bar corresponds to the relative thickness of a bed which contains more than 10 ostracods. The positions of numbered samples are given in Text-figure 4.4.
TEXT-FIG. 4.14. Ostracod frequency and % of carapaces with respect to valves for all ostracod samples from the Upper Whitecliffe and Downton Castle Sandstone formations at Ludford Lane and Ludford Corner (locs 17a, b and 18).
corresponding decrease in the relative frequency of *Londinia*. Carapaces are more common in the Ludlow Bone Bed Member and lowermost 15cm of the Platyschisma Shale Member than in any other part of the section and reach a maximum of 15% with respect to the number of valves (sample 17b/10). In the present study *C. torosa* has not been found above the Upper Whitcliffe Formation, but Bassett *et al.* (1982, fig. 6) record *C. torosa* within the Ludlow Bone Bed Member at Ludford Lane (loc. 17a). This specimen (BGS MR DEY 3694) has been examined by the author and confirms the occurrence of *C. torosa* (with coeval *F. groenvalliana*) at a level 8cm above the base of the Ludlow Bone Bed Member.

In the sections sampled, *N. verrucosa* last occurs 34cm above the base of the Ludlow Bone Bed Member (sample 17b/11). From this level the relative proportions of *Frostiella*, *Londinia* and non-palaeocope ostracods fluctuate greatly (Text-fig. 4.13); *Frostiella* and non-palaeocopes are always present, with *Londinia* varying from 0-23%. After the last occurrence of *N. verrucosa*, ostracod frequencies are low (<0.1 ostracod/ cm²), but increase in the upper metre of the Platyschisma Shale Member, reaching a maximum of 2.0 ostracods/ cm² (sample 17b/28). Carapaces are not preserved in the upper metre of the Platyschisma Shale Member where *Londinia* is uncommon (0-7%).
Previous environmental interpretations of the Upper Whitcliffe Formation have been made by Watkins (1979), Bassett et al. (1982), Allen (1985) and Richardson and Rasul (1990). Watkins (1979) and Bassett et al. (1982) interpreted deposition as subtidal on a proximal shelf, mostly within wave base, shallowing towards the top of the formation with coquinas representing storm events. Allen (1985, p. 90) also recognised "storm related planar to hummocky lamination, cross lamination and current ripples."

Conversely, Richardson & Rasul (1990) have proposed a deepening towards the end of deposition of the Upper Whitcliffe Formation, based on palynofacies at Weir Quarry, Downton (loc. 14b), a locality c.5.5 km W of the Ludford Corner section (loc. 18). Ainsworth (1991) has questioned the palynofacies interpretations of Richardson and Rasul (1990), suggesting that palynomorphs would have been reworked by onshore and offshore sediment movements in the storm dominated environments of the Upper Whitcliffe and Downton Castle Sandstone formations. Alternatively, the Ludlow and Downton areas could have experienced differing localised environmental changes towards the end of deposition of the Upper Whitcliffe Formation and the beginning of deposition of the Downton Castle Sandstone Formation.

The composition of conodont samples that have undergone significant post-mortem sorting reflect the hydrodynamic regime, rather than the original faunal composition (McGoff 1991). It seems unlikely that samples from the base of the Upper Whitcliffe Formation have undergone significant post-mortem sorting as elements are well preserved and relative proportions of individual elements of *O. excavata* remain almost constant, thus reflecting original apparatus composition (Text-fig. 4.8). Elements from the uppermost metre of the Upper Whitcliffe Formation contain a dominance of *C. dubius* and *O. confluens*, often present almost exclusively as abraded specimens of Sa/Sb and Pa elements respectively. Post-mortem sorting seems to have significantly affected these samples as the Sa/Sb and Pa elements of the respective species are the most robust in the apparatus and therefore most likely to withstand abrasion associated with sorting. The conodont faunal variations illustrated in Text-figure 4.7 therefore probably reflect a combination of changes in faunal abundances and hydrodynamic regimes. The preservation of the conodont fauna indicates a more turbulent environment within the top metre of the Upper Whitcliffe Formation compared with the basal 5m sampled. This
increased turbulence could be associated with the shallowing interpreted by Watkins (1979) and Bassett et al. (1982). At Ludlow the absence of *P. serratus* within the topmost 50 cm of the Upper Whitcliffe Formation may be related to this increased turbulence.

**Downton Castle Sandstone Formation**

The marked sedimentological, macro- and microfaunal change at the base of the Ludlow Bone Bed Member has been explained by a sudden regression and subsequent transgression (Allen and Tarlo 1963; Antia and Whitaker 1978; Antia 1979a, 1980a; Richardson and Rasul 1990). Conversely, Smith and Ainsworth (1989, p. 898) have explained the deposition of the Ludlow Bone Bed Member by "repeated storm reworking during a period of reduced sediment supply, probably associated with a raised sea level." Hummocky cross stratification has been documented from the Sandstone Member at Ludford Corner and suggests shallow deposition (water depths of a few metres), possibly in a shoreface environment dominated by storms (Smith and Ainsworth 1989; Siveter et al. 1989).

Richardson and Rasul (1990) stated that the lowermost Downton Castle Sandstone Formation at Ludlow contains a greater proportion of land-derived sporomorphs than the coeval section at Weir Quarry, Downton, although Ainsworth (1991) noted that these differences could be explained by preferential winnowing of the smaller acritarchs from the larger spores. Richardson and Rasul (1990, p. 681) suggested that distribution patterns could be affected by a "pattern of distributionary channels delivering high concentrations of land-derived sporomorphs in a non-uniform fashion along an irregularly prograding shoreline." Ainsworth (1991) has questioned Richardson & Rasul's (1990) palynofacies interpretations suggesting that more recent sedimentological interpretations (Smith & Ainsworth 1989) indicate storm dominated environments in which palynomorphs would have been reworked by on-shore and off-shore sediment movements.

By the end of the Silurian, "ostracods had occupied most of the marine environments and taken up most of the life-styles known from modern ostracods" (Siveter 1984, p. 71). Based on evidence from elsewhere in Europe and also in N America, Siveter (1984, p. 73) suggested that in the marine to restricted marine transition of the British Downton Group that ostracods "for the first time began adapting to salinity changes that included reduced salinity, brackish water, and hypersaline conditions." The species present in the Upper Whitcliffe and
Downton Castle Sandstone formations cannot be directly compared taxonomically with Recent ostracods. However, to assess their palaeoenvironmental and biostratigraphical potential, we can compare other reported occurrences of the same late Silurian species in order to assess their ecological ranges.

*F. groenvalliana* has been reported in a wide range of environments (see Hansch et al. 1991 for details of distribution), from the deeper water, outer shelf areas of the Leba elevation, Poland (Tomczykowa and Witwicka 1974) and the Kaliningrad region (Kaljo and Sarv 1976) to fully marine carbonate facies of Scania, Sweden (Martinsson 1962, 1967). Sarv (1968, 1971) and Kaljo and Sarv (1966) have demonstrated the incoming of *F. groenvalliana* within a fully marine succession in the East Baltic. *F. groenvalliana* has been reported from basal part of the Downton Castle Sandstone Formation in the "basinal" area of the Welsh Basin at Clun, Knighton and Long Mountain (Shaw 1969; present study), across the "shelf" area of Shropshire (Shaw 1969; Siveter 1974, 1978, 1989; Hansch et al. 1991; present study) and at Woolhope and Capel Horeb, Llandovery (present study). Because of its apparently wide ecological (facies) tolerance, the sudden appearance of *F. groenvalliana* at the base of the Ludlow Bone Bed Member is therefore unlikely to be entirely due to the marked facies change at that level.

*L. arisaigensis* has been reported from Arisaig, Nova Scotia from both limestones and shales (Copeland 1960, 1964). In the Welsh Basin *L. arisaigensis* has been recovered from the Downton Castle Sandstone Formation and its lateral equivalents across the "shelf" area throughout Shropshire and at Woolhope and from the "basinal" area at Long Mountain and Knighton (Shaw 1969; Siveter 1974, 1978, 1989; present study). *L. arisaigensis* has also been recovered from the Cefn Einion Formation at Clun (present study) and the Causemountain Formation at Long Mountain (Shaw 1969), and therefore appears to have been tolerant of a wide range of environments. *L. fissurata* has been reported only from the Welsh Basin (Shaw 1969; Siveter 1974, 1978, 1989) and has a similar distribution to *L. arisaigensis* (present study).

*N. verrucosa* is considered conspecific with *N. jurassica* (Gailite), the index species for the late Pridolf 'Stage' of the island of Saaremaa, Estonia, and commonly found in faunally rich and diverse open shelf, marine environments (Sarv 1968, 1971; Kaljo 1970; Meidla and Sarv 1990; Nestor 1990; Hansch and Siveter in press). In the Welsh Borderland,
N. verrucosa is restricted to the Much Wenlock, Ludlow, Downton, Knighton and Long Mountain areas (Shaw 1969, Siveter 1974, 1978; present study), areas which embrace both the "shelf" and "basin" areas of the Welsh Borderland.

_Calcaribeyrichia torosa_, the characteristic ostracod of the Upper Whitcliffe Formation in the Welsh Borderland, is found in the "basin" area in the Downton Castle Sandstone Formation and its lateral equivalents at Long Mountain (Shaw 1969; present study) and on the "shelf" at Ludlow (Bassett _et al._ 1982). The species is also present in the Underbarrow, Kirkby Moor and Scout Hill Flags of Cumbria (Shaw 1971). _Beyrichia cuspidata_ (Gröenwall, 1867), a species characteristic of the marine upper Ludlow of Scania, although in need of taxonomic revision, has been noted as a possible synonym for _C. torosa_ (Siveter 1989).

The ostracod taxa characteristic of the Upper Whitcliffe and Downton Castle Sandstone formations appear to be tolerant across a wide range of environments; the marked turnover in ostracod faunas at the base of the Ludlow Bone Bed Member is, therefore, unlikely to be entirely facies related. In the more offshore, basinal area of the Welsh Borderland at Long Mountain, the ostracod faunal change is not as sudden as at Ludlow (Shaw 1969). For a time the characteristic Upper Whitcliffe species _C. torosa_ persists into the local equivalent of the Downton Castle Sandstone Formation alongside the typical Downton Castle Sandstone Formation ostracods _F. groenvalliana_ and _N. verrucosa_. Some ostracod taxa, for example _C. torosa_, therefore appear to be partly environmentally controlled (see discussion below).

Ostracod frequencies, preservation and faunal compositions are coeval with fine scale sedimentological changes in the Ludford Lane section and these two factors are possibly related (Text-fig. 4.15):

1. The coarsening upwards of the sediments in the Ludlow Bone Bed Member and lowermost 15cm of the Platyschisma Shale Member corresponds with an increase in the proportion of _Frostiella_ and a parallel decrease in the proportion of _Londinia_. Frequency is relatively high and carapaces are most commonly preserved in these strata.

2. The first occurrence of bioturbated synaeresis-cracked siltstones at the base of the Platyschisma Shale Member corresponds to a horizon where ostracod frequency becomes very low but carapaces are still preserved.

3. The onset of cross laminated units with sharp erosive bases corresponds to high frequency ostracod faunas dominated by _Frostiella_ and non-paleocopos, with _Londinia_ very rare.
<table>
<thead>
<tr>
<th>Lithostratigraphy</th>
<th>Characteristic lithology and structures</th>
<th>Characteristic ostracod fauna</th>
<th>Carapace?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downton Castle Sandstone Formation</td>
<td>Cross laminated very fine sandstones with erosive bases shell legs</td>
<td>dominant <em>Frostiella</em> with non-palaeocopae and minor <em>Londinia</em></td>
<td>High not present</td>
</tr>
<tr>
<td></td>
<td>Bioturbated siltstones with synaeresis cracks</td>
<td><em>Frostiella</em> with <em>Londinia</em> and non-palaeocopae</td>
<td>Low present</td>
</tr>
<tr>
<td></td>
<td>Parallel laminated silt/muds coarsening upwards, bioturbated at top, bone beds at base</td>
<td><em>Frostiella</em> increasing upwards with corresponding decrease in <em>Londinia</em></td>
<td>Mod. present</td>
</tr>
<tr>
<td></td>
<td>Bioturbated siltstones with brachiopod coquinas</td>
<td><em>Calcarbelowithia</em> with minor <em>Hemisella</em></td>
<td>V. low not present</td>
</tr>
</tbody>
</table>

TEXT-FIG. 4.15. Summary of the relationship between lithostratigraphy/lithology, and characteristic ostracod fauna/carapace/frequency data for the Upper Whitcliffe and Downton Castle Sandstone formations at Ludlow (locs 17a, b, and 18).
Ostracods are concentrated as lags at the bases of beds (Text-fig. 4.4). Carapaces are no longer preserved.

Local factors also appear to affect the presence and frequency of ostracod faunas in the Downton Castle Sandstone Formation. The Downton Castle Sandstone Formation at Weir Quarry, Downton (loc. 14b) has also been sampled in detail as part of the present study and contains a very sparse ostracod fauna compared with Ludford Corner, which is only 5.5 km E of Downton. It is possible that presence of ostracods could be affected by distributionary channels delivering sediment (and presumably brackish water) along an irregularly prograding shoreline as suggested by Richardson and Rasul (1990) to explain differences in palynofacies between the Ludlow and Downton sections. However, sedimentological evidence does not suggest vast differences in lithofacies at either Ludford Lane, Ludlow or at Weir Quarry, Downton, which are essentially very similar sedimentologically (present study).
CHAPTER 4

CORRELATION

Britain

The base of the Ludlow Bone Bed at Ludford Corner, Ludlow (loc. 18) defines the base of the Downton Group (Holland et al. 1963), formerly regarded as the base of the "Downtonian Stage". At the stratotype section (loc. 18) this horizon is marked by the onset of vertebrate sand deposition (the Ludlow Bone Bed and subsequent bone beds of the Ludlow Bone Bed Member). The presence of bone beds or phosphatic pebble beds has been used to correlate this lithostratigraphical level across the Welsh Borderland to Much Wenlock (Robertson 1927; White and Coppack 1978), Corve Dale (Shergold and Shirley 1968), Downton (Whitaker 1962), Netherton (Stamp 1923; Ball 1951), Kington (Holland and Williams 1985), The Malvern-Abberley Hills (Phipps and Reeve 1967), Woolhope (Squirrell and Tucker 1960), May Hill and Gorsley (Lawson 1954, 1955), Tite's Point (Cave and White 1971), Usk (Walmley 1959) and Cardiff (Waters and White 1978). A thin bone bed is also preserved 75cm above the base of the Downton Castle Sandstone Formation at Ludford Lane and this is possibly the equivalent of the Downton Bone Bed, present in the Platyschima Shale Member in the Downton area (Whitaker 1962).

The base of the Downton Castle Sandstone Formation at Ludlow is coincident with changes in the macro- and microfaunas. The macrofaunal change is documented by Bassett et al. (1982, fig. 6). The microfaunal changes, particularly those displayed by the ostracod faunas, offer a potential for biostratigraphical correlation of the base of the Downton Group in Britain. The base of the Ludlow Bone Bed Member is marked at localities 17a, 17b, and 18 by a turnover from the sparse Calcaribeyrichia - Hemiella faunas of the Upper Whitcliffe Formation to a Frostiella - Londinia - Nodibeyrichia fauna (Text-fig. 4.13). The main species entering the succession at the base of the Ludlow Bone Bed Member are Frostiella groenvalliana, Nodibeyrichia verrucosa, Londinia arisaigensis and L. fissurata, with non-palaeocopole ostracods also present. As discussed above, this changover in ostracod fauna is unlikely to be entirely due to the facies change at this level as these species are known elsewhere in a wide range of environments.

C. torosa, although a characteristic species of the Upper Whitcliffe Formation, has also been recovered from the lowermost Downton Castle Sandstone Formation at Ludford Lane (Bassett et al. 1982) and from equivalent levels within the Causemountain Formation at Long
Mountain (Shaw 1969, present study). This species appears to be environmentally controlled (see above) and it cannot be used as a definitive indicator of Ludlow strata within Britain. *L. arisaigensis*, although common in the Downton Castle Sandstone Formation, has been recovered at Clun and Long Mountain during the present study from levels taken by Cocks *et al.* (1992) to correlate with the Upper Whitcliffe Formation, and thus possibly has limited potential. *L. fissurata* is confined to the Downton Castle Sandstone Formation and could prove biostratigraphically useful.

*N. verrucosa* is restricted to the lowermost 34 cm of the Downton Group at Ludlow and therefore has potential for correlation with other areas of the Welsh Borderland. *F. groenvalliana* is more abundant than *N. verrucosa* and geographically more widespread. In Britain it has been reported from the basal Downton Castle Sandstone Formation and its lateral equivalents at Long Mountain (Shaw 1969), across Shropshire (Shaw 1969; Siveter 1974, 1978, 1988, 1989; Bassett *et al.* 1982; Hansch *et al.* 1991), at Netherton (*F. cf. groenvalliana*; Siveter 1989), at Clun, Woolhope and Capel Horeb, Llandovery (present study) and from the Scout Hill Flags in the Lake District (Shaw 1971). *F. groenvalliana* can therefore be used to indicate basal Downton strata across the Welsh Borderland and into the Lake District.

The only potential embarrassment to an otherwise consistent scheme in Britain is the reported occurrence of *F. groenvalliana* in the Cennen Beds (?uppermost Ludlow) of the Cennen Valley, Wales (Squirrel and White 1978; Bassett *et al.* 1982; Siveter 1989). Siveter (in Bassett *et al.* 1982, p. 16) considered that "the lack of the fine ornamental details because of the coarse sediment in which they are preserved precludes firm specific identification." The Cennen Valley section is no longer exposed, although the author has also examined material from the Cennen Beds of the Cennen Valley (British Geological Survey collections, Keyworth) containing a typical Upper Whitcliffe brachiopod fauna of *P. ludloviensis*, *S. lunata* and *M. nucula*. The specimens of *Frostiella* are not well preserved and present almost exclusively as internal moulds. Well preserved external moulds are needed for positive identification, so, the specimens are here considered to be best assigned to *F. cf. groenvalliana*. The ostracods *Lophoctenella cf. scanensis* and *C. torosa* are also present but do not unequivocally indicate a Ludlow age as *C. torosa* occurs in the Ludlow Bone Bed Member at Ludlow (Bassett *et al.* 1982) and both species have been recovered from levels taken to correlate above the base of the Downton Castle Sandstone Formation at Long Mountain (Shaw 1969; present study). The
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brachiopod fauna, although characteristic of the Upper Whitcliffe Formation, is not diagnostic, as the species are also present in the Ludlow Bone Bed Member at Ludford Lane Ludlow (Bassett et al. 1982, fig. 6). The uppermost Ludlow age for the Cennen Beds is therefore unproven and *F. groenvalliana* is here considered restricted to the Downton Group of Britain until the Cennen Beds can be shown to be unequivocally Ludlow in age.

*International Conodonts.* The base of the Přidolf Series is defined at Požáry near Prague (Bassett 1985), within bed 96 at a level coincident with the first occurrence of the graptolite species *Monograptus parultimus* (the base of the *parultimus* Biozone). The stratotype section has been sampled in detail for graptolites, chitinozoans, conodonts, trilobites, bivalves and brachiopods, with the results summarised by Jaeger et al. (1981), Klíž et al. (1983, 1986) and Klíž (1989, 1992). Graptolites are the most important biozonal fossil group for the type Přidolf and allow detailed correlation of the Přidolf Series throughout the Prague Basin.

Chitinozoans are the second most important group for biozonation of the type Přidolf Series (Klíž 1989). The species *Urnochitina gr. urna* (Eisenack) first occurs (in bed 97) just above the base of the Přidolf Series at Požáry and with further chitinozan studies in other areas outside Czechoslovakia could prove biostratigraphically useful (Paris 1981, Paris and Klíž 1984). The stratigraphically important conodont taxa *O. remscheidensis eosteinhornensis* and *O. crispa* have also been recovered from the section at Požáry. *O. r. eosteinhornensis* ranges from c.2m below the base of the Přidolf Series at Požáry, to a level above the top of the Přidolf Series (Chlupáč et al. 1980; Klíž et al. 1983). *O. crispa* is stratigraphically restricted to the uppermost Ludlow Series at Požáry, appearing only in beds 87-91 and last occurring at a level 50cm below the base of the Přidolf Series (Klíž 1989, fig. 67). There is a similar situation throughout the Barrandian basin: *O. crispa* last occurs just below the base of the *parultimus* Biozone at Lochov Marble Quarry, Lochov Cephalopod Quarry, Hvižďalka, Kolednık Quarry and at Kosov (Klíž et al. 1986, Klíž 1992).

Conodonts from the Upper Whitcliffe Formation at Ludlow offer a direct correlation between the Welsh and Prague basins. Rare specimens of *O. r. eosteinhornensis* (Text-fig. 4.5j) occur in collections from the uppermost Ludlow Series at Ludlow and at other localities across the Welsh Borderland (Collinson and Druce 1966; Aldridge 1975, 1985; Aldridge and
The stratigraphic ranges of *O. cf. crispa* and *O. r. eosteinhornensis* overlap at the top of the Ludlow Series at Ludlow (Text-fig. 4.7). However, *O. crispa* has a much smaller stratigraphic range in both the Welsh and Prague basins, and therefore has greater correlative potential. Until the present study, only one reported occurrence of *O. cf. crispa* (Text-fig. 4.5h) had been documented from Britain, from 30cm below the Ludlow Bone Bed at Ludford Lane, Ludlow (Aldridge and Smith 1985; Aldridge and Schönlaub 1989). This occurrence marked the first (and last) occurrence of *O. crispa* in the Welsh Basin and therefore could be correlated only with the first occurrence of *O. crispa* at Požáry, at a level 2.75m below the top of the Ludlow Series. Consequently it has been suggested (Schönlaub 1986, Aldridge and Schönlaub 1989), that the base of the Přídolí Series at Ludlow occurs at a level above the Ludlow Bone Bed. Two specimens of *O. crispa* have been recovered from the Upper Whitcliffe Formation as part of the present study, one at Tite’s Point, Severn Estuary (loc. 31b) and another at Prior’s Frome in the Woolhope inlier (loc. 24a). A broken specimen of *O. cf. crispa* (Text-fig. 4.5f) has been recovered from sample 18/1 at Ludford Corner (loc. 18), and a specimen of *O. cf. crispa* recovered from the topmost bed of the Upper Whitcliffe Formation at Aston Munslow, Corve Dale Shropshire (GR SO 5124 8658). These new occurrences confirm the presence of *O. crispa* in the Welsh Basin towards the end of deposition of the Upper Whitcliffe Formation, and more importantly provide a range for *O. cf. crispa* at Ludford Corner and Ludford Lane. *O. cf. crispa* can now be shown to range from 15-30cm below the base of the Downton Castle Sandstone Formation at Ludlow (Text-fig. 4.8). This new conodont evidence from Ludlow and other localities in the Welsh Borderland, confirms that base of the Přídolí Series in Britain is very close to the level of the base of the Downton Castle Sandstone Formation. The occurrence of *O. cf. crispa* in the topmost bed of the Upper Whitcliffe Formation at Aston Munslow indicates that the base of the Přídolí Series is at least as high as the base of the Downton Castle Sandstone Formation and possibly at a level above its base. In the latter case, without graptolites (particularly the key graptolite *M. parulimus*) it would not be possible to pinpoint the level of the base of the Přídolí Series in Britain precisely.
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Ostracods. The ostracods in the type section for the base of the Příkolí Series in the Barrandian area are provincial and in need of further study (Kříž 1989; Siveter 1989) and, therefore, cannot be directly correlated with British ostracod faunas. Using the ostracod *F. groenvalliana* and graptolites, the base of the Downton Castle Sandstone Formation can be correlated to Maine, Nova Scotia, Podolia, Scania, Gotland, the Baltic, Poland and Bohemia (Martinsson 1967; Siveter 1978, 1989, fig. 164, and references therein; Bassett *et al.* 1982). Text-figure 4.16 summarises the chain of correlation based on Bassett *et al.* (1982, fig. 7; 1989) and Siveter (1989, fig. 164), including key references, conodont data and recent information from Podolia.

The correlative link between ostracod and graptolite faunas occurs in the Kaliningrad region of the Baltic which then provides a link with the graptolite biozonal schemes of Polish and hence, Bohemian successions. *F. groenvalliana* and the key graptolite *M. parultimus* (Jaeger) occur together only in the Kaliningrad region, in the Dubovskoe borehole, but at separate stratigraphic levels; the first occurrence of *F. groenvalliana* occurring 68m higher than the first occurrence of *M. parultimus* (Kaljo & Sarv 1976, fig. 1; Hansch *et al.* 1991).

The first occurrence of *Frostiella groenvalliana* has been recognised within the fully marine Aigu Member of the Kaugatuma Formation of Estonia (Kaljo and Sarv 1966; Sarv 1968, 1971). At Oheessare on Saaremaa, where the base of the Kaugatuma Formation is shown as coincident with the base of the *parultimus* Biozone, *F. groenvalliana* has also been reported 8m above the base of the formation (Bassett *et al.* 1989, fig. 123).

In Lithuania the first occurrence of *F. groenvalliana* coincides with the first sample taken within the Kaugatuma Regional Stage (4m above its base) in the Stoniskiai borehole (Sarv 1977, fig. 7). In the Pajevonis 13 borehole of Lithuania, *M. parultimus* is reported at the base of the Minija Formation (Paškevičius 1979). Accepting the correlation of the base of the Minija Formation with the base of the Kaugatuma Stage (Bassett *et al.* 1989, fig. 118), this indicates that *F. groenvalliana* and *M. parultimus* first appear at approximately the same level in Lithuania. It is possible that closer sample spacing at a greater degree of definition within the Stoniskiai borehole might recover more examples of *F. groenvalliana*, to enable its occurrence to be tied down with greater accuracy. However, incomplete recovery from the borehole might not allow a more detailed study.

Martinsson (1964) reported *F. lebiensis* at a restricted range of 681.75 - 694.40m in the Leba 1 borehole in northern Poland. *F. lebiensis* is now recognised as a synonym of *F.
TEXT-FIG. 4.16. Correlation of the base of the Downton Castle Sandstone Formation through Europe and Eastern N America, using ostracod, graptolite and conodont faunas. The correlations of the local lithostratigraphical units are based on Bassett et al. (1982, 1989) and Siveter (1989). G refers to the occurrence of the ostracod *Frostiella groenwalliana* within a formation, P denotes the presence of the key graptolite *Monograptus parutilmus* and C indicates the presence of the conodont *Ozarkodina crispa*. The symbols are not intended to indicate exact stratigraphic positions of the species and the columns are not drawn to scale.
groenvalliana (see Hansch et al. 1991); the species occurs within the Lower Podlasie Beds of Poland (Text-fig. 4.16). Tomczyk (1968) has recorded graptolites from Polish boreholes including the Lebork Borehole where M. ultimus directly follows M. formosus. Recovery from most of the Polish boreholes is incomplete, except for the Lebork borehole which has almost complete recovery. Tomczyk (1968) used the upper limit of M. formosus to define the boundary between the Ludlow and the Podlasie Beds. The correlation chart for the Polish Silurian of Tomczykowa and Witwicka (1974, fig. 2) based on ostracod, graptolite and trilobite evidence, places the last occurrence of M. formosus in the Leba 1 borehole at a level between 800 and 850m, at least 230m below the occurrences of F. groenvalliana (lebiensis) reported by Martinsson (1964). The first occurrence of F. groenvalliana is therefore consistently above the level of the base of the parultimus Biozone, most notably at Kaliningrad which is the only locality where the two species occur in the same section.

Since Bassett et al. (1982, pp.14-20) outlined the correlation of the base of the Downton Castle Sandstone Formation across Europe, further information has become available on the distribution of the ostracod F. groenvalliana and the resolution of graptolite biozonal schemes has been increased. A number of potential problems regarding the correlation noted by Bassett et al. (1982) can now be addressed:

1. "There is currently some discrepancy in the interpretation of the ranges of graptolites associated with the lowest Downton ostracod assemblages in Poland" (Bassett et al. 1982, p. 18). Ostracod assemblages from the Lower Podlasie Beds in Poland correlate within the ultimus Biozone but occur above horizons containing M. formosus (Tomczykowa and Witwicka 1974; Tomczyk 1968, 1970). Formosus levels were formerly regarded as being within the ultimus Biozone, although the taxonomy of the formosus group was poorly known (Teller 1969, Jaeger 1977). The graptolite biozonation for the Pfdolf in the Prague Basin (Jaeger 1986) shows that the range of M. formosus spans the Upper Ludlow fragmentalis Biozone and the Pfdolf parultimus and ultimus biozones. The ultimus Biozone has now been subdivided into a (lower) parultimus Biozone and (upper) ultimus Biozone, as M. parultimus and M. ultimus are almost certainly successive members of a lineage (Jaeger 1986). Occurrence of the ostracod F. groenvalliana above levels containing M. formosus is not therefore inconsistent with the occurrence of F. groenvalliana above the base of the parultimus Biozone.
2. Various reviews of the correlation of the Silurian of the East Baltic (e.g. Kaljo 1970, 1978; Kaljo and Sarv 1966) have expressed differing opinions as to the correlation of the base of the Downton Group with the Kaugatuma and underlying Kuressaare beds (Bassett et al. 1982, p. 18). Kaljo (1979) correlated the base of the Kuressaare Beds with the base of a broad *formosus-ultimus* graptolite interval, with *F. groenvalliana* entering slightly higher in the succession (at the base of the Kaugatuma Beds), suggesting that the base of the Kaugatuma Beds are approximately coincident with the base of the *ultimus* graptolite Biozone (Bassett et al. 1982). The latest correlative schemes for the Silurian of the Baltic place the Kuressaare Formation at the top of the uppermost Ludlow *formosus* Biozone and the base of the Kaugatuma Formation coincident with the base of the *parultimus* Biozone (Bassett et al. 1989, fig. 118; Kaljo 1990, fig. 2).

3. The position of the base of the Minija Formation in the East Baltic is marked as uncertain (Bassett et al. 1982, fig. 7) and possibly at a level below the base of the *ultimus* Biozone. Bassett *et al.* (1982, p. 17) report the basal 'Downton' ostracod fauna in Latvia and Lithuania as entering at or closely above the base of the Minija Formation but it is unclear from what authority this has been cited. Paškevičius (1982) and Sidaraviciene (1986) confirm that *F. groenvalliana* is present at the base of the Minija Formation in the Stoniskiai, Vidukle and no. 110 (Arjogal profile) boreholes of Lithuania. If the base of the Minija Formation is below the base of the *parultimus* Biozone (see Bassett *et al.* 1982, fig. 7) then the correlation using *F. groenvalliana* is wrong. The latest published correlation chart for the Silurian of the Baltic (Bassett *et al.* 1989, fig. 118) places the base of the Minija Formation coincident with the base of the *parultimus* Biozone, but a dotted line is used as there is still a degree of uncertainty concerning the exact position of the base of the formation.

Siveter (pers. comm.) has examined material from Podolia and considers *F. modesta* Abushik, 1971 conspecific with *F. groenvalliana*. This further extends the geographic distribution of *F. groenvalliana* to Podolia where it occurs 17 m above the base of the Rashkov Formation (Abushik *et al.* 1985, Koren *et al.* 1989). *O. crispa* last occurs 5 m above the base of the Rashkov Formation in Podolia (Abushik *et al.* 1985; Koren *et al.* 1989, fig. 105). Conodont evidence therefore suggests that the base of the Pfidolf Series is at a level at least 5 m above the base of the Rashkov Formation. This evidence provides an additional example of *F.*
groenvalliana closely following O. crispa stratigraphically, but with no overlap in their stratigraphic ranges (cf. Ludford Comer, Ludlow; Text-fig. 4.16).

According to Viira (1982) and Schönlaub (1986) it is possible that O. crispa ranges into the lowermost Kaugatuma Formation of the E Baltic and, therefore, occurs above levels containing F. groenvalliana. However, Viira (1982) was not able to clearly distinguish O. snajdri from O. crispa and the latest information on conodont faunas from the Baltic suggests that O. crispa is confined to the Upper Paadle Formation, at a level below the Kaugatuma Formation (Männik and Viira 1990).

F. groenvalliana is not always present at the very base of the lithostratigraphical units shown in Text-figure 4.16. However, the distribution is remarkably consistent across the whole of Europe, with F. groenvalliana always occurring above the base of the parultimus Biozone and occurrences of O. crispa and never below these levels. The evidence currently available therefore suggests that F. groenvalliana is restricted to the Přídolí Series.

The correlation of the base of the Downton Castle Sandstone Formation in the Welsh Borderland with the base of the Přídolí Series in Czechoslovakia using the ostracod F. groenvalliana is regarded as approximate in terms of the detailed stratigraphic resolution of the present study. The correlation is indirect as the two key species are both present only at Kaliningrad, and then at different stratigraphic levels (see above; Kaljo and Sarv 1976). Lithostratigraphical correlation between local units has to be used to provide the link between ostracod and graptolite faunas. Often there is a degree of uncertainty regarding these correlations, for example with the position of the base of the Minija Formation in W Latvia and W Lithuania. Sampling in Baltic, Scanian, Polish and N American sections has not been carried out to the same high resolution as at the stratotype for the base of the Přídolí Series at Požáry or at Ludlow for the present study. More detailed sampling is therefore needed on and around the stratigraphic level at the base of the parultimus Biozone to recover more detailed records of F. groenvalliana and to enable occurrences to be more accurately tied in with the base of the parultimus Biozone. With only a limited sample size, borehole data does not often permit detailed studies of these faunas. Borehole recovery is seldom complete, and important faunas may possibly have been lost.

Indirect and approximate correlation using ostracods and graptolites (Text-fig. 4.16) suggests that the base of the Přídolí Series in Britain is coincident with the base of the Downton
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Castle Sandstone Formation. However, the correlation is approximate and further research is needed to strengthen the stratigraphic resolution of the chain of correlation. Conodont faunas from the uppermost Upper Whitcliffe Formation at Ludlow and across the Welsh Borderland offer a direct correlation with the Barrandian Basin and suggest that the base of the Pföldorf Series in Britain is at least as high as the base of the Downton Castle Sandstone Formation and possibly at a low level above its base. At present, the exact position of the base of the Pföldorf Series in Britain cannot be demonstrated without the key graptolite species *M. parultimus*, although the current state of knowledge on British, European and N. American conodont, ostracod and graptolite correlations suggests that the base is almost exactly coincident with the base of the Downton Castle Sandstone Formation at Ludlow.

CONCLUSIONS

1. Conodont faunas from the Lower Whitcliffe and Upper Whitcliffe formations are dominated by *C. dubius*, *O. excavata*, *O. confluentes* and *P. serratus*. Rarer species include *O. wimani*, *O. r. eosteinhornensis*, *O. r. baccata* and *O. cf. crispa*. The latter is restricted to 15-30 cm below the top of the Upper Whitcliffe Formation (Text-fig. 4.7).

2. Ostracod faunas from the Upper Whitcliffe Formation are characterised by *C. torosa*, which also occurs in the Ludlow Bone Bed Member of the Downton Castle Sandstone Formation. *Hemsiella cf. maccociyana* has also been recovered from the Upper Whitcliffe Formation.

3. Conodonts from the Downton Castle Sandstone Formation are scarce, poorly preserved and consist dominantly of Pa elements of *O. confluentes* and Sa/Sb elements of *C. dubius*.

4. *F. groenvalliana*, *L. arisaigensis*, *L. fissurata* and *N. verrucosa* first appear at the base of the Ludlow Bone Bed Member at Ludlow. *N. verrucosa* occurs 0-34 cm above the base of the Downton Castle Sandstone Formation (Text-fig. 4.13).

5. The preservation of the conodonts in the topmost 50 cm of the Upper Whitcliffe Formation suggests that the environment was more turbulent than at the base of the formation. This would be consistent with shallowing towards the top of the formation as proposed by Watkins (1979) and Bassett et al. (1982).

6. The turnover of ostracod faunas at the base of the Ludlow Bone Bed Member is not entirely facies related as the ostracod species, particularly *F. groenvalliana*, are tolerant of a wide range of environments. In the more offshore, basinal area of the Welsh Borderland at Long
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Mountain, the ostracod faunal change is not as sudden as at Ludlow (Shaw 1969). Some ostracod taxa, for example *C. torosa* and *L. arisaigensis* therefore appear to be partly environmentally controlled.

7. Variations in ostracod faunal composition, frequency and numbers of carapaces present coincide with minor lithofacies variations (Text-fig. 4.15).

8. The relatively sparse ostracod fauna and low percentage of land plant spores present in the Downton Castle Sandstone Formation at Weir Quarry, Downton (loc. 14b), compared with the Ludford Lane section, indicates that local factors control ostracod and palynomorph frequencies. Proximity to local channels along an irregularly prograding shoreline could explain these variations (Richardson and Rasul 1990).

9. The ostracod *F. groenvalliana* can be used to correlate the base of the Downton Castle Sandstone Formation across the Welsh Borderland and into the Lake District. The only potential embarrassment to this scheme is the confirmed occurrence of *F. cf. groenvalliana* in sediments of questionable late Ludlow age in the Cennen Valley, SW Wales.

10. Occurrence of the conodont *O. crispa* at Ludlow, at Aston Munslow, and at other localities throughout the Welsh Borderland, allows direct correlation between Ludlow and the stratotype for the base of the Pföldorf Series at Požáry in Czechoslovakia. Conodont correlation suggests that the base of the Pföldorf Series in Britain is at least as high as the base of the Downton Castle Sandstone Formation and possibly at a level above its base.

11. Using the ostracod *F. groenvalliana* and graptolites, the base of the Downton Castle Sandstone Formation can be approximately correlated to Maine, Nova Scotia, Podolia, Scania, Gotland, the Baltic, Poland and approximately to the base of the Pföldorf Series defined at Požáry, Czechoslovakia (Text-fig. 4.16). *F. groenvalliana* occurs consistently above the base of the *parultimus* Biozone and with the current state of knowledge can therefore be assumed to indicate Pföldorf age strata. However, the correlation is based on borehole data which is often incomplete, relies on correlations of local lithostratigraphical units which are still uncertain (e.g. the base of the Minija Formation in Lithuania), and is based on studies which are not to the detailed 'bed by bed' resolution of the present study. Further more detailed research is therefore needed to add greater resolution to the correlative chain.
12. The direct conodont evidence by itself, suggests that the base of the Přídolí Series is at least as high and possibly slightly higher than the base of the Downton Castle Sandstone Formation; the exact position of the base of the Přídolí Series in this case cannot be demonstrated without the key graptolite species *M. parultimus*. The combined information from the conodont and ostracod correlations suggests that the base of the Přídolí Series is concurrent with the base of the Downton Castle Sandstone Formation at Ludlow.
CHAPTER 5

OSTRACOD AND CONODONT DISTRIBUTION ACROSS THE LUDLOW/ PŘÍDOLÍ SERIES BOUNDARY (SILURIAN); THE SHELF AREA OF THE WELSH BORDERLAND SURROUNDING LUDLOW, SHROPSHIRE

ABSTRACT. Conodont and ostracod faunas have been recovered by sampling in detail across the base of the Downton Castle Sandstone Formation in the Welsh Borderland in the area surrounding Ludlow. Conodont and ostracod faunas are similar to faunas from Ludlow (see Chapter 4). The underlying Upper Whitcliffe Formation is characterised by the ostracod Calciari b e y r i c h i a t o r o s a ; the conodont Ozarkodina cf. crispa has been recovered from the uppermost bed of the Whitcliffe Formation at Aston Munslow, Corve Dale. The ostracod Frostiella groenvalliana is confined to the Downton Castle Sandstone Formation but is not always present at the base. Limestones yielding whole conodont elements and calcareous ostracod valves are locally developed in the Much Wenlock area within the Downton Castle Sandstone Formation.

Variations in ostracod frequency, sedimentology and published palynofacies data reflect localised variations in conditions at the base of the Downton Castle Sandstone Formation and are possibly influenced by proximal channels delivering sediment off an irregularly prograding shoreline.

Distribution of the conodont O. cf. crispa and the ostracod F. groenvalliana indicates that the base of the Downton Castle Sandstone Formation is coincident with the base of the Přídolí Series.
INTRODUCTION

The microfaunal characteristics of the Upper Whitcliffe Formation on the Whitcliffe at Ludlow and across the base of the Downton Castle Sandstone Formation at Ludford Corner (loc. 18) and Ludford Lane, Ludlow (loc. 17) are described in Chapter 4. The aim of chapters 5-7 is to trace the base of the Downton Castle Sandstone Formation and its lateral equivalents across the Welsh Borderland, documenting the microfaunal changes across the level and comparing these changes with faunas from the type sections at Ludlow.

Chapter 5 describes exposures surrounding the classic area of Ludlow (Text-fig. 5.1), covering part of the Welsh Borderland to the east of the Church Stretton fault, which is generally defined as the "shelf" area (Holland 1962). In this area sections exposing the base of the Downton Castle Sandstone Formation at Aston Munslow, Corve Dale (loc. 7a), Downton (loc. 14b), and Nethepton (loc. 20) have been studied in detail and an additional 28 individual coeval localities (Text-fig. 5.2) are also documented.

The Upper and Lower Whitcliffe formations along Corve Dale and in the Much Wenlock area cannot be distinguished lithologically or on the basis of macrofaunas (Shergold and Shirley 1968; White and Coppack 1978). For the present study the lithostratigraphic unit Whitcliffe Formation is used for the Much Wenlock area and localities along Corve Dale, and the term Upper Whitcliffe Formation is used for other localities in the area covered by Chapter 5 (Text-fig. 5.1). Subdivision of the Downton Castle Sandstone Formation into three members has been recognised only at Ludlow (Bassett et al. 1982), Kington (Holland and Williams 1985) and in the Downton area (Richardson and Rasul 1990).

LOCALITIES AND HORIZONS

1. CALLAUGHTON MILL. 2.5km SW of Much Wenlock, SO 6198 9746 (Robertson 1927, pp. 86, 87). Whitcliffe Formation, bone bed at base of Downton Castle Sandstone Formation (BGS).

2. WILLEY. 5km ESE of Much Wenlock, SO 6731 9912 (White and Coppack 1978, fig. 1). Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base and 3m above base (BGS and CGM).

3. LINLEY. 6.5km E of Much Wenlock.
TEXT-FIG. 5.1. Study area for Chapter 5 (boxed area bounded to west by Church Stretton Fault). Base map after Bassett et al. (1982).
TEXT-FIG. 5.2. Sampled localities in the shelf area surrounding Ludlow. Base map after Bassett et al. (1982). 1, Callaughton Mill. 2, Willey. 3, Linley Brook. 4, Dean Brook. 5, Brockton. 6, Shipton. 7, Aston Munslow. 8, Diddlebury. 9, Corfton. 10, Siefton. 11, Culmington. 12, Onibury. 13, Clungunford. 14, Downton. 19, Kington. 20, Netherton.
3a. Exposure next to road from Linley Hall to Linley Brook, SO 6870 9817 (Robertson 1927, loc. L17). Downton Castle Sandstone Formation (BGS).

3b. Linley Brook 90m E of Hem Farm, SO 6920 9820 (Robertson 1927, loc. L18). Downton Castle Sandstone Formation (BGS and CGM).

3c. Tributary to Linley Brook, 1km E of Linley Bridge, SO 6940 9815 (Robertson 1927, loc. L19). Downton Castle Sandstone Formation containing a bone bed (BGS).

4. DEAN BROOK. Tributary to R. Severn, 6.5km E of Much Wenlock.


4b. 40m N of 4a, SO 6875 9955 (Robertson 1927, loc. L16). Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base (BGS).

5. BROCKTON. On B4378 6.5km SW of Much Wenlock, Shropshire.

5a. Stream section opposite Ivy Cottage, SO 5755 9388. Whitcliffe Formation (BGS).

5b. Road cutting on B4378, SO 579 939. Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base (BGS and CGM).

5c. Disused quarry behind old school house, SO 5765 9400. Whitcliffe Formation (RJA).

6. SHIPTON. Junction of B4368 and B4378 on Corve Dale, 9km SW of Much Wenlock, Shropshire.

6a. Exposure next to path connecting B4368 and B4378, SO 5634 9186. Whitcliffe Formation (CGM).

6b. Old quarry in farmyard 150m at 26° from NE end of St. James Church, SO 5625 9194. Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base (BGS).

6c. Laneside section 155m at 125° from SW end of St. James Church, SO 5629 9169. Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base (BGS and CGM).

7. ASTON MUNSLOW. 10km NE of Craven Arms, Shropshire.

7a. Car park of Swan Inn, SO 5124 8658. Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base (CGM, RJA and BGS).

7b. Roadside exposure 120m NW of Swan Inn, SO 5113 8671. Whitcliffe Formation (CGM and RJA).
8. DIDDLEBURY. Small exposure at roadside, 10m NW from B4368 on Middlehope road, SO 503 838. Whitcliffe Formation (CGM and RJA).

9. CORFTON. Roadside cutting SE of Sun Inn, Corfton, c.7km ENE of Craven Arms, Shropshire, SO 497 846. Downton Castle Sandstone Formation (CGM and BGS).

10. SIEFTON. c.5km E of Craven Arms, Shropshire.
10a. Quarry in Siefton Batch 1km NNW of B4368, Corve Dale, Shropshire, SO 4770 8475. (?Whitcliffe Formation (CGM).
10b. Temporary roadside trench (no longer exposed), SO 475 833 to 478 835 (Antia 1979b). Whitcliffe Formation and Downton Castle Sandstone Formation.

11. CULMINGTON. Old Quarry S of new house, 500m ENE of Burley, near Culmington, SO 4745 8150. Downton Castle Sandstone Formation with bone bed at base. (CGM and BGS)

12. ONIBURY. c.4km SSE of Craven Arms, Shropshire.
12a. Farmyard exposure 3km WNW of Onibury Church, SO 425 796. Upper Whitcliffe Formation (BGS).
12c. Locality not constrained, on road from Onibury to Norton. Tilestones (Downton Group) (BGS).

13. CLUNGUNFORD. 5km SW of Craven Arms, Shropshire.
13a. Lane in wood, 3.2km E of Clungunford, SO 434 789. Upper Whitcliffe Formation. (BGS)
13b. Old quarry 150m E of Brandhill Farm, 2km E of Clungunford, SO 4236 7883. Upper Whitcliffe Formation (BGS).

14. DOWNTON ESTATE. Area around Downton Castle, c.5km W of Ludlow, Shropshire.
14a. Bank to SE of Downton Bridge, SO 4449 7427. Upper Whitcliffe Formation, Ludlow Bone Bed Member with bone bed at base and Platyschisma Shale Member of Downton Castle Sandstone Formation (DJS).
14b. Weir Quarry, NW bank of the River Teme, c.275m NE of Bringewood Forge Bridge, SO 4560 7525 (Richardson and Rasul 1990, loc. 1). Upper Whitcliffe Formation, Ludlow Bone Bed Member with multiple bone beds, Platyschisma Shale Member and Sandstone Member of Downton Castle Sandstone Formation (CGM).
14c. Track section in field to S of Downton Castle Bridge, SO 4442 7402. Platyschisma Shale Member including the Downton Bone Bed and Sandstone Member of Downton Castle Sandstone Formation (collected in 1968 by Dr L. Jeppsson, University of Lund, Sweden).

19. KINGTON. Herefordshire town c.25km SW of Ludlow.

19a. N side of Kington by-pass, SO 2998 5706 (Holland and Williams 1985, loc. 5). Upper Whitcliffe Formation, Ludlow Bone Bed Member including multiple bone beds, Platyschisma Shale Member, Sandstone Member of Downton Castle Sandstone Formation.

19b. Lane-side exposures on Newton Lane, SO 2902 5716 (Holland and Williams 1985, loc. 3). Upper Whitcliffe Formation, multiple bone beds in Ludlow Bone Bed Member and Platyschisma Shale Member of Downton Castle Sandstone Formation.

Localities in this area have not been studied in detail for the present study. White and Coppack (1978) described ostracods from the section at Willey (loc. 2). Their collections (BGS) have been examined by the author and their identifications confirmed. White and Coppack (1978) found the ostracod *F. groenvalliana* at the base of the Downton Castle Sandstone Formation, a horizon marked at Willey (loc. 2) by a bone bed. Two abraded Pa element fragments of *Ozarkodina confluens* have been recovered from this bone bed (sample 2/2, Text-fig. 5.3).

Bone beds have been recorded at the base of the Downton Castle Sandstone Formation at Callaughton (loc. 1) and Dean Brook (loc. 4b) in the Much Wenlock area (Robertson, 1927; White and Coppack, 1978), but these localities are no longer exposed. *Frostiella groenvalliana* and *L. fissurata* are recorded from the Downton Castle Sandstone Formation at these localities (White and Coppack 1978, p. 28). White and Coppack (1978, p. 29) reported similar ostracod faunas from Linley (locs 3a and 3b), remarking that they closely resemble faunas from the old quarry at Willey (loc. 2). The Downton Castle Sandstone Formation at locality 3b, Linley Brook, has been sampled by the author and contains abundant *F. groenvalliana* associated with the gastropod *Turbocheilus helicites* (J. de C. Sowerby). In one individual limestone bed at Linley Brook (sample 3b/1) these taxa retain their original calcareous carapaces (Chpt 3, Pl. 1, fig. 9) and have yielded whole, unabraded conodont specimens. Specimens of similar limestone beds from the Downton Castle Sandstone Formation at Dean Brook (loc. 4) are held at the BGS (Keyworth).

Ostracod faunas from the Upper Whitcliffe Formation in the Much Wenlock area are dominated by the species *C. torosa* with minor occurrences of *H. cf. maccyiana* and *Lophocenella cf. scanensis*. The ostracod fauna of the Downton Castle Sandstone Formation is dominated by *F. groenvalliana* with minor occurrences of *L. fissurata, L. arisigensis* and a single specimen of *Londinia kiesowi* (Text-fig. 5.4).
TEXT-FIG. 5.3. Conodonts from the Upper Whiscliffe and Downton Castle Sandstone formations in the shelf area of the Welsh Borderland surrounding Ludlow, Shropshire (Text-fig. 5.1). No calculated value can be given for sample 14c as the sample was in the form of a heavy residue donated by Dr. L. Jeppson (University of Lund, Sweden).
<table>
<thead>
<tr>
<th>Formation</th>
<th>Upper Whitecliffe</th>
<th>Downton Castle Sandstone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Locality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 4b 5b 6a 7b 12a</td>
<td>2 3a 4b 5b 7a 11 12 20</td>
</tr>
<tr>
<td>Calkaribeyrichia toreana</td>
<td>P P P P P A P</td>
<td></td>
</tr>
<tr>
<td>Hemiolla cf. maccoyiana</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Lophoconella cf. scocenensis</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Frostiella groenovalliana</td>
<td>P P A P P P P P</td>
<td>P</td>
</tr>
<tr>
<td>P. cf. groenovalliana</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frostiella sp.</td>
<td>P P P P P P</td>
<td></td>
</tr>
<tr>
<td>Lendinia artemigena</td>
<td>P P P P P P</td>
<td></td>
</tr>
<tr>
<td>L. cf. artenigena</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. fuscata</td>
<td>P P P P P P</td>
<td></td>
</tr>
<tr>
<td>L. kiesowi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. sp.</td>
<td>P P P P P P</td>
<td></td>
</tr>
<tr>
<td>non-palaeocopids</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Source of material</td>
<td>W B B B B B B B B</td>
<td></td>
</tr>
</tbody>
</table>

TEXT-FIG. 5.4. Ostracod faunas from the Upper Whitecliffe and Downton Castle Sandstone formations in the shelf area of the Welsh Borderland surrounding Ludlow (Text-fig. 5.1). P = the species is present, A = the species is abundant, W = material collected by White and Coppack (1978), B = material held at the BGS (Keyworth), S = material collected by Dr David J. Siveter, with the remainder collected by the author.
CHAPTER 5

CORVE DALE, CENTRAL SHROPSHIRE

Corve Dale runs parallel with the Much Wenlock Limestone escarpment of Wenlock Edge. Sampled localities 5-11 occur along an approximately NE-SW line (Text-fig. 5.2), parallel with the River Corve and the B4368 road. The exposure opposite the Swan Inn, Aston Munslow (loc. 7b) has been sampled in detail. Bone beds, conodont or ostracod faunas have been collected by the author and the BGS from an additional 12 localities along Corve Dale. The biostratigraphy of the Ludlow Series on Corve Dale has been described (Shirley 1952; Shergold 1967a; Shergold and Shirley 1968), also the sedimentology and macrofaunas across the base of the Downton Castle Sandstone Formation in a temporary bench (no longer exposed) at Siefton (Antia 1979b). Thelodonts from bone beds exposed along Corve Dale (Turner 1973; Antia 1979a) and conodont faunas from Diddlebury (loc. 8) (Collinson and Druce 1966; Druce 1967; Aldridge 1985) have been described and discussed.

Aston Munslow (loc. 7a)
The exposure is immediately N of the B4368 road, in the car park opposite the Swan Inn.

Whitcliffe Formation. 1.95m of the formation is exposed under a large yew tree on the NW face of the car park and 1.34m is exposed on the NE face. The sedimentary log presents combined information from these two exposures (Text-fig. 5.5). A single sample taken by Dr R. J. Aldridge at locality 7b (120m NW of locality 7a) is approximately 3m below the top of the formation. The lithology is similar to the type Upper Whitcliffe Formation and consists of olive grey bioturbated siltstones with shaly horizons, brachiopod coquinas and rare calcareous lenses.

Two well preserved specimens of the ostracod C. torosa have been recovered from sample 7a/4, 0-2cm below the top of the formation at locality 7a and a single specimen was recovered from the formation at locality 7b.

Sample 38/1* from locality 7b is dominated by Ozarkodina excavata with O. confluens, Coryssognathus dubius and minor Panderodus serratus. By contrast, the two faunas from locality 7a are very similar to each other, and are dominated by C. dubius with minor O. confluens, O. snajdri and elements from the reinscheidensis plexus (Text-figs 5.3, 5.5). The
TEXT-FIG. 5.5. Log of the Whitcliffe and Downton Castle Sandstone formations at Aston Munslow (loc. 7a), showing positions of ostracod specimens recovered, conodont samples and faunas
topmost bed of the Whitcliffe Formation (sample 7a/4) has yielded \textit{O. cf. crispa} (Text-fig. 5.3).

\textit{Downton Castle Sandstone Formation}. 1.63m of the formation is exposed. A 0-5cm bone bed marks the base of the formation, although the thickest part of the bed was removed during sampling. The lowest metre of the formation consists predominantly of muddy siltstone with the occasional resistant coarser bed showing cross lamination (Text-fig. 5.5). The succession rapidly coarsens upwards 1.00-1.63m above the base of the formation; medium sand showing cross lamination occurs at the top of the section (Text-fig. 5.5).

The ostracod fauna is very sparse. Only three specimens have been recovered (Text-fig. 5.5). Preservation is very poor and only \textit{F. cf. groenvalliana} and \textit{L. cf. arisaigensis} have been identified. A single hand specimen (BGS 54-120, JD 463) contains a mould identified as \textit{Frostiella} sp.

\textit{O. confluens} (Pa and Pb elements) and \textit{C. dubius} are present in the bone bed at the base of the formation which has produced a calculated total of 122 conodont elements per kg.

\textit{Other localities}
At Brockton (loc. 5b), Shipton (locs 6a-c), and Culmington (loc. 11) bone beds have been reported at the base of the Downton Castle Sandstone Formation, although none are still exposed (BGS records; Turner 1973; Antia, 1979a).

Ostracod faunas from the Upper Whitcliffe Formation at Brockton (locs 5a, b) and Shipton (loc. 6a) contain only \textit{C. torosa}, while those from the Downton Castle Sandstone Formation are almost exclusively dominated by \textit{F. groenvalliana} with minor proportions of \textit{L. arisaigensis}, \textit{L. fissurata} and non-palaeoeco ostracods (Text-fig. 5.4). \textit{F. groenvalliana}, although confined to the Downton Castle Sandstone Formation, is not present immediately at the base of the Downton Castle Sandstone Formation at any locality on Corve Dale.
DOWNTON TO ONIBURY AREA, CENTRAL SHROPSHIRE

Eight localities have been sampled in the area of localities 12-14 (Text-fig. 5.2). Previous research concentrated on the Downton area (Elles and Slater 1906; Allender et al. 1960; Whitaker 1962). Ostracod moulds have been recovered from the Downton Group at Onibury (loc. 12b) and Downton (Shaw 1969). Palynofacies data has been presented from Weir Quarry, Downton (loc. 14b) (Richardson and Rasul 1990).

Weir Quarry, Downton (loc. 14b)

Upper Whitcliffe Formation. 2.70m of the formation is exposed (Text-fig. 5.6). The lithology of bioturbated coquinooidal siltstones with finer grained silty mudstone horizons is very similar to the Upper Whitcliffe Formation exposed at Whitcliffe Quarry, Ludlow (locs 15a-d), although lacking calcareous lenses.

The ostracod fauna is very sparse with only H. cf. maccoyiana (sample 14b/1) and C. torosa (sample 14b/2) present (Text-figs 5.6, 5.7). No conodonts have been recovered.

Downton Castle Sandstone Formation. 1.62m of the formation is exposed (Text-fig. 5.8), although the uppermost 0.42m was not sampled due to dangerous overhanging strata. The base of the formation is marked by a 0-3cm bone bed. The Ludlow Bone Bed Member consists of parallel laminated silty mudstones with two thin conjugate bone beds up to 3mm thick approximately 13cm above the base of the member. The top of the Ludlow Bone Bed Member is marked by a well developed bone bed rich in the gastropod T. helicites. Richardson and Rasul (1990, fig. 3) also took this gastropod-rich bed as the top of the Ludlow Bone Bed Member but measured the bed as 21-24cm above the base of the member rather than 29-31cm as in the present study (Text-fig. 5.8).

The Platyschisma Shale Member consists of parallel laminated muddy siltstones coarsening upwards gradually to bioturbated siltstones with plant-rich horizons and abundant inarticulate brachiopods. A bone bed is exposed 75cm above the base of the formation (Text-fig. 5.8).

Ostracod faunas are very sparse reaching a maximum abundance of 0.2 ostracods per cm² but generally less than 0.1 ostracod per cm² (Text-fig. 5.8). Only 3 beds yielded more than 10 ostracods and these had very similar faunas of Frostiella, Londinia and non-palaeocopse.
TEXT-FIG. 5.6. Sedimentary log of the Upper Whitcliffe Formation and Ludlow Bone Bed (LBB) Member of the Downton Castle Sandstone (DCS) Formation, Weir Quarry, Downton (loc. 14b), showing sampled horizons.
<table>
<thead>
<tr>
<th>Locality</th>
<th>14a</th>
<th>14b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample number</td>
<td>1 2 3</td>
<td>1 2 4 5 6 8 10 11 12 13</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>282 108 66</td>
<td>139 518 166 268 303 276 845 198 768 605 1</td>
</tr>
<tr>
<td>n valves &amp; carapaces</td>
<td>16 30 12 2</td>
<td>4 2 5 9 25 1 31 40 2 4</td>
</tr>
<tr>
<td>Calcariibryrichia toreosa</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Hemiella cf. maccoyiana</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>non-palaeocopes</td>
<td>3 2</td>
<td>4 6 10 9</td>
</tr>
<tr>
<td>Froestiella groenvalliana</td>
<td>7.1 13 4</td>
<td>3 4 1 5 17 1 4</td>
</tr>
<tr>
<td>F. cf. groenvalliana</td>
<td>1.1 1</td>
<td>1 3 4 3</td>
</tr>
<tr>
<td>Londinia aristaigensis</td>
<td>2</td>
<td>1 1</td>
</tr>
<tr>
<td>L. cf. aristaigensis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Londinia cf. fissurata</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Froestiella sp.</td>
<td>2 9 3</td>
<td>1 1 4.1 3 1 1</td>
</tr>
<tr>
<td>Londinia sp.</td>
<td>1 1</td>
<td>1 3 1 1</td>
</tr>
<tr>
<td>Hemiella sp.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Aff. Nodibeyrichia</td>
<td>1 2 4 1</td>
<td>2 1 3 6 7</td>
</tr>
</tbody>
</table>

TEXT-FIG. 5.7. Frequencies of ostracod valves and carapaces from the Upper Whitchcliffe and Downton Castle Sandstone formations, Downton Estate (locs 14a and b), Shropshire. Numbers after decimal points refer to numbers of carapaces.
TEXT-FIG. 5.8. Sedimentary log through the upper part of the Upper Whitcliffe Formation and the Ludlow Bone Bed and Platyschisma Shale members of the Downton Castle Sandstone Formation at Weir Quarry, Downton (loc. 14b). Ostracod faunal composition is plotted for beds containing more than 10 identifiable ostracod specimens and ostracod frequency is plotted for all beds.
ostracods (Text-fig. 5.8). The dominant species is *F. groenvalliana*, with rare specimens of *L. arisaigensis* and *L. fissurata*.

Samples 14b/3 and 14b/7 yielded conodont faunas dominated by Pa elements of *O. confluens* and sample 14b/3 also contained *C. dubius*, fragments of *Oulodus* sp. and two Pa elements of *O. excavata* (Text-fig. 5.3). Sample 14b/7 yielded a single fragment of the acanthodian *Archegonaspis* sp.

**Other Localities**

Downton Bridge (loc. 14a) once exposed the base of the Downton Castle Sandstone Formation (Elles and Slater 1906; Whitaker 1962). The locality is no longer exposed but collections made by Dr David J. Siveter (1982) include *F. groenvalliana*, *L. arisaigensis* and non-palaeocope ostracods from a bed (sample 14a/1; Text-fig. 5.7) immediately above the base of the Downton Castle Sandstone Formation. Like the basal bed in the Ludlow Bone Bed Member at Ludlow, *F. groenvalliana* is present at Downton Bridge as carapaces, although *N. verrucosa* is absent from the Downton section (Text-fig. 5.7).

The Downton Bone Bed was exposed in a field to the north of Downton Bridge (loc. 14c) within the Platyschisma Shale Member (Whitaker 1962). The Downton Bone Bed (sample 14c, Text-fig. 5.3) contains typical Downton Castle Sandstone Formation abraded conodonts dominated by Pa elements of *O. confluens*. It also includes elements of *C. dubius* with minor *O. excavata*, *O. remschiedensis* eosteinhomensis and *Oulodus* sp..

At Onibury (loc. 12a) and Clungunford (locs 13a, 13b) the Upper Whitecliffe Formation contains *C. torosa*. Locality 12b at Onibury has yielded *L. fissurata* from the Downton Castle Sandstone Formation (Text-fig. 5.4). Shaw (1969) based his study of "Downtonian" ostracods on a locality (no longer exposed) of the Temeside Bone Bed at Onibury.

**OTHER LOCALITIES**

**Kington, Hereford and Worcester** (locs 19a, b)

The base of the Downton Castle Sandstone Formation has been recognised at Kington (Holland and Williams 1985). Kington (Text-fig. 5.2) has traditionally been regarded as part of the "basin" area of the Welsh Borderland (Holland 1962, fig. 1). However, for this study Kington has been included in the shelf area as the succession is comparable with that of Ludford Corner,
Ludlow (loc. 18), as multiple bone beds are developed in the Ludlow Bone Bed Member at Kington (Holland and Williams 1985). Locality 19a, on the Kington by-pass, is now very poorly exposed and only a single ostracod specimen of *H. cf. maccoyiana* has been collected from the uppermost Upper Whitcliffe Formation (Text-fig. 5.4). Abundant loose material was available at the locality, but proved to be barren of ostracods. Bone bed specimens were processed for conodonts, but these were also barren.

*Netherton (loc. 20) and Lye, W Midlands*

The old tramway section at Salt Wells Nature Reserve in Netherton, West Midlands has been described by Elles and Slater (1906), King and Lewis (1912), Ball (1951), and Whitehead and Pocock (1947), Antia (1980b) and mentioned by Hains and Horton (1969). Conodonts from the Upper Whitcliffe Formation at this section have been figured (Aldridge 1975, 1985) and used in geochemical studies of Silurian phosphatic fossils (Bertram *et al.* 1992). Arenaceous foraminifera have been recovered from the Upper Whitcliffe Formation (Antia 1980b). A bone bed has also been documented at Lye, W Midlands, and taken to mark the base of the Downton Castle Sandstone (Whitehead and Pocock 1947, fig. 4). The Lye bone bed is no longer exposed, although the unconformity between the Silurian and the overlying Carboniferous has recently been cleared (Cutler and Worton 1992). Using thelodont evidence, Turner (1973, fig. 6) considered the Lye bone bed to be a correlative of the Downton Bone Bed.

*Whitcliffe Formation, (Netherton)* The section has not been logged in detail. The lithology is similar to the type Whitcliffe (see Chapter 4), but the section has been heavily weathered and iron stained to a rusty brown colour. A distinctive bed of limestone nodules (Text-fig. 5.9) previously sampled for conodonts (Aldridge 1975, 1985; Bertram *et al.* 1992) contains abundant *P. serratus*, *C. dubius*, *O. excavata*, *O. confluens*, minor proportions of *P. recurvatus* and single specimens of *O. remscheidensis eosteinhornensis* and *Walliserodus cf. sanctilairi* (Text-fig. 5.3). Chitinozoans and arenaceous foraminifera have also been picked from the light residues of samples 1a and 1b. Sample 20/5, at the top of the formation contains *P. serratus*, *O. excavata* and large, abraded specimens of *O. confluens* (Text-fig. 5.3).
TEXT-FIG. 5.9. Log of the Whitcliffe and Downton Castle Sandstone formations at Netherton (loc. 20), showing sampled horizons.
Downton Castle Sandstone Formation. Only 32cm of the formation is exposed at Netherton, below the topsoil (Text-fig. 5.9). The exposure consists of highly weathered, "rotten" thelodont-rich horizons, with abundant organic matter (often present as black spherules) described as *Pachytheca* sp. (King and Lewis 1912; Whitehead and Pocock 1947; Ball 1951). The thelodont rich horizons are interbedded with more resistant, fine-grained, parallel laminated silty mudstones which also contain organic remains.

Conodont collections consist almost exclusively of *C. dubius* elements with a single Pa element of *O. confluens* obtained from sample 20/4 (Text-figs 5.3, 5.9). A single ostracod specimen of *F. cf. groenvalliana* has been collected by Dr David J. Siveter from the lowermost Downton Castle Sandstone Formation (Siveter 1989, Hansch et al. 1991).
CHAPTER 5

PALAEOENVIRONMENTS

Upper Whitcliffe Formation

Deposition has been interpreted as subtidal on a proximal shelf, mostly within wave base, shallowing towards the top of the formation with coquinas representing storm events (Watkins 1979; Bassett et al. 1982). Using ratios between different microplankton groups, a deepening towards the top of the Upper Whitcliffe Formation at Weir Quarry, Downton has been suggested (Richardson and Rasul 1990, fig. 2).

The conodont faunas from the Whitcliffe Formation at Aston Munslow are similar to those from the uppermost part of the type Upper Whitcliffe Formation at Ludlow; a fauna dominated by *O. excavata* is succeeded by collections dominated by *O. confluens* and *C. dubius* (Text-figs 4.7 and 5.5). The fauna from sample 7a/4, dominated by *C. dubius* with minor proportions of *O. confluens*, *O. snajdri*, and *O. cf. crispa*, is almost directly comparable with the fauna from sample 18/1, 10-15cm below the top of the Upper Whitcliffe Formation at Ludford Corner, Ludlow (loc. 18), differing only in the absence of *remscheidensis plexus* elements (Text-fig. 5.3). In Chapter 4, it was suggested that the conodont faunas towards the top of the Upper Whitcliffe Formation at Ludlow reflect shallowing towards the top of the formation. A similar inference can be drawn from the nature of the conodont faunas at the top of the Whitcliffe Formation at Aston Munslow.

The faunas from samples 20/1a, 20/1b and 115/1* at Netherton (loc. 20) contain an unusually high percentage of *Panderodus* elements compared with samples from the Upper Whitcliffe Formation elsewhere in the Welsh Borderland. *P. serratus* elements present in the bed immediately below the top of the Upper Whitcliffe Formation at Netherton (sample 20/5) represent the highest recorded occurrence of *P. serratus* in the Welsh Borderland. This is also the only locality where the coniform *Walliserodus cf. sancticlairei* has been recovered. The occurrence of chitinozoans in samples 20/1a, b, is unusual as chitinozoans are rare at the base of the Upper Whitcliffe Formation and become even rarer towards the top of the Upper Whitcliffe Formation at Ludlow (Sutherland 1992).
CHAPTER 5

Downton Castle Sandstone Formation

Ratios between different microplankton groups suggest a sudden shoaling occurred at the base of the Ludlow Bone Bed Member and a deepening, including a storm event, within the Platyschisma Shale Member of the Downton Castle Sandstone Formation at Downton (Richardson and Rasul 1990, fig. 2). There are also differences between the palynofloras at Ludford Lane (loc. 17) and Downton (loc. 14b); the uppermost Upper Whitcliffe Formation and lowermost Downton Castle Sandstone Formation at Ludlow is characterised by supposed nearer-shore acritarch species as compared with the Weir Quarry section (Richardson and Rasul 1990). Richardson and Rasul (1990, p. 681) suggest that these differences could be explained by proximity to offshore channels delivering high proportions of land derived palynomorphs.

Ostracod faunas recovered from a limestone bed at Linley Brook (loc. 3b) are very similar to faunas from beds 17a/28 and 17b/24, exposed on Ludford Lane (Text-figs 4.4 and 4.13). Ostracod collections from these limestone beds are also similar to collections from the Downton Castle Sandstone Formation at Willey (White and Coppack 1978). It is, therefore, possible that the Much Wenlock and Ludlow areas experienced similar environmental conditions at the time of deposition of the Downton Castle Sandstone Formation. However, it is unusual for limestones to be deposited in the Downton Castle Sandstone Formation and these are locally developed only in the Much Wenlock area. Unabraded conodont specimens recovered from one of these limestone beds at Linley Brook (loc. 3b) are unusual, as conodont specimens recovered from the Downton Castle Sandstone Formation across the Welsh Borderland are usually heavily abraded; the possibility that these abraded specimens have been transported or reworked from older strata cannot be discounted. These calcareous beds with well preserved conodont elements suggest a marine environment in which conodonts of the genera *Oulodus* and *Ozarkodina* existed during deposition of the Downton Castle Sandstone Formation in the Much Wenlock area. Original calcareous ostracod valves obtained from these beds are also unusual. Elsewhere in the Welsh Borderland ostracods are only present at these levels as decalcified moulds.

The sedimentology of the Downton Castle Sandstone Formation at Aston Munslow is distinct from coeval levels at Ludford Lane, coarsening upwards much more rapidly and lacking multiple bone beds in the lowermost 30cm (see Text-figs 4.4, 5.5). It is possible that
the environment at Aston Munslow was more unfavourable to ostracods than at Ludford Corner/ Ludford Lane.

The section at Weir Quarry (loc. 14b) is distinct from the type section for the base of the Downton Castle Sandstone Formation at Ludford Corner (see Chapter 4). At Ludford Corner and Ludford Lane (locs 17, 18) the sediments coarsen upwards much more rapidly into bioturbated siltstones/ very fine sandstones at the base of the Platyctisma Shale Member (Text-fig. 4.4), and contain a greater frequency of ostracods (Text-figs 4.14 and 5.8) and land derived palynomorphs (Richardson and Rasul 1990). In beds where ostracods are more abundant, the Weir Quarry faunas are similar in composition to those from the Platyctisma Shale Member at Ludlow (see Text-fig. 4.13), although it is not possible to compare directly the ostracod faunas with the palynofacies variations of Richardson and Rasul (1990) as the Weir Quarry ostracod fauna is so sparse.

As discussed in Chapter 4, the sparse ostracod faunas and the low percentage of land derived sporomorphs in the lowermost Downton Castle Sandstone Formation at Weir Quarry, as compared with coeval levels at Ludlow, are possibly related phenomena and could be explained by proximal offshore channels delivering high proportions of land derived palynomorphs (Richardson and Rasul 1990).

CORRELATION

Britain
Bone beds have been used to correlate the base of the Downton Castle Sandstone Formation across the area covered by Chapter 5 at: Much Wenlock (Robertson 1927; White and Coppack 1978), along Corve Dale (Shergold 1967a; Shergold and Shirley 1968; Antia 1979a), at Onibury (Elles and Slater 1906), Downton (Elles and Slater 1906; Whitalker 1962; Richardson and Rasul 1990), Kington (Holland and Williams 1985) and Netherton (King and Lewis 1912; Whitehead and Pocock 1947; Ball 1951). In the absence of a basal bone bed Antia (1979b) used the first occurrence of *F. groenvalliana* and the dissappearance of distinctive Upper Whitcliffe brachiopods to indicate the local base of the Downton Castle Sandstone Formation at Sielton.

In general, ostracod faunas from the Upper Whitcliffe and Downton Castle Sandstone formations in the area surrounding Ludlow are very similar to faunas at Ludlow itself (see
Chapter 4). *C. torosa* is restricted to the Upper Whitcliffe Formation and *F. groenvalliana* restricted to the Downton Castle Sandstone Formation. *F. groenvalliana* occurs at the immediate base of the Downton Castle Sandstone Formation in the area surrounding Ludlow at Willey (loc. 2) and Downton (loc. 14b); *F. cf. groenvalliana* occurs at the immediate base at Netherton (loc. 20). Localities in the area surrounding Ludlow where *F. groenvalliana* is present above the base of the Downton Castle Sandstone Formation are at Linley (locs 3a-c), Brockton (loc. 5b), Culmington (loc. 11) and Downton (loc. 14b). Without detailed bed by bed collections, the assumption that the base of the Downton Castle Sandstone Formation is at the level of the first occurrence of *F. groenvalliana* at Siefton (Antia 1979b) is therefore unsubstantiated. "The fauna below does contain some species (e.g. *Lingula minima* and *L. kiesowi*) which are commonly found in the Downtonian," (Antia 1979b, p. 127) which suggests that the base of the Downton Castle Sandstone Formation at Siefton is possibly at a level below the first occurrence of *F. groenvalliana*.

Bone beds are developed within the Platyschisma Shale Member, Downton Castle Sandstone Formation, at Weir Quarry (Text-fig. 5.8) and Ludford Lane (Text-fig. 4.4); although they are not as well developed as the Downton Bone Bed (loc. 14c), they are possible correlatives.

**International**

The correlation of the base of the Downton Castle Sandstone Formation with the base of the Pföffdolf Series has been discussed in Chapter 4.

The specimen identified as *O. cf. crispa* from the topmost bed (sample 7a/4) of the Upper Whitcliffe Formation at Aston Munslow (loc. 7b) has similar dentition, cavity shape and outline to unequivocal specimens of *O. crispa*, although the curved posterior termination to the element is not well developed (see Chapter 2, Pl. 9, fig. 9). *O. crispa* last occurs at a level 50cm below the base of the Pföffdolf Series at the boundary stratotype at Požáry in Czechoslovakia, and at similar levels throughout the Barrandian Basin (Kříž 1992). The occurrence of *O. cf. crispa* in sample 7a/4 suggests that the base of the Pföffdolf Series at Aston Munslow should be placed at least as high as the base of the Downton Castle Sandstone Formation.

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CHAPTER 5

The restriction of *F. groenvalliana* to the Downton Castle Sandstone Formation in the area surrounding Ludlow, and its occurrence at the base of the formation at Willey (loc. 2), Downton (loc. 14a) and Netherton (loc. 20), is consistent with the correlation of the base of the Downton Castle Sandstone Formation with the base of the Pridolf Series, assuming the chain of correlation outlined in Chapter 4.

CONCLUSIONS

1. Bone beds mark the base of the Downton Castle Sandstone Formation at Willey (loc. 2), Aston Munslow (loc. 7a), Downton (locs 14a, b), Kington (locs 19a, b) and Netherton (loc. 20). Similar bone beds have been reported but are no longer exposed at Callaughton (loc. 1), Brockton (loc. 5b) and Shipton (locs 6a-c).

2. The ostracod faunas from the Upper Whitcliffe Formation of the shelf area are comparable with the sparse faunas of the stratotype at Ludlow, and are characterised by *C. torosa* with rare occurrences of *H. cf. maccloyiana* and *L. cf. scanensis* (Text-fig. 5.10).

3. Conodont faunas from the Upper Whitcliffe Formation show a similar trend to faunas from the stratotype. Conodont faunas at Aston Munslow (loc. 7a) are similar to faunas from Ludford Corner and include a single specimen of *O. cf. crispa* from the topmost bed of the formation. Specimens of *P. serratus* from the topmost bed of the Upper Whitcliffe Formation at Netherton are the highest recorded occurrence of the species in the Welsh Basin.

4. The ostracod faunas from the Downton Castle Sandstone Formation are also similar to the type sections at Ludlow, and are characterised by *F. groenvalliana* with less abundant *L. arisaigensis, L. fissurata, N. verrucosa* and a single recovered specimen of *L. kiesowi*. Unlike at Ludlow, *C. torosa* has not been recovered from the Downton Castle Sandstone Formation in this area (Text-fig. 5.10). Limestones are locally developed in the Downton Castle Sandstone Formation in the Much Wenlock area and preserve original calcareous valves of *F. groenvalliana*.

5. Conodont collections from the Downton Castle Sandstone Formation generally consist of abraded Pa elements of *O. confluens* and Sa/Sb elements of *C. dubius*. Limestones in the Much Wenlock area have yielded complete specimens of *Oulodus* sp., which indicates that conodonts were present in a marine environment in the Much Wenlock area during deposition of the Downton Castle Sandstone Formation rather than reworked from other sources.
**KEY**

- **Londinia arisaigensis**
- **L. cf. arisaigensis**
- **C** Conodont fauna recovered
- **C** Fauna including O. cf. crispa
- **Δ** L. fissurata
- **●** Frostiella groenvalliana
- **•** F. groenvalliana
- **♦** L. kiesowi
- **<<** Hemsiella cf. maccoyiana
- **ς** Lophocstenella cf. scanensis
- **□** Calcaribeyrichia torosa
- ***** Nodibeyrichia verrucosa
- **—** Bone bed

**TEXT-FIG. 5.10.** Summary of the distribution of conodont samples and occurrence of ostracod species from localities in the shelf area of the Welsh Borderland surrounding Ludlow. The stratigraphic columns are not drawn to scale. Symbols indicate the recorded occurrence of a species within a formation and are not intended to indicate exact stratigraphic position or order of occurrence of species.
6. Local variations in ostracod frequency, sedimentology and published palynofacies data for the base of the Downton Castle Sandstone Formation at Ludlow and Downton indicate localised variations in environment which may be related to proximal channels delivering sediment off an irregularly prograding shoreline.

7. The ostracod *F. groenvalliana* is confined to the Downton Castle Sandstone Formation, although it occurs at the very base of the formation only at Willey (loc. 2), Downton (loc. 14a) and Netherton (loc. 20). The species can therefore be used to indicate strata of Downton age, although the first occurrence should not definitively be used to indicate the base of the Downton Castle Sandstone Formation.

8. The occurrence of the conodont *O. cf. crispa* within the topmost bed of the Upper Whitcliffe Formation at Aston Munslow (loc. 7a) suggests that the base of the Přídolí Series at that locality should be at a level at least as high as the base of the Downton Castle Sandstone Formation.

9. Combined with the conodont evidence the occurrence of *F. groenvalliana* at the base of the Downton Castle Sandstone Formation is consistent with the correlation of the base of the Downton Castle Sandstone Formation with the base of the Přídolí Series assuming the chain of correlation outlined in Chapter 4.
CHAPTER 6

OSTRACOD AND CONODONT DISTRIBUTION
ACROSS THE LUDLOW/PŘÍDOLÍ BOUNDARY
(SILURIAN): SHELF LOCALITIES OF THE SOUTHERN
WELSH BORDERLAND INLIERS

ABSTRACT. Conodont and ostracod faunas have been recovered by detailed sampling across the base of the lithostratigraphical equivalents of the Downton Castle Sandstone Formation in the Silurian inliers of the southern Welsh Borderland. Conodont and ostracod collections are similar to collections described from Ludlow (Chapter 4).

Conodonts recovered from Tite's Point and Longhope are abraded and sorted, indicating a turbulent environment. The occurrence of ostracods in the Rushall Beds at Perton is possibly controlled by storm sedimentation and proximal channels delivering plant-rich sediments off an irregularly prograding shoreline.

*F. groenvalliana* always occurs above levels traditionally correlated with the base of the Downton Castle Sandstone Formation using bone beds and phosphatic pebble beds and *O. crispa* always occurs below these levels.
INTRODUCTION

The microfaunal characteristics across the base of the Downton Castle Sandstone Formation at its basal stratotype section at Ludlow and at coeval levels within the shelf area of the Welsh Borderland adjacent to Ludlow are detailed in Chapters 4 and 5 (Text-fig. 6.1). Chapter 6 describes the microfaunal changes across base of the Downton Castle Sandstone Formation and its lateral equivalents (Text-fig. 6.2), across the southern part of the shelf area of the Welsh Borderland which includes the inliers of the Malvern and Abberley Hills, Woolhope, May Hill, Tortworth and Usk (Text-figs 6.1, 6.3). For a review of the Silurian Geology of the area covered by Chapter 6 see Lawson et al. (1967, 1982).

Sections exposing the local equivalents of the Upper Whitcliffe Formation / Downton Castle Sandstone Formation boundary have been studied in detail at Perton Lane (loc. 23), Prior's Frome (loc. 24), Tite's Point (loc. 31b) and Brook House, Usk (loc. 33). An additional 25 coeval localities are also documented (Text-fig. 6.3).

LOCALITIES AND HORIZONS

21a. Small Quarry 50m S of Abberley Hall, SO 745 663. Whitcliffe Flags Member, Upper Ludlow Formation (BGS).
21b. Small old quarry 1500m SW of Hundred House, SO 7405 6505. Whitcliffe Flags Member, Upper Ludlow Formation (BGS).
21c. Woodbury Quarry (working), SO 743 637. Upper Ludlow Formation including Whitcliffe Flags Member, Downton Castle Sandstone Formation (BGS).
21d. Small old quarry 1500m at 113° from Shelsey Beauchamp Church, SO 746 622. Whitcliffe Flags Member, Upper Ludlow Formation (BGS).

22. BROCKHILL QUARRY. 1500m N of Colwall Station, Colwall, near Malvern Wells, Hereford and Worcester, SO 7568 4394 (Penn and French 1971, loc. 38). Whitcliffe Flags Member, Upper Ludlow Formation, Downton Castle Sandstone Formation with bone bed at base (CGM and RJA).

23. PERTON LANE. Exposures to E of Perton Lane, Perton, 5km NNW of Woolhope, Hereford and Worcester.
TEXT-FIG. 6.1. Study area for Chapter 6, the southern Welsh Borderland (outlined by thick black line). Base map after Bassett et al. (1982). The area outlined by a thin line is considered in Chapter 5.
<table>
<thead>
<tr>
<th>SERIES</th>
<th>LUDLOW</th>
<th>ABBERLEY AND MALVERN HILLS</th>
<th>WOOLHOPE</th>
<th>GORSLEY</th>
<th>MAYHILL</th>
<th>TITE'S POINT</th>
<th>USK</th>
</tr>
</thead>
</table>

|          | Downton Castle Sandstone Formation (<17.3m) | Downton Castle Sandstone Formation | Rushall Beds (6-21m) | Clifford's Mesne Sandstone (c.6m) | Clifford's Mesne Sandstone (3-24m) | Downton Castle Sandstone Formation (1.7m) | Speckled Grit Beds (1.5-23m) |
| LUDLOW   | Ludlow Bone Bed                           | Bone Bed                          | Bone Bed             | Phosphatised pebble bed           | Phosphatised pebble bed            | Bone Bed                        | Bone Bed         |

|          | Upper Whitcliffe Flags Member of Upper Ludlow Formation (32m) | Upper Perton Beds (2-21m) | Upper Silstone (2m) | Upper Longhope Beds (3-15m) | Whitcliffe Formation (21.8m) | Upper Llangibby Beds (6-8m) |

23a. 20m S of 3-way road junction at Perton, SO 5971 4035 (Squirrell and Tucker 1960, fig. 2, loc. F). Upper Perton and Rushall beds (CGM, DJS and RJA).

23b. 20m S of locality 23a, SO 5969 4031 (Squirrell and Tucker 1982, fig. 5, loc. 2). Upper Perton Beds (CGM and RJA).

24. PRIOR’S FROME. Exposures opposite Yew Tree Inn, Prior’s Frome, c.5km ESE of Hereford, Hereford and Worcester, SO 5662 3901.

24a. Old quarry face. Upper Perton Beds (CGM and RJA).


25. CAERSWELL FARM. 3.5km SE of Woolhope, Hereford and Worcester, SO 6440 3380. Upper Perton Beds and Rushall Beds with bone bed at base (CGM and BGS).


27. RUSHALL. 3km ESE of Woolhope, Hereford and Worcester, SO 6410 3481. Upper Perton Beds and Rushall Beds with bone bed at base (CGM and BGS).

28. BODENHAM FARM. 5.5km, SE of Woolhope, Hereford and Worcester, SO 6524 3201 (Squirrell and Tucker 1982, loc. 18). Lower Perton Beds and Upper Perton Beds with bone bed at base (BGS).

29. GORSLEY. Linton Quarry, 4km W of Newent, Gloucestershire, SO 6770 2570 (See Lawson 1954 for local lithostratigraphical units). Wenlock Limestone, Upper Blaisdon Beds, Upper Longhope Beds with phosphatic pebble bed at base and Clifford’s Mesne Sandstone with phosphatic pebble bed at base.

30. LONGHOPE. Exposures around Longhope Village, Gloucestershire.


30c. Stream section at Wood Green, SO 6930 1670 (Lawson 1954, fig. 1, loc. C). Upper Longhope Beds and Clifford’s Mesne Sandstone with phosphatic pebble bed at base.

31. TITE’S POINT. Exposure on the S bank of the River Severn near the Berkeley Arms, Purton, Gloucestershire.

31b. Foreshore of Severn Estuary, 250m W of Berkeley Arms, SO 668 046 (Cave and White 1971). Upper Leintwardine Formation, Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base (CGM, RJA and BGS).

32. BROOKEND BOREHOLE. Vine Farm 3km N of Berkeley, Gloucestershire, SO 687 0230 (Cave and White 1968, 1978). Elton/Bringewood Beds, Leintwardine Formation, Whitcliffe Formation overlain by Downton Castle Sandstone Formation and Thornbury Beds.

33. BROOK HOUSE. Exposure on W bank of Cwm-ffrwd Brook, c.2km WSW of Llangybi, Usk Valley, Gwent, SN 3545 9572 (Walmsley 1959, fig. 7). Upper Llangibby Beds and Speckled Grit Beds with multiple bone beds at base.

34. USK. Exposures around Usk, Gwent, SO 375 005. Localities exposing Speckled Grit Beds with fragmentary fish remains (Walmsley 1959).

34a. A few feet below wall in Llandegveth church yard, Llandegveth, SN 338 957.

34b. Old quarry 400m SW of Llangybi Castle, SN 365 972.

34c. Dingle immediately N of Granary Farm, SN 322 968.

34d. Stream section 500m N of Llandewi Court, SN 316 982.

35. RUMNEY BOREHOLE. c.1.5km W of Rumney, Cardiff, ST 2108 7925 (Waters and White 1978). Wenlock Series extending through Ludlow Series including Llanedeyrn Formation, overlain by Raglan Mudstone Formation with fragmentary fish remains at base.
CHAPTER 6

THE ABBELEY AND MALVERN HILLS, CENTRAL HEREFORD AND WORCESTER

The Abberley and Malvern Hills trend in a N-S direction between Hereford and Worcester (Text-fig. 6.2). No localities from this area have been described in detail in the present study. Two localities have been reported to expose strata taken to correlate with the base of the Downton Castle Sandstone Formation.

Woodbury Quarry (loc. 21c) in the Abberley Hills was mentioned by Phipps and Reeve (1967) and documented by Mitchell et al. (1961), who included a simplified log taken before quarrying was extended at the section. The brachiopod communities at Woodbury Quarry have been described (Watkins 1979). Material (BGS) collected by Stubblefield and Smith in 1937 has been examined and includes abundant examples of Calcaribeyrichia torosa associated with decalcified brachiopod rottenstones from the Upper Ludlow Formation. There are no examples of the Hemsiella maccoyiana material that Mitchell et al. (1961) indicated to be present.

The boundary between the Upper Ludlow Formation and the Downton Castle Sandstone Formation at Woodbury Quarry is taken at the lithological change from greenish grey calcareous siltstone to greenish grey sandstone and shale with carbonaceous and phosphatic debris (Mitchell et al. 1961). There is no mention of a bone bed at the base of the Downton Castle Sandstone Formation at Woodbury Quarry and only 1.5m of the formation is exposed (Mitchell et al. 1961).

Exposures of the Whitcliffe Flags Member of the Upper Ludlow Formation around the village of Abberley (locs 21a, 21b and 21d) have also yielded specimens of C. torosa.

Brockhill Quarry in the Malverns (loc. 22) is reported to expose a bone bed at the base of the Downton Castle Sandstone Formation (Salter 1858; Stamp 1923; Phillips 1948; White 1950). At Brockhill, the topmost 3-4.5m of the Whitcliffe Flags Member of the Upper Ludlow Formation consists of thinly-bedded micaceous sandstones and mudstones (Phipps and Reeve 1967) which are much less resistant than the underlying flaggy siltstones. These less resistant sediments are highly weathered and are no longer well exposed at Brockhill. As a result, it has not been possible to locate the bone bed for this study. A single conodont sample from the Whitcliffe Flags Member at Brockhill (loc. 22) yielded Ozarkodina excavata, Coryssognathus dubius and O. confluent in ascending order of abundance (Text-fig. 6.4). No ostracods were recovered from Brockhill Quarry.
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<td><em>O. unassigned</em></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Pb(B)</td>
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</tr>
<tr>
<td>M(A)</td>
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<td></td>
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<tr>
<td>Total number of elements</td>
<td>1294</td>
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<td>44</td>
<td>228</td>
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<tr>
<td>Calculated elements/ kg</td>
<td>600</td>
<td>1056</td>
<td>192</td>
<td>685</td>
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TEXT-FIG. 6.4. Conodont faunas from the Upper Ludlow Formation at Brockhill Quarry (loc. 22), the Upper Perton Beds at Perton (locs 23a, b) and the Upper Longhope Beds at Longhope (loc. 30b).
CHAPTER 6

THE WOOLHOPE INLIER, CENTRAL HEREFORD AND WORCESTER

The Woolhope inlier is situated midway between Hereford and Ledbury. Silurian rocks from Upper Llandovery to Pridolf in age are folded into a NW/SE trending pericline which has a more steeply dipping western limb (Gardiner 1927; Pocock 1950; Squirrell 1958; Squirrell and Tucker 1960, 1982). Localities in the northern part of the inlier at Perton (loc. 23) and Prior's Frome (loc. 24), have been studied in detail for the present study and an additional four localities on the NE margin of the inlier are also considered.

Perton Lane (loc. 23)

Perton is situated on the northernmost margin of the inlier (Text-fig. 6.2), c.1km WSW of Stoke Edith. The main locality sampled (loc. 23a) lies just to the E of Perton Lane which follows the Perton Fault (see Squirrell and Tucker 1960, fig. 2). This locality is an SSSI and has not been logged in detail due problems of access. The locality is well known for its early land floras (Lang 1937; Edwards 1979; Richardson et al. 1981; Richardson and McGregor 1986; Fanning et al. 1988) and is the type locality for the primitive land plant *Cooksonia pertoni* Lang, 1937. Rich eurypterid faunas (see summary in Kjellesvig-Waering 1951) and the problematic taxon *Actinophyllum* sp. have been recovered from the Rushall Beds (Straw 1926; Pocock 1950). Biotite bands are reported from the Perton Beds (Tucker 1960).

*Upper Perton Beds.* The uppermost metre is exposed at locality 23a and approximately 5m are exposed 20m to the S at locality 23b. The beds consist of blue/grey calcareous siltstone with brachiopod coquinas and rare limestone beds and lenses (Text-fig. 6.5).

Non-palaeocope ostracods have been recovered from the topmost Upper Perton Beds (samples 23a/A and B) and a single specimen of *H. cf. maccyiana* recovered from a coquina 6cm below the top of the beds (Text-figs 6.5, 6.6).

Samples 161/1* and 23b/1, taken 1m above the base of the cliff section at locality 23b, are estimated to be from approximately 4m below the top of the Upper Perton Beds. Sample 161/1* contains a much more diverse fauna than 23b/1; *O. excavata, C. dubius, O. confluens* and *Panderodus serratus* occur in both samples (Text-fig. 6.4). Samples 160/1* and 161/1* also contain rare examples of *O. wimani, O. remschiedensis eostehornensis* and *O. snajdri.*
TEXT-FIG. 6.5. Log showing position of samples from the Upper Perton and Rushall beds at Perton (loc. 23a). The horizontal bars represent the faunal composition of samples yielding ostracods.
<table>
<thead>
<tr>
<th>Lithostratigraphy</th>
<th>U. Perton Beds</th>
<th>Rushall Beds</th>
</tr>
</thead>
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<tr>
<td>Bed letter</td>
<td>A  B  C  D  E  F  G  H  J  L  M  N  P  Q  R  S  T  U  W  X  Y</td>
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</tr>
<tr>
<td>Areacm²</td>
<td>113 716 855 650 640 806 614 368 635 1315 902 564 1533 51 513 552 895 328 166 376 905</td>
<td></td>
</tr>
<tr>
<td>n valves</td>
<td>5 8 61 10 5 95 22 12 7 61 68 90 184 4 20 35 59 8 5 49 22 1</td>
<td></td>
</tr>
<tr>
<td>n carapaces</td>
<td>1</td>
<td></td>
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<tr>
<td>Hemiabella cf. maccoyana</td>
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<tr>
<td>Non-palaeocopides</td>
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</tr>
<tr>
<td>F. cf. groenvaldiana</td>
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<td></td>
</tr>
<tr>
<td>Londinia arisagenisis</td>
<td>1 1 2 1 1 1 6 6 1 1</td>
<td></td>
</tr>
<tr>
<td>L. cf. arisagenisis</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Londinia fissurata</td>
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<td></td>
</tr>
<tr>
<td>L. cf. fissurata</td>
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<td></td>
</tr>
<tr>
<td>Londinia sp.</td>
<td>6 1 2 8 8 11 11 1 1 4 6</td>
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</tr>
<tr>
<td>Nothobryoidea sp.</td>
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<tr>
<td>unidentified</td>
<td>6 19 2 3 37 6 5 3 25 27 12 46 1 8 15 26 3 16 4</td>
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</tr>
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TEXT-FIG. 6.6. Frequencies of ostracod valves from the Upper Perton and Rushall beds at Perton Lane, Woolhope (loc. 23a). Single carapace of *L. fissurata* recovered (bed Y). The positions of samples are given in Text-figure 6.5.
Sample 23a/3 contains, in ascending order of abundance, only *C. dubius*, *O. confuens* and *O. excavata*.

**Rushall Beds.** 5.5m are exposed at locality 23a, with the base marked by a lithological change from blue/grey coquinaloidal siltstones (Upper Perton Beds) to olive grey siltstones and very fine sandstones rich in plant and eurypterid fragments (Text-fig. 6.5). This level in the section is also marked by a small cleft, with the underlying Upper Perton Beds forming a large step at the base of the section. The section has not been logged in detail, although as far as possible, each bed in the lowermost 2.40m of the exposed Rushall Beds has been examined and a simplified sedimentary log constructed (Text-figure 6.5).

Ostracod moulds are stained rusty brown, are poorly preserved due to the coarse nature of the sediment, and are generally smaller than specimens obtained from the base of the Downton Castle Sandstone Formation at Ludlow. Abundance is low, ranging from 0.02-0.18 ostracod valves per cm² (Text-fig. 6.5). Ostracods occur almost exclusively in the coarse bases of fining-upwards beds and sporadically in the succeeding finer sediment. Plant and eurypterid fragments are commonly associated with ostracods on bedding planes.

The ostracod fauna is restricted to two sections: the lowermost 50cm and 110-150cm above the base of the Rushall Beds. The lowermost 50cm contains a relatively consistent ostracod fauna dominated by non-palaeocopes, together with approximately equal proportions of *Londinia* and *Frostiella* (Text-fig. 6.5). *Frostiella groenwaliana*, *L. arisaigensis* and *L. fissurata* are present. A specimen of *Nodibeyrichia* sp. was recovered from sample 23a/F (Text-fig. 6.6).

110cm above the base of the Rushall Beds the fauna is dominated by non-palaeocopes, with minor proportions (<15% total) of *Londinia* and *Frostiella* (Text-fig. 6.5). Approximately 150cm above the base of the Rushall Beds the fauna consists of equal proportions of *Frostiella*, *Londinia* and non-palaeocope ostracods. The only carapace recovered from this section is that of *L. fissurata* from 150cm above the base of the Rushall Beds (sample 23a/Y).
Prior's Frome (loc. 24)

The small quarry opposite the Yew Tree Inn at Prior's Frome previously exposed the boundary between the Upper Perton and Rushall beds (Gardiner 1927, fig. 4; Pocock 1950; Squirrel and Tucker 1960, 1982; Brandon 1989). From this locality, the trilobite *Acastella spinosa* (Salter, 1864) was figured from the Upper Perton and Rushall beds (Shergold 1967b), conodonts were figured from the Upper Perton Beds (Aldridge 1985) and used in a geochemical study on Silurian phosphatic fossils (Bertram et al. 1992).

When Gardiner (1927, fig. 4) produced his simplified log of the section and Pocock (1950) visited the section, there was continuous exposure across the boundary between the Upper Perton and Rushall beds. Even though Squirrel and Tucker (1967, p. 13; 1982, p. 14) remarked that "the Ludlow Bone Bed is exposed by shallow digging above a crude footpath which descends the bedding plane surface of the Upper Whitecliffe Formation," deep digging for the present study failed to reveal this bone bed. The present exposure gap of approximately 50cm (Text-fig. 6.7) has been estimated using a published photograph of the section (Gardiner 1927, pl. 39, fig. 2).

**Upper Perton Beds.** An old quarry face (loc. 24a) exposes 2.96m of the beds dipping 26° due west. They consist of coquinoideal siltstones and thin mudstone horizons with rare limestone beds and lenses. A thin bone bed (0-3mm) occurs approximately 1.2m above the base of the section (Text-fig. 6.7). The beds are more calcareous towards the base of the exposure, thus fewer conodont samples have been taken towards the top.

Conodont faunas from the lower metre of the exposure are characterised by *O. excavata, C. dubius, O. confluens, P. serratus* and *P. recurvatus* in ascending order of abundance (Text-figs 6.7 and 6.8). The bed from which samples 162/2* and 24a/2 were obtained has also yielded *O. remschiedensis eosteinhornensis, O. r. baccata, O. wimani*, and *O. crispa*. The two samples from the upper 2m of the Upper Perton Beds contain an abundance of *Panderodus* elements, together with *C. dubius, O. excavata* and *O. confluens*.

A single internal mould of *C. torosa* has been recovered from approximately 0.80m below the base of the Rushall Beds.
TEXT-FIG. 6.7. Log of the Upper Perton and the Rushall beds at Prior’s Frome (locs 24a, b), showing sampled horizons, conodont ranges and the composition of conodont faunas.
<table>
<thead>
<tr>
<th>Lithostratigraphy</th>
<th>Upper Perton Beds</th>
<th>Rushall Beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>24a 162 24a 162 24a 162 24a 162 24a 162 24a 162</td>
<td>24b 24b 24b 24b 24b 24b 24b 24b</td>
</tr>
<tr>
<td>Panderodus recurvatus</td>
<td>sect.</td>
<td>test.</td>
</tr>
<tr>
<td>P. serratus</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>Cercygnathus dabis</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>C. excavata</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>O. crispa</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>O. cf. crispa</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>O. remachildenses baccata</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>O. cf. baccata</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>O. r. easteinhornensis</td>
<td>fac.</td>
<td>loc.</td>
</tr>
<tr>
<td>O. r. sesp. fragments</td>
<td>fac.</td>
<td>morph B</td>
</tr>
<tr>
<td>O. sp. fragments</td>
<td>fac.</td>
<td>morph B</td>
</tr>
<tr>
<td>O. sp. fragments</td>
<td>fac.</td>
<td>morph B</td>
</tr>
<tr>
<td>O. unassigned</td>
<td>morph A</td>
<td>morph B</td>
</tr>
<tr>
<td>Total number of elements</td>
<td>43 1010 1744 681 599 23 29 7 125 3</td>
<td></td>
</tr>
<tr>
<td>Calculated no./kg</td>
<td>229 83 2270 11270 3753 1804 20 668 5 60 9</td>
<td></td>
</tr>
</tbody>
</table>

TEXT-FIG. 6.8. Conodont faunas from the Upper Perton and Rushall beds at Prior's Frome, near Woolhope, Hereford and Worcester (loes 24a, b).
Rushall Beds. The junction between the Rushall Beds and the underlying Upper Perton Beds is no longer exposed, but specimens of the bone bed at the base of the Rushall Beds are available. These specimens (BGS 59-235; Zs 3614-3658) consist of brown-stained coarse sandstone with minor proportions of thelodonts and organic fragments, a few specimens of the brachiopod Salopina lunata and an acanthodian fragment. A simplified log of the exposure above the bone bed (Text-fig. 6.7) and a field sketch of the whole exposure of the Rushall Beds, together with lithological descriptions, is included (Text-fig. 6.9).

The conodonts obtained are fragmentary, abraded and consist dominantly of C. dubius. Ozarkodina confluens is less common and O. excavata, P. recurvatus and O. cf. snajdri are rare (Text-figs 6.7, 6.8).

Other localities
The BGS record bone beds from the base of the Rushall Beds, on the eastern margin of the Woolhope inlier at Caerswell Farm (loc. 25), Whittocks End Farm (loc. 26) and Rushall (loc. 27). C. torosa and non-palaeocopes have been recovered from the uppermost Upper Perton Beds at Rushall (loc. 27) as part of the present study. At Caerswell Farm (loc. 25) the bone bed is up to 35cm thick. A bone bed containing conodonts is developed at the base of the Upper Perton Beds at Bodenham Farm (loc. 28) (Squirrell 1958), but the exposure is now almost completely overgrown.
THE MAY HILL INLIER, W GLOUCESTERSHIRE

Localities in this area have not been documented in detail for the present study. The base of the Clifford's Mesne Sandstone is marked by a phosphatised pebble bed (Text-fig. 6.3), which is well exposed at Linton Quarry Gorsley (loc. 29) where the very attenuated Ludlow Series is represented by only 12.5ft (3.80m) of strata (Pocock 1950, Lawson 1954). Samples processed for conodonts from the Upper Siltstone at Linton Quarry (Text-fig. 6.3), proved to be barren.

A phosphatised pebble bed reported (Lawson 1955, 1982) from an exposure behind Longhope Railway Station (loc. 30a) is now obscured by new buildings and its occurrence in the stream section at Wood Green (loc. 30c) is now almost inaccessible and very poorly exposed. An overgrown cutting on the M50 motorway where a phosphatised pebble bed is absent has been interpreted as exposing the local base of the Downton Castle Sandstone Formation (Allen and Dineley 1976).

A single conodont sample (168/5*) from the Upper Longhope Beds of the Longhope by-pass road cut (loc. 30b) is dominated by Pa elements of *O. confluens*, together with elements of *O. excavata, C. dubius* and small numbers of *P. serratus* and *Oulodus* sp. (Text-fig. 6.4).

THE TORTWORTH INLIER, SW GLOUCESTERSHIRE

The Tortworth inlier is situated to the SE of the Severn Estuary, midway between Gloucester and Bristol (Text-fig. 6.2), and exposes Upper Llandovery to Pfidolf age strata (Curtis 1967, 1972, 1982; Cave and White 1968, 1971). The exposure on the foreshore of the Severn Estuary at Tite's Point has been examined in detail for the present study.

**Tite's Point** (loc. 31)

Silurian rocks are exposed approximately 300m W of a large breakwater on the foreshore of the Severn Estuary at Tite's Point, near Parton (loc. 31b; Text-fig. 6.10). The section was described by Curtis (1967, 1982) and logged in detail by Cave and White (1971). The locality, is covered by tidal mud which shifts seasonally and is only accessible at low tide (Text-fig. 6.10). When the section was sampled for the present study only the more resistant beds were exposed above the estuarine mud; thus, the logged section (Text-fig. 6.11) is based on Cave and White (1971).
TEXT-FIG. 6.10. Map of the exposures of the Upper Leintwardine Formation, Whitcliffe Formation and the Downton Castle Sandstone Formation on the foreshore of the Severn Estuary at Tite's Point (locs 31a, b) (after Cave and White 1971, fig. 2).
TEXT-FIG. 6.11. Log of part of the Upper Leintwardine Formation, the Whitcliffe Formation and part of the Downton Castle Sandstone (DCS) Formation at Tite's Point (loc. 31b) after Cave and White (1971, fig. 3), including conodont ranges and composition of conodont faunas.
Whitcliffe Formation. The measured section for the present study covers beds 2-35 of Cave and White (1971, fig. 3). 22m of the Whitcliffe Formation directly overlie the Upper Leintwardine Formation and are marked at the base by an intraformational conglomerate. The exposed parts of the Whitcliffe Formation consist of a series of N/S trending resistant ridges of dolomitised red-stained limestones which often contain thelodonts and brachiopod coquinas. These resistant beds have been sampled for conodonts (Text-fig. 6.11). The areas between the resistant bands were obscured by mud, although the occasional lenticular interbed of dolomitised limestone protruded and could be sampled. The section was almost certainly better exposed when Cave and White (1971) constructed their log as they document the strata now obscured by mud, as mottled green/brown, friable mudstones and siltstones with occasional harder interbeds.

A specimen of *C. torosa* (BGS 62-254, PN 110) has been recovered from the Whitcliffe Formation next to the tow path (loc. 31a; Text-fig. 6.10).

The resistant dolomitic beds do not process well for conodonts; only poorly preserved, often abraded and fragmentary conodont specimens have been recovered (Text-fig. 6.12). The beds are also heavily iron stained, and produce large heavy residues of haematite and dolomite. Conodont frequencies range from 61 to 6,961 elements per kg. The percentage of *C. dubius* elements gradually increases upwards through the Whitcliffe Formation (Text-fig. 6.11). The percentages of *O. confluens* and *O. excavata* fluctuate greatly throughout the Whitcliffe Formation and show no regular pattern. All samples contain a predominance of Pa elements of *O. confluens* compared to other elements in its apparatus. Sample 31b/2 contains only the Pa elements of *O. confluens* and sample 31b/5 contains twice as many Pa elements of *O. confluens* as the total of all the other elements of its apparatus (Text-fig. 6.12). *Panderodus* elements are last present 7.5m below the top of the Whitcliffe Formation. Rare taxa include *O. crispa*, which was found only in sample 31b/7, approximately 17m below the top of the Whitcliffe Formation. *O. snajdri* and *O. r. baccata* are restricted to sample 31b/4 and *O. r. remscheidensis* is restricted to sample 31b/3.

Downton Castle Sandstone Formation. Only 1.70m of the Downton Castle Sandstone is exposed at Tite’s Point, beyond which the exposure grades into the poorly exposed red mudstones of the Thornbury Beds. The Downton Castle Sandstone Formation was very poorly...
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<th>3</th>
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**TEXT-FIG. 6.12.** Conodonts from the Whitecliff Formation, foreshore of the Severn Estuary, Tite's Point, Gloucestershire (loc. 31b). Positions of samples are given in Text-figure 6.11.
exposed at the time of sampling of the section for the present study. Softer, thinly bedded sandstone channels 30cm into the underlying Whitcliffe Formation. A bone bed which is assumed to correlate with the Ludlow Bone Bed, is present 41cm above the base of the channel (Cave and White 1971). Neither the channelling nor the bone bed were located during sampling for the present study.

Other localities.
The Brookend Borehole (loc. 32) is situated approximately 3km to the S of the exposures at Tite's Point (Text-fig. 6.2). The upper part of the core comprises 27m of Whitcliffe Formation overlain by 7.3m of Downton Castle Sandstone Formation containing bone beds (Cave and White 1968, 1978).

THE USK INLIER, CENTRAL GWENT
The Usk inlier is situated approximately 20km NE of Cardiff and consists of a periclinal structure with rocks from Wenlock to Pridolf age which are best exposed in the southern part of the inlier (Gardiner 1916; Walmsley 1959, 1982; Allender et al. 1960; Squirrel et al. 1969; Barclay et al. 1989). The locality at Brook House (loc. 33) is documented in detail for the present study and an additional 4 localities briefly discussed.

The Upper Llangibby Beds and Speckled Grit Beds are distinct lithologically from the Upper Whitcliffe Formation and Downton Castle Sandstone Formation, respectively. The original lithostratigraphy of Walmsley (1959) has, therefore, been used for the present study (Text-fig. 6.3) rather than the mixture of lithostratigraphic units from Walmsley (1959) and from the Ludlow area (Bassett et al. 1982) as used by Barclay et al. (1989) and Cocks et al. (1992).

Brook House (loc. 33)
The locality (Walmsley 1959, fig. 7) which is an SSSI, is situated mid-way between the villages of Llangybi and Llandegveth, approximately 6km SSW of Usk (Text-fig. 6.13).

Upper Llangibby Beds. Approximately 7m are represented at exposures 1-4, although an exposure gap of approximately 2m occurs at the Llangybi to Llandegveth road (Text-figs 6.13
TEXT-FIG. 6.13. Map showing the exposures of the Upper Llangibby Beds (exposures 2-4) and the Speckled Grit Beds (exposure 1) at Brook House, near Llangybi, Usk (loc. 33); modified after the Ordnance Survey 1:25,000 map and including information from the Nature Conservancy Council (English Nature).
CHAPTER 6

and 6.14). At the base of exposure 4, the beds are highly fossiliferous and contain numerous limestone beds and lenses. Decalcified coquinas rich in the gastropod Holopella sp., the brachiopod Craniops implicata (J. de C. Sowerby) and crinoid ossicles are common. Towards the top of the Upper Llangibby Beds (exposures 1 and 2) the sediments become more bioturbated, less fossiliferous and less calcareous, with coquinas consisting of crushed inarticulate brachiopods including C. implicata and the articulate brachiopod Protochonetes ludlowiensis Muir-Wood.

Three phosphatised internal moulds of the ostracod H. cf. maccoyiana have been recovered from conodont preparations of sample 33/2 (Text-fig. 6.14). External moulds of C. torosa and H. cf. maccoyiana have been recovered from strata at a high level in exposure 4 (Ludlow Research Group Meeting, 1992).

Conodonts from the Upper Llangibby Beds (Text-figs 6.14 and 6.15) are small, fragmentary and range in frequency from 35-236 conodont elements per kg. Most collections have been obtained from the lower, more calcareous part of exposure 4 and have very similar faunas characterised by C. dubius, O. confluens and O. excavata. Less common species, also confined to the base of exposure 4, include Oulodus sp., O. remscheidensis baccata and O. snajdri. The highest sample collected from approximately 3.5m below the top of the Upper Llangibby Beds, contains only C. dubius and O. confluens.

Speckled Grit Beds. The base is exposed in a small overgrown bank on the south side of the lane to the west of the bridge (Text-fig. 6.13, exposure 1). Approximately 40cm of the Speckled Grit Beds are exposed, consisting of friable coarse brown sandstone laminae with thelodons and acanthodians within a mudstone matrix. Two distinct resistant beds of sandstone are visible in the lower 30cm of the exposure and a similar bed is present 30-40cm above the base of the Speckled Grit Beds. Organic fragments are common, particularly the carbonised alga Pachytheca sp.

Other localities.

Localities at Llandegveth Church (loc. 34a), Llangybi Castle (loc. 34b), Granary Farm (loc. 34c) and Llanddewi Court (loc. 34d) previously displayed Speckled Grit Beds with fragmentary fish remains (Walmsley 1959) but none of these are now exposed.
TEXT-FIG. 6.14. Log of the Upper Llangibby and Speckled Grit beds at Brook House, Usk (loc. 33), showing conodont ranges and conodont faunal composition.
<table>
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TEXT-FIG. 6.15. Conodonts from the Upper Llangibby and Speckled Grit beds (Walmsley 1959) at Brook House, Usk, Gwent (loc. 33).
The borehole was drilled to establish the nature of the junction between the Ludlow Series and the overlying sediments at Rumney. Subdivision of the Ludlow Series was not considered possible. The base of the overlying Raglan Mudstone Formation is marked by a 6cm bed containing abundant fish remains and shell fragments, which is tentatively taken to correlate with the Ludlow Bone Bed (Waters and White 1978).

**PALAEOENVIRONMENTS**

*Upper Whitcliff Formation*

Holland (1962, fig. 1) included the inliers of the southern Welsh Borderland and the type area around Ludlow within the Ludlow "shelf" facies. In the Malvern Hills, the "Upper Ludlow Formation is characterised by features and structures indicative of wave action and that these become commoner higher in the section" (Phipps and Reeve 1967, p. 232). They also noted that in the Malverns the uppermost beds in the Whitcliff Flags Member display a transitional change into the Downton Castle Sandstone Formation. Conglomerates and phosphatised pebble beds within attenuated Ludlow successions at May Hill and Gorsley have been taken to indicate "long periods of interrupted deposition, winnowing and erosion in shallow waters" (Lawson 1954, p. 233). No angular unconformity is visible at these levels, so it is not possible to decide whether these attenuated successions are due to non-deposition or emergence (Lawson 1954, 1955). Lawson (1954) proposed that a "Gorsley axis" of uplift existed in Silurian times, producing a thinning of the Ludlow Series to only 12.5ft (3.80m) at Gorsley. Cave and White (1971, fig. 4) also noted thickening of the Ludlow Series away from the Gorsley axis, at Newnham, Tite's Point (loc. 31b) and into the Brookend Borehole (loc. 32).

Biotite bands within the Perton Beds at Perton have been interpreted as detrital, derived from Precambrian exposures on the margin of the Malvern Hills (Tucker 1960). Similar concentrations of biotite are present at Tite's Point and in the Brookend Borehole, but the euhedral habit of the grains indicates that at least some biotite might have been regenerated within the sediment from original small grains (Cave and White 1968, 1971). The dolomitisation and reddening of the strata at Tite's Point are interpreted as secondary effects of the sub-Triassic land surface (Cave and White 1971).
Conodont elements from the Upper Longhope Beds at Longhope (sample 168/5*) and from the Whitcliffe Formation at Tithe Point (samples 31b/1-31b/8) have probably undergone significant sorting; the collections are dominated by abraded Pa elements of *O. confluens* (Text-figs 6.4 and 6.12). Abrasion and winnowing indicate that, compared with the rest of the shelf, a more turbulent environment existed in this area.

General trends in conodont faunal composition towards the top of the Ludlow Series in the southern Welsh Borderland inliers are similar to coeval trends at Ludlow. There is a general increase in the percentage of *C. dubius* towards the top of the Ludlow Series and *P. serratus* disappears just below the top of the Ludlow Series. As discussed in Chapter 4, these trends may possibly be related to a shallowing (see Watkins 1979; Bassett *et al.* 1982; Phipps and Reeve 1967) towards the top of the Upper Whitcliffe Formation.

**Downton Castle Sandstone Formation**

Localised variations of lithofacies at the base of the Rushall Beds in the Woolhope inlier have been proposed to indicate shoals in a shallow sea (Gardiner 1927). Rapid facies changes within the Rushall Beds are also noted by Squirrell and Tucker (1960), although they did not attempt an explanation for the changes. The bone bed at the base of the Rushall Beds has been interpreted as a lag concentrate or shoal deposit formed during marine regression, and the Rushall Beds are interpreted as a marginal marine deposit on a prograding sandy shore which is succeeded by subtidal mud flats (Allen 1985; Brandon 1989).

The Rushall Beds at Perton Lane (loc. 23) are characterised by plant-rich fine sandstones/siltstones with ostracods. At Prior's Frome (loc. 24), only 2.5km to the SE, they comprise conglomerates, very fine sandstones and mudstones but lack ostracods. These localised lithological and ostracod faunal variations are similar to coeval variations between sections in the Ludlow area at Aston Munslow (loc. 7a), Downton (loc. 14b) and Ludlow (locs 17, 18) (see Chapter 5). The Rushall Beds at Perton are characterised by an abundance of land plant fragments, indicating a proximal land source. There is a larger proportion of land derived sporomorphs in the Downton Castle Sandstone Formation at Ludford Lane (loc. 17) than at Downton (loc. 14b) (Richardson and Rasul 1990). Ludford Lane has the most prolific basal Downton Castle Sandstone Formation ostracod fauna collected for the present study and ostracods are also common in the Rushall Beds at Perton. It is, therefore, possible that high
percentages of palynomorphs, land plant fragments and ostracods are related phenomena. High frequencies of land derived sporomorphs could be the result of proximal distributionary channels delivering sediment along an irregularly prograding shoreline (Richardson and Rasul 1990).

The ostracod faunas from the Rushall Beds are concentrated in the coarse bases to fining upwards units. Smith and Ainsworth (1989) proposed that similar beds in the basal metre of the Platyschisma Shale Member at Ludlow were products of storms, therefore, it is possible that the ostracods at Perton had been selectively winnowed and concentrated by storm action.

CORRELATION

Britain

Bone beds are developed in the Malvern Hills (Phipps and Reeve 1967), at Woolhope (Strickland 1853; Gardiner 1927; Squinell and Tucker 1960, 1982); Tite's Point (Cave and White 1971, Curtis 1982) and Usk (Walmsley 1959, 1982), and phosphatic pebble beds occur at May Hill and Gorsley (Lawson 1954, 1955, 1982). All these levels have previously been correlated with the base of the Downton Castle Sandstone Formation at Ludlow.

No bone bed has been located at Perton Lane, although Squinell and Tucker (1960, p. 151) noted the presence of "discrete pockets of bone material within the topmost Perton Beds" which they correlated with the bone bed at Prior's Frome (see above) and the Ludlow Bone Bed. Discrete and sporadic pockets of thelodont dermal denticles have been found just below the top of the Upper Perton Beds at Perton during the present study. Similar pockets occur in the topmost Upper Whitchcliffe Formation at Ludlow (Text-fig. 4.4). The first occurrence of the ostracod *F. groenvalliana* at Perton corresponds to the lithological change at the base of the Rushall Beds, indicating that the base of the Rushall Beds correlates with the base of the Downton Castle Sandstone Formation (as in Text-fig. 6.3).

The boundary between the Whitchcliffe Formation and underlying Upper Leintwardine Formation at Tite's Point is taken at the base of the conglomerate as the brachiopod fauna above this level is similar to that of the Lower and Upper Whitchcliffe formations at Ludlow (Cave and White 1971). The correlation is tentative as the mudstones immediately below the conglomerate do not contain a typical Upper Leintwardine brachiopod fauna. A similar conglomerate bed
occurs at Newnham at this level where brachiopod faunas distinguish the underlying Upper Leintwardine Formation (Cave and White 1971).

The occurrence of *O. crispa* at Tite's Point (sample 31b/7) represents the lowest recorded occurrence of the species in the Welsh Borderland. The sample was taken 17m below the top of the Whitcliffe Formation and it is, therefore, possible that this correlates with a level within the Lower Whitcliffe Formation. Alternatively, the conglomerate at the base of the Whitcliffe Formation at Tite's Point may represent a break in sedimentation and part or all of the Lower Whitcliffe Formation may not be represented.

The conodont *O. wimani* is only present in faunas from the Upper Perton Beds at Perton (loc. 23) and Prior’s Frome (loc. 24a) and from the Upper Whitcliffe Formation at Ludlow (loc. 15b).

*International*

The last occurrence of *O. crispa* at the basal boundary stratotype for the Předolí Series in Czechoslovakia is just below the base of the Předolí Series, and can correlate directly with the stratotype for the base of the Downton Castle Sandstone Formation at Ludlow (see Chapter 4). The conodont *O. snajdri* is also considered to be restricted to the Ludlow Series in the Barrandian Basin (Schönlaub 1986, Kríz 1992).

The occurrence of the *O. crispa* in the lower part of the Whitcliffe Formation at Tite's Point and 2.5m below the top of the Upper Perton Beds at Prior’s Frome, confirms that the Whitcliffe Formation and the Upper Perton Beds correlate to a level near the top of the Ludlow Series.

*O. crispa* follows *O. snajdri* stratigraphically and is thought to be a direct phylogenetic descendant (Aldridge and Schönlaub 1989). *O. snajdri* is also considered to be restricted to the Ludlow Series (Aldridge and Schönlaub 1989, fig. 172), even though *Spathognathodus* aff. *snajdri* has been recovered from the Äigu Member of the Kaugatuma Formation of Estonia (Viira 1982). The base of the Kaugatuma Formation is considered coincident with the base of the Předolí Series as *Monograptus ultimus* occurs at the base of the formation in the SE Baltic (Kaljo 1990). Viira (1982) was not able to distinguish *S. snajdri* from *S. crispa*. However, *O. crispa* is now regarded as confined to the Ludlow Series of the Baltic (Männik and Viira 1990).
so, the material that Viira (1982) identified as *Spathognathodus* aff. *snajdri* probably includes specimens of *O. snajdri* from the Přídolf Series.

If *O. snajdri* is considered a predecessor to *O. crispa*, the occurrence of *O. cf. snajdri* above the base of the Rushall Beds at Prior's Frome suggests that the base of the Přídolf Series at Prior's Frome should be at least as high as the last occurrence of *O. snajdri*. Conodont faunas from the Barrandian Basin (Schönlaub 1986) indicate that *O. snajdri* and *O. crispa* can occur together. *O. snajdri* also occurs higher than *O. crispa* in the Whitcliffe Formation at Tite's Point (Text-figs 6.11 and 6.12) and the Upper Perton Beds at Prior's Frome (Text-figs 6.7 and 6.8). The first appearance of *O. crispa* follows that of *O. snajdri* stratigraphically with their stratigraphic ranges overlapping and *O. snajdri* continuing into the Přídolf Series. It must also be noted that the specimens of *O. cf. snajdri* at Prior's Frome are abraded and the possibility that the specimens have been reworked cannot be discounted. The occurrence of *O. cf. snajdri* above the base of the Rushall Beds cannot, therefore, be taken as an indication that the the base of the Přídolf Series should be placed above the base of the Rushall Beds at Prior's Frome.

The occurrence of *F. groenvalliana* at the base of the Rushall Beds at Perton Lane (loc. 23a) suggests that the base of the Přídolf Series should be placed at this level (see Chapter 4).

**CONCLUSIONS**

1. A bone bed marks the base of: the Downton Castle Sandstone Formation at Brockhill, Malvern (loc. 22); the Rushall Beds at Prior's Frome (loc. 24), Caerswell Farm (loc. 25), Whittocks End Farm (loc. 26), and Rushall (loc. 27); the Downton Castle Sandstone Formation at Tite's Point (loc. 31b), and the Brookend Borehole (loc. 32); the Speckled Grit Beds at Brook House, Usk (loc. 33); the Raglan Mudstone Formation of the Rumney Borehole (loc. 35). Phosphatic pebble beds mark the base of the Upper Siltstone at Gorsley (loc. 29) and the Clifford's Mesne Sandstone at Longhope (locs 30a, c).

2. The Upper Perton Beds at Prior's Frome, the Whitcliffe Formation at Tite's Point and the Upper Llangibby Beds at Usk, become less calcareous stratigraphically higher in the succession. Conodonts recovered from these localities are similar to collections recovered from the Upper Whitcliffe Formation at Whitcliffe Quarry, Ludlow. In all sections studied, *P. serratus* last occurs just below the top of the formation and the proportion of *C. dubius*...
increases steadily upwards. *O. wimani* has been found only at Perton (loc. 23), Prior's Frome (loc. 24a) and Whitcliffe Quarry, Ludlow (loc. 15).

3. Only a few isolated ostracod specimens of *C. torosa* have been recovered from the Whitcliffe Formation (loc. 31a) and the Upper Llangibby Beds (loc. 33) and *H. cf. maccoyiana* recovered from the Upper Perton Beds (loc. 23a) and the Upper Llangibby Beds (loc. 33).

4. Conodont collections from the Downton Group are typical of bone bed conodonts in that they consist predominantly of abraded elements of *C. dubius* and Pa elements of *O. confluens*.

5. Ostracods are common only in the Rushall Beds at Perton where *F. groenvalliana* first appears at a level coincident with a lithological change at the base of the Rushall Beds. The Rushall Beds also commonly contain *L. arisaigensis, L. fissurata* and non-palaeocopes together with a single specimen of *Nodibeyrichia* sp. and one carapace specimen of *L. fissurata*.

6. Conodont collections from Longhope (loc. 30b) and Tite's Point (loc. 31b) are severely abraded and consist of unusually high percentages of Pa elements of *O. confluens*, indicating significant sorting associated with a turbulent environment.

7. The occurrence of ostracods and high percentages of land plants and their spores in the Rushall Beds at Perton are possibly explained by proximal distributional channels delivering high proportions of land plant spores off an irregularly prograding shore.

8. Ostracods in the Rushall Beds at Perton occur almost exclusively at the bases of fining upwards beds and have possibly been concentrated during storm sedimentation.

9. The occurrence of *O. crispa* at Prior's Frome (loc. 24a) and Tite's Point (loc. 31b) confirms that the local Whitcliffe Formation and Upper Perton Beds correlate to a level near the top of the Ludlow Series (see Chapter 4).

10. The occurrence of *O. cf. snajdri* above the base of the Rushall Beds at Prior's Frome does not imply that the base of the Pridolf Series at Prior's Frome should be placed at least as high as this level.

11. Indirect correlation using the ostracod *F. groenvalliana* suggests that the base of the Rushall Beds at Perton (loc. 23a) is coincident with the base of the Pridolf Series.
CHAPTER 7

CONODONT AND OSTRACOD DISTRIBUTION ACROSS THE LUDLOW/ PŘÍDOLÍ SERIES BOUNDARY (SILURIAN): BASIN LOCALITIES OF E CENTRAL WALES AND SHELF EDGE LOCALITIES OF SW WALES

ABSTRACT. Ostracod and conodont faunas are documented across the base of the lithostratigraphical equivalents of the Downton Castle Sandstone Formation in E central and SW Wales. The uppermost Ludlow Series of E central Wales has yielded a typical Upper Whitcliffe Formation ostracod fauna characterised by *Calcaribeyrichia torosa*. Ostracod collections from the basinal Causemountain Formation at Long Mountain show a gradual faunal change, which contrasts with the sudden change at the base of the Downton Castle Sandstone Formation on the shelf at Ludlow (Chapter 4). These variations are consistent with published shelf-basin palynofacies interpretations and reflect continuous sedimentation at the base of the Downton Group (E central Wales).

The base of the Downton Castle Sandstone Formation (the base of the Přídolí Series) can be correlated with a 1mm bone bed and the first occurrences of *Frostiella groenvalliana* and *Nodibeyrichia verrucosa* within the Causemountain Formation at Wallop Hall, Long Mountain. Using ostracod faunas, this level can also be correlated with the bases of the *Platyichnus helicites* Beds at Knighton and the Clun Forest Formation at Clun. The lowest, best developed, of multiple bone beds discovered within the Clun Forest Formation at Clun, is considered a correlative of the Downton Bone Bed.

The occurrence of *F. groenvalliana* in the Long Quarry Formation at Llandovery indicates a Přídolí age. However, the unconformity at the base of the Downton Group in SW Wales cannot be shown to be coincident with the base of the Downton Castle Sandstone Formation at Ludlow. The Cennen Formation of the Cennen Valley is not considered Ludlow in age but possibly an unconformable unit at the base of the Downton Group.
CHAPTER 7

INTRODUCTION

The microfaunal characteristics across the base of the Downton Castle Sandstone Formation and its lithostratigraphical equivalents in the shelf area of the Welsh Borderland are described in Chapters 4-6. Chapter 7 describes the microfaunal changes across the base of lithostratigraphical equivalents of the Downton Castle Sandstone Formation in E central and SW Wales (Text-figs 7.1-7.3). This area embraces part of the Welsh Basin to the west of the Church Stretton fault, which has been termed the "basin" area (Holland 1962). Sections at Wallop Hall, Long Mountain (loc. 36a), and Within's Wood, Clun (loc. 39a) have been studied in detail and an additional 21 individual coeval localities are also documented (Text-fig. 7.2).

LOCALITIES AND HORIZONS

36. LONG MOUNTAIN. Exposures around the Long Mountain area, NW Shropshire, c.8km W of Welshpool, Powys.

36(a). WALLOP HALL. Exposure under trees near ruins of Wallop Hall, Lower Wallop, 2.7km SW of Westbury, SJ 3150 0725 (Richardson and Rasul 1990, loc. 5). Wallop Hall Member of Causemountain Formation including a bone bed (CGM).

36(b). NE area of Long Mountain, Sargeant's Dingle, 800m WSW of March Manor Farm, SN 330 103. Causemountain Formation (BGS).

37. NANTYRHYNAU QUARRY. Exposure behind barn, 5km NNW of Felindre, Powys, SO 1602 8588. Cefn Einion and Clun Forest formations (CGM and BGS).

38. FELINDRE. Exposures around the village of Felindre, Powys, c.13km W of Clun, Shropshire.

38a. Medwaledd Brook. Dry stream bed, c.3km NNW of Felindre, SO 1698 8110 to 1568 8389 (Earp 1938, p. 138). Discontinuous exposures through uppermost Cefn Einion Formation and lowermost Clun Forest Formation (BGS).

38b. Stonehouse Dingle. 1km SE of Felindre, SO 1712 7983 to 1757 8016 (Earp 1940, p. 7). Same strata as for locality 38a (BGS).

38c. Hendre Farm. Trackside exposure 1.7km NW of Felindre, SO 1538 8220. Cefn Einion Formation (CGM and BGS).

39. CLUN. Exposures around the town of Clun, 13km W of Craven Arms, Shropshire.
TEXT-FIG. 7.1. Study area for Chapter 7 (outlined by thick black line). Base map after Bassett et al. (1982). Areas considered in Chapters 5 and 6 outlined by thin line.
TEXT-FIG. 7.2. Chapter 7 localities. Base map after Bassett et al. (1982).
36, Long Mountain. 37, Nantyrhynau Quarry, Clun. 38, Felindre. 39, Clun Forest. 40, Knighton. 41, Builth Wells.
42, Cwm Graig Ddu. 43, Capel Horeb Quarry. 44, Sawdhe Gorge. 45, Cennen Valley.
<table>
<thead>
<tr>
<th>SERIES</th>
<th>LUDLOW</th>
<th>LONG MOUNTAIN</th>
<th>CLUN FOREST</th>
<th>KNIGHTON</th>
<th>BUILTH WELLS</th>
<th>LLANDOVERY LLANDEILO</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRÍDOLF</td>
<td><strong>Downton Castle Sandstone Formation (&lt;17.3m)</strong></td>
<td><strong>Yellow Downton Formation (5-6m)</strong></td>
<td><strong>Clun Forest Formation (up to 600m)</strong></td>
<td><strong>Platyschisma helicites Beds (6-10m)</strong></td>
<td><strong>Green Marls</strong></td>
<td><strong>Long Quarry Formation (15-20m)</strong></td>
</tr>
<tr>
<td>Ludlow Bone Bed</td>
<td>Thin bone bed</td>
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<td>LUDLOW</td>
<td><strong>Upper Whitcliffe Formation (32m)</strong></td>
<td><strong>Causemountain Formation (105-170m)</strong></td>
<td><strong>Cefn Einion Formation (160-240m)</strong></td>
<td><strong>Upper Llan-wen Hill Beds (152m)</strong></td>
<td><strong>Holopella conica Beds (c.68m)</strong></td>
<td></td>
</tr>
</tbody>
</table>

**TEXT-FIG. 7.3.** Correlation of the base of the Downton Castle Sandstone Formation at Ludlow with the stratigraphy of E central and SW Wales (after Cocks et al. 1992).
CHAPTER 7

39a. WITHIN'S WOOD. Cutting for new forestry path near Within's Wood, Clun Forest, SO 317 836. Clun Forest Formation including multiple bone beds.

39b. Floor of forestry track, 4460m at 230° from Church tower, Lydbury North, SO 317 8317. Green Downton Formation (CGM and BGS).

39c. Roadside exposure at Bryn, 1.2km SE of Cefn Einion, SO 295 8535. Cefn Einion Formation (BGS and CGM).

39d. HURST MILL. Exposure next to forestry track in Radnor Wood, c.1.5km ENE of Clun, SO 316 8128. Cefn Einion Formation (CGM and BGS).

39e. FIVE TURNINGS OUTLIER. Old quarry 280m E of Black Gain Farm, SO 297 759 (Stamp 1918, p. 237). Cefn Einion and Clun Forest formations.

40. KNIGHTON. Exposures around the town of Knighton c.23km W of Ludlow, Shropshire.


40c. MEETING HOUSE LANE. Discontinuous section on steep track from Meeting House Farm to Llan-Wen Hill, SO 3023 6940. Upper Llan-wen Hill Beds, Platyschisma helicites Beds including a thin bone bed. Green Downton and Yellow Downton formations (DJS).

41. BUILTH WELLS. NW of Gwennedwr in bank of Nant Gwennedwr, 5km SW of Builth Wells, Powys, SO 061 436 (Straw 1930, p. 84-85). Holopella conica Beds and Green Marls.

42. CWM GRAIG DDU. Valley WSW of Builth Wells, 4km SSE of Garth, SN 968 465 (Straw 1953). Holopella conica Beds and Long Quarry Formation (formerly Tilestones).

43. CAPEL HOREB QUARRY*. North side of A40, 5.5km ESE of Llandovery, SN 8445 3234 (Potter and Price 1965, Cwm Dwr section; Siveter et al. 1989, loc. 5.8). Upper Roman Camp Formation (=Lower Whitcliffe Formation) and Long Quarry Formation (CGM, RJA, BGS).

44. SAWDDE GORGE. River valley c.10km SW of Llandovery, Dyfed.

44a. Exposure in stream bed NW of main bridge over R. Sawdde at Pont-ar-ilechau, SN 7280 2447. Lower Roman Camp Formation (=Upper Leintwardine Formation), Long Quarry Formation.
44b. Small quarry behind Three Horseshoes Inn, Pont ar llechau, SN 7279 2446 (Bassett 1982, fig. 2, loc. 6). Long Quarry Formation.

44c. Exposure next to forestry track, SN 7372 2418, (Bassett 1982, fig. 2, loc. 7G; Siveter et al. 1989, loc. 5.5i). Long Quarry Formation.

45. CENNEN VALLEY. 4km SSW of Llandeilo, Dyfed.

45a. Cutting along W side of A476, SN 6100 1908 to 6102 1902 (Siveter et al. 1989, loc. 5.6e). Cennen Formation (=possible uppermost Ludlow Series) and Long Quarry Formation (BGS, RJA).

45b. Small quarry above A483, S of Llandeilo, SN 6145 1915 (Siveter et al. 1989, loc. 5.7). Long Quarry Formation.

THE LONG MOUNTAIN, NW SHROPSHIRE

The Long Mountain is a NE/SW trending topographic feature to the W of Welshpool, exposing rocks from Llandovery to Pridoli in age (Austin 1925; Palmer 1970, 1973). In the Long Mountain area the base of the Downton Castle Sandstone Formation cannot be distinguished lithologically, but is thought to occur within the upper part of the Wallop Hall Member of the Causemountain Formation, as exposed at Wallop Hall (loc. 36a) (Palmer 1970, 1973). The exposure at Wallop Hall (loc. 36a) has been studied in detail herein. The only other material from the Long Mountain area available for the present study is a specimen (BGS) of the ostracod *C. torosa*, from the Causemountain Formation at Sargeant's Dingle (loc. 36b).

Wallop Hall (loc. 36a)

The exposure is situated under a line of trees adjacent to the ruins of Wallop Hall (Text-fig. 7.4). Ostracods (Shaw 1969) and palynomorphs (Richardson and Rasul 1990) have previously been recovered from this section.

Wallop Hall Member, Causemountain Formation. 4.75m are exposed, consisting of parallel laminated siltstones to very fine sandstones with rare low angle cross laminations, bioturbated siltstone and mudstone horizons (Text-fig. 7.5). A thin bone bed (Text-fig. 7.5, bed K) and a limestone lens rich in gastropods (bed P) are also present. The section shows a gradual transition in macrofauna from sediments rich in articulate brachiopods below the bone bed to...
TEXT-FIG. 7.4. Sketch of the exposure of the Wallop Hall Member of the Causemountain Formation at Wallop Hall (loc. 36a), to show positions of logged sections.
TEXT-FIG. 7.5. Log of the Wallop Hall Member, Causemountain Formation at Wallop Hall, Long Mountain (loc. 36a), showing sampled horizons (A-Z, α-γ).
CHAPTER 7

sediments characterised by gastropods, inarticulate brachiopods and plant fragments above the bone bed (Text-fig. 7.5).

Ostracods, preserved only as moulds of disarticulated valves, range in frequency from 0.01 to 1.35 valves per cm$^2$ (Text-figs 7.6, 7.7). Most ostracod specimens have been collected above the bone bed (bed K); faunas below that level are sparse (Text-fig. 7.7). Ostracod specimens below the bone bed are predominantly $C. torosa$ with rare $H. cf. maccoviana$ and $L. cf. scanensis$; all three species are also present above the bone bed, and last appear within bed M (Text-fig. 7.7). $Londinia arisaigensis$ and $L. fissurata$ first occur just below the bone bed. On the bedding plane surface of the bone bed (Bed K), $C. torosa, Lophoctenella$ sp., $N. verrucosa, L. arisaigensis, L. fissurata, F. groenvalliana$ and non-palaeocope ostracods are present. 0-25cm above the bone bed the fauna is dominated by $Londinia$ with minor proportions of $Nodibeyrichia, Frostiella$ and non-palaeocopes. Beds 3P and 3Q contain abundant $Londinia$, but the other ostracod collections from beds more than 25cm above the bone bed are dominated by non-palaeocopes with minor $Londinia, Nodibeyrichia$ and $Frostiella$.

Eight well preserved $Coryssognathus dubius$ conodont elements have been recovered from the bone bed (Text-fig. 7.8, sample 36a/K). A limestone lens also processed for conodonts (bed 4P), yielded only a few well preserved thelodont dermal denticles.
<table>
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<td>J</td>
<td>K</td>
<td>L</td>
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<td>Are {cm}²</td>
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**TEXT-FIG. 7.6.** Frequency of ostracod valves from the Wallop Hall Member, Causemount Formation, at Wallop Hall, Long Mountain (loc. 36a).
TEXT-FIG. 7.7. Ostracod faunal composition, frequency and ranges of species from the Wallop Hall Member, Causemountain Formation at Wallop Hall, Long Mountain (loc. 36a). Only samples with 10 or more valves present are included in the faunal composition plot.
TEXT-FIG. 7.8. Conodonts from the Causemount Formation at Long Mountain (loc. 36a), the Clun Forest Formation at Clun (locs 37 and 39a) and the Long Quarry Formation at Llandovery (loc. 43).

<table>
<thead>
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<td>see</td>
<td>sim</td>
<td>sim</td>
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<tr>
<td>Coryssognathus dubius</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>M</td>
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<td>1</td>
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</tr>
<tr>
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<td>Sa</td>
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<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sh</td>
<td>2</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Sc</td>
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<td></td>
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<tr>
<td>Total number of elements</td>
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<td>25</td>
<td>77</td>
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<tr>
<td>Calculated no./kg</td>
<td>40</td>
<td>3</td>
<td>216</td>
<td>77</td>
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CHAPTER 7

THE CLUN TO FELINDRE AREA, CENTRAL SHROPSHIRE-POWYS BORDER

The village of Clun is situated approximately 23km WNW of Ludlow, Shropshire. Silurian exposures from Ludlow to Pffolp in age been studied in the area (Stamp 1918; Earp 1938, 1940; Allender 1958; Allender et al. 1960). Recently the BGS mapped the western part of the Clun Forest (part of Montgomery Sheet) and their lithostatigraphical scheme (BGS in press) is used for the present study. The locality at Within’s Wood (loc. 39a), discovered by the present author, is documented in detail. Eight other localities reported by Stump (1918), Earp (1938, 1940) or by the BGS are also considered.

Nantyrhynau Quarry (loc. 37)

This locality, approximately 15km WNW of Clun, was discovered in 1986 by the BGS during field mapping for the Montgomery Sheet. The BGS field report stated that the boundary between the Cefn Einion and Clun Forest formations was exposed within the quarry, at the base of a calcareous bed approximately 2.5m below the top of the section. The quarry exposes well bedded turbiditic siltstones and mudstones which have coquinoid bases and a 10cm thick calcareous bed. The calcareous bed contains abundant orthocones, brachiopods (including Craniops implicata), gastropods (mostly Holopella sp.), eurypterid fragments and a few fish spines (Onchus sp.).

The calcareous bed was processed for conodonts but yielded only two fragments of an O. excavata Pa element (Text-fig. 7.8, sample 37/6). The ostracods C. torosa, H. cf. maccoyiana, Lophoctenella sp., L. arisaigensis, L. fissurata and Frostiella sp. have been recovered from the same bed (Text-fig. 7.9).

Within’s Wood (loc. 39a)

A section through the Clun Forest Formation was recently exposed when a new forestry path was cut at Within’s Wood, approximately 3.5km NE of Clun. Quantities of topsoil and rock debris already partly obscure the exposure and it is possible that this locality will only be temporary. The locality is adjacent to the first and second steps on a footpath which ascends the side of the forestry road cutting (Text-fig. 7.10). Three sedimentary logs have been taken through three fault bounded blocks (Text-fig. 7.11). The beds can be traced across the fault between logs 1 and 2, but the stratigraphic relationship between logs 2 and 3 is unclear (Text-
<table>
<thead>
<tr>
<th>Formation</th>
<th>Cause- mountain</th>
<th>Cefn Elion</th>
<th>Clun Forest</th>
<th>P. helicites Beds</th>
<th>Green Downton</th>
<th>Long Quarry</th>
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<tr>
<td>Source of material</td>
<td>BGS</td>
<td>COM</td>
<td>DIS</td>
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<tr>
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<td>36b</td>
<td>37</td>
<td>38c</td>
<td>39a</td>
<td>39c</td>
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<td>Sample</td>
<td>6</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>1/01</td>
<td>3/01</td>
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<td>P</td>
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<tr>
<td><em>Londinia</em> flavicans</td>
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<td></td>
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<td>5</td>
<td>P</td>
<td>3</td>
</tr>
<tr>
<td><em>L. cf. flavicans</em></td>
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<td></td>
<td>1</td>
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<tr>
<td><em>Londinia</em> sp.</td>
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<td><em>Lepidolites</em> sp.</td>
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<td></td>
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<td>5</td>
<td>20</td>
<td>16</td>
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**TEXT-FIG. 7.9.** Ostracod faunas from the Causemountain Formation at Long Mountain (loc. 36b), Cefn Elion and Clun Forest formations at Clun (locs 37, 39), the *P. helicites* Beds and the Green Downton Formation at Knighton (locs 40b, 40c) and the Long Quarry Formation at Capel Horeb, Llandovery (loc. 43). *P* = species present.
TEXT-FIG. 7.10. Field sketch of the exposure of the Clun Forest Formation at Within's Wood, Clun (loc. 36a), showing the position of logged sections.
TEXT-FIG. 7.11. Log of the Clun Forest Formation at Within's Wood, Clun (loc. 39a), showing sampled horizons.
CHAPTER 7

The thin bone bed at the top of log three has been tentatively taken to correlate with the bone bed of log 2 (Text-fig. 7.11).

The lithology is predominantly parallel laminated siltstones, less common low angle cross laminated siltstones and rare bioturbated horizons. A well developed bone bed is present at the base of sections 1 and 2 and is followed by a succession of eight, millimetre thick bone beds in section 1 (Text-fig. 7.11). Abundant specimens of the gastropod *Turbocheilus* (*Platychemus*) *helicites* are present in a rottenstone at the base of section 3.

A single specimen of *F. cf. groenvalliana* is present in sample 1/03 and *F. groenvalliana*, non-paleacocope ostracods and a specimen of *Londinia* sp. have been recovered from sample 3/01 (Text-fig. 7.9). A spot sample from the Cefn Einion Formation 500m E along the forestry track yielded a specimen of *C. torosa*.

Abraded conodont elements of *O. confluens* and *C. dubius* have been recovered from sample 1/01, which yielded 216 conodont elements per kg.

Other localities

Localities in the vicinity of Felindre at Medwaledd Brook (loc. 38a) and Stonehouse Dingle (loc. 38b), provide discontinuous exposures through the uppermost Cefn Einion Formation and the lowermost Clun Forest Formation (Earp 1938, 1940). These are now very poorly exposed and provided no conodont or ostracod samples for the present study. A locality at Hendre Farm (loc. 38c) has yielded *H. cf. maccoyiana* and *L. arisaigensis* from the Cefn Einion Formation.

*L. arisaigensis*, *L. fissurata*, and non-paleacocope ostracods including *Leperditia* sp., have been recovered from a forestry cutting in the Clun Forest at locality 39b (Text-fig. 7.9), from a lithology similar to the Green Downton Formation at Knighton (Holland 1959). *C. torosa* has been recovered from the Cefn Einion Formation at Bryn (loc. 39c) and Hurst Mill (loc. 39d). The locality at Black Garn Farm (loc. 39e), once exposing the boundary between the Cefn Einion and the Clun Forest formations (Stamp 1918), is now overgrown.
CHAPTER 7

KNIGHTON, SHROPSHIRE-POWYS BORDER

The town of Knighton is situated approximately 23km W of Ludlow. Ludlow and Přídolf strata are exposed around the town (Holland 1959; Allender et al. 1960). Palynomorphs have been recovered (Richardson and Rasul 1990) from a locality on the Gwemaffel Estate (loc. 40a) and the distribution of the inarticulate brachiopod Craniops implicata has been described from the area (Holland 1988). All the localities reported to expose the base of the Platyschisma helicites Beds in this area (Holland 1959) are now very poorly exposed or completely obscured. Collections made by Dr David Siveter from the Platyschisma helicites Beds at Meeting House Lane are described herein.

Meeting House Lane (loc. 40c)

The locality was previously exposed alongside and in the base of a farm track which ascends the S side of Llan-wen Hill. A drainage ditch now prevents rain water from flowing down the track, and from clearing the mud which presently obscures the exposure. The Upper Llan-wen Hill Beds, Platyschisma helicites Beds, Yellow Downton and Green Downton formations are described from this locality (Holland 1959), which was also visited by the Ludlow Research Group (1982). No microfossils have been found from the Llan-wen Hill Beds at this locality.

Platyschisma helicites Beds. These beds are of similar lithology to the irregularly bedded shaly siltstones of the underlying Upper Llan-wen Hill Beds are more micaceous, have decalcified dark brown patches and bands several centimetres thick crowded with bivalves and casts of the gastropod Turbocheilus (Platyschisma) helicites (Holland 1959). A thin bone bed of thelodont dermal denticles is developed within the beds (Allender et al. 1960).

Sample 40a/1, collected from the lowermost bed, contains C. torosa, H. cf. maccoyiana, L. arisaigensis, L. fissurata and abundant non-palaeocene ostracods. Sample 40a/2 contains L. arisaigensis, L. fissurata, and two specimens of Frostiella sp.. Sample 40a/3, from the Green Downton Formation, contains an almost identical fauna to sample 40a/2 (Text-fig. 7.9).
CHAPTER 7

Other localities

Exposures across the base of the *Platyschisma helicites* Beds at Middle Pitts Cottages (loc. 40b) and on the Gwernaffel Estate locality (loc. 40a), reported by Holland (1959), are now almost totally overgrown. Collections made by Dr David Siveter from the *Platyschisma helicites* Beds at Middle Pitts Cottages (loc. 40b) include *L. arisaigensis, N. verrucosa* and non-palaeocope ostracods (Text-fig. 7.9).

SW WALES

The localities in this area occur in a NE-SW trending belt extending from Builth Wells to Llandeilo (Text-fig. 7.2). The unconformable base of the Downton Group, progressively oversteps older and more deformed rocks in a westerly direction, until W of Llandeilo the Downton Group overlies Ordovician strata (Potter and Price 1965; Squirrell and White 1978; Bassett 1982). Very few of the localities in SW Wales have yielded either conodont or ostracod faunas.

*Builth Wells* (loc. 41)

The stratigraphy of upper Silurian exposures from this area has been documented by Straw (1930, 1937) and Marsh (1976). Only sporadic exposures were described across the boundary between the *Holopella conica* Beds and the Green Marls at Gwenddrw (loc. 41) (Straw 1930, p. 85). These are no longer exposed, although ‘*Beyrichia kloedeni* var. *torosa*’ has been reported from the *Holopella conica* Beds at that locality (Straw 1930).

*Cwm Graig Ddu* (loc. 42)

The succession through the Ludlow formations and into the overlying Long Quarry Formation (formerly Tilestones) is exposed in the steep sides of the valley at Cwm Graig Ddu (Straw 1953). The top of the Ludlow Series is marked by a series of old tilestone workings (Straw 1953, fig. 1), although at present there are no exposures and the line of tilestone workings is barely visible.

No exposures across the base of the Long Quarry Formation have been described in the Clawdd British area to the SW of Cwm Graig Ddu (Potter and Price 1965). The Long Quarry Formation is very poorly exposed in this area (Potter and Price 1965).
Capel Horeb Quarry (loc. 43)
The quarry, 5.5km ESE of Llandovery, exposes the unconformity between the Long Quarry Formation and the underlying Upper Roman Camp Formation (Potter and Price 1965; Siveter et al. 1989, loc. 5.8). No conodont or ostracod specimens have been recovered from the Upper Roman Camp Formation which correlates with the Lower Whitcliffe Formation (Potter and Price 1965).

The Long Quarry Formation. The formation is represented by highly micaceous, well bedded fine sandstones and siltstones with decalcified coquinas containing gastropods, bivalves, and less common brachiopods and orthocones. Higher in the Long Quarry Formation the beds become much more flaggy and the decalcified coquinoinds much less common. The section was not logged in detail because of unstable scree slopes and exposures.

_F. groenvalliana_, non-palaeocope ostracods and a small fragment of the acanthodian _Archeogonaspis_ sp. have been recovered from the formation. The conodont _O. renscheidensis eosteinhornensis_, reported from Capel Horeb (Aldridge 1985), has been re-examined and identified by the present author as a fragment of _O. confluens_. _Coryssognathus dubius, O. excavata_ and _P. serratus_ also occur in the same sample (Text-fig. 7.8). The percentage of land plant spores increases upwards through the formation (Richardson and Rasul 1990).

Sawdde Gorge (loc. 44)
The Sawdde Gorge is situated approximately 10km SW of Llandovery, Dyfed, and exposes a Llandovery to Přídolf succession (Potter and Price 1965; Bassett 1982; Siveter et al. 1989).

The Lower Roman Camp Formation, a correlative of the Upper Leintwardine Formation (based on brachiopod faunas and the ostracod _Neobeyrichia lauensis_ : Potter and Price 1965), is overlain unconformably, but with no angular discordance, by the Long Quarry Formation. The unconformity is seen in the base of the R. Sawdde just to the S of the main bridge (loc. 44a), but the Long Quarry Beds are best observed behind the Three Horseshoes Inn (loc. 44b) and at an exposure next to a forestry track (loc. 44c). No microfossils have been recovered from any of these localities.
Cennen Valley (loc. 45)
The Cennen Valley Road section, 4km SSW of Llandeilo, exposes rocks of Ludlow and Přídolf age (Potter and Price 1965; Squirrell and White 1978; Bassett 1982; Siveter et al. 1989). Authors have used differing lithostratigraphic nomenclature, but the stratigraphy employed by Siveter et al. (1989) is adopted herein. In the A476 road cut (loc. 45a), the Long Quarry Formation unconformably overlies the Cennen Formation (Squirrell and White 1978, fig. 2b), but the section is now completely overgrown.

Cennen Formation. 3.55m of the formation rests unconformably on the older Trichrûg Formation and consists mainly of mudstones and siltstones with micaceous sandstones. The fauna (see Chapter 4), includes a typical Upper Whitcliffe brachiopod fauna of P. ludloviensis, S. lunata and M. nucula. Ostracods were identified by the author (BGS collections) as F. cf. groenvalliana, Lophoctenella cf. scanensis and C. torosa. A full list of macrofauna is given by Squirrell and White (1978, table 3). Conodont samples collected by Dr R. J. Aldridge when the section was fully exposed, proved to be barren.

Long Quarry Formation. 40.4m of the formation (formerly Tilestones) unconformably overlies the Cennen Formation and consists of highly micaceous brown to greenish grey flaggy sandstones with conglomeratic horizons (Bassett 1982). F. groenvalliana and H. cf. maccoyiana have been recorded 9.83m above the base of the formation (Squirrell and White 1978, table 3).
Ludlow Series

E central Wales. The thickness of upper Ludlow strata is much greater in E central Wales than on the shelf and probably reflects subsidence of the outer shelf and shelf margin of the Welsh Basin (Bassett et al. 1982). Palynofacies at Downton, Long Mountain and at Knighton all show a change towards more open sea floras towards the top of the Ludlow Series (Richardson and Rasul 1990). Sedimentological evidence suggests a shallowing stratigraphically upwards through the Llan-wen Hill Beds at Knighton (Holland 1959, p. 475).

Very little microfossil information has been obtained from the Ludlow Series of E central Wales for the present study.

SW Wales.
The Ludlow Series of SW Wales, traditionally regarded as part of the basin facies of the Welsh Basin (Holland 1962, fig. 1), has also been described as a sandy shelf facies (Potter and Price 1965). A proximal land area probably existed to the south during deposition of the Upper Roman Camp Formation at Capel Horeb, from which plant debris drifted into a shallow sea (Siveter et al. 1989, p. 97). The depositional environment of the Cennen Formation near Llandeilo has been interpreted as very shallow marine (Squillier and White 1978). Breaks in the succession occur near the top of the Ludlow Series in the Cennen Valley, but the succession is continuous at the Sawdde Gorge (Squillier and White 1978). The apparent 'early' occurrence of Frostiella groenvalliana in the Cennen Formation of the Cennen Valley was attributed to "occurrence in this area in late Ludlow times of a lithofacies comparable with that of the Downton Series" (Squillier and White 1978, p. 9). However, the occurrence of F. groenvalliana does not appear to be lithofacies related (see Chapter 4), so, it is unlikely that a lithofacies comparable with the Downton Group could account for the occurrence of F. groenvalliana in the Cennen Formation of the Cennen Valley in late Ludlow times (cf. Squillier and White 1978, p. 9).

Pfidoll Series

E central Wales. The Platyschisma helicites Beds in the basin at Knighton have no basal bone bed and are thicker than the equivalent Platyschisma Shale Member on the shelf at Ludlow,
 CHAPTER 7

suggestions continuous deposition in the basinal region (Bassett et al. 1982; Allen 1985).
Palynofacies variations at Wallop Hall (loc. 36a) indicate a gradual change to more inshore environments between the late Ludlow and the early Pliodif, followed by gradual change to a more offshore setting and a subsequent return of more onshore conditions (Richardson and Rasul 1990). A similar but less pronounced palynofacies curve has been documented at Knighton (Richardson and Rasul 1990), although onshore and offshore transport of sediment in storm dominated environments probably influenced proportions of microplankton and spores (Ainsworth 1991).

The ecological tolerances of ostracod species present at Ludford Corner, Ludlow, are discussed in Chapter 4. Some of these species, for example F. groenvalliana, are present in a wide range of environments but others, such as C. torosa, appear to be partly environmentally controlled. The ostracod faunal change at Wallop Hall, Long Mountain (loc. 36a), is more gradual than the sudden faunal change at Ludlow (Chapter 4). At Wallop Hall, species such as C. torosa, L. cf. scanensis and H. cf. maccoyiana, co-exist with F. groenvalliana, N. verrucosa, L. arisaigensis and L. fissurata (Text-fig. 7.7). This gradual ostracod faunal change is consistent with the gradual palynofacies variations (Text-fig. 7.12).

Leperditiid ostracods are often regarded as shallow water restricted forms (Siveter 1984). Leperditia sp. occurs within the Green Downton Formation at Clun (loc. 39b) and in a glacial erratic from the Vale of Wigmere, which suggests that by late Downton times the Welsh Basin had become so restricted that only leperditiid ostracods together with inarticulate brachiopods such as Lingula sp. could exist.

SW Wales. The Long Quarry Formation was deposited in a nearshore shallow marine environment (Potter and Price 1965; Squirrel and White 1978; Siveter et al. 1989). An increase in the percentage of spores against acritarchs upwards through the Long Quarry Formation at Capel Horeb (loc. 42) indicates shallowing (Richardson and Rasul 1990).
TEXT-FIG. 7.12. Palynofacies curves showing a sudden change across the base of the Downton Castle Sandstone Formation at Downton (loc. 14b) and a gradual change through the Wallop Hall Member of the Caucemountain Formation at Wallop Hall, Long Mountain (loc. 36a) (after Richardson and Rasul 1990). LBB Mb. = Ludlow Bone Bed Member.
CHAPTER 7

CORRELATION

E central Wales

Bone beds at the base of the Downton Castle Sandstone Formation and its lateral equivalents across the shelf area rarely extend laterally into coeval successions in E central Wales (Straw 1930). Only at Wallop Hall, Long Mountain (loc. 36a) is a thin bone bed developed at a comparable level within the Causemountain Formation (Palmer 1973). Bone beds present in the Clun Forest Formation at Bishop’s Castle, have been correlated with the Downton Bone Bed (Allender et al. 1960).

The ostracod succession *Neobeyrichia lauensis* (Kiesow), *C. torosa*, *F. groenvalliana* and *Leperditia* sp. has been recognised in the Ludlow and Pföldorf Series of Shropshire and E central Wales, and used for correlation (Straw 1930; Shaw 1969; Siveter 1978, 1989). Other correlations of the base of the Downton Castle Sandstone Formation into E central Wales (Text-fig. 7.3) are based on macrofaunas. For example, the basal *Platyschisma helicites* Beds at Knighton (the local equivalent to the Downton Castle Sandstone Formation) have a similar lithology to the underlying Upper Llan-wen Hill Beds, but can still be identified on the basis of a faunal change from articulate brachiopod-dominated faunas to gastropod, bivalve and inarticulate brachiopod faunas (Holland 1959, 1962). Similar faunal successions have been described from the area around Clun and Kerry (Earp 1938, 1940). Concentrations of the inarticulate brachiopod *Craniops implicata* (J. C. de Sowerby) at the top of the Upper Llan-wen Hill Beds at Knighton (locs 40a, c), also provide a correlative link with similar beds in the uppermost Upper Whitcliffe Formation on the shelf at Downton (loc. 14a) and Kington (locs 19a, b) (Holland 1962, 1988).

The first occurrence of *F. groenvalliana* at Wallop Hall is coincident with a thin (1mm) bone bed within the Causemountain Formation (Text-figs 7.5, 7.7). Closely spaced ostracod samples across this level show a gradual change from a fauna similar to that of the Upper Whitcliffe Formation at Ludlow to a fauna comparable with that of the Downton Castle Sandstone Formation (Text-fig. 7.7). *Frostiella groenvalliana* occurs at the base of the Downton Castle Sandstone Formation in the Welsh Borderland (see Chapter 4). *Nodibeyrichia verrucosa* is confined to the lowermost 34cm of the Downton Castle Sandstone Formation at Ludlow and first occurs (with *F. groenvalliana*) at the base of bed K, at Wallop Hall (Text-fig. 7.7). On this basis, the base of the Downton Castle Sandstone Formation (base of the Pföldorf)
should be correlated to the base of bed K within the Causemountain Formation at Wallop Hall (loc. 36a).

The bone beds at Within's Wood (loc. 39c) occur above the first occurrence of *F. groenvalliana*, indicating that these bone beds correlate above the base of the Downton Group and within the Clun Forest Formation. The bone beds are possible correlatives of similar bone beds in the Clun Forest Formation at Bishop's Castle (Allender et al. 1960), the *Platyschisma helicites* Beds at Meeting House Lane at Knighton (loc. 40c), and the Platyschisma Shale Member at Downton (loc. 14c). Conodonts recovered from the lowermost bone bed at Within's Wood (loc. 39c) are also similar to conodont collections from the Downton Bone Bed (loc. 14c).

Ostracod faunas (*Calcaribeyrichia, Hemsiella, Lophoctenella, Londinia*, and minor proportions of *Frostiella* and *Nodibeyrichia*) from assumed coeval horizons (Text-fig. 7.3) at Wallop Hall, Long Mountain (loc. 36a), Knighton (locs 40b, c), and Nantyrhynau Quarry, Clun (loc. 37) are very similar in composition and offer potential correlation of the base of the Downton Castle Sandstone Formation from the shelf at Ludlow to the westernmost part of the basinal area (Text-fig. 7.13).

SW Wales.

The unconformable base of the Downton Group is readily discernable by a marked change in fauna and lithology at the base of the Long Quarry Formation (Straw 1930; Potter and Price 1965). The occurrence of the ostracod *N. lauensis* in the Upper Roman Camp Formation, suggests that the formation below the unconformity at Sawdde, correlates with the Upper Leintwardine Formation (Potter and Price 1965; Bassett 1982; Siveter et al. 1989).

The occurrence of *F. groenvalliana* at Capel Horeb (loc. 43) suggests a Předolci age for the Long Quarry Formation. However, it is not possible to demonstrate that the unconformable base of the Long Quarry Formation is coincident with the base of the Downton Castle Sandstone Formation at Ludlow.

The occurrence of *F. cf. groenvalliana* in the Cennen Formation of the Cennen Valley (loc. 45a) (Chapters 3 and 4) indicates that the Ludlow age (Squirrell and White 1978) is equivocal. The presumed Ludlow age for the Cennen Formation is based on the occurrence of the characteristic Ludlow trilobite *Calymerne neointermedia* Richter and Richter and brachiopod
TEXT-FIG. 7.13. Comparison of ostracod faunas from individual beds at assumed basal Pfidolf horizons (Text-fig. 7.3) along a shelf-basin transect of the Welsh Basin.
Sphaerirhynchia cf. wilsoni (forms) in the lower part of the Cennen Beds (Squirell and White 1978). However, most species in the Cennen Formation, including the characteristic Upper Leintwardine brachiopod Hyattidina canalis (J. de C. Sowerby), also occur in the Tilestones (Long Quarry Formation) (Squirell and White 1978, tab. 3). The upper and lower contacts of the Cennen Formation are unconformable, and it is possible that the Cennen Formation is a local unit at the base of the Downton Group.

International

The occurrence of the ostracod F. groenvalliana within the Causemountain Formation at Wallop Hall (loc. 36), within the Clan Forest Formation at Within's Wood, Clun (loc. 39a) and within the Long Quarry Formation at Capel Horeb (loc. 43), is consistent with a Pfidolf age for these stratigraphic horizons (see chain of correlation in Chapter 4).
CHAPTER 7

CONCLUSIONS

1. Only very sparse ostracod and conodont material has been recovered from below the base of
the Downton Group in E central Wales and SW Wales. The uppermost Ludlow of E central
Wales is characterised by the ostracods C. torosa, H. cf. maccoyiana and L. cf. scanensis.

2. Ostracod faunas from the Causemountain Formation at Wallop Hall show a gradual upward
transition from characteristic Upper Whitcliffe Formation species (C. torosa, H. cf. maccoyiana
and L. cf. scanensis) to characteristic Downton Castle Sandstone Formation species (F.
groenvalliana, L. arisaigensis, L. fissurata, N. verrucosa). All of these species occur together
at a level coincident with a 1mm bone bed.

3. Similar mixed ostracod faunas occur at the base of the Platyschisma helicites Beds at
Knighton (loc. 40c) and within the Clun Forest Formation at Nantyrhynau, Clun (loc. 37).

4. The gradual ostracod faunal change in the basin area is consistent with coeval palynofacies
variations (Text-fig. 7.12) and reflects continued sedimentation in the basin area of the Welsh
Basin at the time when condensed bone bed successions were deposited on the shelf.

5. The ostracod F. groenvalliana is rare in the basin area of the Welsh Borderland. However,
mixed ostracod faunas (see conclusion 2) can be used to correlate the base of the Downton
Sandstone Formation (the base of the Přídol or Series) into E central Wales, where bone beds and
F. groenvalliana are absent (Text-fig. 7.13).

6. The lowest and best developed bone bed discovered at Within's Wood (loc. 39a), most
likely correlates with the Downton Bone Bed and is similar to bone beds described from the
basin area of the Welsh Borderland at Bishop's Castle and Knighton (loc. 40c) (Allender et al.
1960).

7. The occurrence of F. groenvalliana at Capel Horeb (loc. 43) suggests a Přídol age for the
Long Quarry Formation. However, it is not possible to demonstrate that the unconformable
base of the Long Quarry Formation is precisely coincident with the base of the Downton Castle
Sandstone Formation at Ludlow.

8. The Cennen Formation of the Cennen Valley (loc. 45a) is not considered to be Ludlow in
age but possibly an unconformable unit at the base of the Downton Group.
SUMMARY AND GENERAL CONCLUSIONS

Taxonomy

Fourteen multielement conodont species (two in open nomenclature) and eight individual unassigned Ozarkodina elements are described. Ozarkodina crispa, Dapsilodus obliquicostatus and Walliserodus cf. sancticlairei are recorded for the first time from Ludlow Series of the Welsh Borderland. A new subspecies, O. remscheidensis baccata is described from the Upper Whitcliffe Formation. O. crispa and O. snajdri are shown to have co-existed towards end of the Ludlow Epoch; O. crispa is probably a phylogenetic descendant of O. snajdri. The Pa element Pelecysgnathus dubius and the elements previously described as Distomodus(?) dubius are synonymised as Coryssognathus dubius and a septimembrate prionodontid apparatus comprising Pa, Pb, Pc, M, Sa/Sb, Sb and Sc elements is reconstructed. Each element is paired, with a total of 16 elements in the apparatus, including two indistinguishable pairs of Sc elements. Associated small coniform elements appear to represent discrete denticles of crown tissue that were sequentially incorporated into multidenticulate elements during ontogeny.

Ten ostracod species (four in open nomenclature), most of which are beyrichiaceans, are described. Ostracods are most commonly preserved as internal and external moulds of disarticulated valves, occasionally as carapaces with both valves still cojoined but open and mostly in the 'butterfly' position. Moulds of damaged (flattened) valves and pyritised internal moulds are rare. Original calcareous valves of F. groenvalliana are reported for the first time from the Welsh Basin.

Distribution

The Upper Whitcliffe Formation at Ludlow is characterised by the ostracod C. torosa with rare occurrences of H. cf. maccoyiana. Similar faunas, including rare L. cf. scanensis, occur throughout the uppermost Ludlow of the Welsh Borderland and E central Wales. At Ludlow there is a sudden change in the ostracod assemblage at the base of the Downton Castle Sandstone Formation, to a fauna characterised by F. groenvalliana, with L. arisaigensis, L.
SUMMARY AND GENERAL CONCLUSIONS

There is a similar coeval turnover in ostracod faunas across the entire shelf area of the Welsh Basin, although ostracods are much less frequent away from Ludlow. In contrast, the ostracod faunal change at coeval horizons across the basinal area is more gradual. The transition is best shown at Long Mountain, but is also represented at the base of the *Platyschisma helicites* Beds at Knighton and at the base of the Clun Forest Formation at Clun.

Uppermost Ludlow conodont faunas throughout the shelf area of the Welsh Borderland are dominated by *C. dubius*, *O. confluens*, *O. excavata* and *P. serratus*. Very few conodonts have been recovered from these levels in E central Wales and SW Wales. The Upper Whitcliffe Formation at Ludlow shows a trend from well preserved faunas dominated by *O. excavata* to abraded faunas lacking *P. serratus* and dominated by *O. confluens* and *C. dubius*. Similar faunal trends are shown in the Upper Perton Beds at Woolhope, the Whitcliffe Formation at Tite's Point and the Upper Llangibby Beds at Usk. Pa elements of *O. crispa* and *O. cf. crispa* have been recovered in the uppermost metre and from the uppermost bed of the Upper Whitcliffe Formation around Ludlow. Downton Castle Sandstone Formation conodonts are recovered almost exclusively from bone beds and are dominantly *C. dubius* and Pa elements of *O. confluens*. Well preserved elements of *Oulodus* sp. and *O. confluens* have been recovered from limestones within the Downton Castle Sandstone Formation at Much Wenlock.

**Palaeoenvironments**

Conodont faunal trends (outlined above) across the shelf area of the Welsh Borderland reflect an increasingly turbulent environment towards the top of the Ludlow Series, a change which may be related to shallowing. Abraded conodont faunas throughout the Whitcliffe Formation at Tite's Point and from the Upper Longhope Beds at Mayhill reflect a turbulent environment. The sudden change in ostracod faunas at the base of the Downton Castle Sandstone Formation at Ludlow is unlikely to be entirely facies related, but some ostracod species (e.g. *C. torosa*) appear to be environmentally sensitive. The gradual ostracod faunal change across the Ludlow/Prídolf series boundary of the basinal area reflects environmental control of some of these species, is consistent with gradual lithofacies changes and published shelf-basin palynofacies interpretations, and probably reflects continuous sedimentation in E central Wales at that time.
SUMMARY AND GENERAL CONCLUSIONS

Variations in ostracod frequency, faunal composition and carapace preservation within the Downton Castle Sandstone Formation at Ludlow coincide with minor lithofacies variations and may be related phenomena (Text-fig. 4.16). Local variations in ostracod frequency, sedimentology and published palynofacies data at the base of the Downton Castle Sandstone Formation across the shelf area possibly reflect a proximal, storm influenced, irregularly prograding shoreline. Well preserved conodonts (Oulodus sp. and O. confluens) recovered from limestones within the Downton Castle Sandstone Formation at Much Wenlock are not considered to be reworked and suggest the local presence of a marine environment which supported conodont animals.

Correlation

F. groenvalliana allows correlation of the base of the Downton Castle Sandstone Formation across the Welsh Borderland and, by indirect and approximate correlation, to the base of the Přídolí Series defined in Czechoslovakia. Direct and more precise conodont correlations suggest that the base of the Přídolí Series is at least as high as the base of the Downton Castle Sandstone Formation and possibly at a low level within the formation. Combined ostracod and conodont correlations, therefore, suggest that the base of the Přídolí Series in Britain is concurrent with the base of the Downton Castle Sandstone Formation. The occurrence of the conodont O. cf. snajdri within the Rushall Beds at Prior's Frome does not in itself suggest that the base of the Přídolí Series is at a level above the base of the Rushall Beds.

The distributions of F. groenvalliana and O. crispa within the Welsh Basin are consistent with traditional correlations of the base of the Downton Castle Sandstone Formation across the shelf area using bone beds and phosphatic pebble beds. The base of the Downton Castle Sandstone Formation (the base of the Přídolí Series) can be correlated to a level within the Causemountain Formation at Wallop Hall, Long Mountain, to the base of the Platyschisma helicites Beds at Knighton and the base of the Clun Forest Formation at Clun. The lowest and best developed bone bed of the multiple bone beds discovered within the Clun Forest Formation at Clun is considered a correlative of the Downton Bone Bed. The Long Quarry Formation at Llandovery is considered Přídolí in age. However, the unconformity at the base of the Downton Group in SW Wales cannot be shown to be coincident with the base of the
SUMMARY AND GENERAL CONCLUSIONS

Downton Castle Sandstone Formation at Ludlow. The Cennen Formation of the Cennen Valley, SW Wales, is considered equivocally Ludlow in age; it may possibly be early Pridolf in age.

Suggestions for Future Research

The sections at Willey (loc. 2), Linley (loc. 3b), Downton (loc. 14b), Ludlow (locs 17, 18), Netherton (loc. 20), Perton (loc. 23a), Prior’s Frome (loc. 24), Brook House (loc. 33) and Long Mountain (loc. 36a) yielded good conodont or ostracod microfaunas for this study and are currently well exposed. All of these localities (if not already studied) would merit detailed sedimentological and palynological investigation to test the palynofacies model of Richardson and Rasul (1990) against sedimentological and microfaunal variations. It is possible that during deposition of the Downton Castle Sandstone Formation there were periodic influxes of sediment rich in plant fragments and freshwater along the prograding shoreline of the Midland Platform (Text-fig. 1.5). These influxes possibly provided an environment which was favourable to ostracods. Therefore the sections at Downton (loc. 14c), Ludlow (locs 17, 18), Perton (loc. 23a) and Long Mountain (loc. 36a) require further sedimentological investigation to test whether lithofacies variations can explain the observation that the most prolific lowermost Pridolf ostracod faunas are present in sections with high percentages of land plant fragments and spores.

The Sandstone Member of the Downton Castle Sandstone Formation at Ludford Corner where Smith and Ainsworth (1989) documented Hummocky Cross Stratification, requires more detailed collecting for ostracods and palynomorphs to test the microfaunal and floral responses to storm sedimentation.

The sections at Brockhill (loc. 22), Gorsley (loc. 29), Nantyrhynau Quarry (loc. 37), Hendre Farm (loc. 38c), Knighton Meeting House Lane (loc. 40c) and Cennen Valley (loc. 45) yielded little or no conodont or ostracod data but would benefit from sedimentary and palynological study. It would be particularly interesting to compare palynofacies of the condensed succession at Gorsley (on the Gorsley axis) with the section at Tite’s Point (loc. 31b) which has yielded abraded conodont elements which may have been winnowed on a relative highstand during deposition of the Ludfordian of the Welsh Basin. Gorsley and Tite's
SUMMARY AND GENERAL CONCLUSIONS

Point are only 21km apart and may have occupied similar highstand positions towards the end of deposition of the Ludlow Series.

The basinal section at Knighton studied by Richardson and Rasul (1990) contains only a few sample points and needs to be tested by parallel sections. The basin successions at Nantyrhynau (loc. 37), Hendre Farm (loc. 38c) and Knighton (loc. 40c) offer complete sections for palynological study across the base of the Prfdolf Series. Palynological studies of these sections can also test the chain of correlation based on ostracod faunas from the present study. Knighton Meeting House Lane (loc. 40c), if it can be cleared, would be ideal for directly comparing of the palynomorph floras with coeval ostracod faunas. Initial palynological work at Nantyrhynau (loc. 37) is consistent with a gradual microfloral change across the base of the Prfdolf Series as indicated by the ostracod fauna. More detailed sampling is needed to test this gradual palynofacies change and to improve the correlation between shelf and basin (work in progress at University of Sheffield). Initial palynological samples processed by the author have yielded abundant plant fragments and may also yield early arthropod cuticle.

Further studies on conodont and ostracod faunas may yield additional late Ludlow faunas from the Brookend (loc. 32) and Rumney (loc. 35) boreholes. The mid Prfdolf Little Missendon borehole contains calcareous horizons and may also yield conodont faunas. The Tite's Point section (loc. 31b) has yielded specimens of Ozarkodina crispa. It is possible that a parallel section through the Ludlow Series exposed on the northern bank of the Severn Estuary at Newnham (Cave and White 1971) may yield more examples of this stratigraphically important conodont. The Cennen Valley section (loc. 45) needs to be cleared and a detailed bed by bed macrofaunal, microfaunal and sedimentological investigation carried out to determine the age of the Cennen Formation. The lowermost 56cm is most critical as this subsection contains Upper Leintwardine brachiopods and trilobites alongside typical Downton Castle Sandstone Formation ostracods (Squirrell and White 1978, table 3).

The remainder of the sections either yielded a poor fauna or are incompletely exposed. SW Wales yielded a particularly poor conodont and ostracod fauna. Palynomorphs so far obtained from that area are thermally mature, hard to identify and thus further work may not yield additional information.
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REFERENCES


REFERENCES


REFERENCES


FIELD LOCALITIES

The following information is cited for each locality;
(a) A locality number and name (in bold if locality or microfossil material from locality has been examined by the author).
(b) A geographical description, an eight figure national grid reference (if possible) and selected key papers citing the locality.
(c) Stratigraphical position of samples (Text-fig. 1.3) and a comment on the state of the exposure if the locality is poorly or no longer exposed.
(d) Sources of material studied, with a BGS reference and specimen numbers if applicable.

Localities are grouped according to geographical area (Text-fig 1.2) following the broad subdivision of the Welsh Borderland into shelf and basin facies (Holland 1962). Maps showing the distribution of localities are given in Text-figures 4.2, 5.2, 6.3 and 7.2. The list includes localities which expose strata (or lateral equivalents) either from the Upper Whitcliffe Formation, from the Downton Castle Sandstone Formation, or a continuous section across the base of the Downton Castle Sandstone Formation.
APPENDIX 1

Shell localities of the Ludlow Anticline and surrounding area (Chpts 4 and 5)

LOC. 1. CALLAUGHTON MILL. In road at Callaughton Mill, 2.5km SW of Much Wenlock, Shropshire, SO 6198 9746 (Robertson 1927 p. 86-87). Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base, now very poorly exposed, bone bed not located (Sept. 1992) (BGS 18-151).

LOC. 2. WILLEY. Quarry section behind stables, Willey Estate, Willey, 5km ESE of Much Wenlock, Shropshire, SO 6731 9912 (White and Coppack 1978, fig. 1). Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base and 3m above base (BGS and CGM).

LOC. 3. LINLEY. 6.5km due E from Much Wenlock, Shropshire.
3(a) Road from Linley Hall to Linley Brook, E of Linley Bridge, SO 6870 9817 (Robertson 1927, loc. L17; White and Coppack 1978, fig. 3) Downton Castle Sandstone Formation, no longer exposed (Sept. 1992) (BGS 18-84, samples SH 3560-3580).
3(b) Linley Brook 90m E of Hem Farm, SO 6920 9820 (Robertson 1927, loc. L18; White and Coppack 1978, fig. 3). Downton Castle Sandstone Formation. (CGM and BGS 18-85, samples SH 3680-3685).
3(e) Tributary to Linley Brook 1km E of Linley Bridge, SO 6940 9815 (Robertson 1927, p. 87, loc. L19; White and Coppack 1978, fig. 3). Downton Castle Sandstone Formation with bone bed, no longer exposed (Sept. 1992). (BGS 18-85 (Bed A; SH3587. Bed C; SH3635 and 3636. Bed G; SH3639 and 3640)).

LOC. 4. DEAN BROOK. Tributary to R. Severn 6.5km E of Much Wenlock, Shropshire. Localities no longer exposed (White and Coppack 1978).
4(a) Left bank of Dean Brook at mouth of small dry stream, SO 6955 9915 (Robertson 1927, locs L13 and 14; White and Coppack 1978, fig. 3). Downton Castle Sandstone Formation. (BGS 18-92 (samples SH3775-3792; SH4046-4074)).
APPENDIX 1

4(b) Section 40m N of 4a, SO 6875 9955 (Robertson 1927, loc. L16; White and Coppock 1978, fig. 3). Downton Castle Sandstone Formation (BGS 17-123 (samples RT107, 112, 114, 116, 118 and 128)).

LOC. 5. BROCKTON. On B4378, 6.5km SW of Much Wenlock, Shropshire.
5(a) Stream section 950m at 61° from E corner of Lardon Grange, opposite Ivy Cottage, Brockton, Corve Dale Shropshire, SO 5755 9388. Whitcliffe Formation, poorly exposed and inaccessible (Sept. 1992) (BGS 54-267).
5(b) Road cutting 150m towards Much Wenlock from Brockton cross roads on B4378, SO 579 939. Whitcliffe Formation, Downton Castle Sandstone Formation with bone bed at base, bone bed and boundary between two formations obscured by ivy on section (Sept. 1992) (BGS 19-152 (samples RT344 and 347)).
5(c) Exposure in old quarry behind old school house, Brockton. SO 5765 9400. Whitcliffe Formation (RJA).

LOC. 6. SHIPTON. Junction of B4368 and B4378 on Corve Dale, 9km SW of Much Wenlock, Shropshire.
6(a) Exposure 30m SE of B4368 next to path connecting B4368 and B4378, SO 5634 9186. Whitcliffe Formation (CGM).
6(b) Old quarry in farmyard 150m at 26° from NE end of St. James Church, SO 5625 9194. Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base, quarry now overgrown and inaccessible due to farm building (Sept. 1992) (BGS 54-271).
6(c) Laneside section 155m at 125° from SW end of St. James Church SO 5629 9169. Whitcliffe Formation and Downton Castle Sandstone Formation with bone bed at base, bone bed not located (Sept. 1992) (CGM and BGS 54-271).

LOC. 7. ASTON MUNSLOW. Corve Dale, 10km NE of Craven Arms, Shropshire.
7(a) Swan Inn car park on NW side of B4368, SO 5124 8658. Whitcliffe Formation, and Downton Castle Sandstone Formation with bone bed at base (BGS 54-120 (sample JD 463), CGM and RJA).
APPENDIX 1

7(b) Roadside exposure at cross roads 120m NW of Swan Inn, SO 5113 8671. Whitcliffe Formation (CGM and RJA).

LOC. 8. DIDDLEBURY. Small exposure at roadside, 10m NW from B4368 on Middlehope road, Diddlebury, Corve Dale, Shropshire, SO 503 858. Whitcliffe Formation (CGM and RJA).

LOC. 9. CORFTON. Roadside cutting 55m SE of Sun Inn, Corfton, c.7km ENE of Craven Arms, Corve Dale, Shropshire, SO 497 846. Downton Castle Sandstone Formation, only partially exposed (Sept. 1992) (CGM and BGS 54-124 (samples JD 562 and 566)).

LOC. 10. SIEFTON. c.5km E of Craven Arms, Shropshire.
10(a) Quarry in Siefton Batch 1km NW of B4368, Corve Dale, Shropshire, SO 4770 8475. Whitcliffe Formation (CGM).
10(b) Temporary roadside trench, SO 475 833 to 478 835 (Antia 1979b). Whitcliffe Formation and Downton Castle Sandstone Formation, no longer exposed.

LOC. 11. CULMINGTON. Old quarry S of new house, 500m ENE of Burley, near Culmington, Shropshire, SO 4745 8150. Downton Castle Sandstone Formation with bone bed at base (BGS records), no bone bed located (Sept. 1992) (CGM and BGS 66-101 (samples FG 2810, 2812 and 2813)).

LOC. 12. ONIBURY. 4km SSE of Craven Arms, Shropshire.
12(a) Exposure in farmyard next to Gorst Barn, 3km WNW of Onibury Church, SO 425 796 (Smith and Mitchell 1958). Upper Whitcliffe Formation (BGS 54-198 (sample JD 1251)).
12(c) Locality not constrained, on road from Onibury to Norton. Tilestones (Downton Group) (BGS 22-140 (samples Za 4685-4688)).
APPENDIX 1

LOC. 13. CLUNGUNFORD. 5km SW of Craven Arms, Shropshire.

13(a) Lane in wood 3.2km E of Clungunford, SO 434 789. Whitcliffe Formation. (BGS 54-196 (samples JD 1193, 1195, 1208))

13(b) Old quarry 150m E of Brandhill Farm, 2km E of Clungunford, SO 4236 7883. Whitcliffe Formation, almost totally obscured (Sept. 1992) (CGM and BGS 54-197 (samples JD 1211, 1217, 1227 and 1234)).

LOC. 14. DOWNTON ESTATE. Area around Downton Castle, c.6km W of Ludlow, Shropshire.


14(b) Weir Quarry, NW bank of the River Teme, c.275m NE of Bringewood Forge Bridge, Downton Estate, SO 4560 7525 (Richardson and Rasul 1990, loc. 1). Upper Whitcliffe Formation, Ludlow Bone Bed Member with bone bed at base, Platyschisma Shale Member and Sandstone Member of Downton Castle Sandstone Formation (CGM).

14(c) Track section in field to S of Downton Castle Bridge, SO 4442 7402. Platyschisma Shale Member (including Downton Bone Bed) and Sandstone Member of Downton Castle Sandstone Formation, no longer exposed (Dec. 1989) (collected in 1968 by Dr. L Jeppsson, University of Lund, Sweden).

LOC. 15. WHITCLIFFE QUARRY. South bank of the River Teme, Ludlow, Shropshire.

15(a) 250m W of Ludford Bridge, SO 5098 7414 (Siveter et al. 1989, loc. 3.1f). Boundary between Lower Whitcliffe Formation and Upper Whitcliffe Formation at top to convoluted bedding (CGM and RJA).

15(b) 40m W of 15(a), SO 5096 7414. Same strata exposed as at 15(a) (CGM).

15(c) 60m W of 15(a), SO 5092 7415. Possible boundary between Lower and Upper Whitcliffe formations marked by similar convoluted bedding to 15(a) (CGM and RJA).

15(d) 120m W of 15(a), SO 5089 7416. Upper Whitcliffe Formation (CGM and RJA).

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APPENDIX 1

LOC. 16. WHITCLIFFE. Car park to Charlton Arms Hotel, near Ludford Bridge, Ludlow, Shropshire, SO 5116 7416. Upper Whitcliffe Formation, single sample c.10m below Ludlow Bone Bed (RJA).

LOC. 17. LUDFORD LANE. N side of Whitcliffe Road (formerly Ludford Lane), Ludlow, Shropshire.
17(a) Next to roadsign 90m W of junction with A49, SO 5116 7413 (Siveter et al. 1989, loc. 3.2b). Upper Whitcliffe Formation, Ludlow Bone Bed Member with multiple bone beds and Platyschisma Shale Member, Downton Castle Sandstone Formation. (CGM, RJA and BGS (samples DEY 3638-3826)).
17(b) 80m W of junction with A49, SO 5117 7413. Strata sampled as for 17(a).
17(c) 70m W of junction with A49, SO 5118 7413. Strata exposed as for 17a and b, Upper Whitcliffe Formation only sampled.

LOC. 18. LUDFORD CORNER. At junction of A49 and Ludford Lane, Ludlow, Shropshire, SO 5124 7413 (Siveter et al. 1989, loc. 3.2a). Upper Whitcliffe Formation§, Ludlow Bone Bed Member§ with multiple bone beds, Platyschisma Shale Member and Sandstone Member of Downton Castle Sandstone Formation. Only units suffixed by § and the lowermost 7cm of the Platyschisma Shale Member sampled.

LOC. 19. KINGTOWN. Hereford and Worcester town c.25km SW of Ludlow.
19(a) Section on N side of Kington by-pass, SO 2998 5706 (Holland and Williams 1985, loc. 5). Upper Whitcliffe Formation, multiple bone beds in Ludlow Bone Bed Member, Platyschisma Shale Member, Sandstone Member of Downton Castle Sandstone Formation, poorly exposed (Oct 1990).
19(b) Lane-side exposures on Newton Lane, SO 2902 5716 (Holland and Williams 1985, loc. 3). Upper Whitcliffe Formation, multiple bone beds in Ludlow Bone Bed Member and Platyschisma Shale Member of Downton Castle Sandstone Formation.
APPENDIX 1


Shelf localities of the southern Borderland inliers (Chpt. 6)

21(a) Small quarry 50m S of Abberley Hall, SO 745 663. Whitcliffe Flags Member, Upper Ludlow Formation (BGS 32-28).
21(b) Small old quarry to E of road 100m SE of Camp Farm, and 1500m SW of Hundred House, Great Whitley, near Abberley, SO 7405 6505. Whitcliffe Flags Member, Upper Ludlow Formation, overgrown (Sept. 1992) (BGS 28-212 (samples Da 4351 and 4355)).
21(c) Woodbury (working) Quarry, N side of road and 1500m at 33° from church at Shelsey Beauchamp, Worcestershire, SO 743 637. Whitcliffe Flags Member, Upper Ludlow Formation (BGS 28-215 and 59-146 (samples Da 4373, 4388 and 4390)).
21(d) Small quarry 100m SW of Rodge Hill Farm and 1500m at 113° from church at Shelsey Beauchamp, Worcestershire, SO 746 622. Whitcliffe Flags Member, Upper Ludlow Formation (BGS 28-207 (sample Da 4161)).

LOC. 22. BROCKHILL QUARRY. 250m NNE of Brockhill Farm, 1.5km N of Colwall Station, Colwall near Malvern Wells, Hereford and Worcester, SO 7568 4394 (Penn and French 1971, loc. 38). Whitcliffe Flags Member, Upper Ludlow Formation, Downton Castle Sandstone Formation with bone bed at base (CGM, RJA and BGS 28-281).

LOC. 23. PERTON LANE. Exposures to the E of Perton Lane, Perton, 5km NNW of Woolhope, Hereford and Worcester.
23(a) Exposure under an overhang, 20m S of 3-way road junction at Perton, SO 5971 4035 (Squirrell and Tucker 1960, fig. 2, loc. F). Upper Perton and Rushall beds (CGM, DJS and RJA).
23(b) 20m S of 23(a) at base of cliff section, SO 5969 4031 (Squirrell and Tucker 1967, fig. 5, loc. 2). Upper Perton Beds (CGM and RJA).
APPENDIX 1

LOC. 24. PRIOR’S FROME. Exposures opposite the Yew Tree Inn, Prior’s Frome, Woolhope c.5km ESE of Hereford, Hereford and Worcester, SO 5662 3901 (Squirrell and Tucker 1960).

24(a) Old quarry face. Upper Perton Beds (CGM and RJA).

24(b) An old overgrown path separates exposure (a) from (b), creating an approximately 50cm exposure gap. 24(b) is exposed to the south of the path. Rushall Beds with bone bed at base, although bone bed no longer exposed (April 1990) (CGM, RJA and BGS 59-235 (samples Zs 682-693)).

LOC. 25. CAERSWELL FARM. 320m NE of Caerswell Farm, 3.5km SE of Woolhope, Hereford and Worcester, SO 6440 3380. Upper Perton Beds and Rushall Beds with bone bed at base (CGM and BGS 59-147).

LOC. 26. WHITTOCKS END FARM. 550m W of Whittocks End Farm, 3km S of Much Marcle, Hereford and Worcester, SO 6540 2990. Rushall Beds with bone bed at base (BGS 59-147).

LOC. 27. RUSHALL. Road side exposure at Rushall, 3km ESE of Woolhope, Hereford and Worcester, SO 6410 3481 (Squirrell and Tucker 1967, loc. 18). Upper Perton Beds, Rushall Beds with bone bed at base, although no bone bed located (Sept. 1992) (CGM).

LOC. 28. BODENHAM FARM. Small quarry immediately to N of Bodenham Farm, 5.5km SE of Woolhope, Hereford and Worcester, SO 6524 3201 (Squirrell and Tucker 1967, loc. 19). Lower Perton Beds and Upper Perton Beds with bone bed at base, almost totally overgrown (Sept. 1992).

LOC. 29. GORSLEY. Linton Quarry, Gorsley, 4km W of Newent, Gloucestershire, SO 6770 2570 (See Lawson 1954 for local lithostratigraphical names). Wenlock Limestone, unconformity, Upper Blaisdon Beds, unconformity, Upper Longhope Beds with phosphatic pebble bed at base, Cliffords Mesae Sandstone with phosphatic pebble bed at base.
LOC. 30. LONGHOPE. Exposures around Longhope Village, Mayhill, Gloucestershire.
30(a) Exposure behind Longhope railway station, SO 6910 1901 (Lawson 1967, loc. 15).
Upper Longhope Beds, Cliffords Mesne Sandstone with phosphatised pebble bed at base, no longer accessible due to new construction (Nov 1990).
30(b) Road cutting on A4136, Longhope Village by-pass, SO 692 186 (Lawson 1982, loc. 19). Same strata as for 30(a), although now very poorly exposed (RJA).
30(c) Stream section at Wood Green, SO 6930 1670 (Lawson 1954, fig. 1, loc. C). Upper Longhope Beds), Cliffords Mesne Sandstone with phosphatic pebble bed at base, poorly exposed and inaccessible (Sept. 1992).

LOC. 31. TITE'S POINT. Exposures on the S bank of the River Severn at Tite's Point near the Berkeley Arms, Purton, Gloucestershire.
31(a) Ditch to S of tow path of Purton-Gloucester canal, 180m at 244° from the Berkeley Arms, SO 6897 0438 (Cave and White 1971). Whitcliffe Formation (BGS 62-254).
31(b) Foreshore of Severn Estuary, 250m W of Berkeley Arms, Tite's Point, SO 688 046 (Cave and White 1971, fig. 2). Upper Leintwardine Formation, Lower and Upper Whitcliffe formations, and Downton Castle Sandstone Formation with bone bed at base (CGM and RJA).

LOC. 32. BROOKEND BOREHOLE. Vine Farm, 3km N of Berkeley, Gloucestershire, SO 6877 0230 (Cave and White 1968, 1978). Elton/Bringewood Beds, Leintwardine Beds, Whitcliffe Formation, Downton Castle Sandstone Formation and Thornbury Beds.

LOC. 33. BROOK HOUSE. Exposure on the W bank of Cwm-ffrwd Brook near Brook Cottage, c.2km WSW of Llangybi, Usk Valley, Gwent, SN 356 957 (Walmsley 1959, fig. 7). Upper Llangibby Beds and Speckled Grit Beds with bone bed at base.

LOC. 34. USK. Exposures around the town of Usk, Gwent, SN 375 005. Speckled Grit Beds with fragmentary fish remains (Walmsley 1962). All these localities are no longer exposed (Nov 1990).
34(a) A few feet below the wall in Llandegveth church yard, Llandegveth, 6.5km SW of Usk, SN 338 957.
34(b) Old quarry 400m SW of Llangybi Castle, SN 365 972.
34(c) Dingle immediately N of Granary Farm, SN 322 968.
34(d) Stream section 500m N of Llandewi Court, SN 316 982.

LOC. 35. RUMNEY BOREHOLE. To E of River Rhymney c.1.5km W of Rumney, Cardiff, ST 2108 7925 (Waters and White 1978). Wenlock Series extending through Ludlow Series including Llanedeyrn Formation, overlain by Raglan Mudstone Formation with fragmentary fish remains at base.

Basin localities of E central Wales and shelf edge localities on the southern margin of the Welsh Basin (Chpt. 7)

LOC. 36. LONG MOUNTAIN. Exposures around the Long Mountain, NW Shropshire, c.8km W of Welshpool, Powys.
36(a) WALLOP HALL. Exposure under trees near ruins of Wallop Hall, Lower Wallop, 2.7km SW of Westbury, Long Mountain, Shropshire, SJ 3150 0725 (Richardson and Rasul 1990, loc. 5). Wallop Hall Member of Causemountain Formation with bone bed (Palmer 1973).
36(b) NE end of the Long Mountain in a small quarry on the S bank of Sergeant's Dingle, 800m WSW of March Manor Farm, SN 330 103. Causemountain Formation (BGS 17-40 (sample RE 2460)).

LOC. 37. NANTRHYNAU QUARRY. Exposure behind barn, 5km NNW of Felindre, Powys, SO 1602 8588. Cefn Einion and Clun Forest formations (CGM and BGS 143-1776).

LOC. 38. FELINDRE. Exposures around the village of Felindre, Powys SO 1698 8110, c.13km W of Clun, Shropshire.
38(a) MEDWALEDD BROOK. Dry stream bed c.3km NNW of Felindre, Powys, SO 1534 8391 to SO 1568 8389 (Earp 1938, p. 138). Discontinuous exposures showing the general succession through the uppermost Cefn Einion Formation into the Clun Forest Formation.
APPENDIX 1

38(b) STONEHOUSE DINGLE. 1km SE of Felindre, Powys, SO 1712 7983 to 1757 8016 (Earp 1940, p. 7). Same strata as for 38(a) but not well exposed (Nov. 1990).

38(c) HENDRE FARM. Trackside exposure 1.7km NW of Felindre, Powys, SO 1538 8220. Cefn Einion Formation.

LOC. 39. CLUN. c.20m NNW of Ludlow, Shropshire.

39(a) WITHIN'S WOOD. Cutting for new forestry path near Within's Wood, Clun Forest, Shropshire, SO 317 836. Clun Forest Formation with one well-developed bone bed and a succession of thin bone beds.

39(b) CLUN FOREST. Floor of forestry track, 4460m at 230.5° from church with tower, Lydbury North, Shropshire, SO 3176 8317. Similar to Green Downton Formation of Holland (1959) (CGM and BGS (samples DEY 7523-7553)).

39(c) Roadside exposure at Bryn 1.2km SE of Cefn Einion, Shropshire, SO 2951 8535. Cefn Einion Formation (BGS).

39(d) HURST MILL. Exposure next to forestry track in Radnor Wood, c. 1.5km ENE of Clun, Shropshire, SO 3162 8128. Cefn Einion Formation (CGM and BGS).

39(e) FIVE TURNINGS OUTLIER. Old quarry 280m E of Black Garn Farm, SO 297 759 (Stamp 1918, p. 237). Cefn Einion Formation with an exposure gap followed by lowest Clun Forest Formation, almost completely overgrown (Nov 1990).

LOC. 40. KNIGHTON. Exposures around the town of Knighton, c.23km W of Ludlow, Shropshire.

40(a) Old quarry immediately W of bridge on Gwernaffel Estate, SO 273 706 (Holland 1959, p. 462; Richardson and Rasul 1990, loc. 6). Upper Llan-wen Hill and Platyschisma helicites beds.


40(c) MEETING HOUSE LANE. Discontinuous track and trackside exposures on steep track from Meeting House Farm to Llan-wen Hill, SO 3023 6940. Upper Llan-wen Hill Beds, Platyschisma helicites Beds [including a small bone bed], Green Downton and Yellow Downton formations, poorly exposed (May 1990) (DJS).
APPENDIX 1

LOC. 41 BUILTH WELLS. NW of Gwendwr in the banks of Nant Gwendwr, 5km SW of Builth Wells, Powys, GR SO 061 436 (Straw 1930, p. 84, 85; 1937). *Holopella conica* Beds and Green Marls, succession no longer fully exposed, with only sporadic and very small exposures (Nov 1990).

LOC. 42. CWM GRAIG DDU. Valley WSW of Builth Wells, 4km SSE of Garth, SN 968 465 (Straw 1953). *Holopella conica* Beds overlain by Long Quarry Formation (formerly Tilestones) with junction marked by a line of quarry workings (Straw 1953, p. 217), no exposure (Sept. 1992).

LOC. 43. CAPEL HOREB. North side of A 40, 5.5km ESE of Llandovery, SN 844 5324 (Potter and Price 1965, Cwm Dwr section; Siveter *et al.* 1989, loc. 5.8). Upper Roman Camp Formation (=Lower Whitcliffe Formation) unconformably overlain by Long Quarry Formation and Raglan Marls Group (CGM, RJA and BGS (sample Z1 5371)).

LOC. 44. SAWDDE GORGE. River valley c.10km SW of Llandovery, Dyfed.  
44(a) Exposure in stream bed NW of main bridge over R. Sawdde at Pont-ar-Ilechau, SN 7280 2447. Lower Roman Camp Formation (=Upper Leintwardine Formation), Long Quarry Formation.  
44b Small quarry behind Three Horseshoes Inn, Pont-ar-Ilechau, SN 7279 2446, (Bassett 1982, fig. 2, loc. 6). Long Quarry Formation, section partially obscured by new construction (Nov. 1990).  
44c Exposure next to forestry track, SN 7372 2418, (Bassett 1982, fig. 2, loc. 7G; Siveter *et al.* 1989, loc. 5.5i). Long Quarry Formation.

LOC. 45. CENNEN VALLEY. 4km SSW of Llandeilo, Dyfed.  
45(a) Cutting along W side of A476, SN 6100 1908 to 6102 1902 (Siveter *et al.* 1989, loc. 5.6e). Cennen Formation (=possible uppermost Ludlow Series) and Long Quarry Formation (BGS, RJA).  
45b Small quarry above A483, S of Llandeilo, SN 6145 1915 (Siveter *et al.* 1989, loc. 5.7). Long Quarry Formation.
### APPENDIX 2

#### SAMPLES PROCESSED FOR CONODONTS

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PUBLISHED PAPERS


**APPENDIX 3**

**Stereo-Axis of Ostracod Shells 18, 129**

1962  
_Frostiella groenvalliana_  
Paratypes: British Museum (Natural History), London, nos. OS 6618 (9 RV: PI. 18, 132, fig. 4), OS 6619 (tecnomorphic LV: PI. 18, 132, fig. 1), OS 6620 (9 LV: PI. 18, 132, fig. 2), OS 6621 (tecnomorphic RV: PI. 18, 132, fig. 6). All from Planycyclina shale Member, Downton Castle Sandstone Formation, Downton Group, c. 1.5 m above the Ludlow Bone Bed on N side of Ludlow Lane, Ludlow, Shropshire, Great Britain (Grid Ref.: SO 5119 7413); coll. D. J. Siveter. OS 13922 (tecnomorphic LV: PI. 18, 132, fig. 5); loose material, Downton Group, Ludlow Corner excavation, Ludlow (Grid Ref.: SO 5123 7413); coll. C.G. Miller.

**Explanation of Plate 18, 132**

Fig. 1, or LV, detail of apertural margin of pseudoradular lobe (LS 3184T); figs. 2, 3, 9 LV (LS 3183T): fig. 2, detail of ornament on ventral side of carina; fig. 3, ext. ant.; Figs. 4-6, tecnomorphic LV (OS 6619, 1780/tm long): ext. lat. Fig. 7, tecnomorphic RV (OS 6622, 1370/tm long): ext. lat.

**Stere-Axis of Ostracod Shells 18, 131**

1962  
_Frostiella groenvalliana_  
Holotype: Palaeontological Inst. Univ. Lund, Sweden, no. 4084T; 9 left valve.

**Explanation of Plate 18, 130**

Fig. 1, or LV, detail of apoprostost of pseudoradular lobe (LS 3185T); Figs. 2, 3, 4 LV (LS 3183T): fig. 2, detail of ornament on ventral side of carina; fig. 3, ext. ant.; figs. 4-6, or RV (OS 2603, 2200/tm long); fig. 4, ext. lat.; fig. 5, ext. vent.; fig. 6, detail of pseudoradular lobe; Figs. 7, or LV, ext. lat.; fig. 8, or RV: PI. 18, 128, figs. 1-3; PI. 18, 130, figs. 2, 3); LO 2184T (or LV: PI. 18, 126, figs. 4, 5, 6; PI. 18, 130, fig. 1). Both Moberg & Gronwall coll. (1909, pl. 6, figs. 6, 7); "Bed 4" zone Grünwald, at Rønnön, Sweden.

**Stereo-Axis of Ostracod Shells 18, 128**

1962  
_Frostiella groenvalliana_  
Holotype: Palaeontological Inst. Univ. Lund, Sweden, no. 4084T; 9 left valve.

**Explanation of Plate 18, 129**

Fig. 1, or LV, detail of apoprostost of pseudoradular lobe (LS 3185T); Figs. 2, 3, 9 LV (LS 3183T): fig. 2, detail of ornament on ventral side of carina; fig. 3, ext. ant.; Figs. 4-6, tecnomorphic LV (OS 6619, 1780/tm long): ext. lat. Fig. 7, tecnomorphic RV (OS 6622, 1370/tm long): ext. lat.
**Frostiella groenvalliana**

*Diagnosis:* Frostiella species with well developed lobation and prominent cusps on the anterior lobe and the anterior lobule of the syllobium. In adults cristal loop on the presadductorial lobe complete, drawn out in sagitto-dorsal direction or nearly rounded. Valve surface smooth except for the striate cruminal field and the ornament (reticulostriation/striation/punctation) on lateral facet of the presadductorial lobe.

*Remarks:* F. groenvalliana differs from the other *Frostiella* species particularly by its more distinctly developed lobal cusps and the characteristic form of its presadductorial lobe, a feature which is also obvious in juveniles. Niemistö (1977) assumed that *F. groenvalliana* and *F. lehmani* are synonymous. Their morphological characteristics and stratigraphical ranges are both very similar to each other. Only in the development of the presadductorial lobe is there a slight difference. In specimens hiestrei described as *F. lehmani* there is mostly a more rounded cristal loop (not pointed and somewhat distorted as in “typical” *F. groenvalliana* specimens) on the presadductorial lobe. Furthermore, it is probable that the “typical” *F. groenvalliana* is restricted to the basal Pföldl in Britain (Downton Group) and the Baltic whereas specimens with a more rounded cristal loop have a somewhat greater stratigraphical range (and may pass over continuously into the *F. cornuta* lineage). In the Baltic area such changes appear to correlate with ecological ranges from shallow water facies (*groenvalliana* specimens) to somewhat deeper water conditions (*lehmani* specimens). This assumption is supported by the occurrence of the latter in the probably deeper, basal (outer shelf) area represented in, for example, the Leba elevation (Tomczykowa & Witwicka 1974) and the Kaliningrad region Dubovskoe boreholes (Kaljo & Sarv 1976). *F. groenvalliana* and *F. lehmani* are considered as ecomorphological intraspecific variants. Compared to the Scanian (shell) material of *F. groenvalliana*, Welsh Basin specimens (moulds) have a less ventrally dropping lateral profile to the lateroventral lobal connection (terconmorphs) and crystatas (females). This and other minor morphological differences are judged to be of intraspecific significance.

*Distribution:* *F. groenvalliana* is considered generally indicative of early Pföldl Series (Upper Silurian) levels in an area extending from Podolia to eastern North America (Siveter 1989, 258-263, fig. 164). However, it should be noted that *F. groenvalliana* ("Iebiensis") and the key graptolite *Monograptus parultimus* Jaeger) for the base of the Pföldl in the Czechoslovakian stratotype area do not occur coevally in any of the relevant sections. *M. parultimus* and *F. groenvalliana* ("Iebiensis") occur geographically together only in the Dubovskoe borehole (Kaliningrad region; Kaljo & Sarv 1976), but at different horizons (Koressare horizon and the younger Aigu Member, Kaugatuma horizon respectively). As possibly indicated by conodont correlation (Schlönhoib, H.P. in: Ernst, J. et al., *Neu. Geol. Bundesanst.* 205, 1980) the Ludlow-Pfungd boundary may be slightly above the first occurrence of *F. groenvalliana* at Ludlow, Britain (i.e. may be in the Downton Group) and parts of the Baltic. Sweden: Gritsöll’s “Bed 3” and “Bed 3” at Elnita and Ramshka, Scania (Martinsson 1963, 1967); top part of Öved-Ramsåsa Group s.s. (Sver. geol. Unders. Arb., ser. C, no. 58, 1987).


East Baltic area: Oesuuare I borehole, Venekjula and Eige, Isle of Saaremaa, Estonia; Kaugatuma Formation (Sarv 1968, 1970, 1971). Piltene 1, 3, 12, Kolka 5, 14, Pavilosta 31, Ventrib 3, Tauti 33 and Ezere boreholes, Latvia; Minija and basal part of Jura formations (Gailite & Ulst 1974, Gailite 1978, 1979, Sarv 1982). Sontulki and Vidoska boreholes, Lithuania; Minija Formation (Sarv 1968, 1982). Borehole 110 of Arjogal profile, Lithuania; Minija Formation (Berdan 1983). Possibly also occurs in Stonehouse Formation, Nova Scotia, Canada (Martinsson *et al.*, *Jb. Geol. Bundesanst.* 201, 129, 1986) the Ludlow-Pfungd boundary may be slightly above the first occurrence of *F. groenvalliana* at Ludlow, Britain (i.e. may be in the Downton Group) and parts of the Baltic.


Poland: Borehole Lesa I (Martinsson 1964). Several boreholes of the Penbaltic area (cf. Tomczykowa & Witwicka 1974, 58); lowermost Podlazi.  


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