MICROFOSSIL DISTRIBUTION ACROSS THE BASE OF THE WENLOCK SERIES IN THE TYPE AREA

by J. E. MABILLARD *and* R. J. ALDRIDGE

ABSTRACT. Rich microfossil assemblages have been recovered from closely spaced samples collected from the uppermost Llandovery and lowermost Wenlock strata of the Wenlock Edge area. Large numbers of acritarchs, chitinozoans, conodonts, foraminiferans, ostracods, and other microfossils occur through the sampled sequence and provide a much better basis for correlation of the base of the Wenlock Series than can currently be achieved with macrofossil groups. The boundary cannot be shown to be coincident with the base of any biozone, but lies within the *amorphognathoides* conodont interval, between the base of acritarch zone 5 and the last occurrence of *Pterospathodus amorphognathoides*. At the stratotype locality for the base of the Wenlock Series, these horizons are separated by about 40 cm of strata. Elsewhere, the range of *P. amorphognathoides* encompasses much greater thicknesses of strata and, even using several fossil groups, the position of the boundary can only be broadly delimited.

IN 1971 the Stratigraphy Committee of the Geological Society of London established a working group to review the classification of the Wenlock Series of the Silurian System in the type area around Wenlock Edge, Shropshire. The results of this study (Bassett *et al.* 1975) included sections on lithostratigraphy, biostratigraphy, and chronostratigraphy. The revised chronostratigraphy, with the Wenlock Series divided into Sheinwoodian and Homerian Stages, was subsequently accepted by the Subcommission on Silurian Stratigraphy of the IUGS and the area is now ratified as the international type for the series (Holland 1980*a*, *b*). The base of the Wenlock Series was defined by Bassett *et al.* (1975, p. 13) at a standard section in Hughley Brook (NGR SO5688 9839), 200 m south-east of Leasows Farm (text-fig. 1).

In their consideration of the biostratigraphy of the Wenlock Series in the type area Bassett *et al.* (1975) concentrated on the graptolites, treating brachiopods and other macrofossils more briefly. They were able to establish the presence of graptolites through the succession, representing an almost complete zonal sequence from the late Llandovery *crenulata* Biozone to the late Wenlock *ludensis* Biozone. Although no graptolites were recorded from strata between 10 m below and 3·0–4·5 m above the Llandovery–Wenlock boundary, it has been assumed that the base of the *centrifugus* Biozone coincides with the base of the Wenlock Series (Holland 1980*a*).

Although microfossils were not considered in detail by Bassett *et al.* (1975), they noted the potential of several groups for correlation of the Wenlock Series and for recognition of the Llandovery-Wenlock boundary. Our sampling of the boundary beds has revealed extremely rich microfossil assemblages, and the purpose of this paper is to complement the data on macrofossils with detailed records of microfossil distribution in the uppermost Purple Shales and lowermost Buildwas Formation of the Wenlock type area. Our material is from two sections (text-fig. 1), the boundary stratotype near Leasows Farm and a parallel section in Harley Brook, near 'Domas' (NGR SJ5958 0077). These localities are numbers 25 and 24 of the Micropalaeontology Unit, Department of Geology, University of Nottingham.

At both localities, the lower Wenlock Buildwas Formation is conformable on the upper Llandovery Purple Shales. The boundary is not sharp, with a gradual lithological change apparent from the predominantly maroon mudstones and limestones of the Purple Shales to the calcareous, olive-grey, silty shales of the Buildwas Formation. At the Leasows section, the maroon colouration

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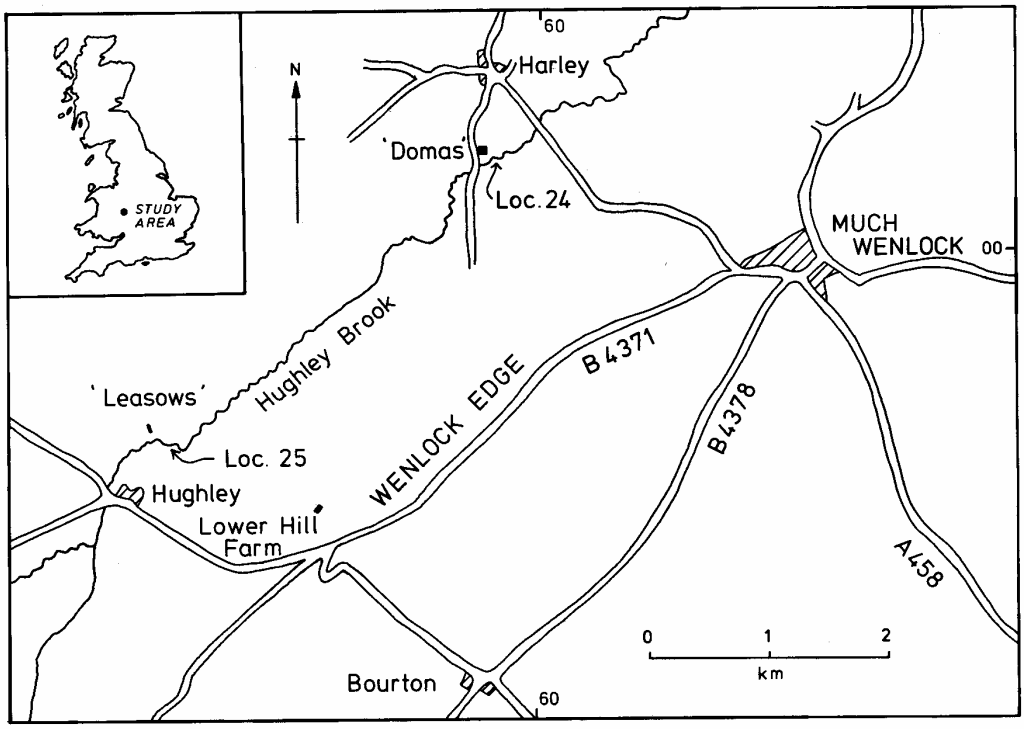


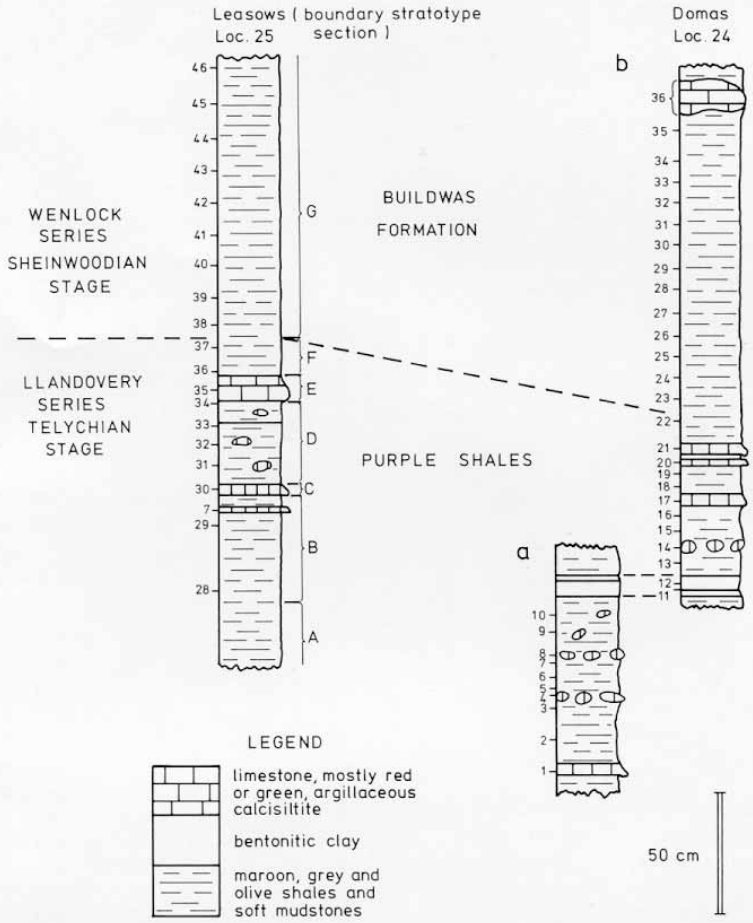
TEXT-FIG. 1. Localities of the sampled sections.

terminates fairly abruptly some 20 cm below the base of the Buildwas Formation, which, by definition, is also the base of the Wenlock Series. Macrofossils, particularly brachiopods, are common through the exposed sequence. The benthic macrofauna of the Purple Shales in the Wenlock Edge area is referable to the *Clorinda* or mixed *Clorinda–Costistricklandia* Community (Ziegler, Cocks and McKerrow 1968), and that of the Buildwas Formation to the *Dicoelosia biloba* Community (Hurst, Hancock and McKerrow 1978). Both formations appear to have been deposited in an open-marine, offshore shelf environment.

METHODS OF STUDY

Following reconnaissance sampling, a total of fifty-six samples was carefully collected 'bed-by-bed' from the two localities, with all lithologies represented (text-fig. 2). The mean sampling interval was less than 10 cm, and at each sampled horizon the smallest practicable thickness of sediment was removed.

Large numbers of microfossils were recovered from all samples except the probable bentonitic clay at 'Domas' (Sample 24/12). The standard sample weight processed for larger microfossils was 1 kg, except for samples 25/42–46, which weighed 500 gm. Shales were disaggregated using petroleum spirit followed by hot water, and limestones were digested with 10% acetic acid; all residues were washed through a 75 μm sieve. 'Heavy' and 'light' fractions of each residue were separated using bromoform; the heavy fraction, in which conodonts were concentrated, was picked completely, while a representative split of the larger light fraction was picked for other microfossils. Palynomorphs



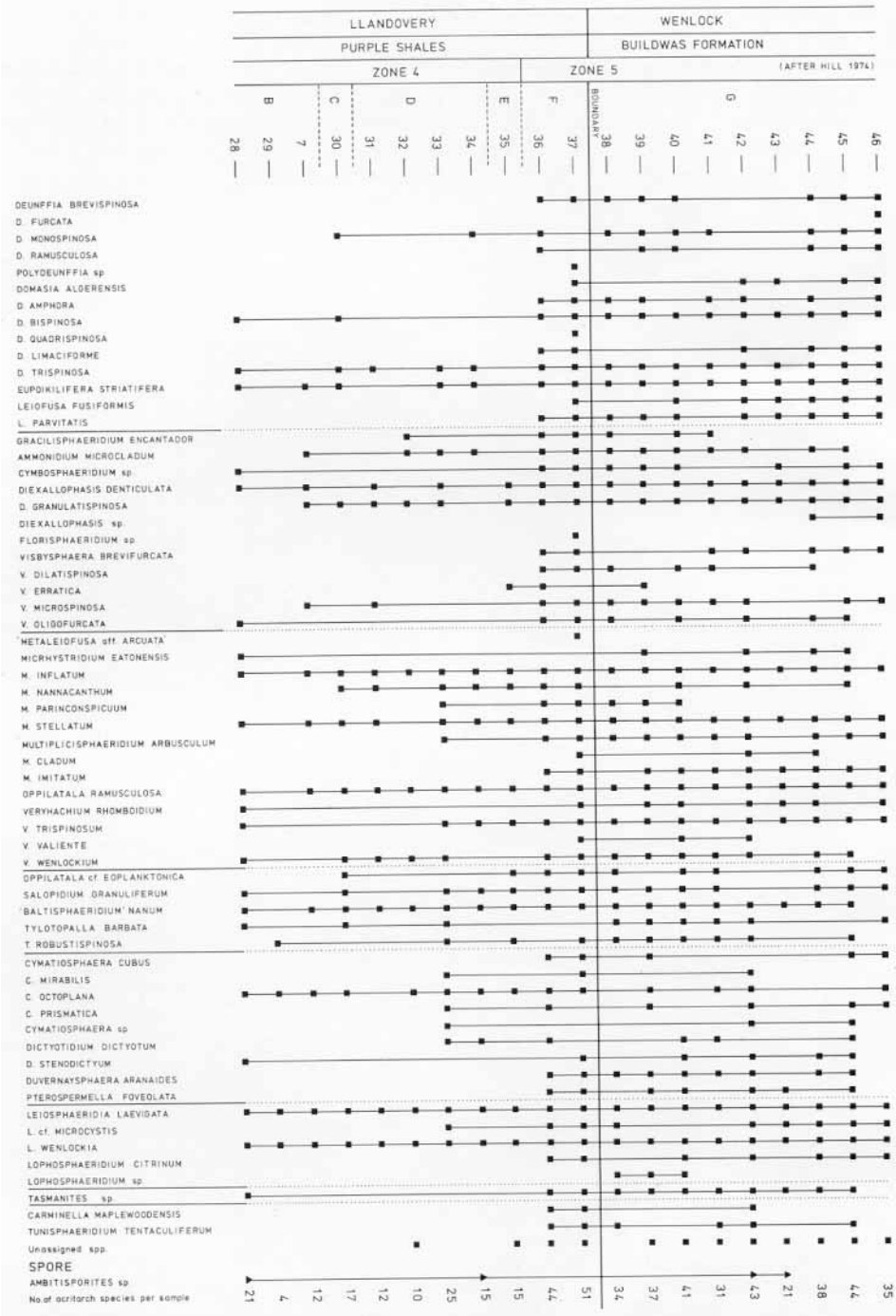
TEXT-FIG. 2. Measured sections at the two localities, showing sampled horizons. Units A–G at Leasows after Bassett *et al.* (1975, p. 13).

were extracted by preparation methods similar to those described by Neves and Dale (1963) and Sarjeant (1974).

MICROFOSSIL DISTRIBUTION

Acritarchs

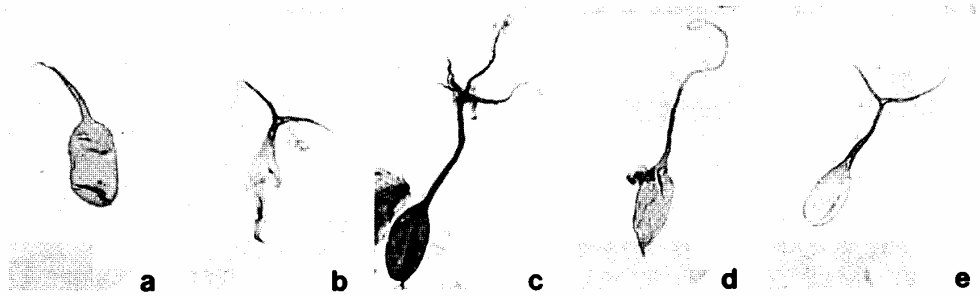
All palynological preparations from Leasows and Domas contain acritarchs (text-figs. 3, 4) which always form the greatest part of the assemblage. Chitinozoans, scolecodonts, melanosclerites, spores, organic linings of foraminiferal tests, fragments of graptolite theca, and structureless organic matter also occur in varying proportions. The preservation of acritarchs is good to excellent with body colour pale green to yellow, or brown in thicker-walled forms, which indicates a low thermal maturity. As most preparations contain many thousands of specimens no attempt was made to



TEXT-FIG. 3. Acritarch assemblages from the stratotype section for the base of the Wenlock Series at Leasows. For taxonomic comments and the authorship of most species see Dorning (1981*a*) and Aldridge *et al.* (1979).

determine absolute abundance. The relative proportions of species in preparations from the Purple Shales and Buildwas Formation have been documented by Hill (1974).

At Leasows, acritarchs are uncommon in the greater part of the Purple Shales (units B–E), particularly in the limestones. Assemblages from these lower, maroon-coloured units are dominated by thick walled sphaeromorphs such as *Leiosphaeridia wenlockia* Downie. In the uppermost Purple Shales (unit F) there is a significant increase in abundance and diversity which coincides with the lithological change to beds transitional to those of the overlying Buildwas Formation.



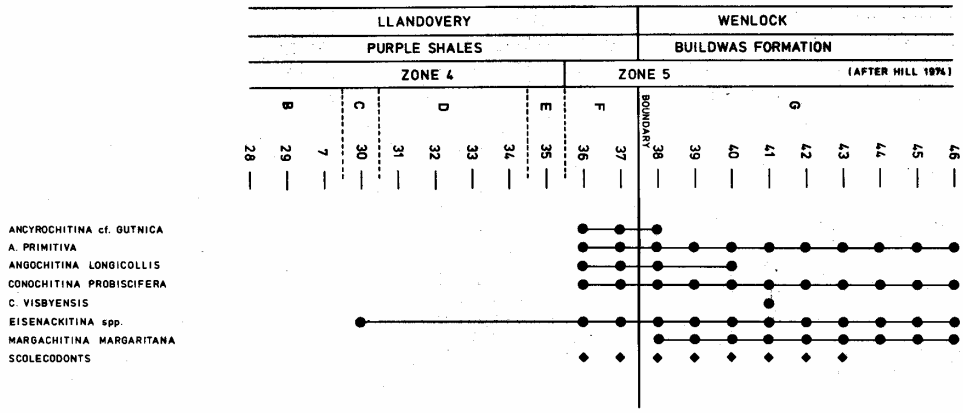
TEXT-FIG. 4. Some acritarch species of restricted stratigraphical distribution in the Llandovery–Wenlock boundary beds, all × 500. *a*, *Deunffia brevispinosa* Downie, sample 25/37, slide 15, co-ordinates Q36/4. *b*, *Domasia amphora* Martin, sample 24/19, slide 4, co-ordinates M35/4. *c*, *Deunffia ramusculosa* Downie, sample 25/36, slide 15, co-ordinates Q31/1. *d*, *D. monospinosa* var. *tonawadensis* Thusu, sample 25/46, slide 4, co-ordinates N49. *e*, *D. furcata* Downie, sample 25/46, slide 4, co-ordinates V51/3. All slides are stored in the collections of the Micropalaeontology Unit, Department of Geology, University of Nottingham.

Almost all of the sixty-two species and varieties of acritarch recorded from the type section have ranges that span the Llandovery-Wenlock boundary. However, the occurrence of stratigraphically restricted species of *Deunffia* and *Domasia* enables the application of the biozonation proposed for this interval by Hill (1974). *Deunffia brevispinosa* Downie, *D. ramusculosa* Downie, and *Domasia amphora* Martin, which appear in the uppermost Purple Shales (unit F), are diagnostic of acritarch zone 5 (Hill 1974). Assemblages from the underlying beds (units B–E) which lack these species, are assigned to zone 4. The base of zone 5 thus occurs about 15 cm below the base of the Wenlock Series in the Leasows section. Within the Buildwas Formation assemblages of zone 5 include *Deunffia monospinosa* var. *tonawadensis* Thusu and *D. furcata* Downie, which is abundant at the top of the section.

Assemblages from the Purple Shales and Buildwas Formation at Domas are almost identical to those from Leasows. Species diagnostic of zone 5 first appear in sample 24/18, although *D. furcata* has not been recorded.

Chitinozoans

With the exception of two specimens of *Eisenackitina* recorded from unit C, chitinozoans occur only in units F and G of the type section (text-fig. 5). Specimens are dark brown to black, compressed, but with appendages well preserved. Most of the recorded species have ranges known to traverse the Llandovery-Wenlock boundary (Aldridge *et al.* 1979; Jenkins and Legault 1979). *Conochitina visbyensis* Laufeld and a number of specimens similar to *Linochitina cingulata* (Eisenack) were found only in the Buildwas Formation. Similar assemblages, with *Eisenackitina* spp., *Sphaerochitina* spp., and *C. probiscifera* Eisenack common, occur at Domas.



TEXT-FIG. 5. Chitinozoan distribution in samples from the stratotype section for the base of the Wenlock Series at Leasows. For the authorship of species see Dorning (1981*b*).

	LLANDOVERY											WENLOCK								
	PURPLE SHALES											BUILDWAS FORMATION								
	B			C	D				E	F		G								
	28	29	7	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
DAPSILODUS OBLIQUICOSTATUS	3	1			6	6	34	9	5	54	15	32	25	11	45	4	3	1	7	15
DECORICONUS FRAGILIS	6	2	3	18	115	67	213	74	37	199	256	256	176	163	197	27	46	7	2	113
PANDERODUS cf. RECURVATUS	42	10	3	48	185	76	174	54	29	156	127	249	18							
P. LANGKAWIENSIS	25		1	38	127	52	140	53	11	106	73	222	26							
P. UNICOSTATUS	224	90	351	127	131	102	127	67	22	138	473	503	198	79	130	15	25	6	3	3
PANDERODUS spp.	2	2		9	27	18	27	9	6	13	2	7				2	2			
PSEUDOONEOTODUS BECKMANNI	27	1	42	5	12	5	25	13	7	19	48	10	4	11	5		2			4
P. BICORNIS				11	11	8	29	15	7	6	104	12	7	6	8	2	1	4	3	4
P. TRICORNIS	10	13	70	3	19	6	10	3	3	3	16	1								
WALLISERODUS cf. CURVATUS		2	9	3	15		25	6	1	32	18	23	17	13	15	2	3	1		
CARNIODUS CARNULUS	53	26	68	46	130	171	341	224	134	213	291	22	7							
DISTOMODUS STAUROGNATHOIDES	4	1	31	15	8	7	11	4	5	6	65	12	1							
JOHNOGNATHUS HUDDLEI			3	2	4			1	2	1	6									
KOCKELELLA RANULIFORMIS	1	1			2				1	8	2	3								
OULODUS PETILA			5																	
OULODUS sp.	5	3	11		1	2			1	1	6	3								
OZARKODINA EXCAVATA	3		5	6	10		11	11	7	18	43	32	9	11	5			3		2
PTEROSPATHODUS CELLONI	51	22	54																	
P. AMORPHOGNATHOIDES				25	134	66	84	64	26	51	153	91	31	6						
P. PENNATUS (Pa. element)		2	13																	
No. of species per sample	14	14	15	14	17	13	14	15	17	17	17	16	12	8	7	6	7	6	4	6

TEXT-FIG. 6. Conodont distribution in samples from the stratotype section for the base of the Wenlock Series at Leasows. All species are multi-element and the numbers given are totals for all elements of each apparatus.

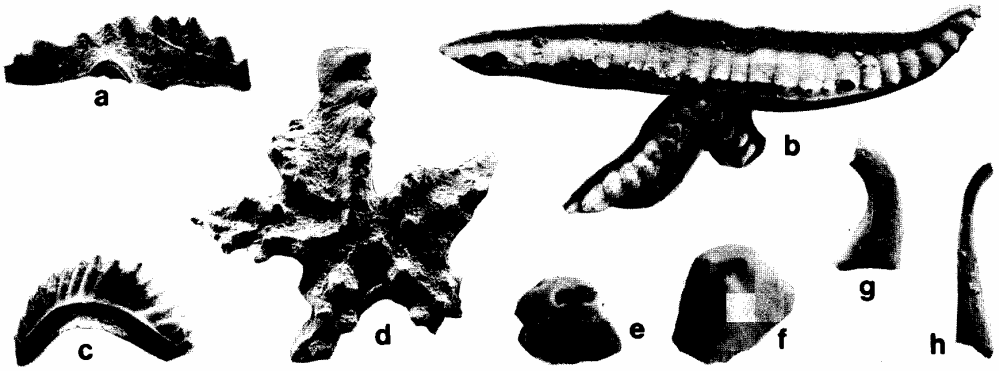
Conodonts

Conodonts were recovered from all lithologies represented in the type section (text-figs. 6, 7). Preservation is good, with discrete elements pale to dark amber in colour. Abundance is moderate to high in the Purple Shales, but falls sharply in the basal Buildwas Formation. More than 18,000 specimens belonging to twenty-one multielement species were examined from Leasows.

Diverse assemblages from the lower beds of the type section (unit B) are characterized by *P. celloni* (Walliser) and *P. pennatus* (Walliser), and are referable to the *celloni* Biozone (Walliser 1964). *P. amorphognathoides* Walliser first appears in sample 25/30 and is the diagnostic species in conodont collections from the uppermost Purple Shales and lowermost Buildwas Formation (unit C to unit G, sample 25/40). The range of *P. amorphognathoides* defines an *amorphognathoides* interval (Aldridge and Mabillard 1981) which may not be fully equivalent to the *amorphognathoides* Biozone defined by Walliser (1964) as the eponymous species of his succeeding zone, *Kockelella patula* Walliser, has not yet been found in Britain. Along with *P. amorphognathoides*, several other species disappear within the lowest beds of the Buildwas Formation, including *Carniodus carnulus* Walliser, *Distomodus staurognathoides* (Walliser), *Panderodus langkawiensis* (Igo and Koike), *P.* cf. *recurvatus* (Rhodes), and *Pseudooneotodus tricornis* Drygant. The succeeding beds bear a considerably diminished fauna, almost exclusively composed of coniform elements, with no additional species making their debut.

The lowest beds exposed at Domas contain conodont faunas with *Pterospathodus amorphognathoides*, and the *celloni* Biozone has not been recognized in the river cliff nor in adjacent strata in the stream bed. *P. amorphognathoides* occurs throughout the Purple Shales and, along with its characteristic associates, is absent in beds of the Buildwas Formation above sample 24/38. The collections from Domas, which contain in excess of 22,000 specimens, are directly comparable in composition with those recognized at Leasows.

We have also examined conodont specimens from samples of the Lower Hill Farm Borehole core, sunk by the Institute of Geological Sciences in 1973 at SO5817 9788, on the outcrop of the Coalbrookdale Formation (see Bassett *et al.* 1975, pp. 4–6). The top of the *amorphognathoides* interval can be recognized at a depth of 239·14 m and the base at 242·21 m; samples from the Purple



TEXT-FIG. 7. Representative elements of some conodont species with restricted stratigraphical ranges in the Llandovery–Wenlock boundary beds, all × 40. *a*, *Pterospathodus celloni* (Walliser), lateral view of Pa element, sample 25/29, BM × 1055. *b*, *P. amorphognathoides* Walliser, upper view of Pa element, sample 24/20, BM × 1056. *c*, *Carniodus carnulus* Walliser, lateral view of Pb? element, sample 24/20, BM × 1057. *d*, *Distomodus staurognathoides* (Walliser), upper view of Pa element, sample 25/7, BM × 1058. *e*, *Pseudooneotodus bicornis* Drygant, upper view of two-tipped, squat, conical element, sample 25/45, BM × 1059. *f*, *P. tricornis* Drygant, upper view of three-tipped, squat, conical element, sample 25/7, BM × 1060. *g*, *Panderodus* cf. P. *recurvatus* (Rhodes), lateral view, sample 25/31, BM × 1061. h, *P. langkawiensis* Igo and Koike, lateral view, sample 25/6, BM × 1062. (All specimens housed in the collections of the British Musuem (Natural History).)

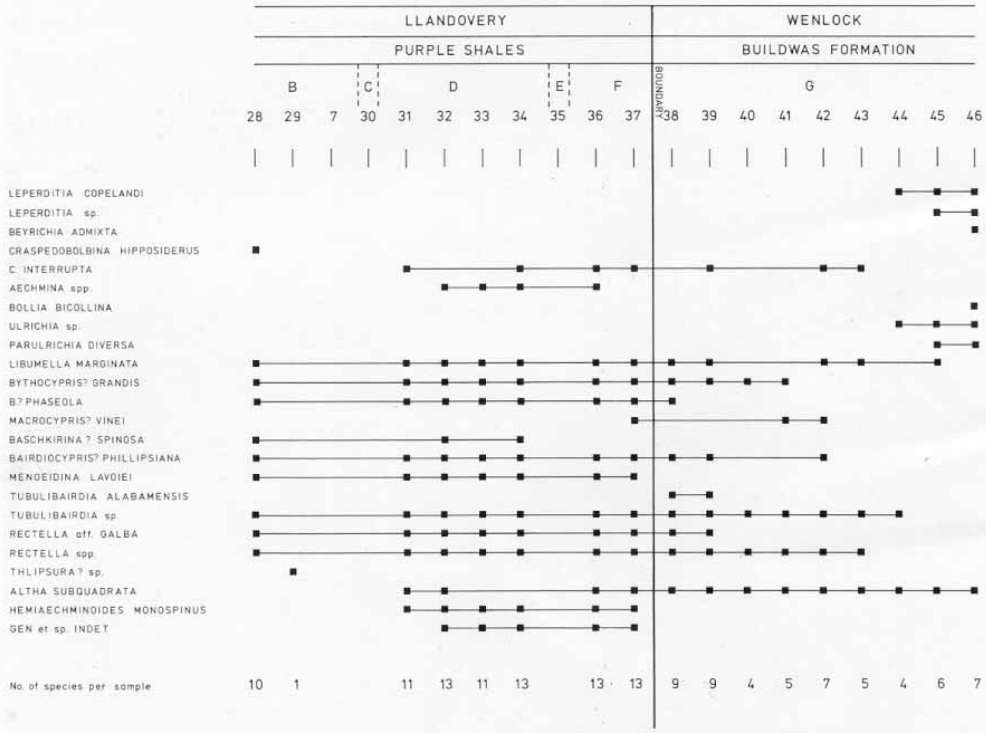
Shales below this contain *P. celloni*. The base of the Buildwas Formation in the core was recorded at 239·69 m by Bassett *et al.* (1975, p. 13).

'*Conodont Pearls*'

Large numbers (more than 8,000 specimens) of small, concentrically laminated, transparent or opaque phosphatic spheres, suspected to be conodont pearls (Glenister *et al.* 1976), were recovered from the Purple Shales (units B–F). In contrast, only sixty-four specimens were recorded from the Buildwas Formation (sample 25/38 at the base of unit G). The decrease in abundance and disappearance of conodont pearls coincides with the disappearance, and possible extinction, of several conodont species. Similar distributions occur at Domas.

Foraminifera

The large numbers of foraminiferans recovered from limestones and shales of the Leasows and Domas sections have been discussed in detail elsewhere (Mabillard and Aldridge 1982). Assemblages from the Purple Shales are dominated by *Ammodiscus exsertus* Cushman, with *Hyperammina* spp., *Webbinelloidea tholus* (Moreman), *Psammosphaera cava* Moreman, and *Hemisphaerammina* sp., and rare *Thurammina irregularis* Moreman and *Turritellella workmani* Dunn. In the basal 20 cm of the Buildwas Formation a faunal change to assemblages of small numbers dominated by *Hyperammina* spp., *Lagenammina* sp., and *Lituotuba* sp. takes place.



TEXT-FIG. 8. Ostracod distribution in samples from the stratotype section for the base of the Wenlock Series at Leasows.

Ostracods

Large numbers of well-preserved ostracods, occurring as carapaces and isolated valves, were recovered from the washings of mudstone samples from both sections (text-figs. 8,9). Limestones contain similar assemblages to adjacent argillaceous beds, but specimens are more difficult to extract and were not examined in detail. Samples from Leasows yielded more than 7,000 specimens

TEXT-FIG. 9. Some ostracod species of restricted stratigraphical distribution in the Llandovery–Wenlock boundary beds. *a*, *Craspedobolbina hipposiderus* Siveter, lateral view of broken left valve, sample 25/28, BM OS12315, ×30. *b*, *Ulrichia* sp., right lateral view, sample 25/46, BM OS12316, ×40. *c*, *Parulrichia diversa* (Jones and Holl), lateral view of right valve, sample 25/46, BM OS12317, ×50. *d*, *C. interrupta* (Jones), left lateral view of female, sample 25/10, BM OS12318, ×30. *e*, *Menoeidina lavoiei* Copeland, dorsal view, sample 25/32, BM OS12319, ×40. *f*, *Rectella* aff. *R. galba* Neckaja, right lateral view, sample 25/34, BM OS12320, ×40. *g*, *Beyrichia admixta* Jones and Holl, left lateral view, sample 25/46, BM OS12321, ×40. *h*, *Bollia bicollina* Jones and Holl, left lateral view, sample 25/46, BM OS12322, ×45. *i*. *Leperditia copelandi* Lundin, sample 25/46, BM OS12323, ×45. (All specimens housed in the collections of the British Museum (Natural History).)

belonging to more than twenty-five species. Abundance is moderate to high in the Purple Shales, becoming moderate to low in the Buildwas Formation.

At Leasows, assemblages from the Purple Shales (units B–F) are dominated by metacopes, particularly species of *Tubulibairdia*. Palaeocopes are represented almost exclusively by *Libumella marginata* Copeland, an oepikellacean. The lowest beds (unit B) are characterized by *Craspedobolbina hipposiderus* Siveter which, together with *Menoeidina lavoiei* Copeland, *Baschkirina*? *spinosa* Copeland, and *Hemiaechminoides monospinus* Morris and Hill, is confined to the Purple Shales. *C. interrupta* (Jones), which is present in the uppermost Purple Shales (unit F), ranges into the Wenlock and is a characteristic component of assemblages in the lowest beds of the Buildwas Formation. Within the basal 70 cm of the Buildwas Formation *Rectella* aff. *galba* Neckaja and other species of *Rectella* disappear. *Bythocypris*? *grandis* (Jones and Holl), *B*? *phaseola* Jones, *Bairdiocypris*? *phillipsiana* (Jones and Holl), *Tubulibairdia* and further species of *Rectella* are also lost, but are known to occur at higher levels in the Wenlock of the type area (Petersen 1975). *T. alabamensis* Lundin is present just above the Llandovery–Wenlock boundary and *Macrocypris*? *vinei* Jones appears slightly higher in the Buildwas Formation. In the highest beds at Leasows, assemblages dominated by *Altha subquadrata* Jones are also characterized by the appearance of *Bollia bicollina* Jones and Holl, *Parulrichia diversa* (Jones and Holl), *Beyrichia admixta* Jones and Holl, *Leperditia copelandi* Lundin, and undescribed species of *Leperditia s.l.* and of *Ulrichia s.l.*

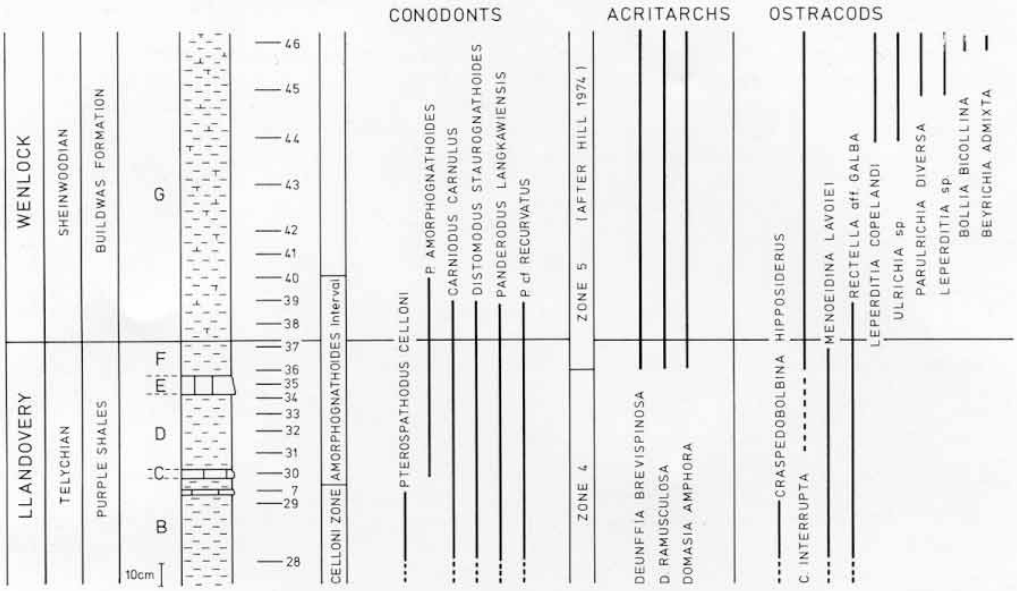
Ostracod collections from Domas comprise more than 12,000 specimens. The assemblages from the Purple Shales are comparable with those from Leasows, but *C. hipposiderus* has not been recognized. The assemblages identified in the lowermost Buildwas Formation at Leasows are also present at Domas, but the palaeocope fauna that characterizes the uppermost beds collected in the type section is not represented in the Domas exposure.

BIOSTRATIGRAPHY

Several species of acritarchs, conodonts, and ostracods have stratigraphically restricted distributions in the sections studied and are of value in delimiting the base of the Wenlock Series (text-fig. 10). The acritarchs *Deunffia brevispinosa*, *D. ramusculosa*, and *Domasia amphora* appear in uppermost Llandovery strata (unit F at Leasows), with their stratigraphic base in the type area coincident with a change in lithofacies that may offer an improved potential for preservation. However, their ranges also begin within the *amorphognathoides* conodont interval elsewhere in the Welsh Borderland, and they seem to offer a good basis for correlation. Conodont faunas do not appear to have been affected by the lithofacies changes in the latest Llandovery, and the base of the *amorphognathoides* biozone, recognized at 65 cm below the base of the Wenlock at Leasows, provides an excellent datum for correlation. The local extinction of *Pterospathodus amorphognathoides*, 30 cm above the base of the Wenlock at Leasows, may be a less reliable event, but the disappearance of this species along with several others in the lowest Wenlock is widely recognized (Aldridge 1976).

Several ostracod species have apparently restricted distributions in the type area, but most are undescribed or poorly known and their biostratigraphical value cannot be assessed. Palaeocope species, especially of the genus *Craspedobolbina*, are the most useful, with *C. hipposiderus* occurring in the lower beds (unit B) at Leasows, succeeded by *C. interrupta*, which spans the Llandovery–Wenlock boundary. *Parulrichia diversa*, *Bollia bicollina*, and *Beyrichia admixta* are known only from the Wenlock (Siveter 1978).

The base of the Wenlock Series at Leasows cannot so far be shown to be coincident with the base of any biozone, microfossil or macrofossil, and its position in other sections can only be assessed through establishing the local ranges of species known to be of restricted distribution in the type area. It is wise to use information from as many groups as possible, but at present a combination of acritarch and conodont ranges provides the best basis for correlation. Thus, the Llandovery–Wenlock boundary lies within the *amorphognathoides* conodont interval, between the base of acritarch zone 5 and the disappearance of *Pterospathodus amorphognathoides*; these horizons are separated by approximately 40 cm of strata in the type section. At Domas, in the type area, the same interval is



TEXT-FIG. 10. Ranges at Leasows of selected microfossil taxa of value in correlating the base of the Wenlock Series.

represented by approximately 90 cm of strata. On a somewhat broader scale, conodonts alone allow a guide to correlation, with the *amorphognathoides* interval spanning the Llandovery–Wenlock boundary and restricted to a thickness of 95 cm of strata in the type section. It is important to note, however, that this interval is represented in much greater thicknesses elsewhere. At Domas, only 4 km from Leasows, the base of the *amorphognathoides* biozone is not exposed but the species ranges through 2 m of the available section, and in the Lower Hill Farm Borehole, little more than 1 km from Leasows, the stratigraphical thickness representing the *amorphognathoides* interval is approximately 3 m. In the Coralliferous Group of Marloes Bay, south-west Dyfed, Wales, the *amorphognathoides* interval occupies at least 40 m of strata (Mabillard and Aldridge 1983) and in the Ringerike District of the Oslo Region, Norway, it occurs through 30 m (Worsley *et al.* 1983). Thus, in areas of rapid sedimentation, it may only be possible to delimit the base of the Wenlock rather broadly even when several fossil groups are taken into account. However, determinations may be improved somewhat when macrofossil distributions in the type section have been documented in the same detail as we have provided for the microfossils.

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JOHN E. MABILLARD
Petroleum Development Oman, P.O. Box 81
Muscat, Sultanate of Oman

RICHARD J. ALDRIDGE
Department of Geology, The University,
Nottingham NG7 2RD

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