The Charmouth 16A borehole Dorset U.K.: Palynology of the Penarth Group and the basal Lias Group (Upper Triassic – Lower Jurassic)

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Palynomorphs from a succession proved in a cored borehole at Charmouth, in the Dorset and East Devon Coast World Heritage Site, amplify the incomplete palynological documentation of the Penarth Group and basal Lias Group previously available from coastal exposures and a borehole in east Devon. Units examined are the upper Westbury Formation, the Lilstock Formation, including beds (the Cotham Member) that are typically poorly exposed, and the Blue Lias, to a level in the Hettangian Stage. Miospore associations increase in diversity upwards through the upper Westbury Formation and the Cotham Member, into the basal Langport Member; associations from higher beds, particularly in the Blue Lias Formation, are less diverse. A change from dinoflagellate cyst-dominated to acritarch-dominated organic-walled microplankton associations occurs above the basal Langport Member.

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Introduction

The Charmouth 16A borehole (British Geological Survey registered number SY39SE/5) was one of a series of boreholes drilled in 1973 in connection with a study, by the former Institute of Geological Sciences Engineering Geology Unit, of coastal landslipping in the Lyme Regis - Charmouth area (Institute of Geological Sciences, 1974, p. 3). The borehole site [SY 36560 93077] is in the Dorset and East Devon Coast World Heritage Site, at an elevation of 3.39 m above OD.

Drilling was supervised by M. G. Culshaw, who also logged core at the site. The core was subsequently examined by Dr A. Whittaker. Depths used in this account are based on an unpublished log (Whittaker, 1974) in which the terminal depth of the borehole is 3.04 m less than that published (Institute of Geological Sciences, 1974). Coring, with a nominal core diameter of 92.1 mm (Culshaw, 1973), commenced at 54.47 m, and the borehole was terminated at 88.84 m (Whittaker, 1974). The succession cored is summarised in Table 1

Higher beds in the Lias Group were cored in the adjacent Charmouth 16 borehole [SY 36533 93090] which was terminated in the Blue Lias at a depth of 58.88 m (Institute of Geological Sciences, 1974) ; this section overlaps the top of that cored in borehole 16A by about 4.4 m.

The Charmouth 16A borehole ('Borehole 16A') was terminated 2.72 m below the top of the Westbury Formation, which is 9.88 m thick in the Lyme Regis (1901) Borehole [SY 336 930], *c.*3 km to the west (Warrington and Scrivener, 1980). In contrast, Richardson (1906) recorded only 5.13 m at outcrop in the Culverhole - Charton Bay coast sections, *c.*6 km west of Lyme Regis [*c.*SY 270 894 - SY 300 900]. Hart (1982) and Gallois (2003) illustrated *c.*5.65 m and *c.*7.5 m respectively from those sections, and Edwards and Gallois (2004) recorded 6 to 8 m in the Sidmouth district. The suggestion (Callomon and Cope, 1995) that the formation comprises 'up to 15 m of marine black shales' in this area, is clearly erroneous.

The Cotham Member is 2.64 m thick in Borehole 16A, compared with 1.88 m in the Lyme Regis borehole (Warrington and Scrivener, 1980). Richardson (1906) recorded 1.75 m in the Culverhole - Charton Bay section; Hart (1982), Mayall (1983) and Gallois (2003) illustrated 1.83, 1.6 and *c.*2 m respectively for those sections, and Callomon and Cope (1995) recorded 'about 1.5 m'. Edwards and Gallois (2004) recorded up to 1.5 m in the Sidmouth district.

Formation/Member	**Depth to base (m)**	**Thickness (m)**
Lower Lias		
Blue Lias Formation	74.64	(20.17 m cored)
Penarth Group		
Lilstock Formation	86.12	11.48
Langport Member	83.48	8.84
Cotham Member	86.12	2.64
Westbury Formation	(seen to TD: 88.84)	(2.72 m seen)

Table 1. *Summary of the lithostratigraphic units examined in this paper.*

The Langport Member is 8.84 m thick in Borehole 16A, compared with *c*.6.73 m in the Lyme Regis borehole (Warrington and Scrivener, 1980). Richardson (1906) recorded 7.62 m in the Culverhole - Charton Bay sections, and Hart (1982) illustrated 8.33 m for those sections. Hallam (1960) recorded 7.85 m from exposures in Pinhay Bay [SY 319 908], and Hesselbo and Jenkyns (1995) and Hesselbo *et al.* (2004) illustrated *c*.6.8 m for that section. Callomon and Cope (1995) recorded about 8 m in the coast sections, and Edwards and Gallois (2004) recorded up to 9 m in the Sidmouth district; a 4.8 m-thick section illustrated by Gallois (2003) from Culverhole Point is overlain unconformably by Cretaceous rocks and is incomplete.

PALYNOLOGY

Previous work

The coastal sections between Pinhay Bay, east Devon, and West Bay, Dorset, provided material for an early study of Lower Jurassic palynomorph assemblages by Wall (1965), who recorded organic-walled microplankton, mostly acritarchs, and spore and pollen associations from Blue Lias Bed H.29 (Lang, 1924), in the Hettangian *planorbis* Zone, upwards into the Toarcian (*levesquei* Zone).

Orbell (1973) sampled the Penarth Group at outcrop farther west in Charton Bay, east Devon, and recorded palynomorphs from four levels in the lower *c*.3 m of the Westbury Formation and ten in the upper *c*.6.4 m of the Langport Member ('White Lias') of the succeeding Lilstock Formation. Fisher (1985) reported palynomorphs from three samples from the Westbury Formation, three from the Langport Member and one from the basal Lias in the same area. The incomplete sampling of the Penarth Group by these workers resulted from the upper part of the Westbury Formation and the lower part of the Lilstock Formation, including the Cotham Member and basal Langport Member, being obscured by landslip.

A more complete palynological record of the Penarth Group was obtained by Warrington (1997), who utilised core from the Lyme Regis (1901) borehole (Jukes-Browne, 1902; Warrington and Scrivener, 1980). However, collections of material from this borehole only provided samples representing four levels in the Westbury Formation, two in the Cotham Member, and two in the Langport Member. Samples were not available from the basal (Pre-planorbis) beds of the Blue Lias Formation in this borehole, but overlap with Wall's (1965) study was provided by three from higher levels in that formation (Warrington, 1997).

Charmouth 16A borehole: samples

Samples from this borehole, held in the British Geological Survey (BGS) collections, allowed a more detailed study of most of the Penarth Group (Figure 1). Three samples from the top of the Westbury Formation cover an interval not sampled by Orbell (1973), and amplify the solitary record from a comparable level in the Lyme Regis borehole (Warrington, 1997). Four samples from the Cotham Member cover an interval not sampled by Orbell (1973) or Fisher (1985), and amplify the record from the Lyme Regis borehole (Warrington, 1997). The four lowest samples from the Langport Member cover an interval not sampled by Orbell (1973), and the ten examined from this member greatly amplify the record from the Lyme Regis borehole (Warrington, 1997).

Four samples from the basal (Pre-planorbis) beds of the Blue Lias Formation (Figure 1) cover an interval not sampled in the Lyme Regis borehole. Sample MPA 40792, from a bed identified by Whittaker (1974) as the equivalent of Bed H.29 of Lang (1924), and one from a slightly higher level, provide overlap with the lowest levels in Wall's (1965) study, and cover an interval not sampled in the Lyme Regis borehole.

In Borehole 16A, and the Lyme Regis borehole, the palynological study extends above the level, in Bed H.25 of Lang (1924), of the lowest record of the ammonite *Psiloceras* which is used to mark the base of the Hettangian, and of the Jurassic, in Britain (Cope *et al.*, 1980; Warrington *et al.*, 1980). Page (2002) considered that psiloceratid ammonites from beds H.25 and 26 may be *Neophyllites* and suggested a broad correlation with the *imitans* and *antecedens* biohorizons of Page and Bloos (1998), but retained a level in Bed H.25 as the base of the Jurassic.

Charmouth 16A borehole: palynomorph assemblages

The palynomorph assemblages (Figure 1) comprise miospores (spores and pollen) and organic-walled microplankton. The latter are indigenous to the depositional environment of the lithologies sampled and, with associated foraminifer test linings and scolecodonts, indicate marine conditions; the miospores are derived from a contemporary flora and are allochthonous to the depositional environment. Miospores dominate the majority of the assemblages, though organic-walled microplankton and other remains are commonly a significant component and are dominant in the lower part of the Cotham Member and the upper part of the Pre-planorbis Beds.

The miospore associations increase in diversity upwards through the Westbury Formation and Cotham Member, into the basal Langport Member (sample MPA 40806). Associations from higher beds, particularly in the Blue Lias Formation, are less diverse.

Associations from the upper beds of the Westbury Formation are dominated by pollen, principally *Ricciisporites tuberculatus* and circumpolles (*Classopollis* spp., *Geopollis zwolinskae, Granuloperculatipollis rudis*), together with smaller numbers of *Ovalipollis pseudoalatus, Rhaetipollis germanicus* and *Vesicaspora fuscus*. Other determinable specimens are mostly or exclusively (MPA 40813) spores (*Acanthotriletes* spp., *Carnisporites anteriscus?*, *Cingulizonates rhaeticus, Convolutispora microrugulata, Cornutisporites seebergensis, Deltoidospora* spp., *Densosporites* spp., *Kraeuselisporites reissingeri, Leptolepidites argenteaeformis, Limbosporites lundbladii, Microreticulatisporites fuscus, Perinosporites thuringiacus, Retitriletes* spp., *Stereisporites* spp., *Triancoraesporites ancorae, Zebrasporites interscriptus*), but include pollen (*Alisporites* spp., *Chasmatosporites magnolioides, Lunatisporites rhaeticus, Protohaploxypinus* cf. *microcorpus, Quadraeculina anellaeformis*); these taxa are represented by very few specimens.

Associations from the lower half of the Cotham Member (MPA 40808 to 40810) are dominated by *Alisporites* spp., which are relatively more abundant than in Westbury Formation associations, and *Classopollis* spp., *O. pseudoalatus* and *R. tuberculatus* which are relatively less abundant. They include, with the exception of *C. seebergensis, Densosporites* spp., *G. rudis* and *T. ancorae*, which are not recorded above the Westbury Formation in this section, all the taxa present in that formation, and additional spores (*Baculatisporites* sp., *Calamospora* spp., *Osmundacidites* sp., *Kyrtomisporis laevigatus, Lycopodiacidites rugulatus?*, *Todisporites minor?*) and pollen (*Cycadopites* sp., *Tsugaepollenites? pseudomassulae*). Many taxa present in the lower half of the member were also recorded near its top (MPA 40807), or at higher levels in this section. Exceptions are *G. zwolinskae* and *P.* cf. *microcorpus*, the highest occurrences of which are at the base of the member (MPA 40810), and *L. rhaeticus, O. pseudoalatus, P. thuringiacus, R. germanicus, V. fuscus* and *Z. interscriptus*, which are not recorded above the middle of the member (MPA 40808). The association from near the top of the member is dominated by *Classopollis* spp., together with smaller numbers of *Acanthotriletes varius, Calamospora* spp., *Convolutispora microrugulata, M. fuscus, R. tuberculatus* and *T. minor*. The spores *Carnisporites spiniger, Polycingulatisporites bicollateralis, Porcellispora longdonensis* and *Semiretisporis maljavkinae* were only recorded at this level; other taxa that appear at this level (*Contignisporites problematicus, Converrucosisporites luebbenensis?, Gliscopollis meyeriana, Podocarpites* sp.?) were also recorded higher in the section.

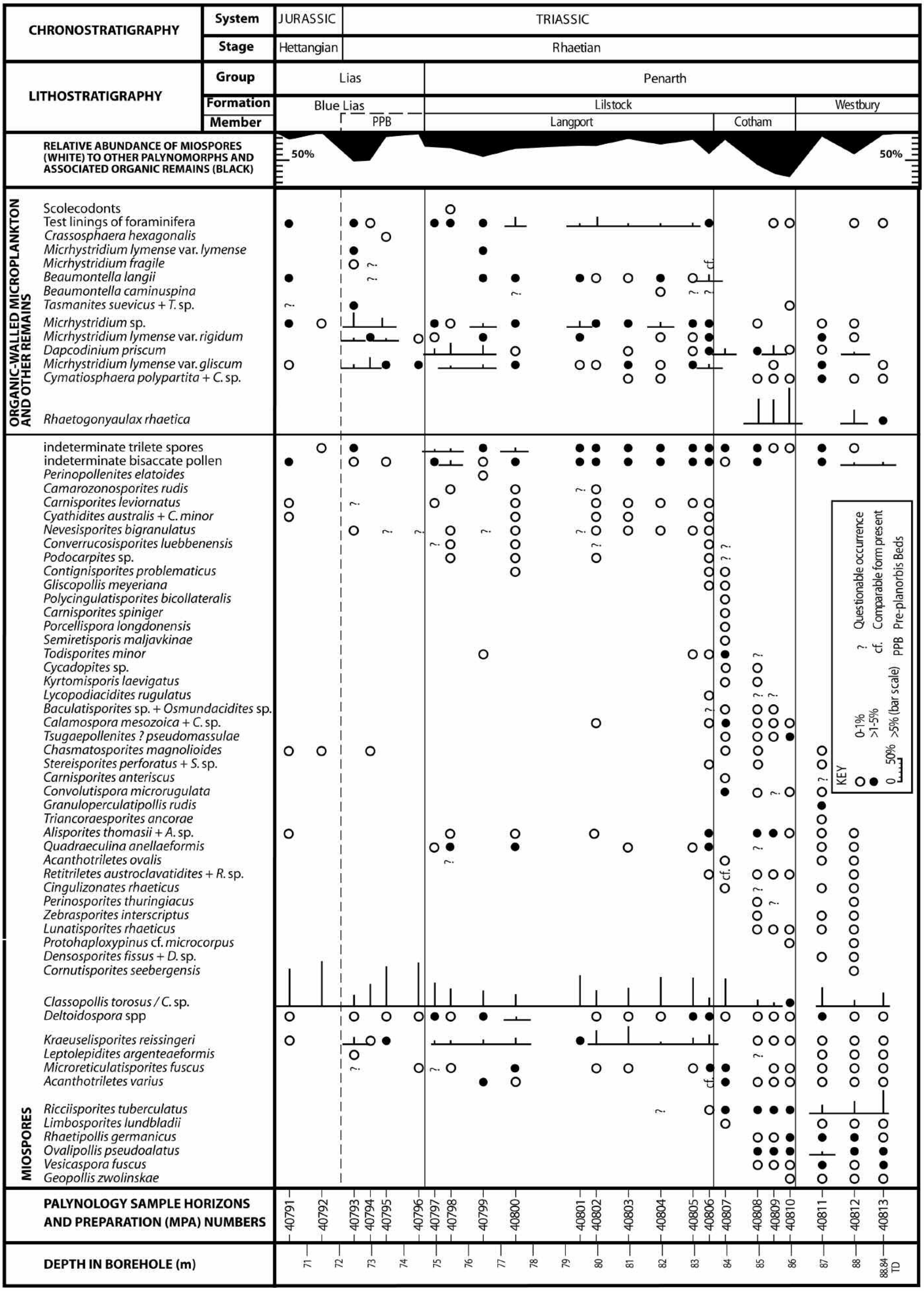

Figure 1. *Distribution and relative abundances of palynomorphs from Charmouth 16A Borehole. Preparations are held in the palynology collections at BGS, Keyworth, and are registered in the MPA series.*

An association from the base of the Langport Member (MPA 40806) is similar to that from the upper part of the Cotham Member; dominant taxa are the spores *K. reissingeri* and *M. fuscus*, together with circumpolles and other pollen (*Alisporites* spp. and *Q. anellaeformis*). The spores *Carnisporites leviornatus, Cyathidites* spp. and *Nevesisporites bigranulatus* appear at this level in the section.

Associations from higher in the member are similar in character to that from the lowest level sampled (MPA 40806) but, with the exceptions of MPA 40802 and 40800, are markedly less diverse. These associations are dominated by *K. reissingeri* and circumpolles with, at various levels, *A. varius, Deltoidospora* spp., *M. fuscus* and *Q. anellaeformis*. Other taxa are present in smaller numbers and comprise those recorded from lower levels in the section, with the exceptions of *Baculatisporites* sp.?, *Gliscopollis meyeriana, Lycopodiacidites rugulatus, Osmundacidites* sp.?, *Retitriletes* spp. and *Stereisporites* spp., which were not recorded above the lowest sampled level (MPA 40806). The spore *Camarozonsporites rudis* appears near the middle of the member (MPA 40802) and is present in most associations from the member above that level.

Associations from the Blue Lias Formation are less diverse than many of those from the Langport Member. They are dominanted by circumpolles with, at some levels, smaller numbers of the spore *K. reissingeri*. Other taxa occur only sporadically and in very small numbers, and include only some of those present lower in the section (*Alisporites* spp., *Carnisporites leviornatus, Chasmatosporites magnolioides, Cyathidites* spp., *Deltoidospora* spp., *L. argenteaeformis, M. fuscus* and *N. bigranulatus*); *L. argenteaeformis, M. fuscus* and *N. bigranulatus* were not recorded above the Pre-planorbis Beds in this section.

The organic-walled microplankton associations include acritarchs, dinoflagellate cysts and prasinophyte algae.

Associations from the upper beds of the Westbury Formation include acanthomorph and herkomorph acritarchs (*Micrhystridium* spp., *Cymatiosphaera* spp.), and the dinoflagellate cysts *Dapcodinium priscum* and *Rhaetogonyaulax rhaetica*; dinoflagellate cysts are dominant except in the highest association (Figure 1).

Associations from the lower half of the Cotham Member are dominated by dinoflagellate cysts, principally *R. rhaetica*, but include a few acritarchs and *Tasmanites*, a prasinophyte alga. In contrast, the association in the highest sample from the member (MPA 40807) is sparse and comprises only *D. priscum; R. rhaetica* was not recorded above the lower part of the member in this section.

Associations from the lower half of the Langport Member are dominated by acritarchs, principally the acanthomorph *Micrhystridium*. Dinoflagellate cysts include small numbers of *D. priscum* and *Beaumontella* spp. Associations from near the top of the member (MPA 40797 to 40799) include *Micrhystridium* spp. but are dominated by dinoflagellate cysts (D. priscum with, at one level, smaller numbers of *Beaumontella langii*). Associations from the Blue Lias Formation are dominated by *Micrhystridium* spp. but some include dinoflagellate cysts (*B. langii*) or prasinophyte algae (*Crassosphaera hexagonalis, Tasmanites* spp.).

Other remains observed in the palynomorph preparations include scolecodonts and test linings of foraminifera (Figure 1). The former were recorded only near the top of the Langport Member; the latter occur throughout the section studied, but are most abundant in the lower and middle parts of the Langport Member (MPA 40800 to 40806).

Discussion

Through the upper part of the Westbury Formation and the Cotham Member, miospore associations from Borehole 16A display changes in composition, relative abundances, and diversity similar to those recorded from those units elsewhere in south-west Britain: e.g. in the Lyme Regis borehole (Warrington, 1997), west Dorset; at St Audrie's Bay (Hounslow *et al.*, 2004) and in Selworthy 2 borehole (Warrington *et al.*, 1995; Edwards, 1999), west Somerset; in High Ham R8 borehole, central Somerset (Warrington *et al.*, 1986); in Dundry borehole, north Somerset (Warrington *in* Kellaway and Welch, 1993), and at Lavernock, South Glamorgan (Orbell, 1973; Warrington *in* Waters and Lawrence, 1987). Some taxa disappear and others appear within these units in this section, but the upward increase in diversity is reflected in an increase in the total number of miospore genera recognised from 12, in the lowest Westbury Formation association, to 26 in that from the top of the Cotham Member, and from 6 to 19, respectively, in the case of spore genera alone.

The associations from the Langport Member are similar in composition to those recorded by Orbell (1973) from the member at Pinhay Bay. The association from the base of the member, with 22 genera, including 16 spore genera, is slightly less diverse than that from the top of the Cotham Member. Those from higher in the Langport Member show lower, but very variable, diversities. Hallam (1960), Wignall (2001) and Hesselbo *et al.* (2004) have documented evidence of penecontemporaneous movement of the Langport Member sediments, including slumps and debris flows containing limestone intraclasts; the latter feature occurs in Borehole 16A (Whittaker, 1974; Appendix 1). Hesselbo *et al.* (2004) interpreted the Langport Member in south Devon as comprising gravity-flow deposits shed from a storm-dominated carbonate ramp. The variability in the miospore associations (Figure 1) may be related to the penecontemporaneous disturbance and reworking evident in the sediments, and the integrity of the palynomorph succession may also be affected by reworking.

Miospore associations from the Blue Lias are generally less diverse than those from the Langport Member (Figure 1).

The miospore associations from the Penarth Group in Borehole 16A are of Rhaetian (latest Triassic) age, as also, by definition, are those from the Pre-planorbis Beds of the Blue Lias.

Organic-walled microplankton associations from the Westbury Formation and Cotham Member are dominated by dinoflagellate cysts; those from the Langport Member and Blue Lias are dominated by acritarchs (Figure 1). The presence of *Rhaetogonyaulax rhaetica* is indicative of the Rr dinoflagellate cyst zone *sensu* Powell (1992). This was regarded as Rhaetian, with its top, at the highest occurrence of *R. rhaetica*, marking the base of the Jurassic; however, *R. rhaetica* ranges into the basal Hettangian (Warrington 1981; Hounslow *et al.* 2004).

The succession examined from Borehole 16A is marine. However, in the nearest outcrop sections, on the south Devon coast, algal stromatolites, signifying shallow water or emergent conditions, occur in the upper part of the Cotham Member, above deformed beds interpreted as a seismite produced by earthquake activity (Mayall, 1983); Simms (2003) suggested that a bolide impact may have caused the necessary disturbance. The stromatolitic developments occur above a level that Hesselbo *et al.* (2004) correlated with a desiccation-cracked erosion surface that overlies similar deformed beds at St Audrie's Bay, west Somerset; they interpreted this surface as a sequence boundary, between a falling stage to lowstand systems tract, represented by the lower part of the Cotham Member, and the inception of a transgressive systems tract in the overlying beds. A desiccation-cracked erosion surface has not been recognized above the deformed beds in exposures in south Devon where the Cotham Member appears to comprise a more continuous sedimentary record than in west Somerset (Mayall, 1983). However, 'cracks ... filled with different lithologies from higher levels' were noted between 85.11 and 86.12 m in Borehole 16A (Whittaker, 1974; Appendix 1), in the lower half of the member, though whether these features, observed in the confines of a 92.1 mm-diameter core, are analogous to those seen in the west Somerset exposures is, perhaps, debateable.

The abrupt disappearance of *Rhaetogonyaulax rhaetica* around the middle of the Cotham Member in Borehole 16A may occur immediately below the level of the suggested sequence boundary, as does a marked decline in numbers of that taxon at St Audrie's Bay, where, however, this dinoflagellate cyst ranges into the basal Hettangian (Warrington, 1981; Hounslow *et al.*, 2004). Sea-level, salinity and other environmental changes through the Penarth Group-basal Lias Group succession therefore influenced the relative abundances of this taxon, and other dinoflagellate cysts and acritarchs (Warrington, 1981), rather than their stratigraphical distribution.

The abrupt loss of some miospores, including *Ovalipollis pseudoalatus* and *Rhaetipollis germanicus*, at the same level as *R. rhaetica* in Borehole 16A, does not occur consistently in other sections. A 'rapid decline' in the numbers of these pollen and *Ricciisporites tuberculatus* was used by Orbell (1973) to define the boundary between a lower (*Rhaetipollis*) and an upper (*Heliosporites*) zone in the lower part of the Cotham Member. Hesselbo *et al.* (2004, figure 4) equated this level with a major negative $\delta^{13}C_{org}$ excursion (their 'initial carbon-isotope excursion') that occurs between 0.1 and 0.3 m above the desiccation-cracked erosion surface, or sequence boundary, in west Somerset. However, the apparently synchronous 'rapid decline' in these pollen taxa, illustrated from sections in South Glamorgan, Oxfordshire and Nottinghamshire (Orbell, 1973), does not occur consistently in sections in Somerset and South Glamorgan (see above) and others throughout central and eastern England documented by the author. In these the decline is usually phased, with a reduction in the numbers of *R. germanicus* preceding that in *O. pseudoalatus* which, as in Borehole 16A, precedes that in *R. tuberculatus*. These changes may all occur within the Cotham Member (Lott and Warrington, 1988; Warrington *in* Old *et al.*, 1987, 1991), though the decline in *R. germanicus* may occur in the underlying Westbury Formation (Warrington, 1977, 1978; Warrington in Waters and Lawrence, 1987, Powell *et al.*, 1992, Frost, 1998, Gaunt *et al.*, 1992, Barclay *et al.* 1997), and that in *R. tuberculatus* at the top of the Cotham Member, or in higher beds (Warrington, 1978; Warrington in Powell *et al.*, 1992, Frost, 1998, Hounslow *et al.*, 2004).

Correlation of the palynological records with a carbon isotope event, with implications for a possible causal relationship with Central Atlantic Magmatic Province volcanic emissions and gas hydrate dissociation (e.g. Pálfy *et al.*, 2001; Hesselbo *et al.*, 2002), rather than biogeographical changes related to the progress of a marine transgression (e.g. Warrington, 1981), requires further study. Though apparently indicated by some palynological documentation from the UK, it is not necessarily supported by the majority of the records from that region.

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Appendix 1

Log of the section of the Charmouth 16A Borehole sampled for palynology (after Whittaker, 1974).

(Abbreviations: Lst. - limestone; Mudst. - mudstone; Siltst. - siltstone; calc. - calcareous)

	Thickness (m)	Palynology (MPA) sample and depth
LOWER LIAS: Blue Lias Formation (*pars*.: from 69.98m)		
Lst., medium grey; nodular top; some pyrite	0.10	
Mudst., medium to dark grey; some shell material and lst. nodules in top 0.10m; many echinoid spines at 70.27m	0.21	
Lst., medium pale grey	0.08	
Mudst., medium grey, with brown tint	0.02	
Lst., medium grey; silty	0.02	
Mudst., medium grey	0.03	
Lst., medium to pale grey; with calcite veins	0.05	40791 (70.46 m)
Mudst., medium grey, hard, calc.; 0.01m lst. at 70.52m	0.05	
Lst., pale grey; with a calcite string	0.09	
Mudst., medium to dark grey; some 'beef' at base	0.12	
Lst., medium grey; very fine grained	0.34	
Mudst., medium grey, blocky, calc.; with echinoid spines, fish scales and *Psiloceras* [= Lang H.29]	0.49	40792 (71.46 m)
Shale, dark grey; some shelly material	0.13	
Mudst., medium grey; very shelly, with *Ostrea*	0.10	
Lst., medium grey; very shelly; some pyrite	0.18	
Mudst., medium to dark grey, hard, calc.; with *Psiloceras* [= Lang H.25]	0.07	
Lst., medium grey; shelly, large bivalves	0.09	
Mudst., medium to dark grey	0.12	
Lst., medium grey; nodular top; some shelly material	0.13	
Mudst., medium to dark grey; many *Ostrea* at top; thin-shelled oysters and fish scales in lower half	0.04	
Lst., medium grey; with shells	0.09	40793 (72.46 m)
Mudst., medium grey; hard, calc. and with burrows and oysters below 72.56m	0.09	
Mudst., dark grey; shelly	0.13	

	Thickness (m)	Palynology (MPA) sample and depth
Lst., medium grey; nodular top; some shells	0.09	
Mudst., dark grey	0.02	
Lst., medium grey; shelly	0.09	
Shale, dark grey; many *Ostrea* and echinoid spines	0.33	40794 (72.96 m)
Lst., medium grey; few fossils	0.12	
Mudst., dark grey; *Ostrea*-rich bands	0.05	
Lst., medium grey; with shells	0.08	40795 (73.46 m)
Shale, medium to dark grey; with echinoid spines	0.07	
Lst., medium grey	0.04	
Shale, dark grey; with *Ostrea* and echinoid spines	0.06	
Lst., medium grey; near-vertical calcite veins	0.14	
Shale, dark grey; a few shells	0.19	
Mudst., medium grey, calc.; with shells	0.06	
Lst., medium grey; hard calc. mudst. wisps; upper 0.05m shelly	0.19	
Mudst., dark grey; a few shells	0.02	
Lst., medium grey	0.05	
Shale, dark grey; a few shells	0.05	
Lst., medium grey; three bands separated by mudst. partings	0.03	
Shale, dark grey, with brown tint	0.20	40796 (74.46 m)
Mudst., dark grey, shelly	0.01	

PENARTH GROUP: Lilstock Formation; *Langport Member* (top: 74.64m)

	Thickness (m)	Palynology (MPA) sample and depth
Lst., very light grey, fine grained; wispy patches of darker grey porcellanous lst ; 0.01m-deep U-shaped burrows in the top	0.36	40797 (74.96 m)
Mudst., medium grey, hard, calc.; with listric surfaces	0.03	
Lst., very light grey; conglomeratic appearance in places; minor slump structures and marly wisps with listric surfaces at 75.46m	0.71	40798 (75.46 m)
Mudst., dark grey; many listric surfaces	0.02	
Lst., very light grey; near-vertical stylolitic fissure; some marly partings	1.10	40799 (76.46 m)
Mudst., dark grey; many listric surfaces	0.01	
Lst., very light grey; wisps of dark grey mudst. and irregular stylolite-like surfaces imparting slumped appearance. Many rounded paler grey lst. pebbles up to 0.01m diameter below 77.00m; pebbly bands and non-pebbly stylolitic lsts alternate. Pebbly band at 78.28m contains rather angular lst. fragments up to 0.05m diameter	1.71	40800 (77.46 m)
Lst., pale creamish-grey, fine grained, hard; some pebbles of paler grey lst. and a few wispy patches of mudst.	0.21	
Lst., medium grey; many paler grey lst. pebbles (0.03m diameter)	0.13	
Lst., pale creamish grey; pebbly	0.10	
Lst., medium grey; many angular and rounded pale grey lst. pebbles, increasing in size from c.0.005 to 0.03m towards the base	0.13	
Lst., pale creamish grey; brecciated in top 0.04m, with many medium grey mudst. wisps with listric surfaces below; distinctly brecciated appearance below 80.50m	2.66	40801 (79.46 m) 40802 (79.96 m) 40803 (80.96 m)
Lst., pale creamish grey; wispy mudst. partings; conglomeratic appearance in places	1.10	40804 (81.96 m)
Lst., medium grey, fine grained, porcellanous	0.25	40805 (82.96 m)
Lst., pale creamish grey; wispy mudst. partings; conglomeratic appearance in places	0.07	
Lst., medium grey, fine grained, rather porcellanous; marly in top 0.05m	0.25	40806 (83.46 m)

Lilstock Formation; *Cotham Member* (top: 83.48m)

	Thickness (m)	Palynology (MPA) sample and depth
Siltst., medium grey, fine grained, blocky; faint lamination in places; finely micaceous	0.09	
Mudst., dark grey; marly; with bivalves	0.09	
Lst., medium pale grey; silty; some shells and calcite veinlets	0.19	
Mudst., medium dark grey, with green tint; many listric surfaces and silty wisps and patches below 84.03m; ostracods (?) at 84.14m	0.31	40807 (83.96 m)
Mudst., medium greenish grey; pale buffish grey silt wisps; faint lamination. Silty partings more numerous below 84.46m; striped appearance in lowest 0.13m	0.50	
Siltst., pale buffish grey; many dark greenish grey mudst. partings imparting striped appearance	0.17	
Siltst., pale greenish grey; medium grained; some calcite veining	0.12	
Siltst., pale buffish grey, with green tint	0.16	40808 (84.96 m)
Mudst., pale greyish green, blocky; with grey siltst. wisps and laminae; striped appearance in places. Cracks filled with different lithologies from higher levels.	1.01	40809 (85.46 m) 40810 (85.96 m)

	Thickness (m)	Palynology (MPA) sample and depth
Westbury Formation (top: 86.12m)		
Mudst., very dark grey; slightly shaley; traces of 'beef' at top; listric surfaces; many scattered bivalves, including *Rhaetavicula contorta*	1.51	40811 (86.96 m)
Lst., very dark grey; argillaceous	0.10	
Mudst., very dark grey; moderately fissile; hard, calc. below 88.68m; some wisps of soft, pale grey silt; scattered shells	1.03m	40812 (87.96 m)
Lst., medium grey; a few shells, including *Rhaetavicula contorta* (0.08m seen above Terminal Depth: 88.84m)		40813 (88.84 m)

Appendix 2

Author citations for palynomorph species.

Miospores

Acanthotriletes ovalis Nilsson 1958
Acanthotriletes varius Nilsson 1958
Alisporites thomasii (Couper) Nilsson 1958
Calamospora mesozoica Couper 1958
Camarozonosporites rudis (Leschik) Klaus 1960
Carnisporites anteriscus Morbey 1975
Carnisporites leviornatus (Levet-Carette) Morbey 1975
Carnisporites spiniger (Leschik) Morbey 1975
Chasmatosporites magnolioides (Erdtman) Nilsson 1958
Cingulizonates rhaeticus (Reinhardt) Schulz 1967
Classopollis torosus (Reissinger) Balme 1957
Contignisporites problematicus (Couper) Döring 1965
Converrucosisporites luebbenensis Schulz 1967
Convolutispora microrugulata Schulz 1967
Cornutisporites seebergensis Schulz 1962
Cyathidites australis Couper 1953
Cyathidites minor Couper 1953
Densosporites fissus (Reinhardt) Schulz 1967
Geopollis zwolinskae (Lund) Brenner 1986
Gliscopollis meyeriana (Klaus) Venkatachala 1966
Granuloperculatipollis rudis Venkatachala & Góczán, emend. Morbey 1975
Kraeuselisporites reissingeri (Harris) Morbey 1975
Kyrtomisporis laevigatus Mädler 1964
Leptolepidites argenteaeformis (Bolkhovitina) Morbey 1975
Limbosporites lundbladii Nilsson 1958
Lunatisporites rhaeticus (Schulz) Warrington 1974
Lycopodiacidites rugulatus (Couper) Schulz 1967
Microreticulatisporites fuscus (Nilsson) Morbey 1975
Nevesisporites bigranulatus (Levet-Carette) Morbey 1975
Ovalipollis pseudoalatus (Thiergart) Schuurman 1976
Perinopollenites elatoides Couper 1958
Perinosporites thuringiacus Schulz 1962
Polycingulatisporites bicollateralis (Rogalska) Morbey 1975
Porcellispora longdonensis (Clarke) Scheuring, emend. Morbey 1975
Protohaploxypinus cf. microcorpus (Schaarschmidt) Clarke 1965
Quadraeculina anellaeformis Maljavkina 1949
Retitriletes austroclavatidites (Cookson) Döring, Krutzsch, Mai and Schulz 1963
Rhaetipollis germanicus Schulz 1967
Ricciisporites tuberculatus Lundblad 1954
Semiretisporis maljavkinae Schulz 1967
Stereisporites perforatus Leschik 1956
Todisporites minor Couper 1958
Triancoraesporites ancorae (Reinhardt) Schulz 1967
Tsugaepollenites? pseudomassulae (Mädler) Morbey 1975
Vesicaspora fuscus (Pautsch) Morbey 1975
Zebrasporites interscriptus (Thiergart) Klaus 1960

Dinoflagellate cysts

Beaumontella caminuspina (Wall) Below 1987
Beaumontella langii (Wall) Below 1987
Dapcodinium priscum Evitt, emend. Below 1987
Rhaetogonyaulax rhaetica (Sarjeant) Loeblich & Loeblich, emend. Below 1987

Acritarchs

Cymatiosphaera polypartita Morbey 1975
Micrhystridium fragile Deflandre 1947
Micrhystridium lymense var. gliscum Wall 1965
Micrhystridium lymense var. lymense Wall 1965
Micrhystridium lymense var. rigidum Wall 1965

Prasinophyte algae

Crassosphaera hexagonalis Wall 1965
Tasmanites suevicus (Eisenack) Wall 1965