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The biostratigraphy of the Upper Pliensbachian–Toarcian (Lower Jurassic) sequence at Ilminster, Somerset

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ABSTRACT – Temporary road sections for the A303 bypass at Ilminster, Somerset, revealed Upper Pliensbachian and Toarcian sediments from an alternating limestone–marl facies, in marked contrast to the limestone-dominated Dorset coast succession. The lithostratigraphy is described, with the standard ammonite zonation providing chronostratigraphical correlation. The uppermost Pliensbachian (Spinatum Chronozone) and much of the Toarcian (Serpentinum, Bifrons, Variabilis, Thouarsense and Pseudora-diosa chronozones) of the classic Dorset coast Lower Jurassic sequence are represented by the Beacon Limestone Formation, formerly the 'Junction Bed' (a highly condensed carbonate deposit). The Tenuicostatum Chronozone is largely missing from the sequence. Elsewhere in southern and eastern England this interval is poorly or rarely exposed. The argillaceous units have yielded rich microfaunas and -floras (foraminifera, ostracods, calcareous nannofossils and palynomorphs), the biostratigraphical distributions of which are analysed and discussed in relation to contemporary evolutionary patterns and other UK records. This study provides an insight into the micro-biostratigraphy of the Late Pliensbachian to Toarcian interval for onshore southern England. *J. Micropalaeontol.* **28**(1): 67–85, May 2009.

KEYWORDS: *Pliensbachian–Toarcian, Ostracoda, Foraminifera, palynology, nannofossils*

INTRODUCTION

In 1987, roadworks near Seavington St Michael, in connection with the construction of the A303 Ilminster bypass (Fig. 1), created new exposures of the Beacon Limestone Formation, providing an opportunity to study and sample this generally poorly exposed unit. In contrast with earlier studies of the Beacon Limestone Formation, these sections were the subject of detailed micropalaeontological sampling. Preliminary studies of the bypass site commenced in connection with a joint archaeological and geological survey co-ordinated by Mr R. A. Croft (Somerset County Council). By early 1988, however, little exposure remained, and the sections described in Appendix A herein had been largely covered by soil and seeded. A small

exposure of the succession was, however, left clear and remained only poorly visible in 1999. The former exposures are described in detail in Appendix A; their location is shown in Figure 1, while Figure 2 illustrates the sedimentary record of the two sections sampled at Ilminster. The sequence is clearly condensed and the ammonite evidence for the Tenuicostatum Chronozone suggests that it is, at best, highly condensed and there may be breaks in sedimentation within the earliest Toarcian horizons.

The occurrence of ostracods from this section was published previously separately (Boomer, 1992), while Bown & Cooper (1989) made taxonomic observations on some of the calcareous nannofossils recorded at Ilminster. This is the first attempt to synthesize microfaunal events and biostratigraphy in this sequence.
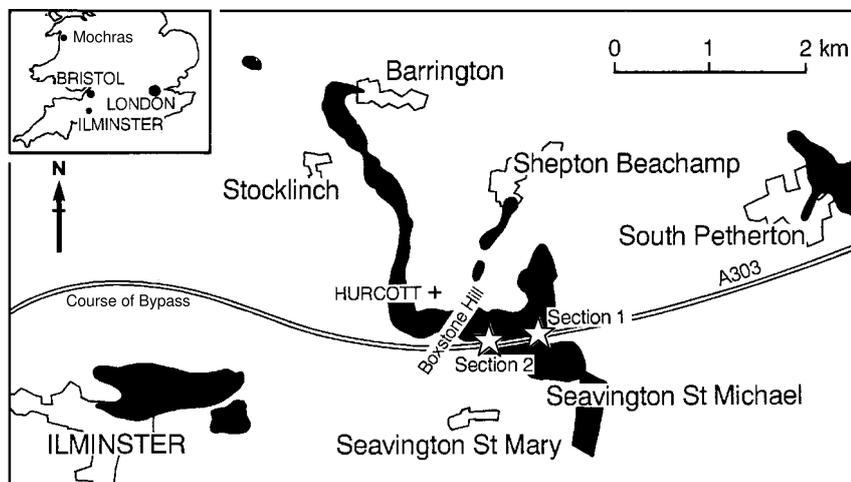

Fig. 1. Location map of the Ilminster exposures (in black), key sections marked by stars.
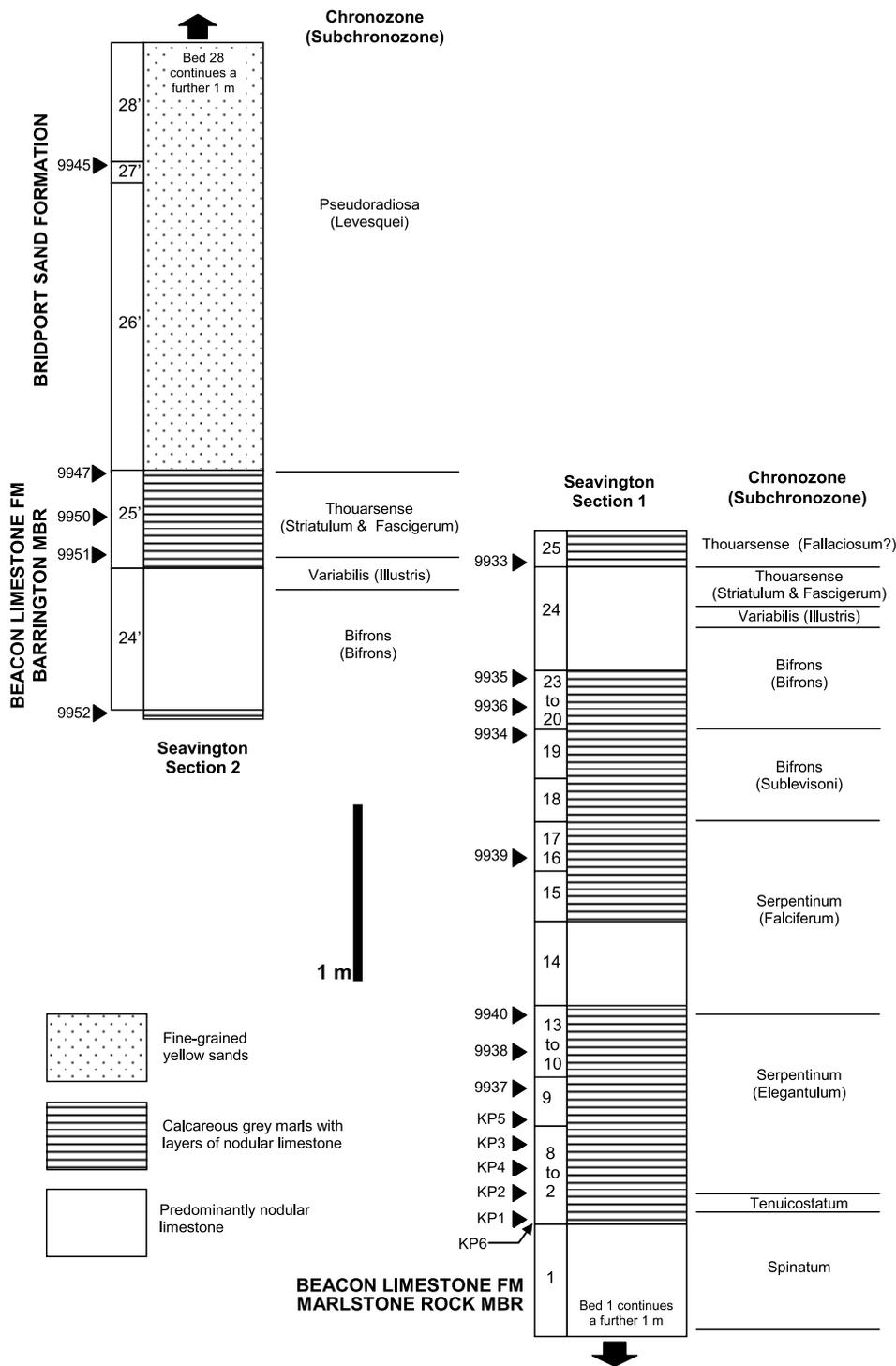
Fig. 2. Lithology, ammonite biostratigraphy and sampled levels from the Barrington and Seavington composite sections.

HISTORY OF RESEARCH IN THE ILMINSTER DISTRICT

The 'Middle' and 'Upper Lias' Junction Bed in Somerset (now formalized as the Beacon Limestone Formation, Table 1, (Cox *et al.*, 1999) has long been known as a rich source of fossils. In particular, ammonites and brachiopods are abundant, and also well-preserved vertebrate and insect remains are also known. In

addition, a rich microfauna and -flora have now been recovered. A local collector, Charles Moore, amassed a large representative collection of fossils, which are now housed in the Bath Geology Museum. He described the rocks of the small building-stone quarries surrounding the town of Ilminster and his publications are now classic (Moore, 1853, 1866). An associate, H. B. Brady, studied the foraminifera Moore had obtained and published an

Formation		Member		
Toarcian	Bridport Sand Fm			Studied interval
		Down Cliff Clay Mbr		
	Beacon Limestone Fm	Eype Mouth Limestone Mbr (South Dorset)	Barrington Mbr (North Dorset & Somerset)	
Pliensbachian		Marlstone Rock Mbr		
	Dyrham Fm	Thorncombe Sand Mbr		
		Down Cliff Sand Mbr		
		Eype Sand Mbr		

Table 1. Lithostratigraphy of the late Pliensbachian to Toarcian interval in SW England.

important early work (Brady, 1867; with a preliminary note in 1865, Brady's foraminiferal collection is now housed in Charles Moore's collection at the Bath Museum (P. Copestake, pers. comm.).

Much later, excavations associated with farm buildings at Barrington, northeast of Ilminster, created renewed interest in the 'Junction Bed'; not least because 'upwards of 1000 specimens' had been collected (Hamlet, 1922; Pringle & Templeman in Buckman, 1922). Spath had also recorded adjacent localities (in Buckman, 1922), but these sites and those at Barrington were largely obscured by the time the Geological Survey remapped the area between 1931 and 1946. The related memoir nevertheless contains the best summary of relatively recent exposures (Wilson et al., 1958). Since then it appears that only one other complete section has been seen, in a reservoir excavation near Stocklinch (Howarth in Cope et al., 1980: 54). The same work also provides a chronostratigraphical correlation of the Pliensbachian and Toarcian parts of the 'Junction Bed'. The Barrington section was reviewed by Howarth (1992) and elements of the ammonite fauna were figured in the associated monograph.

LITHOSTRATIGRAPHY
The 'Middle' and 'Upper Lias' Junction Bed (sensu Wilson et al., 1958, after Woodward, 1887) in Dorset and Somerset was consolidated into a single formation by Cox et al. (1999): the Beacon Limestone Formation (with the type section designated as Thorncombe Beacon on the Dorset Coast). The formation comprises two distinct units. The lower member, termed the 'Marlstone' by Moore (1853; after Wm Smith, 1817) and stabilized by Cox et al. (1999) as the Marlstone Rock Member, comprises calcarenitic bioclastic limestones, with occasional lenses of sandy or calcarenitic marl. In south Dorset this unit is rarely more than 0.6 m thick (Howarth in Cope et al., 1980, Column P1), but thickens locally to around 6 m in the Ilminster district (Howarth in Cope et al., 1980, Column P2).

The Marlstone Rock Member is overlain, in south Dorset, by between 0.5 m and 2.6 m of micritic limestones with occasional marl beds (Howarth in Cope et al., 1980, Column Tl – the Eype Mouth Limestone Member of Cox et al. (1999). The clay content increases northwards and, in the Ilminster district, the upper sedimentary sequence is typified by an alternation of argillaceous, often concretionary, limestones and marls, varying

between 0.5 m and 2.6 m in thickness (Howarth in Cope et al., 1980, Column T2; Table 1, this work). Buckman (1922: 45) termed these the 'Barrington Beds' and Cox et al. (1999) proposed the Barrington Member, after Bristow & Westhead (1993). It is these interbedded marls and argillaceous limestones that are the focus of this paper.

The macrofauna of the Marlstone Rock Member is often abundant, and dominated by benthic fauna, especially brachiopods and bivalves. Belemnites are common at certain levels, whereas ammonites are rare. Where lithologies are suitable, rich assemblages of ostracods, foraminifera and calcareous nannofossils were recovered. In contrast, the Barrington Member yielded very abundant pelagic biotas, while benthic macrofaunas are generally uncommon. The former are dominated by ammonites, belemnites and calcareous nannofossils, while the latter include occasional brachiopods, bivalves, gastropods, crinoid fragments and ophiuroid ossicles. The most common remains are the spines and other fragments of echinoids. The benthic microfauna is, nevertheless, abundant and consists of abundant, diverse ostracods and foraminifera.

In Somerset and Dorset, frequent evidence of erosion within the Barrington Member includes intraclasts and derived, worn and planed-through ammonites (as noted by Hallam, 1967). Ferruginous and/or glauconitic staining is common, especially in West Dorset, where there is a remarkable lithological similarity to the Ammonitico Rosso of southern Europe (Hallam, 1967).

CHRONOSTRATIGRAPHY AND STANDARD ZONATION (KNP)
Although still in frequent use in Britain (e.g. Howarth, 1992; Callomon & Cope, 1995), the standard ammonite zonation proposed by Howarth in Dean et al. (1961) and later used with modifications by the same author in Cope et al. (1980, 1992) has been superseded. Considerable recent work, particularly in France, Spain, Portugal and Germany, has facilitated the refinement of earlier schemes and the zonation described by Elmi et al. (1997) for the North West European Ammonoid Province (sensu Page, 1996) is therefore employed here, as reviewed by Page (2003). As discussed extensively elsewhere (e.g. Callomon, 1985; Page, 1995, 2003), Jurassic ammonite zones are chronozones, not biozones, and are used in this sense herein and are so-labelled to avoid ambiguity. Representative collections were deposited in the Somerset County Museum.

(a) Upper Pliensbachian Stage – **Spinatum Chronozone** (Seavington section 1, beds 1–2; Barrington, Seavington Marlstone Rock Member, including Bed 1 (part), see Figure 2. The entire Marlstone Rock Member can be assigned to the Spinatum Chronozone, as *Pleuroceras* was recovered from the basal surface of Bed 1. *In situ* evidence suggests that the Apyrenum Subchronozone includes virtually the entire Bed 1, at least up to within 10–15 cm of the top; *P. solare* (Phillips) is present at this level. Additional records from this subchronozone include *P. gigas* Howarth (from *in situ* and loose specimens of the subchronozonal index, *P. apyrenum* (Buckman), itself). That the top of Bed 1 includes part of the Hawskerense Subchronozone is indicated by specimens of *P. spinatum* (Bruguière) and *P.* cf. *hawskerense* (Young & Bird), both collected as loose specimens. Two other rare taxa were obtained from loose blocks of Bed 1, but it is not known precisely from which subchronozone they came. These two specimens are identified as *Lioceratoides* cf. *serotinus* (Bettoni) and *Leptaleoceras leptum* Buckman. The latter is now unique in Britain, the type and two paratypes of the species having been destroyed. This specimen has now been described and figured by Howarth (1992, p. 163–164, pl. 30, fig. 3).

(b) Lower Toarcian – **Tenuicostatum Chronozone** (Seavington section 1, Bed 3; Barrington, Bed 1 (part)–Bed 2). Although no positive identifications were possible, the poorly preserved dactylioceratids of Bed 3 include fine-ribbed forms comparable to the Tenuicostatum Chronozone species. A specimen of *Tiltoniceras* sp., collected from a loose block, supports an upper Semicelatum (II) Subchronozone age for Seavington Bed 3 (equivalent to the Semicelatum (I) Subchronozone of Subboreal areas: see Page, 1996, fig. 6). A similar age was suggested for Bed 2 at Barrington (=Howarth in Cope *et. al.*, 1980 column T2). It would appear that the Tenuicostatum Chronozone is, therefore, either absent (represented by only a few reworked specimens) or highly condensed at Ilminster. Unfortunately no sediment samples were recovered from these intervals, making it impossible to confirm the age through micro-biostratigraphy.

(c) Lower Toarcian – **Serpentinum Chronozone, Elegantulum Subchronozone** (Seavington section 1, beds 4–12; Barrington, beds 3–11). The most abundant elements of the Elegantulum Subchronozone faunas at Seavington comprise macro- and microconchs of *Harpoceras* ex gr. *serpentinum* (Schlotheim). Dactylioceratids are common at certain levels; however, *Cleviceras exaratum* (Young & Bird) is rare and known only from two loose specimens. No ammonites are known from Seavington section 1, beds 4 and 5; these levels are provisionally included in the Exaratum Subchronozone, and may represent parts of the subchronozone apparently absent at Seavington but present at Barrington (i.e. Bed 3, the 'Leptaena Clay', and Bed 4, the 'Fish Bed').

(d) Lower Toarcian – **Serpentinum Chronozone, Falciferum Subchronozone**, (Seavington section 1, beds 13–16; Barrington beds 12–23). Dimorphic *Harpoceras* ex gr. *falciferum* (J. Sowerby) is abundant and characteristic microconchs including '*H. exiguum*' (Buckman, 1928). Dactylioceratids are frequent, and are dimorphic, with macroconchs assignable to the morphogenus *Nodicoeloceras* (Buckman) and microconchs being typical *Dactylioceras* spp. Occasional *Hildaites* cf. *levisoni* (Simpson) are also present.

(e) Middle Toarcian – **Bifrons Chronozone, Sublevisoni Subchronozone** (Seavington section 1, beds 17–19; Barrington, beds 24–26). The lower part of this subchronozone (beds 17–18) yields an abundant and distinct fauna, dominated by *Hildoceras* ex gr. *sublevisoni* Fucini, nodose dactylioceratids ('*Nodicoeloceras*' spp.) and common *Dactylioceras sensu stricto*. Rare specimens of *Harpoceras* aff. *falciferum* and a single *Ovaticeras ovatum* (Young & Bird) were also recovered. The latter species had not previously been recorded south of the Midlands (i.e. Oxfordshire and Northamptonshire, etc.), but is common in North Yorkshire (Howarth, 1992; Page, 2004). The specimen of *Ovaticeras ovatum* was described and figured by Howarth (1992, p. 142–143, pl. 23, fig. 4). The higher part of the subchronozone contains abundant, but small (*c*. 1–2 cm) *Dactylioceras* ex gr. *commune* (J. Sowerby) and rarer *Hildoceras* (including *H.* cf. *lusitanicum* Meister), *Harpoceras* and a lytoceratid. The Sublevisoni, Tethysi and Lusitanicum horizons (= zonules *sensu* Page, 1995) of the subchronozone of Elmi *et al.* (1997) are probably present, but are not yet clearly separable at Ilminster.

(f) Middle Toarcian – **Bifrons Chronozone, Bifrons Subchronozone** (Seavington section 1, beds 20–24, to 45 cm below top; Seavington section 2, Bed 24', lowest 75 cm; Barrington, Bed 27, lower part). The upper beds yield abundant *Dactylioceras*, marls and an intraclastic pebble bed are recorded with occasional *Hildoceras* ex gr. *bifrons* (Bruguière), suggesting the Bifrons Horizon of Elmi *et al.* (1997). The basal horizon of this subchronozone, with *H. apertum* (Gabilly), is not yet proven at Seavington. The almost total absence of post-Sublevisoni Subchronozone dactylioceratids in Somerset is noteworthy; in southern England *Hildoceras* spp. dominate the assemblages, whereas in North Yorkshire the dactylioceratids *Zugodactylites, Peronoceras* and *Catacoeloceras* are frequently the commonest ammonites (Page, 2004). *Peronoceras* and *Catacoeloceras* do, however, occur very rarely in the district, for instance in the nearby lane section at Hurcot (Wilson *et al.*, 1958: 56; pers. obs.); they were not recorded by Howarth (1992) at Barrington.

Bed 23 and, especially, the lower parts of beds 24 and 24', contains an abundance of *Hildoceras semipolitum* Buckman, and so correlates with the Semipolitum Horizon of Elmi *et al.* (1997). The single loose specimen of *Catacoeloceras* would have also come from this level. The latter genus was also recovered *in situ* at Hurcot, 5–10 cm below abundant *Haugia* (= Variabilis Chronozone). A single *Harpoceras subplanatum* (Oppel) was recovered from the lowest part of Bed 24, while several others were collected as loose specimens.

(g) Middle Toarcian – **Variabilis Chronozone** (Seavington section 1, Bed 24, *c*. 40–45 cm below top; Seavington section 2, *c*. 3–15 cm below top of Bed 24', Barrington, Bed 27, middle part): Rare specimens of *Haugia* spp. appear in the lower part of Bed 24, associated with abundant *Hildoceras semipolitum* Buckman, indicating the base of the Variabilis Chronozone *sensu* Elmi *et al.* (1997). At Seavington this zone is highly condensed, being only around 10–15 cm thick, and is characterized by a ferruginous layer with abundant ammonites, which are typically ferruginous-stained and have etched surfaces, or are enclosed in intraclastic or oncolitic pebbles. The fauna of the intraclastic band consists largely of *Haugia* ex gr. *phillipsi* (Simpson), with occasional *Phymatoceras* spp. proving the presence of the Illustris Subchronozone (Phillipsi Horizon). Immediately below this

band, a single *Haugia* cf. *variabilis* (d'Orbigny) would suggest the preceding Variabilis Subchronozone (and Variabilis Horizon). The Vitiosa Subchronozone at the top of the Variabilis Chronozone is not recognized at Seavington.

(h) Upper Toarcian – **Thouarsense Chronozone**, including **Striatulum–Fascigerum Subchronozones** (Seavington section 1, Bed 24, from 30 cm below top, to top of bed; Seavington section 2, Bed 24', top 3 cm, and basal part of bed 25'; Barrington, Bed 27, upper part). The base of the Thouarsense Chronozone is placed at the first occurrence of *Grammoceras* spp.; it is readily correlated at Seavington, where *G. striatulum* (J. de C. Sowerby) occurs in abundance, immediately above *Haugia*. The coarser-ribbed *G. thouarsense* (d'Orbigny) becomes dominant towards the top of bed 24. Additional records include rare *Pseudopolyplectus bicarinatus* (Zieten), *Phymatoceras* sp. and poorly preserved fragments, which may be either a grammoceratid (*Pseudogrammoceras*) or a phymatoceratid (*Esericeras*). There is presently insufficient *in situ* information to clearly separate the Thouarsense and the Fascigerum subchronozones or recognize the basal Bingmanni Subchronozone. Nevertheless, the possible *Esericeras* in the top 5 cm of Bed 24 may indicate the base of the Fascigerum Subchronozone (index: *Esericeras fascigerum* Buckman).

(i) Upper Toarcian – **Thouarsense Chronozone, Fallaciosum Subchronozone?** (Seavington section 1, bed 25; Seavington section 2, bed 25', except basal part.; Barrington, Bed 28). Howarth (in Dean *et al.*, 1961: 482) drew the base of the Fallaciosum 'Subzone' at the first occurrence of *Pseudogrammoceras*, but later noted that the genus had subsequently been recorded lower, in the Variabilis 'Zone' (in Cope *et al.*, 1980: 53). The base of the subchronozone is, therefore, drawn here at the replacement of *Grammoceras*-rich faunas by the *Pseudogrammoceras*-dominated assemblages. Only one other genus appears to be associated with *Pseudogrammoceras*: a single poorly preserved *Hudlestonia*, in preservation typical of Bed 25'.

(j) Upper Toarcian – **Pseudoradiosa Chronozone, Levesquei Subchronozone** (Seavington section 2, beds 26' to 28'; Barrington, beds 29–32). A single ammonite fragment was recorded, as apparently coming from the Bridport Sand Formation at Seavington, from 'Bed' 27. The preservation of the specimen and the associated limestone fragments and belemnites suggest, however, that this level comprises fragments incorporated into periglacially moved 'material' and, therefore, has no value for stratigraphical correlation. Comparison with Barrington suggests that a Pseudoradiosa Chronozone, Levesquei Subchronozone age is likely for the *in situ* Bridport Sand Formation below (Bed 26). A non-sequence is, thus, present at the base of the formation, as indicated by the irregular and ferruginous-stained basal contact between beds 25 and 26, plus the absence of Dispansum Chronozone deposits – which are present at Barrington.

MICROBIOSTRATIGRAPHY

The microfossil biostratigraphy of the Late Pliensbachian and Toarcian stages is less well known than for the rest of the Lower Jurassic in Britain, largely as a result of problems of sedimentary facies development and lack of exposure. The two classic sequences of international importance are the coastal sections of Dorset and Yorkshire. In Dorset, the youngest Pliensbachian (Spinatum Chronozone) is represented by the Marlstone Rock Member, while most of the Toarcian (Tenuicostatum to basal Levesquei chronozones) is composed of condensed limestones, which together comprise the 'Junction Bed', now designated the Beacon Limestone Formation (Cope *et al.*, 1980: 53–54, fig. 10A, Column T1). The succeeding latest Toarcian sediments are represented by a decalcified sand facies (Bridport Sand Formation), which occurs throughout much of southwest England at different chronostratigraphical levels (Arkell, 1933, fig. 30; Davies, 1969). In contrast, the Yorkshire coast sequence is more argillaceous, with Pliensbachian shales and ironstones overlain by thick Toarcian shale and paper shales; however, the burial history of these rocks has resulted in a degree of lithification that does not facilitate the easy extraction of calcareous microfossils although they are clearly present at some horizons (Copestake & Johnson, 1989). Over much of central England, the Upper Pliensbachian Marlstone Rock Formation commonly occurs as an ironstone, while the Toarcian is developed in a clay and shale facies that is poorly accessible except in boreholes and rarely represents the full stage (Cope *et al.*, 1980, figs 10A–10B).

For reasons of sedimentary development and exposure, the biostratigraphy of the Pliensbachian/Toarcian boundary interval is poorly known in the UK. The exception to this is the Mochras Borehole, west Wales, which was cored throughout and penetrates one of the thickest Lower Jurassic sequences in Europe (1305 m), entirely within an argillaceous facies. Commercial wells generally provide an incomplete picture of the boundary interval (due to the rare occurrence of ammonite biostratigraphical evidence). For example, detailed micropalaeontological work was undertaken in the Fastnet and Celtic Sea basins (Ainsworth, 1986, 1987; Ainsworth & Horton, 1986; Ainsworth *et al.*, 1989c; Rutherford & Ainsworth, 1989). We will refer to the Mochras sequence in our discussions below, despite the fact that, apart from the ostracods (Lord, 1978; Boomer, 1991; Boomer & Whatley, 1992) little has been published about this important section (calcareous nannofossils – Bown, 1987, p. 8, text-fig. 2; foraminifera – Johnson, 1977; Copestake & Johnson, 1981, 1989).

Ainsworth *et al.* (1998a, b) provided a detailed summary of the microbiostratigraphy and lithostratigraphy of the offshore Wessex Basin. The Pliensbachian–Toarcian interval in the offshore, English Channel wells is developed as a significantly thicker and more complete section than that of the condensed limestones on the Dorset Coast. The occurrence of Upper Pliensbachian and Toarcian sediments, of a dominantly argillaceous nature, from Somerset is obviously of considerable interest. The sequence is only 23 km north of the Dorset coast but is very different from the Beacon Limestone Formation occurring at Thorncombe Beacon. Microfossil samples were studied in relation to the detailed survey of lithostratigraphy and ammonite biostratigraphy outlined above (and Appendix A). Figure 2 gives sample numbers in relation to the beds and Ammonite zonation recognized at Seavington. Figure 3 provides an indication of the overall pattern of changing diversity across all microfossil groups, together with indices of appearance and extinction rates. The biostratigraphical record for each fossil group is present separately in Figures 4–7.

Palynological preparations are housed in the collections of the British Geological Survey, Keyworth, Specimens figured by
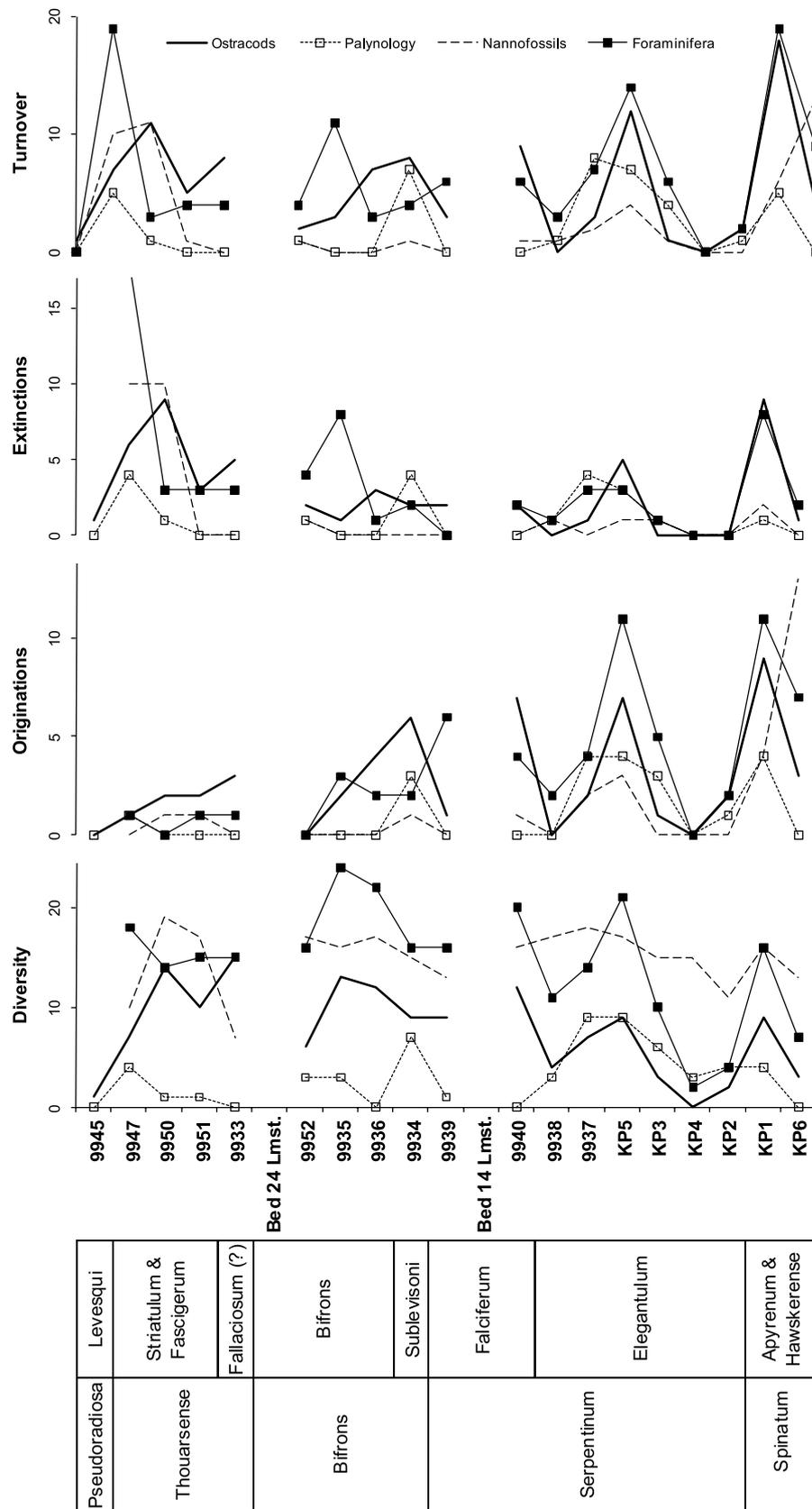
Fig. 3. Faunal diversity (number of species), species originations, extinctions and faunal turnover (originations + extinctions) in the Ilminster sequence.
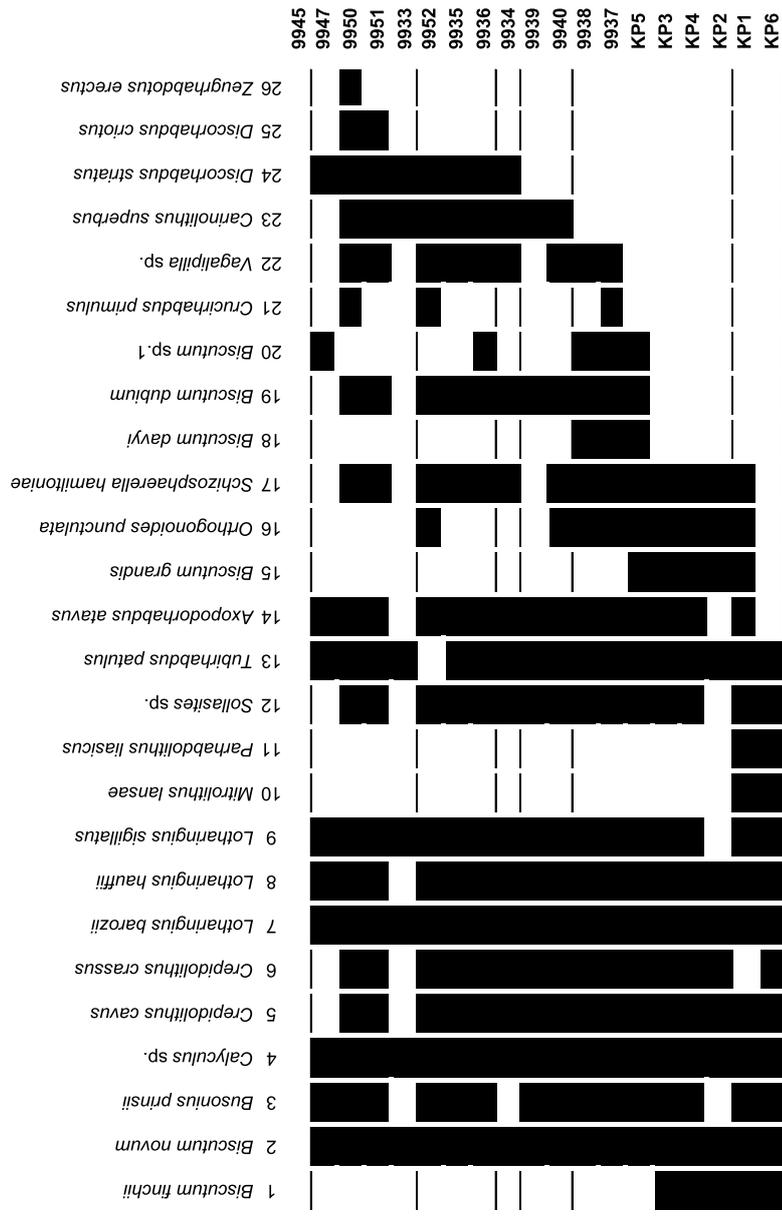
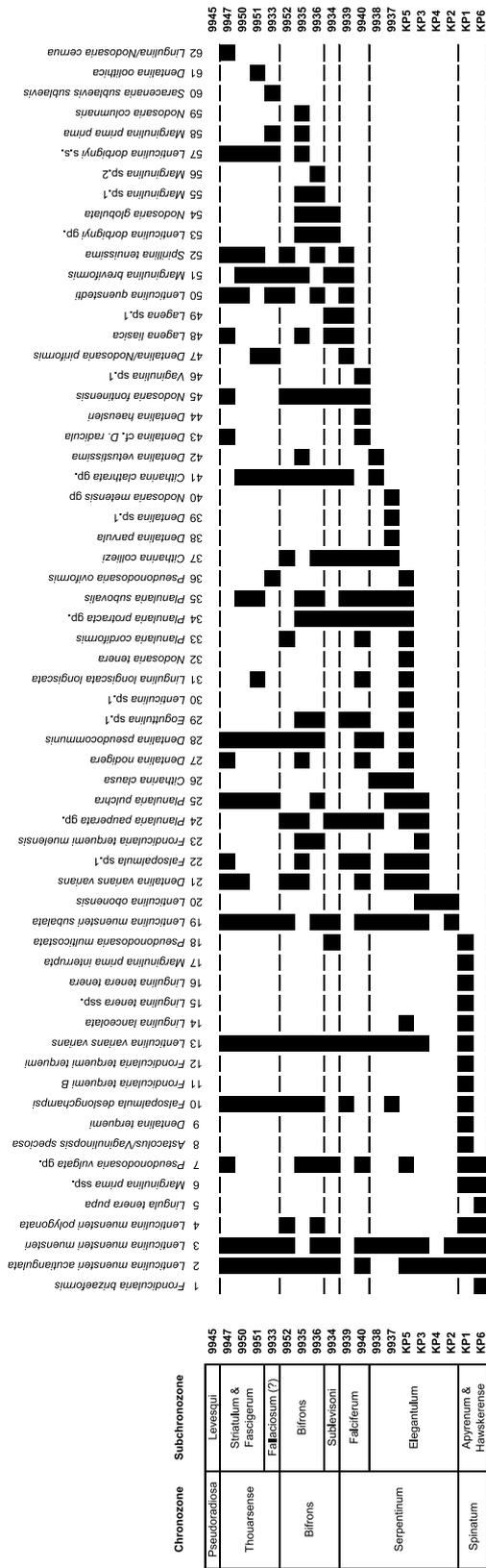**Fig. 4.** Calcareous Nannofossil occurrence in the Ilminster sequence (presence–absence).

Fig. 5. Foraminiferal occurrence in the Ilminster sequence (presence–absence).
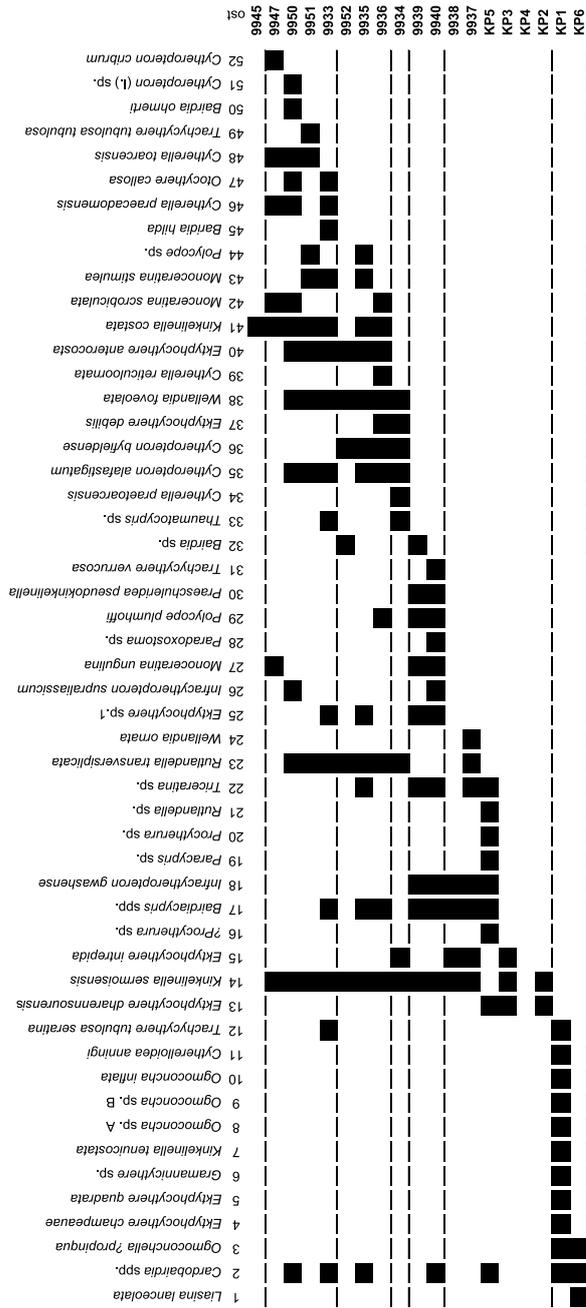
Fig. 6. Ostracod occurrence in the Ilminster sequence (presence–absence).

Species columns (left to right):
1 Bisaccate pollen - undifferentiated
2 *Cerebropollenites macroverrucosus*
3 *Perinopollenites elatoides*
4 *Tasmanites* spp.
5 Small sphaeromorph acritarchs
6 *Cyathidites minor*
7 *Cyathidites* sp.
8 *Duplexsporites problematicus*
9 *Concavissimisporites* sp.
10 Foraminifera test linings
11 Scolecodont
12 Spore - indeterminate
13 *Classopollis classoides*
14 *Ischyosporites variegatus*
15 *Micrhystridium* sp.
16 Pollen indeterminate
17 *Botrycoccus* sp.
18 *Chasmatosporites* sp.
19 *Crassosphaera hexagonalis*
20 *Nannoceratopsis gracilis*

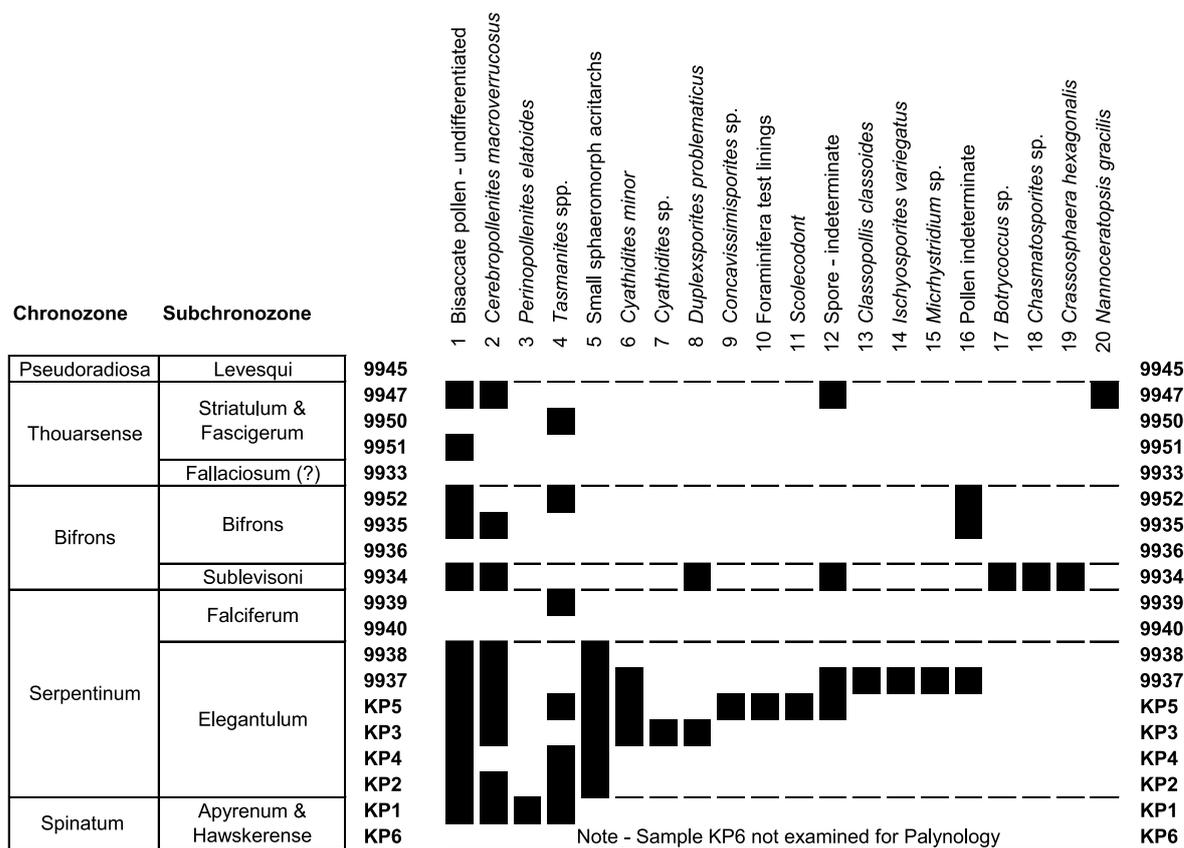| Chronozone	Subchronozone	Sample
Pseudoradiosa	Levesqui	9945
Thouarsense	Striatulum & Fascigerum	9947 / 9950 / 9951
Thouarsense	Fallaciosum (?)	9933
Bifrons	Bifrons	9952 / 9935 / 9936
Bifrons	Sublevisoni	9934
Serpentinum	Falciferum	9939 / 9940
Serpentinum	Elegantulum	9938 / 9937 / KP5 / KP3 / KP4 / KP2
Spinatum	Apyrenum & Hawskerense	KP1 / KP6

Note - Sample KP6 not examined for Palynology

Fig. 7. Palynological occurrence in the Ilminster sequence (presence–absence).

Boomer (1992) are housed at the Natural History Museum, London, and all other material is held by University College London. The paper is presented with a view to establishing major faunal events and biostratigraphical ranges of microfossils through the sequence at Ilminster; occurrences are therefore given simply as presence–absence.

Calcareous nannofossils

The Upper Pliensbachian to Lower Toarcian interval is of great interest as it records the transition from earliest Jurassic nannofloras dominated by murolith coccoliths, such as *Parhabdolithus liasicus* Deflandre, *Mitrolithus elegans* Deflandre and *Crucirhabdus primulus* Prins, to late Early Jurassic/early Middle Jurassic nannofloras dominated by placolith coccoliths, such as *Similiscutum* spp., *Biscutum novum* (Bown), *Lotharingius hauffii* Grün & Zweili and *L. sigillatus* (Bown). This interval also includes the diversification of the Biscutaceae coccolith group with the appearance of forms such as *Biscutum grande* Bown, *B. finchii* Crux, *Discorhabdus striatus* Moshkovitz & Ehrlich and *Sollasites* spp., and the development of radical morphologies, for example, *Calyculus* spp. and *Carinolithus superbus* Deflandre. In contrast, the Late Toarcian was a time of evolutionary quiescence.

Eighteen of the nineteen Ilminster samples yielded diverse, abundant and well-preserved nannofossil assemblages (Fig. 4). The dominant species are *Biscutum novum*, *Crepidolithus crassus* Deflandre, *Lotharingius hauffii* and *L. sigillatus* and, together with the occurrence of *Axopodorhabdus atavus* (Bown), *Bussonius prinsii* (Bown), *Calyculus* spp., *Crepidolithus impontus* (Grün

et al.) and *Sollasites* spp., they represent assemblages characteristic of uppermost Pliensbachian–Toarcian age throughout northwest Europe.

A number of species have first appearances and last occurrences within the section and these are of biostratigraphical interest. The presence of *Mitrolithus jansae* (Wiegand) and *Parhabdolithus liasicus* (last occurrences, Spinatum Chronozone) with *Crepidolithus impontus* (first appearance in Spinatum Chronozone) in the lowest samples (KP6, KP1) places them in the NJ5b *Crepidolithus impontus* NF (Nannofossil) Subzone (Bown *et al.*, 1988; Bown & Cooper, 1998), which has a Spinatum–Tenuicostatum Chronozone age range. The first appearance of *Carinolithus superbus* is slightly problematical as samples KP1 to 9938 all yield forms that are transitional from *Calyculus* to *Carinolithus*, the true end-member morphology is not observed until sample 9940 (Falciferum Subchronozone) which also has the first appearance of *Discorhabdus striatus*. These two datum levels are in close agreement with previously published results, e.g. Crux (1987), Bown *et al.* (1988) together these give their names to zones, NJ6 and 7.

The last occurrences of *Biscutum finchii* and *B. grande* in sample KP3 (Elegantulum Subchronozone) biscutacean genus, and its stratigraphical level is comparable with those reported by de Kaenel *et al.* (1986) and are similarly in agreement with Bown *et al.* (1996). The last occurrence of *Similiscutum avitum* de Kaenel & Bergen in Sample KP4 (also Elegantulum Subchronozone) marks the disappearance of this earliest biscutacean genus, and its stratigraphic level is comparable with those reported by

de Kaenel & Bergen (1993) and de Kaenel & Bergen, (1996). The typical bicyclic biscutacean coccoliths, *Biscutum davyi* Bown and *Biscutum dubium* Bown, have first appearances in samples KP1 and KP2, respectively. The former species has been reported only from the Ilminster section (Bown & Cooper, 1989) and has a restricted range between samples KP1 and 9938. However, a similar coccolith, recorded here as *Biscutum* cf. *B. davyi* (having a very narrow or closed central area) in this study, ranges higher (to sample 9947). The top of the *Lotharingius hauffii* acme is recorded in the Bifrons to Thouarsense Chronozone interval, with abundances dropping from 40% to 9% in samples 9934 and 9936, and from 5% to 0% in samples 9952 and 9951; *L. hauffi* comprises only 1% of the assemblages above this level. This interval sees a corresponding abundance increase in the *Lotharingius sigillatus* group.

Foraminifera

Abundant and diverse assemblages of foraminifera were recovered from the Pliensbachian–Toarcian interval at Ilminster (Fig. 5). Of the 19 samples studied, 18 yielded foraminifera. Sample 9945 from the Bridport Sand Formation (formerly the Yeovil Sands) in Seavington section 2, was barren; 62 species and subspecies were recognized from the remaining 18 samples. Foraminiferal diversity is approximately double that of the ostracods throughout the sequence (Fig. 3).

The character of the assemblages differs significantly from that of other British sections through the same interval, particularly at the oldest levels. Other studies of Pliensbachian–Toarcian foraminifera include those of Brady (in Moore, 1866 – Ilminster), Barnard (1950 – Northamptonshire), Adams (1957 – Lincolnshire), Horton & Coleman (1977 – Leicestershire), Coleman (1982 – Winterborne Kingston Borehole, Dorset), and Copestake & Johnson (1981, 1989 – included the Mochras Borehole, west Wales) and Ainsworth *et al.* (1998a). In all of these areas the foraminiferal faunas contain arenaceous and miliolid elements, as well as the ubiquitous lagenine forms. In the northern North Sea this interval is marked by an almost wholly arenaceous fauna (Nagy, 1985), whereas onshore Britain and in western Europe, the faunas are more mixed. The uppermost part of the Pliensbachian (Spinatum Chronozone) is rarely microfossiliferous when developed in Marlstone Rock facies, while the Late Toarcian Down Cliff Clay Member on the Dorset Coast (and also present offshore in the Wessex Basin) yields a diverse assemblage of largely calcareous foraminifera (Copestake & Johnson, 1989).

In areas where the Spinatum Chronozone is represented by argillaceous sediments, such as the Mochras Borehole, North Sea and Yorkshire Coast, foraminiferal assemblages are often well represented (P. Copestake, pers. comm.). Mochras is marked by an influx of *Ophthalmidium* and *Spirillina* (Copestake & Johnson, 1989). Early Toarcian foraminiferal assemblages are dominated by *Reinholdella* species, a pattern which persists into the Serpentinum Chronozone. Considerable faunal turnover takes place in that zone and there is a marked appearance of arenaceous and miliolid forms. Many of the plexa originating in the Pliensbachian and earlier become extinct at this level, allowing many new species to subsequently appear (Bifrons Chronozone and younger). Thereafter the fauna takes on a more Middle Jurassic aspect, a trend also seen in the ostracods. The assemblages found at Ilminster differ from this general pattern in that they are exclusively hyaline in nature and, with the exception of rare occurrences of *Spirillina tenuissima* Gümbel, are entirely composed of members of the Suborder Lagenina. Certain markers seen elsewhere, such as the *Reinholdella* influx in the Tenuicostatum Chronozone, are not recorded at Ilminster due to the lack of samples from this interval. The lack of any miliolid and agglutinating taxa at Ilminster may indicate a primary environmental control.

The predominant genera comprise *Lenticulina*, *Planularia* and *Citharina*. Members of the *Lenticulina muensteri* Roemer plexus are common throughout the Seavington sections and form the main part of the background fauna. A number of events are of stratigraphical significance. First, the influx of *Lenticulina obonensis* (Cubaynes) in samples KP2 to KP3, a species which has been recorded only once before in Britain, by Brady (1865) from the same area under the name of *Planularia cornucopiae* Brady. Ruget (1982, p. 66) described *L. obonensis* from the Early Jurassic of Spain, ranging through the Tenuicostatum and Serpentinum chronozones. However, it has a more restricted range at Ilminster, where it occurs in great abundance in the lower part of the Serpentinum Chronozone.

A second stratigraphically important species of *Lenticulina* is *L. dorbignyi* Roemer. At Mochras this taxon first appears close to the top of the Crassum (=Bifrons, this work) Subchronozone, Bifrons Chronozone (Copestake & Johnson, 1989) and has an identical first appearance here. A primitive morphotype (as *L. dorbignyi* gp) has an earlier first appearance lower, within the Sublevisoni Subchronozone, Bifrons Chronozone. Such forms have not been recognized elsewhere. This early morphotype generally has palmate later chambers while the ornament is much less organized than that of *Lenticulina dorbignyi s.s.* This ancestral form has its last occurrence immediately after the true *L. dorbignyi s.s.* first appears and is, therefore, considered to be an evolutionary antecedent and not a phenotypic variant.

Extinction levels within the *Marginulina prima* plexus provide useful stratigraphical markers and three subspecies are present at Ilminster. *Marginulina prima spinata* Terquem was recovered in the two stratigraphically lowest samples (KP6, KP1). Horton & Coleman (1977, p. 10) give this subspecies an extinction level within the Exaratum Subchronozone in the Winterborne Kingston Borehole, whereas at Ilminster it is restricted to samples of Spinatum Chronozone age. Copestake & Johnson (1989) noted the species as having a total range from the Upper Sinemurian to the Lower Toarcian, although their top occurrence in the Wessex Basin is given as only Upper Pliensbachian. *Marginulina prima interrupta* Terquem co-exists with *M. prima spinata* in the Spinatum Chronozone, possessing a similar extinction level. The third subspecies recorded, *M. prima prima* Terquem, occurs much higher in the section, in samples 9935 and 9933 (Bifrons–Thouarsense Chronozone age). The presence of *Lingulina tenera pupa* Terquem and *L. tenera tenera* in the basal two samples also places them as Spinatum Chronozone. The *Lingulina tenera* plexus finally becomes extinct at this level (KP1) and, as discussed above, the large extinction rate at this level is in part due to the condensed nature of the sequence with two major extinction events (end Pliensbachian and Tenuicostatum–Serpentinum boundary) 'compressed' into a

single event. A number of key disappearances and first appearances are recorded by Copestake & Johnson (1989) at the Pliensbachian–Toarcian boundary. The boundary is succeeded in many areas by '*Reinholdella*'–dominated assemblages, reflecting major environmental changes. The nature and degree of these changes varies depending on the palaeogeographical and palaeodepth settings.

The genus *Citharina* is also abundant in the Ilminster sections. Two species are particularly common, *C. clathrata* Terquem and *C. colliezi* (Terquem), both appearing at approximately the same level towards the top of the Elegantulum Subchronozone (samples 9937, 9938). *Citharina clathrata* in particular is very abundant throughout the upper part of the Serpentinum and Bifrons chronozones. Copestake & Johnson (1989) recorded the first British appearance of *C. clathrata* at Mochras in the Apyrenum Subchronozone, Upper Pliensbachian; however, it is not widespread below the Serpentinum Chronozone of the Lower Toarcian. *Citharina colliezi* occurs from the base of the Tenuicostatum Chronozone but, as with *C. clathrata*, only becomes widely distributed through the English Midlands within the Serpentinum Chronozone. This sudden influx of sixteen *Citharina* forms is a very distinctive event in the Ilminster succession and may be a useful marker for the Serpentinum Chronozone.

The Ilminster sequence has yielded a diverse assemblage of calcareous benthic foraminifera with no evidence of the agglutinating or miliolid forms known to be common in contemporaneous sequences elsewhere in the UK and its continental shelf, particularly at Mochras and the Yorkshire Coast (Copestake & Johnson, 1989). The bulk of the sequence at Ilminster can be correlated with foraminiferal zone FJ9 (Ainsworth *et al.*, 1998a) from the Wessex Basin/English Channel area, while a comparison with the zonation of Copestake & Johnson (1989) indicates an equivalence to their zones JF12b to JF15. Zone JF16 is present on the basis of ammonite evidence, but the marker foraminiferal species, *Nodosaria regularis* ssp. A (Terquem) and *Palmula tenuistriata* (Franck), are absent at Ilminster.

Ostracoda

British Lower and Middle Toarcian ostracods have been described from the East Midlands (Bate & Coleman, 1975), on the basis of which an ostracod biozonation was proposed for that interval. Park (1987, 1988) included a review of Pliensbachian ostracods from the Dorset coast in her review of Early Jurassic ostracod biostratigraphy from southern Britain and the southern North Sea. However, there does not seem to be any stratigraphical overlap between those records and the present study. Subsequent work (Boomer, 1992) included a taxonomic review of the ostracod assemblages recovered at Ilminster as well as a study of Lower Jurassic ostracods from the Mochras Borehole, west Wales (Boomer, 1991); preliminary results for the upper part of that sequence were published by Lord (1978). Ostracods have also been described from Pliensbachian to Aalenian sediments from exploration wells offshore south of Ireland (Ainsworth, 1986, *et seq.*) and the Wessex Basin (Ainsworth *et al.*, 1998a).

The sections at Ilminster represent an important time in the evolution of early Jurassic ostracods. It was during this period that the Suborder Metacopina (ranging from the Silurian to the early Toarcian) became extinct, freeing biotopes that were filled following an evolutionary radiation within the superfamily Cytheracea. The reasons so far put forward for the demise of this otherwise successful group are well documented (Lord, 1982; Boomer *et al.*, 2008). It is known that their disappearance corresponds with the widespread/global sea-level highstand during the earliest Toarcian (Tenuicostatum–Serpentinum boundary), a period which included an oceanic anoxic event and a globally recognized carbon isotope excursion (Hesselbo *et al.*, 2000). Boomer *et al.* (2008) discussed the demise of this group in detail.

The assemblage of metacopine ostracods in the lowest two samples (Fig. 6) KP1 and KP6, Spinatum Chronozone, is quite distinct (note that sample KP6 was not available when the ostracods from Ilminster were first published by Boomer, 1992). These specimens belong to the genera *Ogmoconcha* and *Ogmoconchella*. Within the former genus are examples of the morphological group referred to as the 'vallate-*Ogmoconcha*' genus *Hermiella*; these have in the past been referred to as 'Tethyan' forms of the genus *Ogmoconcha*, due to their occurrence in the sediments of southern Germany, Portugal, Italy, North Africa, etc. (Malz, 1975; Maupin & Vila, 1976; Maupin, 1977; Exton, 1979; Lord *in* Farinacci *et al.*, 1979; Boutakiout *et al.*, 1982; Boomer *et al.*, 1998). Within the UK, these forms were recorded only from Ilminster (Boomer, 1992), the Mochras Borehole (Boomer, 1991) and offshore Ireland (Ainsworth, 1987).

The assemblage from sample KP1 is also similar to those recorded from the Apennines by Lord (in Farinacci *et al.*, 1979) and comparable to samples recovered from the Wessex Basin (Ainsworth *et al.*, 1998a) and Djebel Zaghouan, Tunisia (A. Lord, pers. obs.).

Sample KP1 includes the youngest record of both *Cytherelloidea anningi* Lord, although only one specimen was recovered, preserved partly pyritized, unlike the glassy to translucent calcite preservation for most other taxa. A few poorly preserved (pitted, abraded and weakly pyritized) specimens of *Ektyphocythere quadrata* Boomer & Lord were also recorded. These two species are more commonly recorded from the earlier Margaritatus Chronozone of the Upper Pliensbachian and they are probably reworked. The ostracod assemblage from sample KP1 (assessed as Spinatum Chronozone on sparse ammonite evidence) bears a great similarity to those described from the late Tenuicostatum Chronozone of the Mochras Borehole. The occurrence within this sample of some heavily 'pitted' specimens mentioned above suggests that some reworking may have occurred at this level.

The succeeding sample (KP2) introduces a species which has previously only been described from its type locality in Morocco (ranging from 'early to mid-Toarcian'), *Ektyphocythere dharennsourensis* Boutakioult *et al.* has a distinctive outline and strong sexual dimorphism. This species continues to sample KP5; only in sample KP3 are the male dimorphs present. The nature of the hinge and of the anterior marginal pore canals suggest a possible ancestral position with respect to the genus *Praeschuleridea*, which occurs in the younger part of the section. The resemblance between these earliest Toarcian examples and contemporary assemblages described from North Africa, suggests a possible palaeoceanographical link at this time.

While some of the species recorded by Bate & Coleman (1975) were found at Ilminster, others are absent, i.e. species of

Procytherura, *Eucytherura* and *Camptocythere*. Direct bio-stratigraphical correlation between the present material and the East Midlands is not possible due to the absence at Ilminster of two of the zonal fossils designated by Bate & Coleman (i.e. *Camptocythere toarciana* Bate & Coleman and *Kinkelinella persica* Bate & Coleman, both described in that work). The ranges of the two remaining zone fossils described by those authors accord well with the ranges recorded at Ilminster (see Fig. 6, *Ektyphocythere intrepida* Bate & Coleman and *E. debilis* Bate & Coleman). It should be noted that the ranges of these last two species, although apparently concurrent in both the East Midlands and Somerset, are much shorter than their total ranges recorded in the Mochras Borehole. This is also true for many of the species recorded from the other two sites.

In summary, samples KP1 to KP5 contain an ostracod fauna that suggests a strong palaeoceanographical link with parts of southern Europe and North Africa during the latest Pliensbachian?–earliest Toarcian. Sample KP1 contains an assemblage which may indicate reworking; indeed, some samples higher up in the section also include badly etched specimens (also possibly indicative of erosion/reworking). With only a few exceptions, there is considerable similarity between the present ostracod material (Serpentinum and Bifrons chrono-zones) and those described by Bate & Coleman (1975) from the Lower and Middle Toarcian of the East Midlands. The ostracod assemblages at Ilminster can be correlated with the uppermost part of zone OJ8 and all of Zone OJ9 of the English Channel (Ainsworth *et al.*, 1998a).

Palynomorphs

The samples yielded a disappointingly sparse, and generally poorly preserved, palynoflora (Fig. 7). In the past, coeval strata from southwest England have yielded diverse, well-preserved palynomorph assemblages (Woollam & Riding, 1983; Ainsworth *et al.*, 1998a). However, the zone of weathering at Ilminster may have been especially well developed; alternatively the paucity of palynomorphs may be due to oxidation during, or soon after, deposition. Whatever the primary cause, it is clear that the palynological remains within the Ilminster sequence are of limited environmental and biostratigraphical application.

Of the taxa that were recorded, miospores numerically domi-nate the productive samples; gymnospermous pollen grains occur in greater numbers than pteridophytic spores. The miospore assemblages are characteristic of the early to middle Jurassic, with few taxa of biostratigraphical significance within this broad interval. The occurrence throughout of the pollen grain *Cerebropollenites macroverrucosus* Schultz is indicative of a post-Sinemurian age. All the spores identified are relatively long ranging within the Jurassic (Srivastava, 1987).

A single dinoflagellate cyst specimen was recovered from the Ilminster samples. *Nannoceratopsis gracilis* Alberti was found in sample 9947; this taxon ranges from the Upper Pliensbachian to Bajocian and is widespread throughout the northern hemisphere (Woollam & Riding, 1983). Clumps of small (18–23 μm in diameter) sphaeromorph acritarchs were recorded from samples KP2 to 9938 (Serpentinum Chronozone, Elegantulum Subchronozone). This association is characteristic of the Lower Toarcian of Europe (see Loh *et al.*, 1986; Riding, 1987). Of the few species recognized, only one (*Nannoceratopsis gracilis*) can

be correlated with the Dinocyst Zonation of the English Channel/Wessex basin by Ainsworth *et al.* (1998a). That species occurs only in a single sample (9947, top of the Thouarsense Chronozone) and gives an indication of a Late Pliensbachian to Late Toarcian age.

Microbiostratigraphical summary

The microbenthos (ostracods and foraminifera) yielded well-preserved and diverse assemblages of marine aspect. Both groups show generally good agreement with assemblages from elsewhere in the UK in terms of stratigraphical ranges. The main exception to this is the absence of Spirillinid and Reinholdellid foraminiferal assemblages, which may be due in part to the absence of significant Tenuicostatum Chronozone development at Ilminster; however, a primary environmental cause cannot be ruled out. It must be noted that the lack of microbiostratigraphical samples from the Tenuicostatum Chronozone undoubtedly generates an unusually abrupt, apparent 'extinction' horizon.

The microplankton records varied between well-preserved, diverse calcareous nannofossil assemblages and low-diversity pollen, spore and dinocysts assemblages. The nannofossil species present are generally long ranging and there is little stratigraphi-cal value in these records, although there are a few key events in the lower part of the sequence associated with faunal turnover in the Pliensbachian–Toarcian boundary interval (disappearance of *Mitrolithus jansae* and *Parhabdolithus liasicus*). The paly-nomorph record was particularly disappointing, especially since it was during the Pliensbachian and Toarcian that dinocysts diversified prior to becoming very important during the later Jurassic. The palynomorphs from Ilminster, although sparse, are consistent with the ammonite biostratigraphy. The associ-ation of terrestrially derived elements (miospores) with indig-enous marine forms (microplankton) indicates a marine environment of deposition throughout but with a degree of terrestrially-sourced input. The occurrence of *Tasmanites* (gen-erally associated with high levels of organic productivity) is sporadic throughout the sequence but most concentrated in the lower part of the Serpentinum Chronozone, correlating with marked faunal turnover in the lowest part of the sequence.

DISCUSSION OF THE PLIENSBACHIAN–TOARCIAN SEQUENCE AT ILMINSTER

The Pliensbachian–Toarcian biotic turnover was not one of the 'Big Five' mass extinctions (Newell, 1967; Jablonski & Chaloner, 1994), but it was nevertheless an important event and was recognized as such by Hallam (1961). For benthic microfauna (foraminifera and ostracods), the significance of the Pliensbachian–Toarcian biotic turnover in the Paris Basin was demonstrated in range charts published by Apostolescu & Bourdon (1956, tables II–IV), Apostolescu (1959, table 1) and in the 'Colloque sur le Lias' (1961). Subsequent work through-out Europe, has documented the microfaunal and -floral turnover in much greater detail, for example Riegraf (1985) for southern Germany. However, very high-resolution micro-biostratigraphical analysis of this interval remains elusive for palaeoenvironmental and facies reasons.

The Ilminster sections reveal a Late Pliensbachian–Toarcian sequence (Spinatum to Pseudoradiosa ammonite chronozones)

with good macro- and microfossil assemblages. The interval is rarely exposed inland, but is especially important in the area of southwest England, since, on the Dorset coast only 23 km away, this time period is represented largely by the condensed limestones of the Beacon Limestone Formation, a remanié carbonate deposit. This formation is generally difficult to assess for detailed biostratigraphical purposes because of hiatuses, low-sedimentation rates and reworking. The micropalaeontology of condensed limestones are often restricted to thin-sections work and acid-digests (palynomorphs usually occur in low densities in limestones). At Ilminster the occurrence of interbedded calcareous marls has provided an insight in the local calcareous and organic-walled micropalaeontology of this period.

The Ilminster sequence is more calcareous than the full Toarcian record observed in the Mochras Borehole but, more significantly, lacks the bituminous shale facies usually encountered in the Early Toarcian throughout much of western Europe and, thus, provides diverse, well-preserved benthic microfossils. In Yorkshire, the Wessex Basin, Paris Basin, southern Germany, northern Switzerland, etc., early Toarcian (typically the earliest part of the Serpentinum Ammonite Chronozone) bituminous shale sequences occur (e.g. Posidonienschiefer Formation of southern Germany), reflecting anaerobic or dysaerobic bottom conditions with consequent paucity or absence of benthos. In such areas the ranges of benthic species are interrupted, with certain species recolonizing as 'Lazarus taxa' (Wignall & Benton, 1999) after the 'oxygen-minimum event', and the pattern of temporary absence and reappearance reflects the differing tolerances of individual species to such reduced-oxygen conditions. In many cases, extinction events can be linked to the change in bottom-water environments. Ilminster is a section of considerable importance and our samples yielded calcareous and organic-walled plankton, calcareous benthos and terrestrially derived spores and pollen.

One disappointing aspect of the Ilminster section was our inability to study the Pliensbachian–Toarcian boundary interval in detail. Adequate evidence exists to show that the late Spinatum Chronozone, Upper Pliensbachian, is present but the samples from around the boundary were poorly constrained and it is apparent that the Tenuicostatum Chronozone is probably all but absent. This boundary and the lower Toarcian interval is of interest because of macro- and microfaunal turnover around this period, with particular significance for the ostracods as it includes the extinction of the Suborder Metacopina (Boomer et al., 2008), an important Palaeozoic group that had thrived to this point, surviving both the end-Palaeozoic and the Triassic–Jurassic boundary extinction events. This major faunal event associated with the Early Jurassic is now considered to have occurred not at the Pliensbachian–Toarcian boundary, but at the Tenuicostatum–Serpentinum (or Falciferum) Chronozone boundary (Boomer et al., 2008), neither of which are recorded in detail at Ilminster. Significant faunal turnover is recognized in most groups at Ilminster, with 11 foraminiferal taxa and 11 ostracod taxa not surviving into the Toarcian.

The changing faunal record at Ilminster is presented not just as biostratigraphical range charts (Figs 4–7) but also as combined records of faunal diversity, species appearance, species extinction and overall faunal turnover (appearance plus extinction for any given sample) in Figure 3. Inevitably such plots will have 'edge effects', i.e. the oldest samples often have (apparent) highest rates of 'appearance' and the youngest samples the (apparent) highest rates of 'extinction' where long-ranging taxa continue beyond the interval studied. Nevertheless, some important observations can be made.

The most striking section in the plots of microbiostratigraphical change (Fig. 3) is the marked diversity decrease, with associated increased faunal turnover, between samples KP1 and KP2, i.e. the Pliensbachian–Toarcian 'boundary'. It must be remembered, however, that the lack of any microfossil samples of Tenuicostatum Chronozone age means that the interval between the two aforementioned samples spans a period from latest Spinatum to early Serpentinum Chronozones. This period includes both the widely recognized end-Pliensbachian and early Toarcian extinction events seen in many groups (e.g. Copestake & Johnson, 1989; Boomer et al., 2008). Following the diversity decrease within the early part of the Serpentinum Chronozone at Ilminster there is a second diversity rise and fall accompanied by marked faunal turnover (Elegantulum Subchronozone, Serpentinum Chronozone). This is most noticeable in the benthos (ostracods and foraminifera), with the plankton being little affected, suggesting that this primarily reflects changes in the bottom-water conditions. Given the temporal framework, this second event may be related to the further development of dysaerobic conditions known from elsewhere in Europe during the early Toarcian. It is also significant that this interval of marked faunal turnover (broadly equivalent to the Toarcian Oceanic Anoxic Event across Europe) coincides with the occurrence of the sphaeromorph actritarch horizons. These are known to be strongly associated with Toarcian carbon-isotope excursions (and Oceanic Anoxic Events) and are even recorded in abundance in the Mochras Borehole where bottom-water conditions remained oxic through the Early Toarcian (van de Schootbrugge et al., 2005).

CONCLUSIONS

The sediments and microfossils indicate deposition in relatively shallow-water, marine conditions, well-oxygenated and largely unaffected by the dysaerobia seen elsewhere in the major depositional basins of Europe at this time.

The poor palynoflora, with the presence of only one dinocyst species, some miospores and Pteridophytes indicates a depositional position in mid-shelf conditions, with some influence of land-derived material. However, all other macro- and microfossil groups studied reflect a normal marine shelf environment.

The calcareous nannofossils have provided a useful biostratigraphical correlation with other sites in northwest Europe (cf. Bown, 1987); however, the assemblages are not comparable with the exceptional Paris Basin Toarcian nannofloras described by Goy (1981).

The foraminiferal assemblages yielded important Toarcian records of diverse and well-preserved assemblages, which provides supplementary documentation of ranges for a number of important species groups (data used by Copestake & Johnson, 1989); assemblages are unusual in that they contain exclusively hyaline forms.

The ostracods are represented by a remarkably good Toarcian record without interruption by bituminous facies. The diversification of cytheracean taxa following the demise of the

metacopines in earliest Toarcian is clearly displayed but, unfortunately, sampling resolution covering the metacopine extinction event itself is poor and the event cannot be elucidated in detail at this locality.

APPENDIX A: DESCRIPTION OF SECTIONS

Roadworks on the Ilminster bypass intersected the outcrop of the Ilminster Beacon Limestone Formation for a distance of around 700 m, north to northwest of Seavington St Michael (Fig. 1). No single exposure revealed a continuous section and, therefore, it was necessary to correlate the beds seen in various small pits and cuttings in order that a more complete record could be made. Section 1, as described below (Fig. 2), is therefore a composite, based on observations of around 100 m of this exposure. Lateral variation was nevertheless great and it was necessary to record the westernmost exposure separately (Section 2).

Section 1 – Composite, based on excavations and cuttings centred on Grid Ref. ST 406157; north of Seavington St Michael. Bed numbers also marked on Figure 2.

BEACON LIMESTONE FORMATION; BARRINGTON MEMBER
UPPER TOARCIAN – THOUARSENSE CHRONOZONE, FALLACIOSUM SUBCHRONOZONE?

25	Clay, brown-weathered; passes up into a loam subsoil. Lowest 15 cm contains a discontinuous band of irregularly sized limestone concretions, composed of pale-grey-coloured argillaceous micrite. Belemnites and small bivalves common, also *Pseudogrammoceras* sp.	*c*. 20 cm *in-situ*?

UPPER TOARCIAN – THOUARSENSE CHRONOZONE, THOUARSENSE–FASCIGERUM SUBCHRONOZONES

24   Limestone, argillaceous micrite, weathering a pale-buff colour. A 5 cm thick seam of grey marl is present 5 cm below the top of the unit, and a 1–2 cm seam at around 7 cm above the base. A band at around 30–40 cm below the top is iron-stained and contains intraclasts and eroded ammonites; the latter frequently have etched surfaces covered with a dark ferruginous veneer. Faunal records from Bed 24 include belemnites. From the top 5 cm – *Grammoceras* cf. *striatulum* (J. de C. Sowerby), *G. thouarsense* (d'Orbigny), *Esericeras* or *Phlyseogrammoceras* sp.; from 5–10 cm below the top (= marl seam) – *G.* cf. *striatulum*, *G. thouarsense*; from 15 cm below top – *G. striatulum*, cf. *Pseudogrammoceras* sp., *Pseudopolyplectus bicarinatus* (Zieten); from 20 cm below top – *G. striatulum, G.* sp. cf. *Phymatoceras* sp. (poorly preserved), *Pseudogrammoceras* or *Esericeras* sp.; from 30 cm below top – *G. striatulum*.

UPPER TOARCIAN – VARIABILIS CHRONOZONE

From 35 cm below the top of Bed 24 (=ferruginous band) – *Haugia phillipsi* (Simpson) (abundant), *Phymatoceras* sp., *Hildoceras semipolitum* Buckman (fragment).

LOWER TOARCIAN – BIFRONS CHRONOZONE, BIFRONS SUBCHRONOZONE

	From 45 cm below top of Bed 24 – *H. semipolitum* (abundant); from 55 cm below top (= marl seam) – *H. semipolitum;* from 60 cm below top (basal 7 cm) – *H. semipolitum*, (abundant), *Hildoceras* aff. *bifrons* (Bruguiere), *Harpoceras subplanatum* (Oppel).	Total for Bed 24 60–75 cm.
23	Marl, grey, with occasional ammonites and 'Mummien', i.e. ammonites forming the core of oncolitic pebbles, *H. semipolitum* present.	7 cm
22	Ferruginous band, full of small (1–2 cm) irony pebbles, and with occasional ochreous-stained ammonite fragments: *Hildoceras* cf. *bifrons* and a lytoceratid present.	10 cm
21	Marl, grey, with *Hildoceras* sp. and a lytoceratid.	0–5 cm
20	Limestone, argillaceous micritic, weathering a pale buff colour; grey when fresh. In one or two bands, with a marl seam between: *Dactylioceras* sp. and *H.* cf. *bifrons* present.	7–15 cm

LOWER TOARCIAN – BIFRONS CHRONOZONE, SUBLEVISONI SUBCHRONOZONE

19	Nodular argillaceous limestones and grey marl; consisting of irregular, thin lenticles, in three bands, with marl between. *Dactylioceras* ex gr. *commune* (J. Sowerby) (abundant small specimens) and occasional *Hildoceras* cf. *sublevisoni* Fucini present; also *Harpoceras* sp. cf. *falciferum* (J. Sowerby), a lytoceratid and a pectenid bivalve.	25–30 cm

18	Limestone, argillaceous micritic. Nodular and rubbly, with marl in upper part, becoming harder below. Contains occasional iron-stained intraclasts, some of which are ammonites. *Hildoceras sublevisoni*, *Dactylioceras* sp. and *Nodicoeloceras* sp. are abundant, and associated with occasional *Harpoceras* sp. and *Ovaticeras* sp.	25 cm
17	Limestone, hard grey argillaceous micritic; in two beds separated by a marl parting. Upper bed contains *H. sublevisoni*, *Dactylioceras* sp., *Nodicoeloceras* sp., small rhynconellids, belemnites and crinoid fragments, and passes upwards into Bed 18. Lower bed contains pinkish-coloured micritic intraclasts, also *D.* cf. *commune* and *H. sublevisoni*.	15 cm

LOWER TOARCIAN – SERPENTINUM CHRONOZONE, FALCIFERUM SUBZONE

16	Marl, grey, full of small nodules (1–2 cm), especially towards the top; *Harpoceras falciferum* [M] and [m] abundant.	10–15 cm
15	Irregular lenticles and scattered smaller nodules of argillaceous limestone in grey marl – *H. falciferum* present.	20–30 cm
14	Limestone, soft argillaceous micritic, thinly and irregularly bedded – pale greyish-buff colour. *H. falciferum* common; also contains *Hildaites* cf. *levisoni*, *Dactylioceras* sp.	40–50 cm
13	Marl, grey, with irregular lenticles of argillaceous micrite; *H. falciferum* present.	12–15 cm

LOWER TOARCIAN – SERPENTINUM CHRONOZONE, ELEGANTULUM SUBCHRONOZONE

12	Limestone, argillaceous micritic; thin nodular bed with irregular surfaces.	7–8 cm
11	Marl, grey, with small (<1 cm) limestone nodules.	12 cm
10	Limestone, argillaceous micritic, similar to bed 12.	7–9 cm
9	Marl, grey; with small limestone nodules (<1 cm) concentrated around a band towards the middle of the bed. This band yields *Dactylioceras* sp. The marl below contains *Harpoceras serpentinum* (Reinecke) and *Dactylioceras* sp.	25–28 cm
8	Limestone, argillaceous micrite; irregular band, with common ammonites on upper surface (*H. serpentinum*).	7 cm
7	Marl, grey; *H. serpentinum* present.	9 cm
6	Band of irregularly sized argillaceous micrite nodules (up to 5 cm in diameter).	0–5 cm
5	Marl, grey; greenish tinged.	3 cm
4	Marl, grey; laminated & sandy, seams rich in shell debris. Basal 5–10 cm rusty coloured, occasional irony nodules. The junction with Bed 3 is marked by a thin ochreous seam.	15–17 cm

LOWER TOARCIAN – TENUICOSTATUM CHRONOZONE

3	Limestone, concretionary argillaceous micrite, in part sandy. *Dactylioceras* sp. present on base of bed.	0–5 cm

MARLSTONE ROCK MEMBER
UPPER PLIENSBACHIAN – SPINATUM CHRONOZONE

2	Sand, calcareous and marly; with occasional concretions of bioclastic and sandy limestone (sandy calcarenite). *Pleuroceras* ex gr. *hawskerense* (Young & Bird) present; also abundant large belemnites and occasional brachiopods.	10–12 cm
1	Limestone; hard, sandy and bioclastic calcarenite; pale brownish-buff coloured, frequently with ferruginous staining. Contains occasional calcitic ooliths and abundant brachiopods, belemnites and bivalves. Occasional lenticles of softer sandy-marl occur at various levels in the unit; one, around 25 cm below the top, was associated with a large *Pleuroceras gigas* (Howarth). *P.* cf. *solare* is locally common, *c*. 15–20 cm below the top of bed 1. Additional faunal records include *P. spinatum* (Bruguiere), *P.* cf. *hawskerense* (Young & Bird), *P. solare* (Phillips), *P. apyrenum* (Buckman), *Lioceratoides serrinotu*, *Leptaleoceras lepturn* Buckman, *Tetrarhynchia tetrahedra* (J. Sowerby), *Lobothyris punctata* (J. Sowerby), *Pseudopecten aequivalis* (J. Sowerby), *Entolium* sp., *Chlamys* sp., *Oxytoma* sp., *Pleuromya* sp. and a large pleurotomariid gastropod. Excavated blocks suggest the total thickness of bed 1 is around 2–2.5 m. The basal part has an irregular contact with bluish-grey sandy silts; this layer contains abundant belemnites, brachiopods and *Pleuroceras* sp.	*c*. 1.6 m seen *in situ*

Section 2 – Cutting on north side of bypass on brow of Boxstone Hill [Grid ref ST 402155].
?QUATERNARY
BRIDPORT SAND FORMATION

28'	Sand, rusty weathering; passes into subsoil with lenses of limestone brash.	*c*. 2 m
27'	Band of widely spaced limestone nodules, composed of pale-grey argillaceous micrite. Belemnites and shell fragments common, also a fragment of *Pseudogrammoceras* sp.	0–5 cm

UPPER TOARCIAN – ?PSEUDORADIOSA CHRONOZONE, LEVESQUEI SUBCHRONOZONE

26'	Sand, rusty weathering, with pale grey patches containing some mud. Rusty at base.	1.6 m

BEACON LIMESTONE FORMATION; BARRINGTON MEMBER
UPPER TOARCIAN – THOUARSENSE CHRONOZONE, FALLACIOSUM SUBCHRONOZONE

25'   Clay, dark-grey; with bands of lenticular limestone concretions composed of grey argillaceous   55 cm
micrite. Near the junction with the Bridport Sand Fm., black streaks are present in the clay. At
7–15 cm below the top of the bed, a band of nodules is associated with abundant belemnites and a
fragment resembling *Pseudogrammoceras* sp.

UPPER TOARCIAN – THOUARSENSE CHRONOZONE, THOUARSENSE–FASCIGERUM SUBCHRONOZONES
     The basal 10–15 cm of 25' contains abundant, usually fragmentary, ammonites and belemnites,
also small (<1 cm) limestone nodules – *Grammoceras striatulum*, *G. thouarsense* and
Pseudogrammoceras sp. occur.

24'   Limestone, argillaceous micrite – grey when unweathered – with abundant ammonites, belemnites   Total for
and shell-fragments. Divisible into three units: – (c) topmost 2–3 cm; contains abundant   24' = 80 cm
Grammoceras cf. *striatulum*, belemnites and fragments of a thin-shelled (?Inoceramid) bivalve. The
upper surface of this layer has a ferruginous coating and occasionally passes laterally into a 5–10
cm thick ochreous band.

UPPER TOARCIAN – VARIABILIS CHRONOZONE
     (b) 3–15 cm below top of 24'; a layer full of derived and broken ammonites, typically encased in
intraclastic pebbles *or* oncolites (i.e. 'Mummien'); *Haugia* ex gr. *phillipsi* is abundant. Some
intraclasts have decayed and ochreous cores.
     (a) lowest *c*. 75 cm of Bed 24', contains abundant *Hildoceras semipolitum*. Some specimens have an
epifauna consisting of small (5–10 mm long) serpulids and oysters. *Haugia* cf. *variabilis* (d'Orbigny)
present 30 cm below top of bed 24', with abundant *Hildoceras semipolitum*.

LOWER TOARCIAN – BIFRONS CHRONOZONE, BIFRONS SUBCHRONOZONE
     Hildoceras semipolitum abundant without *Haugia* present in lowest 50 cm of 24'
     Marl seam, grey; with small nodules. Thickness not known (base of section).

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