بسم الله الرحمن الرحيم

IN THE NAME OF GOD THE COMPASSIONATE THE MERCIFUL

THE UNIVERSITY
of LIVERPOOL

PATTERNS OF MICROFAUNAL OCCURRENCE ACROSS THE CENOMANIAN-TURONIAN BOUNDARY IN ENGLAND

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ABSTRACT

The Cenomanian-Turonian boundary mass extinction (the second largest Cretaceous extinction event) has been fully documented in three sections, Eastbourne and Westbury in the south, and South Ferriby in the north of England. All three sections comprise the uppermost Cenomanian and lowermost Turonian strata representing the uppermost *Rotalipora cushmani* and the lower part of the *Whiteinella archeocretacea* Zones.

A detailed study of foraminifera in both coarse fraction (>250 μm) and fine fraction (63-90 μm) as well as ostracods has been done. Based on percentage of coarse benthic foraminifera, 5 assemblages (A to E) at Eastbourne and 4 assemblages (A to D) at Westbury, have been recognised by cluster analysis. The clusters are controlled by sequential palaeoecological changes not by local facies: when facies return to pure chalks above the Plenus Marls the fauna is very restricted compared to the diverse fauna in the chalks below the Plenus Marls.

In both southern sections cluster A is characterised by a diversified and high abundance assemblage, while the diversity decreases dramatically in cluster B upwards, which indicates a stressed environment. Clusters D and E are characterised by a low diversity (at Eastbourne about 1/4 initial value) and high dominance assemblage represented by a few species. Abundance falls severely only above the bed 8 of the Plenus Marls Formation.

The Black Band in South Ferriby section conforms to a succession of 11 beds, lettered here A to I, which are characterised by a particular lithology and microfaunal assemblages.

Stable isotopes of carbon and oxygen have been studied from the late Cenomanian - early Turonian interval, during which $\delta^{13}C$ exhibits a positive excursion with a maximum value of +5.3 ‰ (PDB). In southern sections the peak of the excursion occurs at the top of Plenus Marls and lowest part of Melbourn Rock, while at South Ferriby the peak of $\delta^{13}C$ excursion coincides with lower part of the Black Band succession.

The extinctions exhibit a selective pattern affecting the largest species first in both benthic and planktic foraminifera. In both Westbury and South Ferriby only one extinction step is apparent, while at Eastbourne two prominent extinction steps are recognisable. These intervals correlate with rising $\delta^{13}C$ values and falling $\delta^{18}O$ values.

At Eastbourne the podocopid/platycopid changes is in parallel by $\delta^{18}O$ values. The proportion of podocopids in the Grey Chalk and bed 2 to the middle of bed 4, where $\delta^{18}O$ values are more positive is high, while platycopids are nearly totally dominant in the rest of the section, where $\delta^{18}O$ values decrease.

Diversity of fine benthic foraminifera is low and it seems that the assemblage is more influenced by sea level fluctuation than by changes in $\delta^{13}C$ and $\delta^{18}O$ values.

The comparison between the results obtained in this thesis and two rival models for the Cenomanian-Turonian boundary mass extinction, famine and high productivity, has been done. Although there are some evidence to support each model, some problems still exist in both of them. Two main factors, less food and low oxygen levels, have been proposed as the main causes of the Cenomanian-Turonian boundary mass extinction, although the ultimate cause (s) remain elusive.

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CHAPTER 1

CHAPTER 1

INTRODUCTION

The late Cenomanian - early Turonian event is now regarded as one of the major global bioevents, which marks the second-largest Cretaceous mass extinction. The Cenomanian-Turonian boundary event is well represented in Britain in two depositional basins, the Anglo - Paris and Cleveland basins, each characterised by a different lithological succession. In the Anglo-Paris Basin (northern France and southern England) the Cenomanian-Turonian boundary is related to a distinctive lithological unit, the Plenus Marls to lower portion of the Ranscombe Chalk Member. In the Cleveland Basin and on the East Midland Shelf (north-east England from the Yorkshire Coast to Lincolnshire) the Cenomanian-Turonian boundary event is associated with another distinct lithology, the Black Band. Besides a lot of ignorance about the cause(s) of the event, the relationship of this event to the condensed succession represented by the Black Band is also not clearly understood.

1.1. "Aims of the study"

The fundamental aims of this study are to investigate the possible causes of the Cenomanian-Turonian boundary mass extinction by analysing patterns of changes across the Cenomanian-Turonian boundary of microfossils (foraminifera + ostracods), sediments, stable isotopes (of C + O) and to seek correlations between these. This has been done to evaluate evidence for or against two rival hypotheses, the productivity and famine models. These models will be discuss in detail later and are therefore only mentioned briefly here.

1.1.1. Productivity model

Jarvis *et al.* (1988) argued for a massive increase in oceanic productivity, which caused an expansion of the oxygen minimum zone in the water column. This in

turn first caused the extinction of the benthic foraminifera and ostracods and then as the oxygen minimum zone moved upward in the water column, a successive extinction of the planktic foraminifera happened.

1.1.2. Famine model

Paul and Mitchell (1994) argued for a reduction in oceanic primary productivity during the Cenomanian -Turonian boundary event. They speculated that the low productivity would have led to famine amongst zooplankton population, including planktonic foraminifera, which are low in the food chain. This in turn led to starvation of benthic and planktic foraminifera and ostracods and consequently the extinction of many taxa.

To investigate possible cause(s) of the Cenomanian-Turonian boundary event three sections at Eastbourne, Westbury and South Ferriby have been studied (Figure 1.1). The section at Eastbourne has been used as a standard section in this study. This section has certain advantages over other sections as follow.

1. The Cenomanian Turonian boundary succession at Eastbourne, south England, is the thickest in the Anglo - Paris Basin.

2. The 8 m thick Plenus Marls succession shows more lithological detail than thinner successions (e.g. Dover).

3. Most of the ammonite zones recognised in the Western Interior Basin, USA are detectable at Eastbourne.

4. Stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) show the most complete curves. This provides an ideal opportunity to compare this section with other more condensed sections (South Ferriby and Westbury).

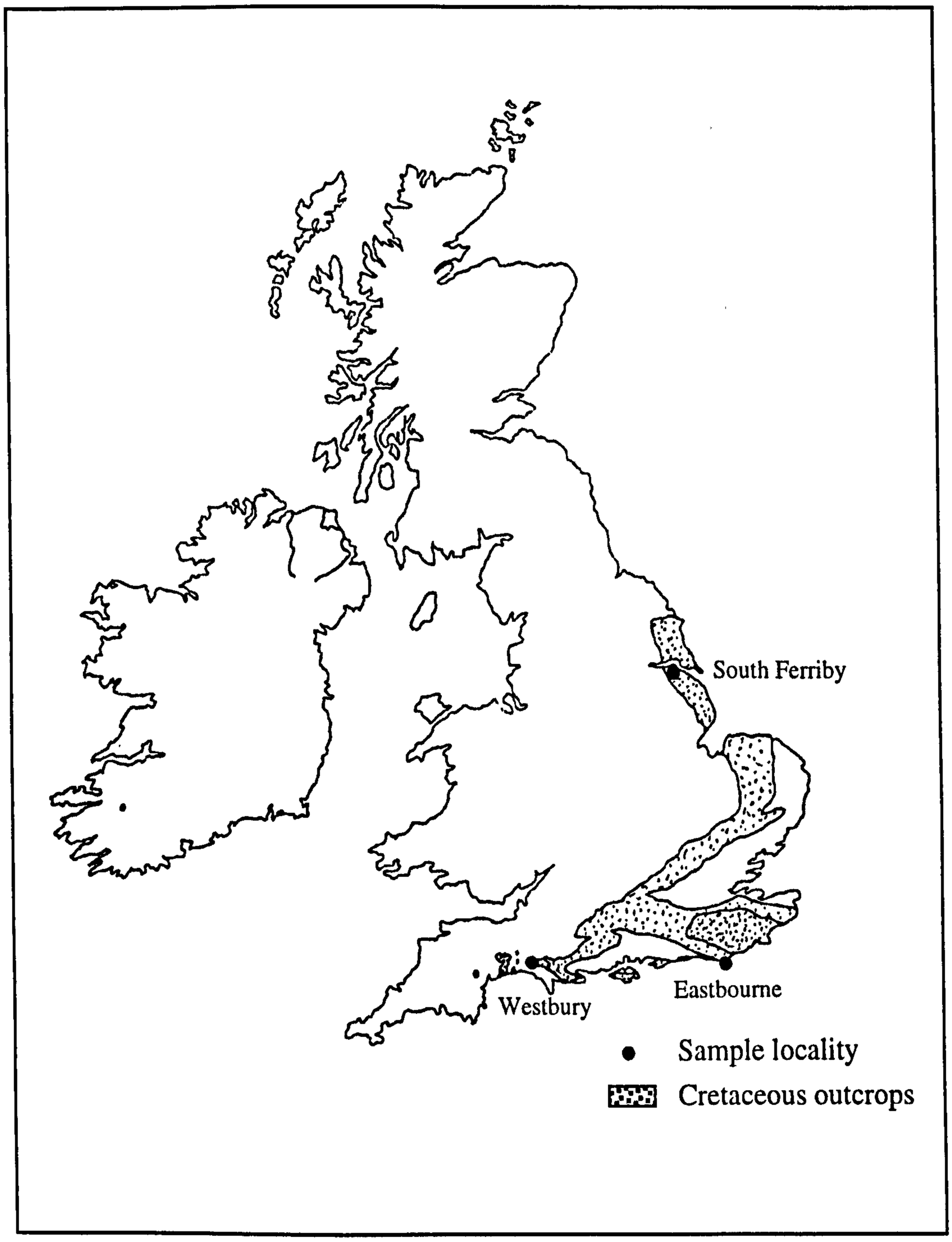


Figure 1.1. Map showing locations of sections mentioned in the text.

1.2. Rhythmical bedding of the Cenomanian sediments and its effect on the microfaunal assemblages

One of the characteristics of the Cenomanian of SE England and northern France is rhythmically-bedded marl and indurated chalk (Jukes-Brown and Hill, 1903; Kennedy, 1969; Carter and Hart, 1977). House (1985, 1986) argued that rhythmically bedded successions were due to orbital forcing (Milankovitch control) and Gale (1990) produced a Milankovitch time scale for the Cenomanian of the Anglo-Paris Basin. He recognised that chalk-marl rhythms could be approximately grouped into bundles of five. The chalk marl rhythms and bundles of five rhythms were attributed to the 21 000 year (precession cycle) and the 100 000 year (eccentricity cycle) Milankovitch orbital cycles, respectively. Two separate processes have been invoked to explain Milankovitch control. First, variable input of clay (dilution cycles), caused by changing volumes of freshwater run off (Arthur *et al.*, 1986; Bottjer *et al.*, 1986) and second, coccolith productivity cycles with a more or less constant clastic supply. This productivity was controlled by variation in sea surface temperatures. It has been shown that chalks were deposited at temperatures about 2° C warmer, on average, than marls (Ditchfield and Marshall, 1989). According to these authors, dilution cycles are unlikely to have produced the chalk-marl rhythms in the Anglo - Paris Basin.

The contrast between the chalk and marl decreases upwards from the base of the sequence, reflecting an overall decline in the clay content of the sediments (Jarvis *et al.*, 1988). Rhythmic beds become less pronounced in the upper part of the succession and individual rhythms are thicker. A distinctive marl unit in the late upper Cenomanian chalks marks the Plenus Marls Formation, which consists of five marl chalk rhythms. Based on faunal and lithological grounds Jefferies (1962, 1963a) recognised eight individual beds (numbered 1-8 in ascending order) and demonstrated that they could be traced throughout the whole of the Anglo - Paris Basin. In general, the thickness of individual beds decreases towards the top of the formation. The base of the Plenus Marls Formation is marked by a well-developed erosion surface (Jefferies, 1962, 1963a; Robinson, 1986), known in the literature as the sub-Plenus

erosion surface. Based on five chalk-marl rhythms in the Plenus Marls, Gale (1990) considered that deposition of this distinct formation lasted approximately 100 000 years.

The role of Milankovitch cycles in controlling foraminiferal assemblages in the Cenomanian of southern England has been investigated by Leary *et al.* (1989), Cottle (1989) and Paul (1992). The results show that abundance and foraminiferal assemblage changes across chalk-marl rhythms in southern England are consistent with changes in primary productivity brought about by variation in surface water temperature induced by orbital forcing (precession). In general abundance of benthic foraminifera is higher in the marls than in the chalks.

1.3. The Cenomanian-Turonian boundary mass extinction (background)

The changes in the microfaunal assemblage in the Plenus Marls and underlying Chalk have been reported and discussed by Jefferies (1962, 1963b) in detail. He stated that there was not a great change in the faunal community between the underlying chalk (*subglobous* Zone) and bed 1 of the Plenus Marls.

"Bed 1 and the top of the subglobosus Zone are very similar in fauna. This is surprising in view of the fact that bed 1 is much muddier than the subglobosus Zone" (Jefferies, 1963b, p. 602).

He thought that the biggest change in the faunal community was at the base of bed 2, which he considered to be a result of shallowing of the basin with a considerable rise in temperature.

"A rapid rise in temperature occurred at the beginning of bed 2 times, and caused a vast change in the fauna and led to the preservation of aragonitic fossils" (Jefferies, 1963b, p. 607).

He also reported of some macrofauna in beds 4-6 , which show affinity with the central Russian province and regarded this as due to a cooling of the water.

"And then [temperature] started to decrease again allowing species with northern affinities to enter the Anglo-Paris Basin during the deposition of beds 4-6" (Jefferies, 1963b, p. 607).

Finally, he concluded that all the changes in the Plenus Marls were mainly a result of changing sea-water temperature.

1.4. Geochemical characteristics ($\delta^{13}C$ and $\delta^{18}O$) of the Cenomanian-Turonian boundary

The carbon and oxygen isotopic composition of carbonates is reported in conventional "δ" notation as parts per thousand (‰) difference between an isotopic ratio ($^{18}O/^{16}O$, $^{13}C/^{12}C$) in a sample compared to the same ratio in an international standard (Marshall, 1992). The data are generally both referred to the PDB carbonate standard. The oxygen isotopic composition of a carbonate mineral, which is precipitated in equilibrium with its environment, is determined by the oxygen isotopic composition and the temperature of the fluid from which the mineral precipitated (Marshall, 1992). Relative changes in temperature/ocean composition can be determined by analysing primary changes in the isotopic composition of well-preserved fossils and even of bulk nannofossil ooze (Ditchfield and Marshall, 1989) and also by comparing results from organisms which lived in different habitats (pelagic, benthic: infaunal and epifaunal) and different latitudes (e.g. Pirrie and Marshall, 1990 a,b). According to Ditchfield and Marshall (1989) several factors could have affected the ^{18}O composition of the rock. These are diagenetic processes, changes in nannofloral composition and changes in the isotopic composition of the water mass. The negative oxygen isotopic composition in lower Palaeozoic limestones and even in their best-preserved fossils and cements (Popp, Anderson and Sandberg, 1986) could suggest either that oceanic temperatures were much higher than today or that oceanic composition was different (see discussion in Hudson and Anderson, 1989).

Stratigraphic variations in the carbon isotopic composition of marine carbonates can be interpreted in terms of changes in the balance of different components of the carbon cycle (Berger and Vincent, 1989; de Boer 1986; Delaney, 1989). Probable causes of a positive $\delta^{13}C$ excursion are depletion of ^{12}C in the marine water column due to high photosynthetic productivity, due to enhanced preservation of organic matter or due to a combination of high productivity and enhanced preservation (Pratt, 1985). In some instances these excursions have been

correlated with episodes of black shale deposition or other evidence for expanded oxygen minimum zones in the world ocean (Schlanger *et al.*, 1987).

Diagenesis can affect the isotopic record. The most common processes involved in changing the isotopic composition of a rock are cementation and replacement (including recrystallization). Both may involve the precipitation of new carbonate with a different composition from that which formed in the depositional environment (Marshall, 1992).

Normal $\delta^{13}C$ in chalks are in the range of +1.5 to +3‰ (Pomerol, 1984). Schlanger *et al.* (1987) quote +2.0‰ to 3.0‰ for limestone above and below the Cenomanian-Turonian boundary event; Jarvis *et al.* (1988) found +2.3‰ to +2.7‰ $\delta^{13}C$ in the main part of the Mellbourn Rock at Dover, and +2.2‰ to 2.7‰ for the Grey Chalk beneath the Plenus Marls.

1.5. Organic rich sediments in the Cenomanian-Turonian boundary

One of the characteristics of the Cenomanian-Turonian boundary is deposition of large amounts of organic matter (Jenkyns, 1980; Herbin *et al.*, 1986; Schlanger *et al.*, 1987). Such organic-rich sediments have been regarded as a sign of oxygen deficiency at the time they were deposited. These sediments are associated with an exceptionally high ratio of ^{13}C: ^{12}C which has been interpreted as a preferential extraction of ^{12}C by marine plankton. It has been postulated that because of anoxia on the sea-floor, ^{12}C was not recycled back into the general oceanic supply (Scholle & Arthur, 1980). It was also suggested that such conditions were associated with high sea-levels and great transgressions (Schlanger & Jenkyns, 1976; Fischer & Arthur, 1977; Jenkyns, 1980).

1.6. Phytoplankton and productivity

Primary production of organic matter in the open ocean involves a wide range of unicellular planktonic organisms whose activities are governed by nutrient supply and solar radiation (Pedersen and Calvert, 1990). The role of light for photosynthesis is obvious. In the tropical ocean, the amount of light reaching the sea is never limiting, but is often insufficient for sustained production in higher latitudes. Apart from the light, which is required for photosynthesis, primary productivity of the oceans is affected by other factors, among which nutrient supply is the most important. Nutrients generally are present in very low concentrations in the euphotic zone, because they are consumed by the phytoplankton. Nutrients are returned to the water at depth by bacterial degradation of the organic debris that settles from surface water. Sustained plankton production can take place, therefore, only if nutrients are supplied to the euphotic zone, from below by vertical mixing, or by horizontal supply ultimately from the land. Vertical mixing generally is more important in open oceans. The rate of vertical mixing depends on the vertical stability of the water column, which allows upward mixing by turbulence or by upwelling. The production of organic matter in the open ocean, therefore, is basically controlled by nutrient supply to the euphotic zone and this, in turn, is governed by vertical stability in the water column.

1.7. Relation between productivity and deposition of organic carbon

The relation between productivity of surface water and organic matter in the sediments has been discussed by Demaison and Moore (1980). They showed that there is no systematic correlation between primary production and the organic carbon content of bottom sediments in the oceans. They stated that:

"The traditional view is that fields of high surface productivity in the ocean should be associated with high organic enrichment of underlying sediments; however after exhaustive investigation we could not find a systematic correlation between primary biologic productivity and organic carbon content of bottom sediments in the oceans" (Demaison and Moore, 1980, p. 1180).

De Boer (1986) has argued for a low productivity phase related to burial of organic matter and subsequent reduced availability of nutrients because they were not recycled to the surface water. Jarvis *et al.* (1988), however presented a model for the Cenomanian-Turonian boundary event which assumed high productivity in surface waters and consequently deposition of high amounts of organic matter in the sediments. Data from abundance of nannofossils at Dover (Lamolda *et al.*, 1994) and at Menoyo, N. Spain (Paul *et al.*, 1994) suggest lower productivity during Late Cenomanian times.

1.8. Depth stratification of the Cretaceous planktonic foraminifera

Planktic foraminifera are specifically adapted to a given water mass, therefore changes in temperature, nutrient supply and oxygen content result in changes of the planktic foraminiferal assemblages inhabiting this watermass (Bé, 1977). The classification of life habitats of modern planktic foraminifera (Bé, 1977) has been applied to comparable Cretaceous morphotypes by Hart & Bailey (1979), Hart (1980) and Wonders (1980). In this matter three groups can be recognised as follow.

1- Shallow-water fauna (0-50 m) - epipelagic (non-keeled forms of the genera *Hedbergella, Whiteinella, Heterohelix* and *Guembelitria).*

2- Intermediate-water fauna (50-100 m) - mesopelagic (incipiently - keeled forms of the genera *Praeglobotruncana* and *Dicarinella*).

3- Deeper water fauna (with adults normally below 100 m) - bathypelagic (keeled forms such as *Rotalipora* and *Marginotruncana*).

As indicated by Hart and Bailey (1979) the distribution of an individual species and its appearance in time are a function of the water depth over the shelf during any particular interval. They have suggested that the *Rotalipora* lineage was adapted to life in the adult growth stage at a specific depth in the water column, and that during ontogeny an individual sinks down to that level from the surface waters. This sinking in the water column is a result of an increase in size, thickness of the test, and degree of ornamentation. This concept can be tested by considering data from the modern

oceanic environment (Bé, 1977). *Rotalipora greenhornensis* is more heavily calcified, and has a thicker test, than *Rotalipora cushmani* and would, by this model, have lived in the adult stage slightly lower in the water column than *Rotalipora cushmani.* The fact that *Rotalipora greenhornensis* is much rarer in the shelf succession of southern England supports this idea and suggests that the water was generally of insufficient depth for the adult form to become fully developed (Hart, 1985). Specimens found in southern England are generally much smaller than those from other parts of the world and have a much less well developed ornamentation (Hart, 1985).

1.9. The circulation patterns across the Cenomanian-Turonian boundary

In modern oceans the oxygen content increases with depth as a result of cold, oxygen-rich, bottom water coming from the poles. Surface temperatures for the open ocean vary from approximately 28° C in the tropical regions to -2° C in polar seas. Under sea ice, sea water becomes so dense by cooling and addition of salt displaced from the pure ice above that it sinks to the bottom of the ocean and light, warmer water flows along the surface towards the poles (convection currents) to replace it. However, it has been suggested that the Cretaceous period appears to have been ice free and that very cold water did not exist. Instead an exceptionally warm, equable climate governed this period (Barron, 1983). The occurrence of a more equable climate is supported by the occurrence of tropical and temperate faunas and floras, in the terrestrial record, at higher latitudes than at present. During this time there was no connection between the North Atlantic and the Tethyan Ocean (de Boer 1986). Brass *et al.* (1982) have suggested that during periods of globally warm equable climate, such as existed during much of Mesozoic time, the model of oceanic bottom water formation may have been quite different from that of today. They proposed that in the absence of formation of cold, polar, deep-water masses, warm saline water may have become the major bottom water. Such warm, saline bottom water (WSBW) is thought to have formed on low-latitude shelves. Brass *et al.* (1982) suggested that rates of bottom water production and overturn of deep-water masses during episodes of high

sea level have been more rapid than those of today. It has been pointed out (Fischer & Arthur, 1977; Berger, 1979; Arthur *et al.*, 1984) that with higher temperature and salinity, gases would be less soluble, so that warm, saline water would not transfer oxygenated water to the deep oceans very well.

1.10. Oxygen minimum zone (OMZ) in the water column of the Cenomanian-Turonian boundary

Sea water dissolves oxygen at or close to the ocean surface. The supply comes mainly from the atmosphere, with a small addition from primary producers, i.e. photosynthetic organisms. Ocean-surface waters are often supersaturated with oxygen, because of the entrapment of air bubbles and the abundance of oxygen released by producers (Broecker and Peng, 1982). In the upper part of the photic zone, the producers generate more oxygen than they use up by respiration, but a balance is attained farther down the water column. Below this level, the oxygen content of seawater drops conspicuously because of respiration by organisms and the decay (i.e. oxidation) of organic matter. In deep oceanic waters, generally below 1000 m, the oxygen level rises again, in response to the sinking and spreading of oxygen-rich, relatively dense, cold surface waters from polar or subpolar latitudes (e.g. North Atlantic Deep Water and Antarctic Bottom Water). Thus, in a standard ocean-water profile, the least amount of dissolved oxygen is generally recorded at depths of several hundred meters where the utilisation of oxygen by organisms and organic debris is high and is not replenished by cold polar water. This is the oxygen minimum zone (OMZ), present in all major and marginal ocean basins. The least value of dissolved oxygen within the OMZ ranges from <1 to >3 ml/l (Figure 1.2).

According to Schlanger & Jenkins (1976), during significant periods within Aptian-Albian and Cenomanian-Turonian time large regions of the world ocean were characterised by a strongly developed oxygen minimum zone that reached to within 300 meters of the surface. The absence of evidence for anoxia in Anglo - Paris Basin sediments has been explained by Jarvis *et al.* (1988) as being due to the relatively

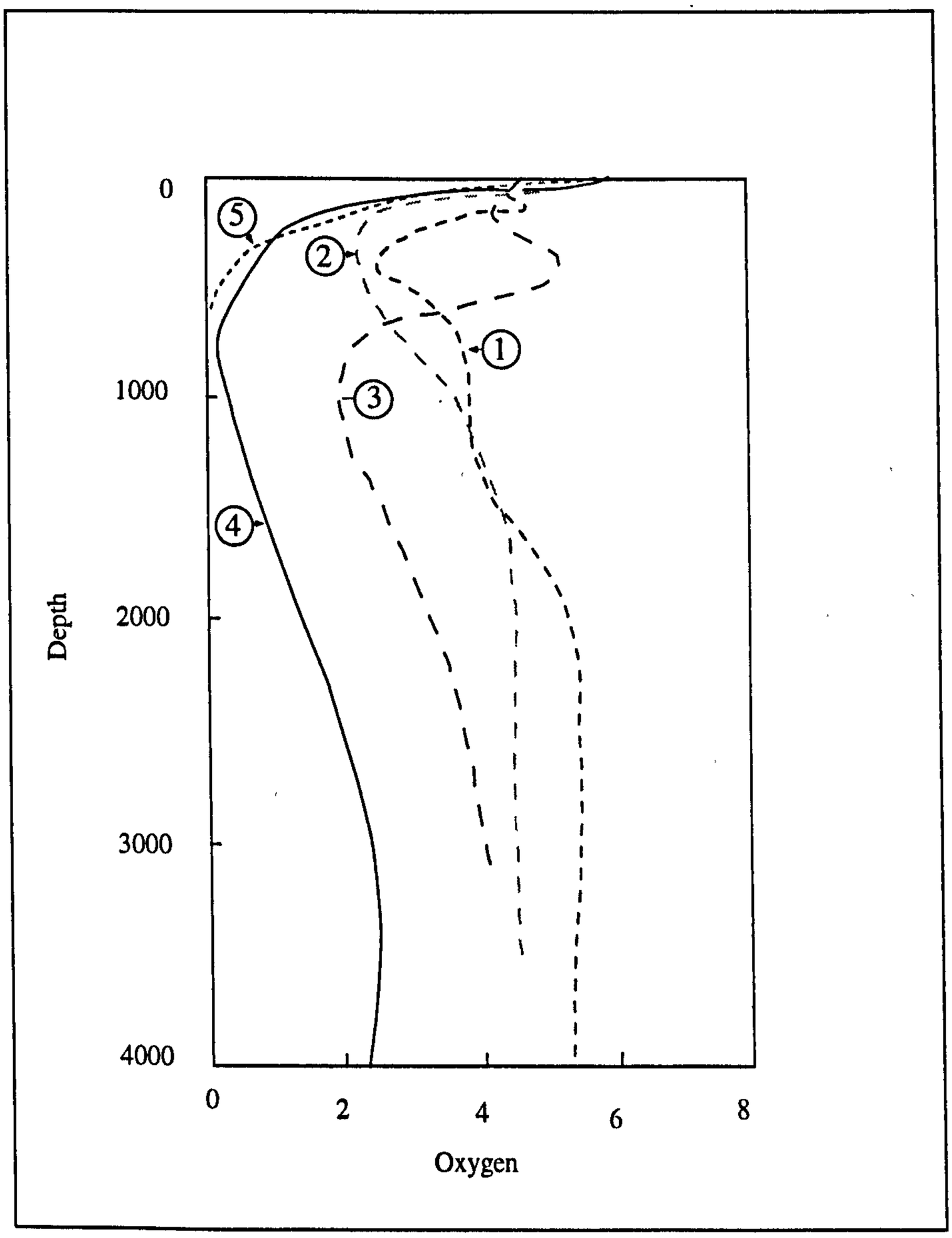


Figure 1.2. Typical oxygen profiles in major and marginal basins; depth in metres, O2 in ml/l. 1= Eastern South Atlantic; 2=Gulf of Mexico; 3=Indian-ocean; 4=Eastern North Pacific; 5=Santa Barbara Basin California. Redrawn from Sen Gupta and Machain-Castillo 1993.

shallow water of the area at that time. Shallow water masses are subject to wave and tidal currents which ensure that they are well mixed and well oxygenated, even in areas with a strong oxygen minimum layer. The evidence of the oxygen minimum zone at the Cenomanian-Turonian boundary was thought to result from high sea level, which was at least 300 m above the present sea level and consequently coincided with a major transgression in the late Cenomanian. However, Hancock (1989) and Jeans *et al.* (1991) considered that both the Schlanger and Jarvis anoxic events corresponded to falling sea level. Jeans *et al.* (1991) claimed that a eustatic fall in sea level occurred and proposed a glaciation model for this time interval. They regarded the increased clay content of the Plenus Marls as due to post-deposional alteration of siliclastic detritus brought in by the rejuvenated rivers during a regressive phase and considered that the regression continued throughout the Plenus Marls and overlying Melbourn Rock. Based on an increase in the proportion of sand-size particles in the sediments, they suggested a glacial mechanism which was supported by presence of occasional dropstones, and they considered that there is no evidence for even dysaerobic water in the sediments. Recently Ulicny' (1992) has rejected the interpretation of Jeans *et al.* (1991) and stated that:

"The transgressive nature and widespread extent of the late Cenomanian organic rich facies are difficult to explain by regressive deposition in more or less isolated basins. It is also unclear how a rapid immigration of the 'pulse fauna' and penetration of 'cold allochthonous bottom waters' into the central part of the Anglo-Paris basin (Jeans *et al.*, 1991) can correlate with a sea- level drop" (Ulicny, 1992, p. 637).

According to Ulicny (1992) the Cenomanian-Turonian boundary event was initiated by a rapid rise in sea level which continued during the rise in $\delta^{13}C$ values, but was reversed after the peak of the carbon excursion.

Paul and Mitchell (1994) argued that the Cenomanian-Turonian boundary event was initiated by a very sudden drop in sea level, followed by a slower but still rapid rise during which organic carbon was buried in increasing amounts, and that sea level remained high during the plateau and recovery phases of the carbon excursion.

1.11. Expansion of the oxygen minimum zone in the water column and its effect on the Cenomanian-Turonian boundary mass extinction

The late Cenomanian mass extinction event has been investigated in detail by Jarvis *et al.* (1988), who used sedimentology, isotopes, geochemistry and micropalaentology to investigate the faunal changes at this time. Their work was largely based on a section in southeast England (Dover). They found that there is a direct correlation between $\delta^{13}C$ values and the principal extinction levels for benthic foraminifera, planktic foraminifera, ostracods, dinoflagellate cysts and calcareous nannofossils, which show a mass extinction pattern. The stepped disappearance of keeled planktic foraminifera, was used by Jarvis *et al.* (1988) to argue that the pattern of extinction was the biological response to the progressive expansion of the oxygen minimum zone the top of which rose in the water column. This in turn, was caused by a massive increase in oceanic productivity. Brass *et al.* (1982) suggested that mechanisms for this productivity increase were a salinity driven circulation for the Cretaceous oceanic, and consequently the formation of a prominent oxygen minimum zone in the water column. So Jarvis *et al.* regarded the Cenomanian-Turonian boundary event as an oceanic anoxic event and argued that $\delta^{13}C$ values reach a peak in the highest levels of the Plenus Marls. According to Jarvis *et al.* (1988), the $\delta^{13}C$ values indicate the position of the oxygen minimum zone in the water column. As the top of the oxygen minimum zone rose in the water column it impinged on the largest and deepest-dwelling planktonic foraminifera first, causing the extinction of *Rotalipora* spp. (*Rotalipora greenhornensis* at the top of the bed 1 of the Plenus Marls, and then *Rotalipora cushmani* in the top of the bed 3). The intermediate water fauna, double keeled planktics, dicarinellids and praeglobotruncanids became extinct next. At the peak of $\delta^{13}C$ values, oxygen-depleted waters has risen in shelf seas to their shallowest depth, possibly within 50 m of the surface, and this meant that only the shallow-water fauna, hedbergellids and whiteinellids, were not affected by oxygen-depleted waters and so survived. High productivity and consequently high amounts of

organic matter have also been suggested by Hilbrecht, Hubberton & Oberhänsli (1992) during the Cenomanian-Turonian boundary event.

1.12. Benthic foraminiferal community and anoxia

Bernhard (1993) suggested that benthic foraminifera survive anoxia by using alternative strategies-either metabolic depression (dormancy) or encystment. Linke and Lutze (1993) have suggested that encystment may possibly be an adaptation to rapid changes during unfavourable conditions. The agglutinated cysts provide an excellent shelter against mechanical and chemical disturbance. Enhanced bacterial growth in the interspace between cyst and foraminiferal secretion (Langer, 1992) provides the foraminifera with an additional food source and they may also be facultative anaerobes (Bernhard, 1993). Also, some benthic species of foraminifera characterised by thin walled, inflated chambers and relatively coarse pores, show an adaptation to a meroplanktonic habit to avoid anoxia (Todd, 1958; Mullineaux and Lohmann, 1981). Bernhard (1986) noted that most anaerobic species in the Cenomanian lack ornamentation, but *Lenticulina* tests from dysaerobic assemblages have slightly developed ornamentation. He also reported that anaerobic assemblages contain mainly species with small tests; medium size occurring rarely. Dysaerobic assemblages contain more medium-sized species. Small size in benthic foraminifera is thought to reflect either early reproduction under optimal environmental conditions or to be due to adverse environmental conditions (Boltovskoy and Wright, 1976). Koutsoukos *et al.* (1990) demonstrated that a minute assemblage mainly composed of calcareous hyaline foraminifera and agglutinated species predominated in mid-Cretaceous low oxygen faunas from England and Brazil. It has been shown (Phleger and Soutar, 1973; Bernhard, 1986; Perez-Cruz and Machain-Castillo, 1990) that faunas from the oxygen minimum zone are characterised by high abundance, low diversity, small size and high dominance, typically with 2 or 3 calcareous species constituting up to 80% of the total assemblage.

1.13. The difficulties in studying the Cenomanian-Turonian boundary ostracods

There are some difficulties in studying the ostracods. Although Cenomanian ostracods of southern England have been studied by Weaver (1982), the ostracods of Cenomanian-Turonian of northeast England have not been investigated thoroughly. In addition ostracods of British post-Cenomanian chalk are poorly known, those of the Turonian least of all. These problems, combined with a general lack of taxonomic study, make the identification of species difficult.

1.14. Changes in the ostracods community of the Cenomanian-Turonian boundary

Ostracods live in an environment, which is affected by temperature, bottom topography, transparency, salinity, alkalinity, dissolved oxygen and depth (Puri, 1971). Neale (1964) has pointed out how difficult it is to assign any faunal changes to a specific ecological factor. He pointed out that the most important ecological factors affecting the distribution of ostracods are salinity and temperature, while depth, substrate, food supply, shelter and predators are secondary factors. Of these factors salinity changes must have played an insignificant role in the open shelf seas of the Cretaceous (Weaver, 1981). However, the effect of temperature on reproduction should not be ignored. A "sensitive phase" of temperature requirement during reproduction may affect even sex ratio (Puri, 1971), and decrease in temperature is often accompanied by increase in size (Brady, 1884). Jarvis *et al.* (1988) studied the ostracods of the Cenomanian-Turonian boundary in southern England (Dover) and concluded that there is a gradual change in the ostracod assemblage from podocopid-dominated to platycopid-dominated. The latter are quite dominant taxa (mainly *Cytherella ovata*) in bed 8 of the Plenus Marls, where podocopids made up <5% of the fauna and were represented by just one species, *Imhotepia euglyphea* (Jarvis, 1988; cited by Whatley, 1991). Babinot & Crumiere-Airaud (1990) found that *Cytherella ovata* (making 70-80% of the total fauna), together with *Bairdia*, were the dominant

taxa in the late Cenomanian and lower part of the Turonian, while higher up in the succession the genus *Macrocypris* joins them. Whatley (1991) has suggested that periods of platycopid dominance may have been associated with periods of reduced oxygen levels induced by relatively high sea level. He has argued that *Cytherella* and *Cytherelloidea*, because of their filter feeding habit, were able to survive in water with reduced oxygen by virtue of the increased amount of water passed over their respiratory surface (by means of brachial plates), while other, non-filter-feeding ostracods became extinct. He has reported that Bairdiacea also possess a large branchial plate, which enables them to survive in unfavourable low oxygen environments. Besides, modern *Cytherella* and *Cytherelloidea* brood their young thus providing them with more oxygen at a critical time in their development. So this mechanism of breeding will allow platycopids to survive, while the podocopids would be the victims of the stressful environment because they can not reproduce successfully. Jarvis *et al.* (1988) have reported of some new species in the lower part of Turonian in south of England, which include *Mosaeleberis* sp. A, *Cythereis* cf. *longaeva*, *Curfsina senior*, *Cytherelloidea obliquirugata* and *Parvacytheris subparva*. Horne *et al.*, (1990) believe that the Turonian ostracod fauna at Dover was probably derived from Cenomanian stock that survived the harsh conditions in refuges on the basin margin.

1.15. The relation between water depth and food

The most important factor affecting the absolute abundance of each species at any time is the available food supply (Tolderlund & Be', 1971). According to Corliss and Chen (1988) water depth distribution of benthic foraminifera is controlled by the flux of organic carbon to the sea floor. Also laboratory-induced food stress has been shown to reduce growth rates (Bé *et al.*, 1981; cited by Leary and Hart, 1989). The relationship between depth and food supply to the sea floor has been discussed by Berger and Diester-Haass (1988) in detail. According to them, when the effects of differential dissolution are excluded, the benthic to planktic ratio in deep-sea

foraminifera can be read as a productivity index. With the assumption that the food consists of organic matter produced in the euphotic zone which rains down from above, there is a decreasing supply of organic matter to the sea floor as one leaves the shelves and proceeds to greater depths in the pelagic realm. It is the supply of food which governs the abundance of the benthic foraminifera, rather than the depth as reflected by pressure, temperature, oxygen and other related factors (Phleger and Soutar, 1973; Miller and Lohman, 1982; Lutze and Coulbourn, 1984; Altenbach, 1985). As a consequence of the depth-productivity relationship, benthic activity decreases rapidly away from the coastal zone and down the continental slope (Smith and Hinga, 1983). Increasing depth, is accompanied by reduction in benthic abundance, while planktics do not decrease or do so more slowly. Therefore, planktonic% increases with decreasing productivity and increasing depth.

1.16. High sea level stand in Cenomanian-Turonian boundary and its effect on the microfauna

Figure 1.3 shows that sea-level rose during late Cenomanian-early Turonian time (Hancock and Kauffman, 1979; Haq *et al.*, 1987), although a sea level fall has also been proposed for this time interval (Hancock, 1989; Jeans *et al.*, 1991). Suess (1875) postulated that the exceptionally prominent late Cretaceous transgression was a result of world-wide changes of sea level which he called *eustatic*. It has been suggested that this high sea level was due to an increase in the production rate of oceanic crust, which caused elevation of the sea floor and a consequent rise in sea level (Hays and Pitman, 1973). The relation between Cenomanian-Turonian high sea level and low diversity and abundance of benthic foraminifera and ostracods has been investigated by some workers. Hart (1982; cited by Leary and Peryt, 1991) considered that the high sea level of the Turonian was the main reason for the low diversity. Peryt (1988) also related reduction in diversity of the latest Cenomanian - early Turonian benthic assemblage to the deepening of the sea. Lamolda (1982) has indicated that low abundance and diversity of ostracods in the Cenomanian-Turonian in the central - west

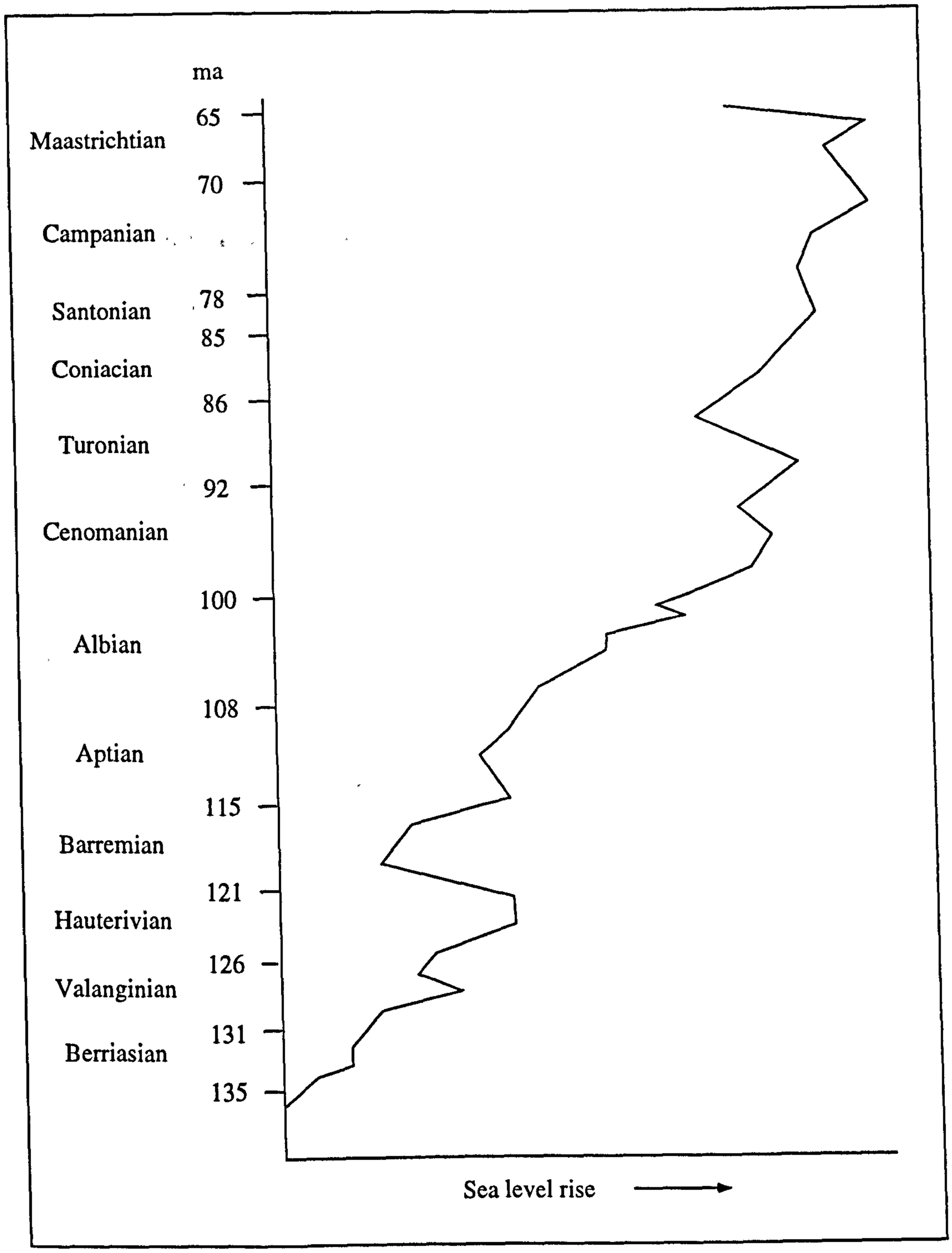


Figure 1.3. Cretaceous sea-level changes in north-west Europe (Late Cretaceous after Hancock & Kauffman 1979).

part of the Basque-Cantabrian Basin in Spain was related to deep water and that the ostracod fauna shows deeper waters during the lower and middle Turonian in that area. However, Leary and Peryt (1991) suggested that the late Cenomanian sea-level rise appears to have been initiated below bed 1 of the Plenus Marls, where the benthic diversity was highest. In his view sea-level high stand itself cannot be considered as the only cause of low benthic diversity.

1.17. Relation between morphology and mode of life with substrate

Benthic foraminifera occupy many niches within the sediment profile. In oxygenated deep-sea sediments, foraminifera occupy epifaunal and shallow (0-2 cm) or deep (>2 cm) infaunal microhabitats (Corliss, 1985; Thies, 1990). It has been suggested that morphologies of benthic foraminiferal tests vary with respect to sedimentary microhabitat. Corliss (1985), analysing deep Atlantic sediments, noted that foraminiferal species with flattened tests more commonly occurred deeper in the cores. He suggested that distribution is related to oxygen concentrations of the sediments, although oxygen measurements were not taken. Corliss and Chen (1988) showed that planoconvex trochospiral morphotypes occur more commonly in surficial (0-1 cm) sediments and planispiral or cylindrical and ovate morphotypes occur more commonly deeper in the cores (>1 cm). They suggested that these morphotype patterns may be related to carbon flux. Bernhard (1986) noted that fossil anaerobic foraminiferal assemblages typically had flattened morphologies, whereas assemblages from oxygenated deposits had more spherical morphologies with lower ratios of surface area to volume. However, Sen Gupta and Machain-Castillo (1993) have argued that there is no correlation between test morphology of foraminifera and dysoxic-suboxic environments. Some taxa which live infaunally in well-oxygenated sediments also occur near the sediment surface in dysaerobic environments. Because there is a decrease in the dissolved oxygen content downward in the sediments (Fenchel and Riedle, 1970), infauna are assumed to be tolerant of lower oxygen habitats (Corliss and Emerson, 1990). The oxygen demand of some species is

extremely low and they are part of the living system of the sulphide "biome", being present in the redox-potential-discontinuity layer (with both O_2 and H_2S) immediately above anoxic sediments (Sen Gupta and Luisa-Castillo, 1993). However, recently it has been suggested (Jorissen, 1988; Corlis and Emerson, 1990; Barmawidjaja *et al.*, 1992) that the microhabitat preference of individual taxa may change as a function of the depth of the redox potential discontinuity layer and/or the amount of food in the substrate. Therefore, motile species may be found in different microhabitats. This group of species is regarded as highly adaptable and tolerant because they can change habitats from epifaunal to infaunal in soft muddy substrates (Koutsoukos *et al.*, 1990; Linke and Lutze, 1993).

Linke and Lutze (1993) argued that dominance of epibenthic foraminifera reflects the scarcity of food particles in the sediments. In contrast, dominating infaunal species represents areas with a high flux of organic particles (e. g. below areas of high productivity associated with coastal upwelling). Corliss and Chen (1988) argued also that the epifaunal-infaunal ratio appears to be related to the organic-carbon content of surface sediments and that infaunal species dominate assemblages in environmens with relatively high organic-carbon. It has been suggested (Byers, 1977; Jarvis *et al.*, 1988; Koutsoukos *et al.*, 1990; Leary and Peryt, 1991) that dominance of infaunal groups associated with relatively high organic-carbon values may be because they are more tolerant of low oxygen concentrations and therefore the first to profit from the high availability of food.

1.18. Trophic structure and mass extinction

The distribution of feeding types as a function of enviromental setting often provides much insight into the community biology of a habitat (Rhoads and Young, 1970). The main feeding types include: deposit feeders, obtaining food from the organic content of ingested sediment, suspension feeders, obtaining nutritional needs through a filtering mechanism, and carnivores, feeding on living and/or dead animals. Deposit feeders may be further subdivided into two categories as: 1) non selective

deposit feeders, feeders that simply ingest the substratum in which they live deriving their nutrient from the contained living and non living organic matter: and 2) selective deposit feeders, discriminately collecting detritus from the sediments. Because most deposit feeders have very limited mobility, food patch selection is not generally an important aspect of foraging behaviour (Lopez and Levinton, 1987).

Sheehan and Hansen (1986) suggested that during the low productivity period of the Cretaceous-Tertiary boundary deposit feeders were relatively immune from that crisis, because they believed that deposit feeders would have been independent of the sudden decline of phytoplankton. According to their argument huge storage of organic matter in the sediments would allow deposit-feeding species to survive for long periods, in contrast to suspension feeders, which would have immediately lost their food supply and succumbed quickly. Lopez and Levinton (1987) showed that particulate organic matter is relatively indigestible, whereas microbial material can be absorbed with great efficiency. In sediments well below the photic zone, the only significant microbes are bacteria. However, bacterial abundance in sediment appears to be far too low to satisfy the energetic needs of deposit feeders (Cammen, 1980; Lopez and Levinton, 1987). It has been demonstrated that food supply is of crucial importance in population growth and that food is rapidly exhausted in sediments, resulting in population crashes (Tenore, 1977; Tenore and Hanson, 1980; Alongi and Tenore, 1985). Billett *et al.* (1983) demonstrated that the organic carbon and nitrogen contents of detritus are very low compared with values for living phytoplankton. Marsh and Tenore (1990) argued that it is possible that the macronutrient requirements of deposit feeders may be satisfied to a large extent by recycled materials, while it is their micronutrient requirements that are dependent on fresh detrital particulate organic material.

However, it has been argued by Jablonski and Raup (1995) that during the Cretaceous-Tertiary boundary mass extinction some deposit-feeding groups appear to have suffered very strongly. Recently Levinton (1996) has argued that the responses of deposit feeders in Recent environments are on the same scale as those of suspension

feeders. Although deposit feeders ingest sediment and digest and assimilate a fraction of the organic matter, they would not be immune to a shortage of phytoplankton in the overlying water column for very long. He has documented the Cretaceous-Tertiary mass extinction and concluded that the survival of some deposit feeders is due to other factors than food supply. Thus, from the ecosystem point of view, there is not much difference between suspension feeding and deposit feeding, especially in shallow shelf species, and the main source of food for deposit feeders in this environment is very recently deposited phytodetritus. This in turn depends directly on phytoplankton production.

1.19. Metabolic adaptation of benthic foraminifera during famine period

Linke (1992) argued a metabolic adaptation of deep-sea benthic foraminifera to seasonally varying food input. He has shown that benthic foraminifera are capable of competing in the struggle for the limited food supply that characterises most deep-sea environments and have developed morphological and physiological adaptation to survive in this extreme habitat. The survival strategy of this group in the famine periods is a rapid turnover of ATP, which allows these foraminifera to take quick advantage of sudden nutrient inputs; this state of readiness, however, is maintained at the cost of the protoplasm, which benthic foraminifera are apparently capable of metabolising in times of starvation. However, it is not clear that all the benthic foraminifera can take advantage of such a survival strategy in famine periods.

1.20. Harries model for the mass extinction

The dynamics of survival of macroinvertebrates following the Cenomanian-Turonian mass extinction event have been discussed by Harries (1993) and Harries and Kauffman (1990). In these papers the pattern of survival has been utilised to investigate possible causal factors which may have played a role in forcing the mass extinction. In the Harries model three phases of mass extinction have been recognised. The first interval is characterised by higher rate of extinction than origination (E»O). In

the second interval, which is called the survival interval, the rate of extinction is approximately equal to the rate of origination (E≈O). The third and last period is called the recovery interval, where the rate of origination is higher than that of extinction (E«O). According to the model formulated by Harries and Kauffman, following the main Cenomanian-Turonian extinction interval, there is a thin interval which is characterised by very low diversity, the "crisis zone" in the most complete sections faunal diversity approaches zero. In the Harries model the mechanisms which may have been critical to survival during the Cenomanian-Turonian boundary were suggested to be: physiological mechanisms (chemosymbioses, dormancy), trophic/life habit mechanisms (ecological generalist, opportunists), habitat mechanisms (refugia, 2nd habitat) and evolutionary mechanisms (paedomorphosis, rapid evolution). The terms "Lazarus taxa" and "Lazarus genera" have been applied respectively to those species which disappear from the record and then reappear unchanged, and the genera which show gaps in their stratigraphic ranges during the mass extinction event, but are represented by new species in the post-extinction strata. By considering different types of survival mechanisms displayed by the macroinvertebrates of the Cenomanian-Turonian interval, Harries concluded that an expanding oxygen minimum zone was an important mechanism of extinction during this interval, but he considered that there are some survival mechanisms which suggest the event may be more multi-casual. It has been shown by Kauffman & Sageman (1990) that bioturbation directly correlates with degree of oxygenation. The virtually unchanged bioturbation record across the Cenomanian-Turonian boundary event (e.g. Dover section in southern England) does not support the incursion of oxygen-depleted waters.

1.21. Different patterns of mass extinction

Kauffman (1986) defined three major concepts of mass extinction, which are graded, catastrophic and stepwise patterns. In graded mass extinctions, extinction rates are higher than background level, but taxa disappear randomly throughout this interval, possibly along an ecological gradient from initially stenotopic to more

eurytopic groups. This pattern is attributed to accelerated intervals of environmental change resulting from terrestrial cause (such as climate), producing global ecological crisis. Catastrophic mass extinction theory (Alvarez *et al.*, 1980) views global annihilation among genetically and ecologically diverse organisms as occurring near-simultaneously (days to centuries) as a direct or indirect result of enormous perturbations of the global environment usually attributed to extraterrestrial causes (such as impact or radiation). Stepwise mass extinction (Keller, 1983, 1986; Kauffman, 1986) occurs as a series of discrete steps of highly accelerated or catastrophic extinction intervals, each affecting only a portion of the global biota. Individual extinction steps may also be characterised, even predominantly, by ecological shock to surviving species manifested in abrupt population decline and/or restriction to refugia: the latter reappear in the recovery fauna as "Lazarus taxa".

CHAPTER 2

CHAPTER 2

LITHOSTRATIGRAPHY, GELOGICAL SETTING, MATERIAL AND METHODS

2.1. Lithostratigraphy

2.1.1. Southern England

The lithostratigraphic schemes introduced for the Chalk of Sussex and Kent have been discussed by Robinson (1985, 1986, 1987) and Mortimore (1983, 1986, 1988), and their schemes are shown in Figure 2.1. However, In this thesis the stratigraphic terms Grey Chalk, Plenus Marls, Ranscombe Chalk Member (Melbourn Rock Beds and Holywell Beds) are used.

Grey Chalk

The term Grey Chalk was introduced by Phillips (1821) for all the Chalk which was located below his "chalk with few organic remains". Mantell (1818) defined the term "Chalk Marl" which is equivalent to "Grey Chalk" of Phillips. Price (1877) employed the term "Grey Chalk" which is equivalent to upper part of Phillips' "Grey Chalk" and "Chalk with few organic remains". However, Grey Chalk constitutes the upper part of the Lower Chalk, which consists mainly of marly chalk (vs. lower part, chalk marl, which shows rhythmic alternation of marl and chalk). The Grey Chalk also constitutes the upper part of the Lower Chalk of Kennedy (1969) and the interval is equivalent to bands 17 and 18 of the Kennedy (1969) at Eastbourne.

Plenus Marls

This distinctive marl unit was first recognised by Phillips (1818, p. 46-7). He described it as a "bed of soft marle" which was located at the base of Shakespeare Cliff, west of Dover. Whitaker (1872) recognised the presence of belemnites in Phillips' bed and called it his "marl with belemnites". Hill and Jukes-Brown (1886, p.

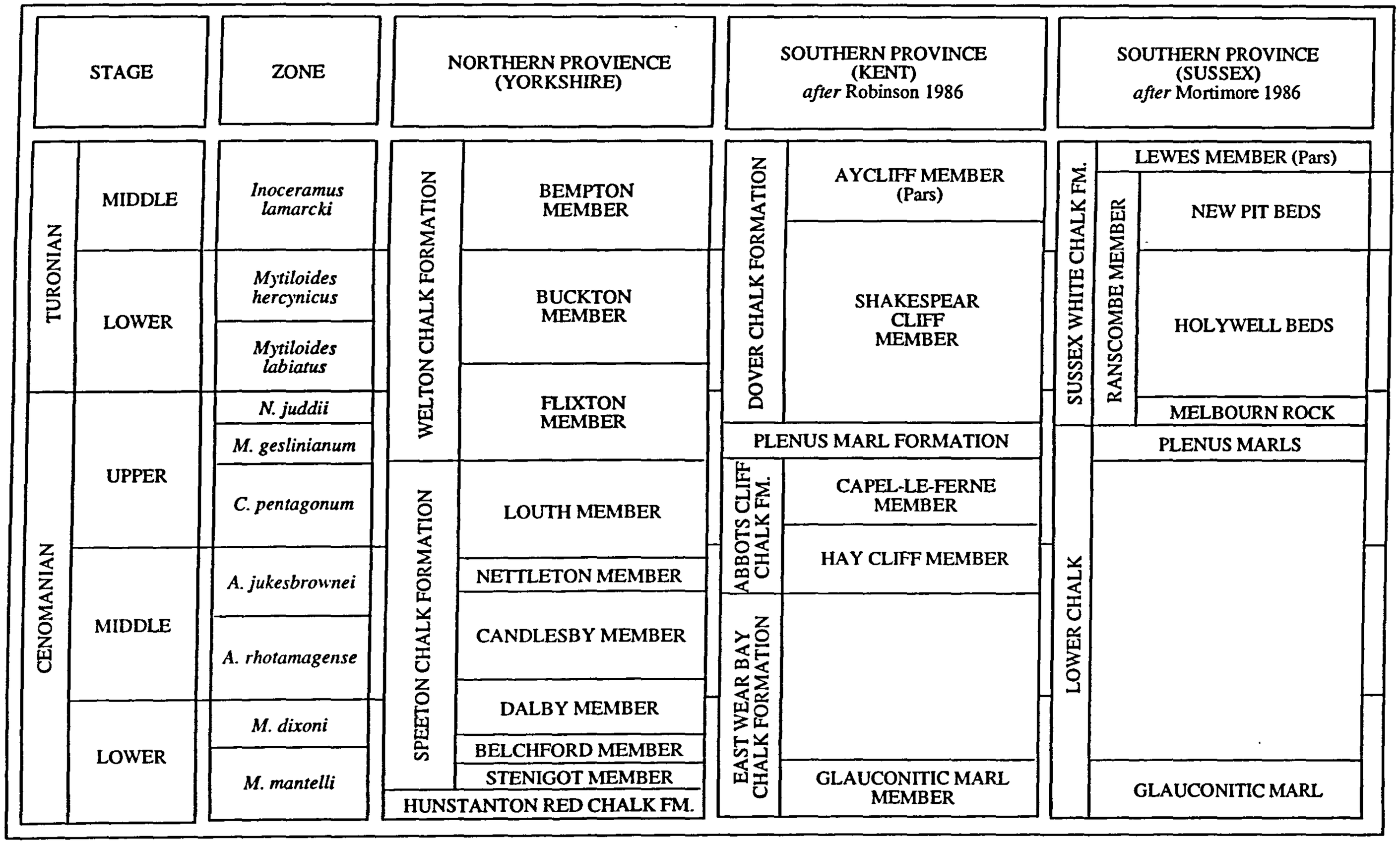


Figure 2.1. Lithostratigraphic schemes for the Upper Cretaceous deposits of England. Redrawn from Mitchell 1993.

216) described a "Zone of *Belemnitella plena*" which is located below the Melbourn Rock. It seems that Rowe (1900, p. 317) introduced the term "Plenus Marls" in describing the grit-bed at the base of the "Zone of *Rhynchonella cuvieri*." Jefferies (1962, 1963a) divided the Plenus Marls into eight beds each characterised by a distinctive fauna and demonstrated that they could be traced right around the Anglo - Paris Basin. Two prominent erosion surfaces were recognised in the Plenus Marls. The more important one, the sub-Plenus erosion surface (SPES) is at the base and the second one was called the sub-bed 4 erosion surface. The formational status for the Plenus Marls of the Anglo-Paris Basin, was introduced by Robinson (1986, p. 149). He described the Plenus Marl Formation with a proposed reference section at Shakespeare Cliff, Kent and the base of this formation was defined as the sub-Plenus erosion surface (of Jefferies, 1962).

The Plenus Marls contain some species that show close affinity with forms occurring in the central Russian province (Jefferies: 1962, 1963a). Distinctive fauna in the Plenus Marls includes: *Orbirhynchia multicostata* Pettitt in bed 1, *Syncyclonema membranacea* in bed 2, *Actinocamax plenus* (Blainville) in beds 3 to 6, *Lyropecten (Aequipecten) arlesiensis* (Woods) in beds 4 to 6 and *Orbirhynchia wiesti* (Quenstedt) in bed 7. The distribution of macrofauna is shown in Figure 2.2.

Ranscombe Chalk Member

In Sussex, the Plenus Marls are overlain by the Ranscombe Member of the Sussex White Chalk Formation (Mortimore, 1986; Lake *et al.*, 1987). The Ranscombe Member embraces the Melbourn Rock Beds, Holywell Beds and New Pit Beds. However, in the studied sections only the first two sets of beds have been investigated.

Melbourn Rock Beds

These represent a sequence of indurated nodular chalks immediately overlying the Plenus Marls. This dramatic change in lithology marks the base of the Melbourn

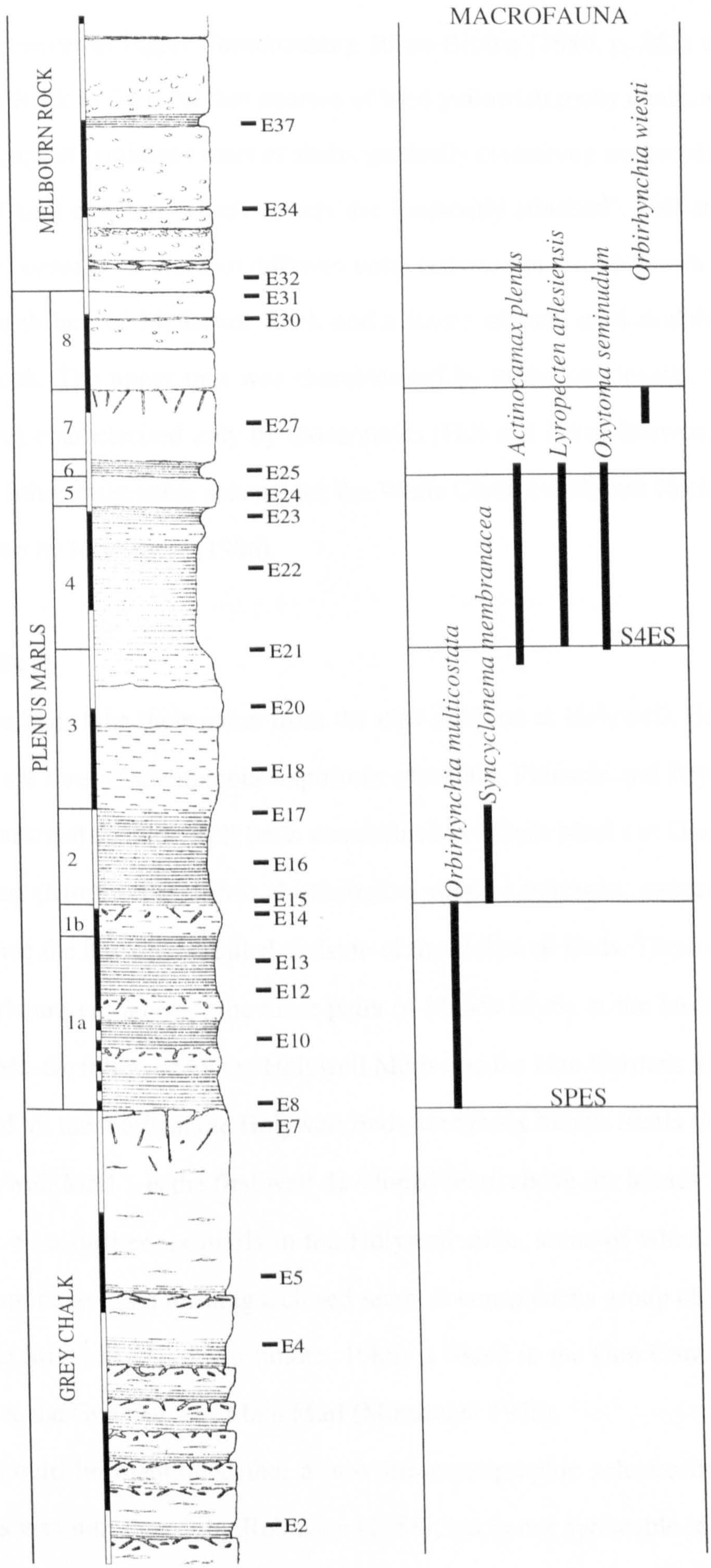


Figure 2.2. Important elements of the macrofaunal succession in the Plenus Marls SPES - sub Plenus erosion surface, S4ES - Sub-bed 4 erosion surface. 1a - 8 Jefferie's bed numbers. Horizontal lines indicate rhythm boundaries.

Rock Beds (uppermost Upper Cenomanian). Jukes-Brown (1880, p. 252) described the Melbourn Rock as "several thin courses of hard yellowish rocky chalk, separated by layers of greyish laminated marl or shale, generally containing numerous nodules or pebbles of hard chalk, to which oysters are frequently attached". Hill and Jukes-Brown (1886) considered that two different units occurred in the Melbourn Rock, an upper yellowish bed of Melbourn Rock and a lower whitish hard nodular bed of Melbourn Rock. The upper unit was characterised by numerous fossils, while the lower unit was characterised only by inoceramids (Hill and Jukes-Browne, 1886, p. 231). A new lithostratigraphic scheme for the White Chalk (Melbourn Rock upward) was introduced by Mortimore (1986).

Holywell Beds

These beds take their name from the cliff sections at Holywell, Eastbourne, where there are three discontinuous exposures (the Cafe, Pinnacle and Foyle Track). The basal marker of the Holywell Beds was defined as Meads Marl 1 at Gun Gardens, Beachy Head (Mortimore, 1986). Lithological marker horizons, especially marl seams, provide the basis for detailed division of the Holywell Beds. Three distinctive suits of marls are recognised, the three pairs of Meads Marls at the base (MM1-2; MM3-4; MM5-6), followed by the Holywell Marls and the Gun Gardens Marls. Most distinctive of all the marls in the Holywell Beds are the six Meads Marls (Mortimore, 1986). Holywell Marl 1 is the first well developed seam above the Meads Marls, and is followed by a further six marls in the Holywell suite, some of which develop a griotte texture rather than forming a closed seam. A conspicuous group of three marls (the Malling Street Marls of Mortimore, 1986) is found in the Gun Gardens section 14.5 m above the Gun Gardens Main Marl (Mortimore 1966).

It should be mentioned that a new lithostratigraphic scheme in the North Downs area was introduced, by Robinson (1986), but is not applicable to the Sussex and Wessex sections considered here. Recently a new stratigraphic scheme for the southern England has been proposed by Gale (1996), which was as follow:

Ballard Cliff Member

The Ballard Cliff Member was defined as the basal part of the White Chalk Formation and includes beds from the top of the Plenus Marls up to the top of Meads Marl 6. At Ballard Cliff, where the stratotype of the section has been chosen (SU 046 812), this member lies directly above the Plenus Marls and comprises 1-5 m of thinly bedded nodular chalk containing abundant intraclasts concentrated in marls and shallow scours. Besides the 6 Meads Marls beds, there are also 4 beds containing the ammonite *Sciponoceras*.

Holywell Member

Introduced for interval above the Ballard Cliff Member up to the Lulworth Marl and embraces Holywell Marls 1-4, Gun Gardens Marls 1-2 and its top is defined by the Lulworth Marl (Malling Street Marl 1 of Mortimore, 1986). The member is characterised by nodular, intraclastic chalk at Eastbourne, which is conspicuously rhythmic on a half meter scale. Beds are defined by thin flasered grey marls, which feel rough due to sand-grade bioclasts. The bioclasts are commonly inoceramid, and rarely micocrinoid, debris. The important marker beds through the section are: a bed between Holywell Marls 2 and 3, called *Roveacrinus* bed 1, which is characterised by high abundance of microcrinoid (*Roveacrinus*) debris and a dark, flaser marl, which contain numerous intraclasts called the Compton Pebble Marl.

Gale's (1996) paper was published during the final stages of this thesis and it has not been possible to use the new terminology introuduced in that paper.

2.1.2. Northern England

The Lower part of Chalk Group of the East Midlands Shelf is represented by a condensed sequence of marly chalks. The lithostratigraphic scheme used to subdivide the Anglo-Paris Basin succession of southern England cannot be applied to this area (Hart, 1993). An alternative lithostratigraphy has been developed (Wood & smith, 1978; Jeans, 1980; Mitchell 1993). The literature review for the Cretaceous rocks of

northern England and the lithostratigraphic schemes used in this thesis are shown in Figure 2.3. In this thesis it is the Black Band succession and overlying chalks of the Flixton Member together with the uppermost part of the Ferriby Chalk Formation that are considered in detail.

Historical background

Judd (1867) was the first person to report various coloured layers, green, pink and purplish-red, on describing the lowermost part of the Welton Chalk Formation. The term "black band" was first used by Dakyns and Fox-Strangeways in 1886 (p. 9) in the following sentence: "At or near the top of the Lower Chalk there is often a black carbonaceous band, which is well seen at Speeton Cliffs near high-water mark, and also in numerous places along the western escarpment of the wolds". The term "black band" was first used in the index to this work (Dakyns & Fox-Strangeways, 1886, p. 22). The only named section was that at Speeton which is thus taken as the type locality. Unfortunately the section that Dakyns and Fox Strangeways showed in their figure (Dakyns & Fox-Strangeways 1886, p. 10) was cut by a nearly horisontal thrust which in some places cuts out beds and in alters only a few metres away, repeats beds. This was noted by Lamplugh (1896) and Rowe (1904), but subsequently this thrusted succession has been published as a standard (e.g. Hart and Bigg 1981; Hart *et al.*, 1991).

Welton Chalk Formation

The erosion surface at the base of the Black Band was used by Wood and Smith (1978) to define the base of their Welton Chalk Formation. The Welton Chalk Formation can be divided into three distinctive litholological units which can be traced throughout the Cleveland Basin (e.g. Hart *et al.*, 1992, but see Mitchell, 1995 for details of Speeton) and these were given member status by Mitchell (1993). Consequently, two new members (Buckton Member and Bemton Member) were introduced above the Flixton Member of Jeans (1980, 1991), Figure 2.3. Welton

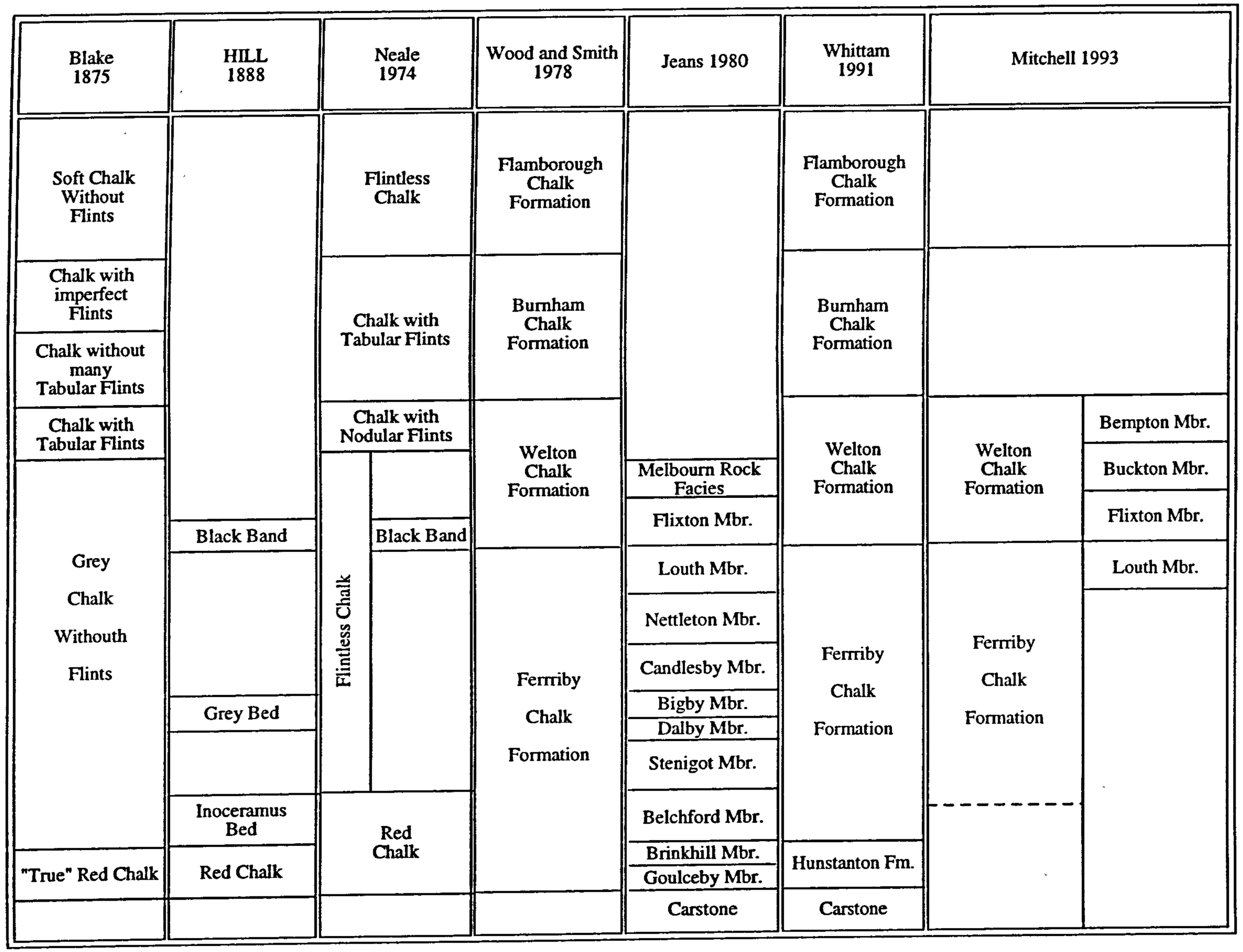


Figure 2.3. History of the development of the lithostratigraphy used for the Upper Cretaceous of northern England. Redrawn from Mitchell 1993.

Chalk Formation overlies the Ferriby Chalk Formation. Details of the Ferriby Chalk Formation at South Ferriby have been given by Gaunt *et al.*, (1992) and Mitchell (1993). In this thesis, only the upper part of the Ferriby Chalk Formation, Louth Member, is studied.

Flixton Member

This member was introuduced by Jeans (1980, 1991). Although the Flixton Member has never been formally defined, the succession at the named locality has been described in detail by Jeans (1991). Mitchell (1993) defined the base of the Flixton Member to coincide with the base of the Welton Chalk Formation and thus at the erosion surface at the base of the Black Band. This follows the original usage of Jeans (1980, 1991). The member can be divided into two distinctive parts: a lower part characterised by marls and shales with subsidiary limestones (the "Black Band succession" of Hart and Bigg, 1981; Hart *et al.*, 1991 and Dodsworth, 1996) and an upper portion characterised by poorly fossiliferous limestones and thin marls.

The Black Band succession

The Black Band is well exposed in the Rugby Cement Company's Quarry at South Ferriby, where it is unaffected by thrusting and can be conveniently studied. The Black Band succession at South Ferriby is, herein, divided into 11 beds, lettered: A, B, C, D, E, F1, F2, F3, G, H and I. Recently Dodsworth (1996) has divided the lowermost part of the Welton Chalk Formation in the eastern England to a successive eight beds, lettered A to H and the term Black Band is applied only to central dark, laminated marl layers (beds C-E). Correlation between the Dodsworth's beds and the beds recognised in this thesis (Figure 2.4) shows that beds C-D of Dodsworth are equal to black shale beds of this thesis, which are beds F1-F3.

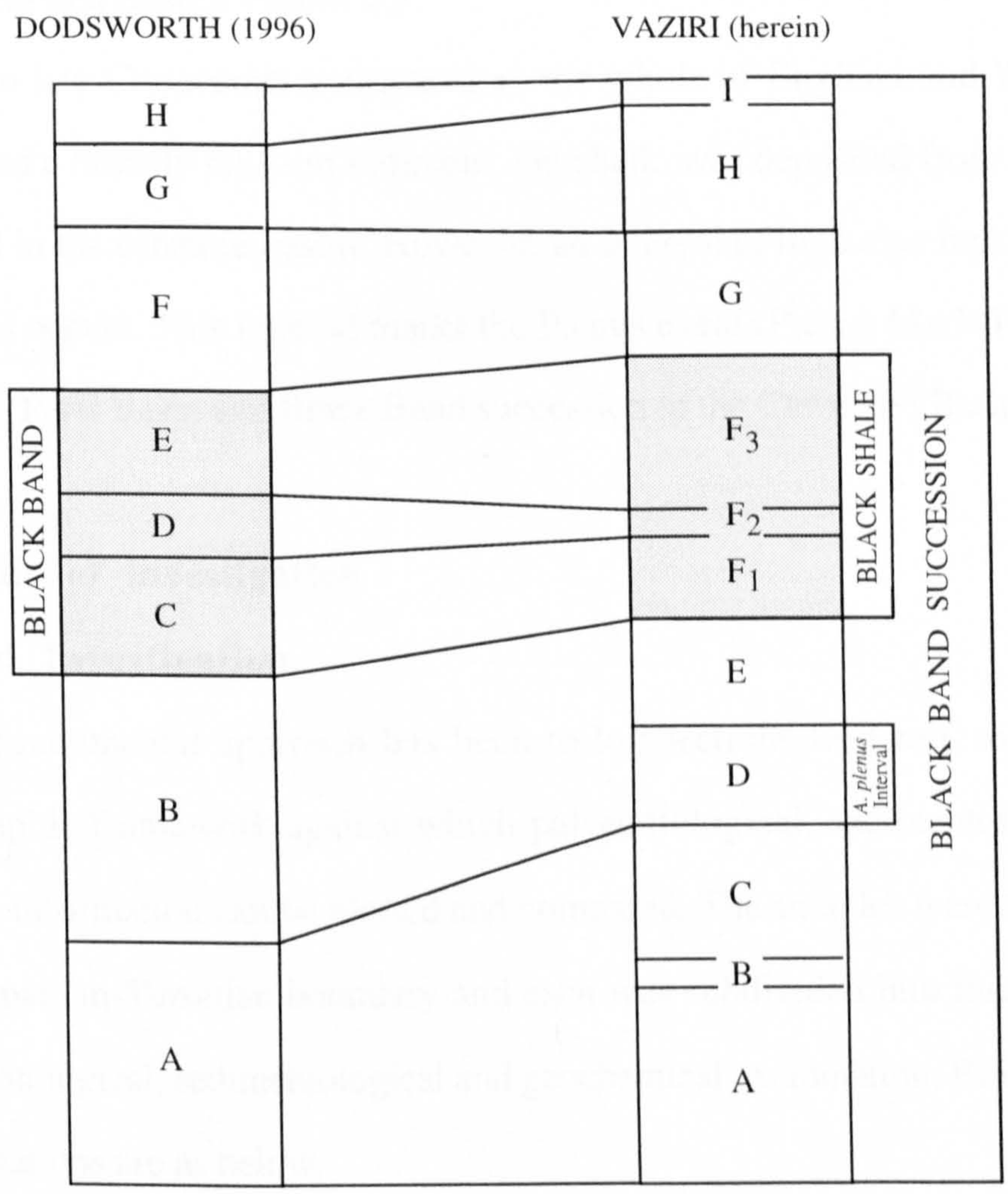


Figure 2.4. Correlation between bed number of Dodsworth (1996) beds and beds recognized in this thesis

2.2. Geological setting

During the late Cenomanian and early Turonian, the studied sections were situated in different basins. Eastbourne in the Anglo - Paris Basin (southern England), Westbury in the Wessex Basin (a small sub-basin within the Anglo - Paris Basin) and South Ferriby in the Cleveland Basin (northern England, on the southern margin of the Southern North Sea Basin), Figure 2.5.

Due to late Cretaceous transgression, the whole of England and Wales was submerged and a broadly uniform sediment, the chalk, was deposited from Yorkshire to Devon and in the offshore basins. However, an interval of high clay input in all the studied basins occurs. This interval marks the Plenus event (Plenus Marls Formation) in the Anglo - Paris Basin and Black Band succession in the Cleveland Basin.

2.3. Methods of investigation

2.3.1. Field Investigation.

The fundamental approach has been to log sections in detail, to provide a lithostratigraphic framework against which palaeontological, sedimentological and geochemical information can be plotted and compared. The samples were taken close to the Cenomanian-Turonian boundary and each was subdivided into three parts for micropalaeontological, sedimentological and geochemical examination. Brief details of field investigations are as below.

At Eastbourne 47 samples were collected from the top of the Grey Chalk to the top of Gun Gardens Marl 2 and also the Lulworth Marl. In the Grey Chalk and Plenus Marls samples were taken from both chalks and marls, while in Melbourn Rock and Ranscombe Chalk Member only the marls were sampled. At South Ferriby 20 samples were collected from the top of the Ferriby Chalk Formation to the base of the Bempton Member of the Welton Chalk Formation. Because of difficulties in processing the hard chalks of Ferriby Chalk Formation, samples were collected only from marls of this part of the section. At Westbury 16 samples were collected from the top of the Grey

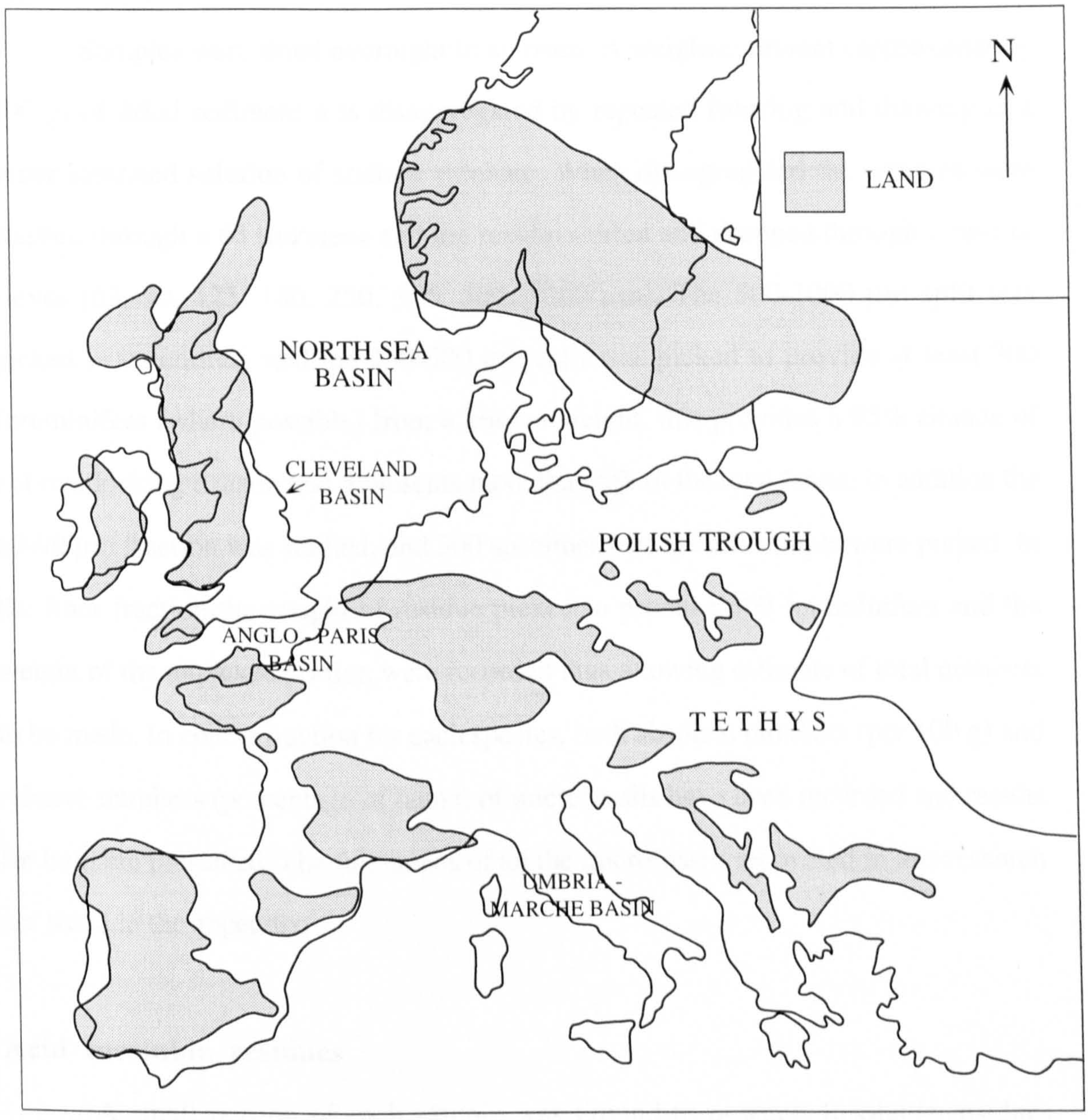


Figure 2. 5. Late Cenomanian shorelines in Europe. Basins mentioned in the text are indicated. Redrawn from Tyson and Funnell (1987).

Chalk to the top of the Meads Marls 5/6 (griotte marl 1), among which only one sample (W11) was not processed.

2.3.2. Laboratory

Microfossils

Samples were dried overnight in an oven. A weighed amount (approximately 100 g) of dried sediment was disaggregated by repeated freezing and thawing in a super saturated solution of sodium sulphate. When dissagregated the samples were washed through a 63 μm sieve and the residues dried and dropped through a nest of sieves (63, 90, 125, 180, 250, 355, 500, 1000 μm). The 500-1000 μm split was picked in its entirety and the 250-500 μm split was picked to provide at least 300 foraminifera (where possible) from a known weight, this provides a 95% chance of not overlooking a taxon that represents more than 5% of the total fauna. In addition the 63-90 μm fraction was studied, and 300 specimens from each sample were picked. In the finer fraction the weight of residue picked to produce 300 foraminifera and the weight of the unpicked portion were recorded thus allowing estimate of total numbers to be made. In coarse fraction for each species, both absolute numbers (per 100 g) and relative numbers (percentage of fauna) of microfossils have been recorded and results for both are presented. The full names of all the microfossils recovered in this research are listed in the appendix.

Acid insoluble residues

A small portion of each sample was ground to powder. Insoluble residues were determined by dissolving an accurately weighted sample of approximately 0.1 g powder in a large excess of 10% HCl, filtering, washing, thoroughly drying and weighing the residue.

Stable isotopes

Stable isotope analysis were based on bulk sediments. A small sample of powder, approximately 3 mg, was used to determine stable isotope ratios of carbon and oxygen in the Liverpool University Stable Isotope Laboratory. All samples were roasted in a low pressure plasma oven for four hours to remove any organic matter. Gaseous CO_2 for analysis was released by reacting the powder with 2 ml anhydrous 100% orthophosphoric acid in a constant temperature bath at 50° C for at least three hours or until the reaction was complete. Results were corrected using standard procedures (Craig 1957) and are expressed as per mil (‰) deviation from the Pee Dee Belemnite (PDB) international standard.

2.3.3. Diversity and P %

It is obvious that the number of taxa in a sample is dependent on the number of specimens which are picked. In addition, simply stating the number of taxa gives no information on the population structure (Mitchell, 1996), hence in this thesis in addition to simple diversity (species richness) two other methods are used to investigate diversity.

Fisher' s α-diversity index

The logarithmic series model, introduced by Fisher, Corbett and Williams (1943) describes mathematically the relationship between the number of species and the number of individuals in a sample. Values can be read from a logarithmic series model (Murray 1973, 1991). The values on recent normal marine shelves range from 5 to 20 and in the slope or bathyal environment from 5 to 25 (Murray, 1991).

Shannon diversity index

Shannon heterogeneity index H(S) is sensitive to both number of species and abundance of the species and assumes that all species are represented in the sample. Values are usually found to fall between 1.5 and 3.5 and only rarely surpass 4.5 (May, 1975). The maximum diversity which could possibly occur would be found in a

situation where all species were equally abundant. Buzas and Gibson (1969) plotted H(S) against depth for foraminiferal assemblages from the continental shelf and ocean off the east coast of the U.S.A. Diversity peaks were found at 35-45 m, 100-200 m and deeper than 2500 m. The use of information theory in diversity studies has been discussed by Beerbower and Jordan (1969).

P %

P % which has been used as an indicator of the palaeobathymetry, is actually the proportion of planktic foraminifera expressed as a percentage of the total assemblage in the >250 μm size fraction, but is commonly incorrectly called the P/B ratio. P % is generally very low on the shelves, but high in basins. However, in the outer shelf or at the shelf margin values show a significant rise (Stehli & Creath, 1964; Kafescioglu, 1971; Gibson, 1989; Murray, 1991).

2.3.4. Morphotype groups

In this thesis, an attempt has been made to investigate all the foraminiferal morphotype groups which are present in the sections. The classification of benthic foraminifera is based on external characteristics such as chamber arrangement, coiling pattern and general configuration of the test. The morphotypic classification for the benthic foraminiferal assemblages that were recognised and their inferred modes of life are summarised in Figures 2.6 and 2.7.

Planktic morphotypes have also been divided into three major groups as below:

1. Non-keeled morphotype (hedbergellids - whiteinellids), with no peripherally keel.

2. Singled-keeled morphotype (rotaliporids), with only one peripherally keeled.

3. Double-keeled morphotye. For convenience, this morphotype includes all species with two genuine peripheral keels (dicarinellids and marginotroncanids) and those with pustulos margins (preglobotruncanids).

MORPHOGROUP	CHAMBERS	TEST FORM	LIFE POSITION	FEEDING STRATEGY	Example
CH-A	Multilocular	Irregular globular chambers connected by necks	Epifaunal to shallow infaunal	Passive deposit feeders	*Ramulina*
CH-B1	Multilocular	Flattened to very low spiral side with a convex umbilicus, of variable height	Epifaunal	Passive herbivores and free-living deposit feeders	*Gyroidinoides* *Lingulogavelinella - involuta*
CH-B2	Multilocular	Planispirally coiled lenticular	Epifaunal to deep infaunal	Active deposit feeders grazing omnivores	*Lenticulina*
CH-B3	Multilocular	Planispiral/low trochospiral biconvex rounded	Epifaunal to shallow infaunal	Active deposit feeders	*Gavelinella baltica*
CH-B4	Multilocular	Plano-convex (± central boss)	Epifaunal (umbilical face half buried)	Active deposit feeders and browsing omnivores	*Gavelinella reussi*
CH-C1	Multilocular	Globular (± ribs)	Infaunal	Deposit feeders and grazing omnivores	*Globulina*
CH-C2	Unilocular Multilocular	Elongate (± flattened, ± ribs)	Infaunal	Deposit feeders and grazing omnivores	*Laevidentalina* *Frondicularia*

Figure 2.6. Calcareous hyaline foraminiferal morphotypes, adapted from Koutsoukos & Hart (1990).

MORPHOGROUP	CHAMBERS	TEST FORM	LIFE POSITION	FEEDING STRATEGY	Example
AG-A	Unilocular Multilocular	Tubular or branching	Erect-projecting from sediment	Suspension feeders (nutrient poor environments)	*Bathysiphon*
AG-B	Bilocular	Planispirally coiled	Epifaunal-	Active deposit feeders	*Ammodiscus*
AG-C	Multilocular	Elongate-mixed growth form	Infaunal	Detrital / bacterial scavengers	*Tritaxia* *Textularia* *Reophax* *Marssonella* *Ammobaculites*

Figure 2.7. Agglutinated foraminiferal morphotypes, adapted from Jones & Charnock (1985).

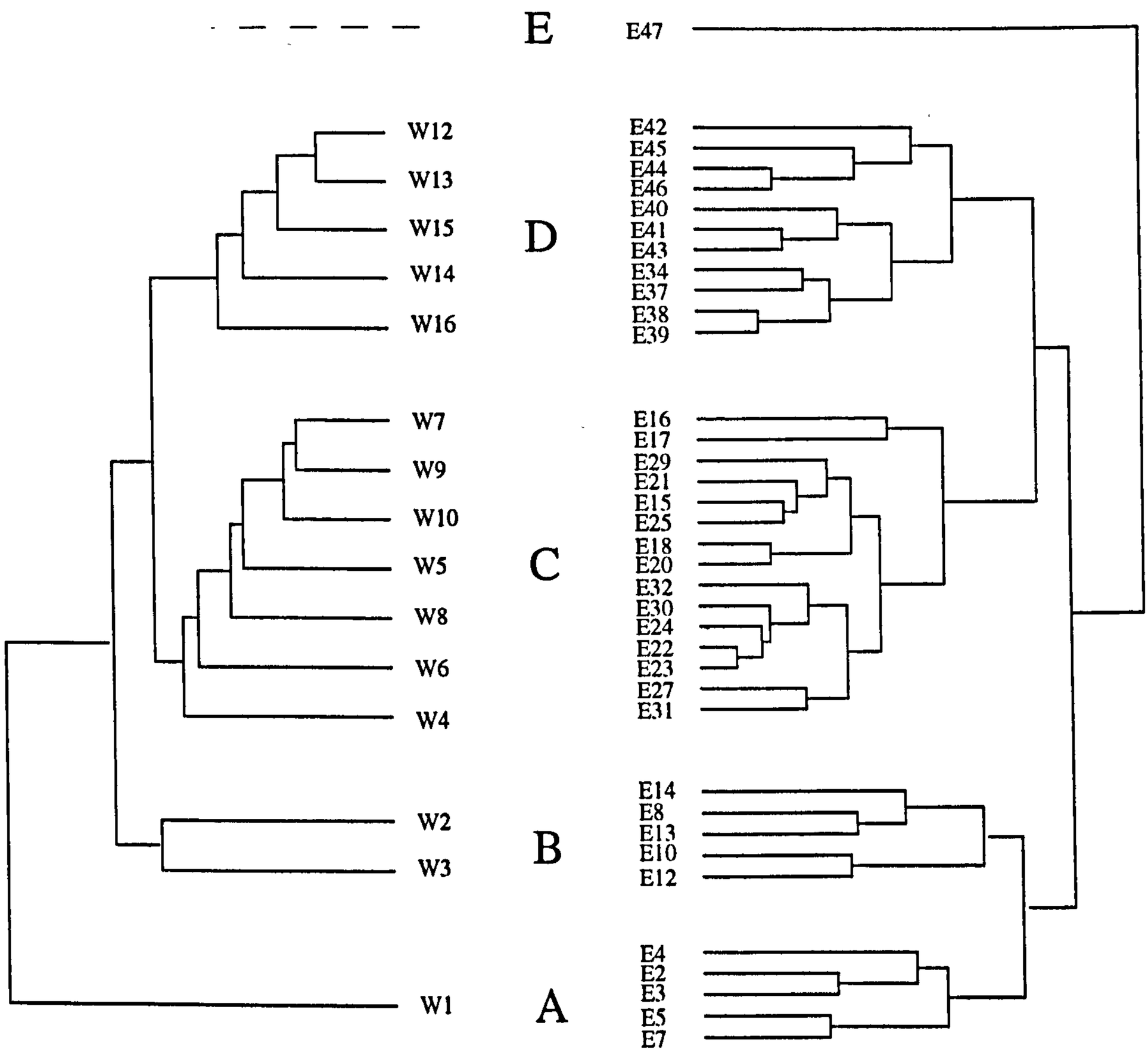
2.3.5. Statistical analysis of the Cenomanian-Turonian boundary from Southern England

A total of 37 samples from the Cenomanian-Turonian boundary of the Eastbourne section and 15 samples from the Westbury section have been analysed. Where possible at least 300 benthic foraminifera were picked from the coarse fraction (250-500 μm fraction) and per cent of each species in each sample calculated. These data were then subjected to a cluster analysis using the software package "Data Desk" in an Apple Macintosh Classic computer.

Based on percentage of different species in each sample, five clusters can be recognised in the Eastbourne section and four in the Westbury section. The clusters occur in stratigraphic succession and are labelled A_E to E_E at Eastbourne and A_W to D_W at Westbury (Figure 2.8). At Westbury the upper part of the section was not sampled, so any equivalent of cluster E_E could not be recognised. The clusters can be defined stratigraphically as follows:

Cluster A	Pre Plenus Marls
Cluster B	Bed 1 of the Plenus Marls
Cluster C	Bed 2 to lower part of the Melbourn Rock
Cluster D	Post Plenus Marls
Cluster E	Lulworth Marl

The important species of each cluster are shown in Figure 2.9. This Figure is based on average percentage of species, which occur in each cluster. As is obvious, two pairs of clusters (A_E with A_W and D_E with D_W) show the same assemblages, while there are different compositions to clusters B_E and B_W and C_E with C_W (during the Plenus Marls). Therefore, when a composite cluster analysis including both the Eastbourne and Westbury was prepared samples from the same stratigraphic levels did not cluster with each other. However, the main point is that the clusters are arranged in stratigraphic succession and not by paleoecological conditions.



Clusters and Beds/Formation

C – Bed 2 to top of bed 8/ base of Melbourn Rock

B – Bed 1 of the Plenus Marls

A – Pre Plenus Marls (Grey Chalk)

E – Lulworth Marl

D – Post Plenus Marls

Figure 2.8. Complete linkage cluster analysis of the samples of coarse benthic foraminifera across the Cenomanian - Turonian boundary from Eastbourne and Westbury.

Characteristics of clusters

Characteristics of coarse benthic foraminiferal assemblages in different clusters are discussed briefly as follow.

Clusters A and B generally are characterised by typical late Cenomanian fauna (Carter & Hart, 1977; Hart *et al.*, 1981), low dominance, high diversity and a mixed assemblage of both epifaunal and infaunal foraminifera. Significant taxa belong to tritaxiids, gavelinellids and coiled vaginulinids (Figure 2.9). At Westbury, cluster C is composed of species mainly belonging to gavelinellids and coiled vaginulinids, while at Eastbourne gavelinellids, textulariids and verneuilinids are dominant. In both sections, cluster D is characterised by a low diversity, high dominance of eggerellids and gavelinellinids, while in cluster E (Eastbourne), eggerellids, gavelinellids and tritaxiids are important.

Clus.	Eastbourne	Westbury
A	*Tritaxia* spp. *Gavelinella baltica* + *G. cenomanica* *Lenticulina* spp.	*Tritaxia* spp. *Gavelinella baltica* + *G. cenomanica* *Lenticulina* spp.
B	*Tritaxia* spp. *Lingulogavelinella involuta* *Gavelinella baltica* + *G. reussi* *Lenticulina* spp.	*Lingulogavelinella involuta* *Gavelinella berthelini* + *G. reussi* *Lenticulina* spp. *Textularia* spp.
C	*Lingulogavelinella globosa* *Gavelinella berthelini* + *G. reussi* *Gaudryina austinana* *Textularia* spp.	*Gavelinella berthelini* + *G. reussi* *Lingulogavelinella globosa* *Lenticulina* spp.
D	*Gavelinella berthelini* + *G. reussi* *Marssonella* spp. *Lingulogavelinella globosa*	*Gavelinella berthelini* + *G. reussi* *Marssonella* spp. *Lingulogavelinella globosa*
E	*Gavelinella berthelini* + *G. reussi* *Marssonella* spp. *Tritaxia* spp.	Has not been processed

Figure 2.9. Comparision between different assemblages in clusters A -E at Eastbourne and Westbury.

CHAPTER 3

CHAPTER 3

CENOMANIAN-TURONIAN BOUNDARY AT EASTBOURNE

3.1. Cluster A_E (Pre Plenus Marls)

As discussed in the previous chapter, based on statistical data (cluster analysis) five clusters at Eastbourne have been distinguished, labelled A_E - E_E. Characteristics of clusters A_E are as below.

3.1.1. Lithology and samples

The thickness of the measured interval is 4 m and the top is defined by a prominent erosion surface (the sub Plenus erosion surface of Jefferies, 1963a, SPES), which separates this cluster from cluster B. The alternation of chalk and marl is characteristic of the pre Plenus Marls interval (Grey Chalk). However, the uppermost part of the interval consists only of chalk facies, Figure 3.1.

The interval includes samples E2 to E7, of which the 63-90 μm fraction of samples E2, E4 and E7 has been examined and the coarse fraction (> 250 μm) of all except sample E6.

3.1.2. Stable isotopes and acid insoluble residues

A detailed curve for carbon and oxygen stable isotopes has been produced for the lower part of the Cenomanian-Turonian boundary event at Eastbourne and integrated with the curve of Gale *et al.* (1993) for the higher part of the excursion, which is shown in Figure 3.2.

In cluster A, the carbon isotope $\delta^{13}C$ curve starts around 2.7‰ PDB and does not show any significant change throughout the interval. The values oscillate between 2.6‰ and 2.8‰, Figure 3.2.

Oxygen isotope values, $\delta^{18}O$ vary from -3.5‰ to -2.6‰ PDB in this interval. Values start at about -3.2‰ PDB and after some oscillation, reach -3.1‰ PDB at the top of the interval, Figure 3.2. The amount of acid insoluble residue (AIR) ranges

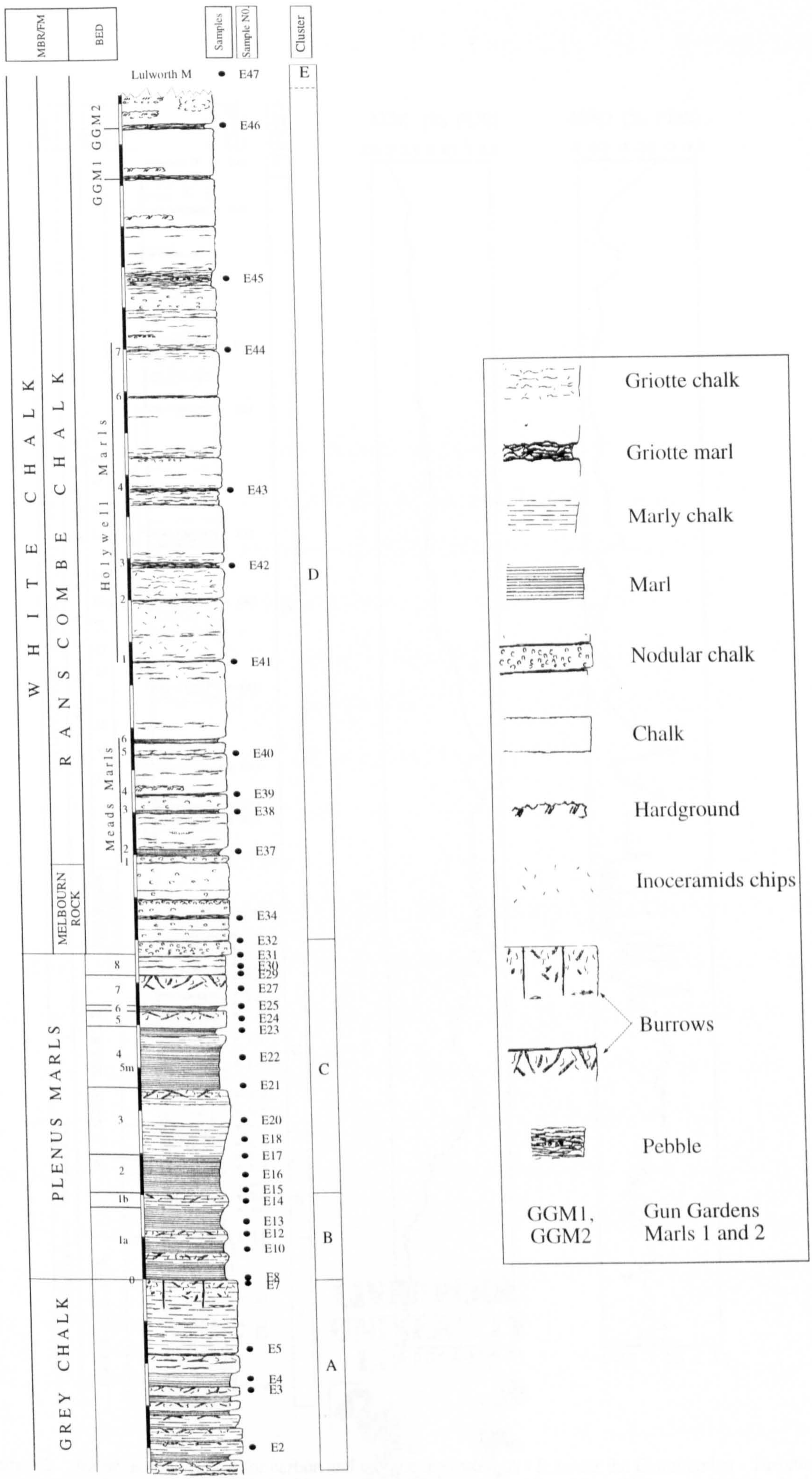


Figure 3.1. Lithostratigraphy of the Upper Cenomanian - Lower Turonian at Eastbourne (Beachy Head). Scale in metres.

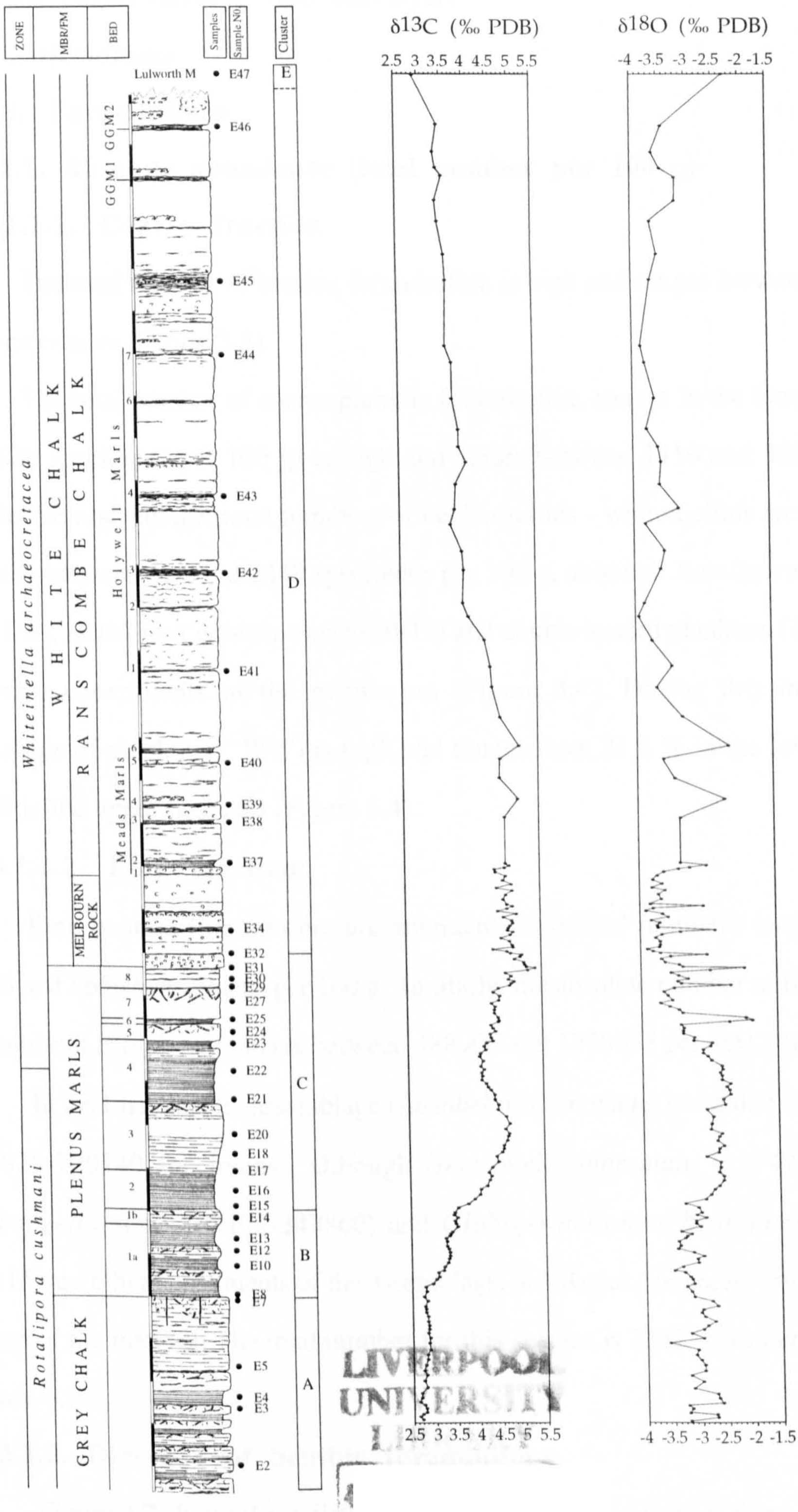


Figure 3.2. Stable isotope curves for carbon and oxygen in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Upper part of curves are reproduced from Gale *et al.* (1993). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

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between 2 and 13%, which shows that the Grey Chalk within this interval is fairly pure chalk. Higher values are from marl layers.

3.1.3. Microfauna

3.1.3.1. Foraminifera

3.1.3.1.1. Absolute abundance (total number per 100 g)

3.1.3.1.1.1. Coarse fraction

The total number of benthic foraminifera is high and ranges between 909 and 1940 specimens (Figure 3.3).

The total number of coarse planktic foraminifera, except in the lowest sample (E2, 626 specimens per 100 g) is high and varies between 1410 and 3033 (Figure 3.3). In the assemblage, total numbers of hedbergellids - whiteinellids are very high and vary between 456 and 2448 specimens per 100 g, although *Rotalipora cushmani* (100-568), *Rotalipora greenhornensis* (0-12) and double-keeled planktics (10-144) are the other constituents of the population (Figure 3.4). During this interval the percentage of planktics ("P%") is high and ranges from 31.8 % in the lower part to 70.6% in the uppermost part (Figure 3.4).

3.1.3.1.1.2. Fine fraction

Fine benthic foraminifera are abundant, estimated numbers range between 47788 and 86562 specimens per 100 g. Similarly, the absolute number of fine planktic foraminifera is high and ranges between 488908 and 1278655 per 100 g (Figure 3.5).

In the fine planktic assemblage *Guembelitria cenomana* is the dominant species (194828-700740 specimens), although *Heterohelix moremani* (119470-354492), *Hedbergella* spp. (107172-349860) and *Globigerinelloides bentonensis* (36760-129115) are other constituents of the assemblage. *Schakoina cenomana* only appears at the top of the interval. The total number for this species is 7352 specimens per 100 g (Figure 3.6).

3.1.3.1.2. Diversity of benthic foraminifera

Figure 3.7 shows three different diversity curves for benthic foraminifera. The values for each diversity in cluster A is as below.

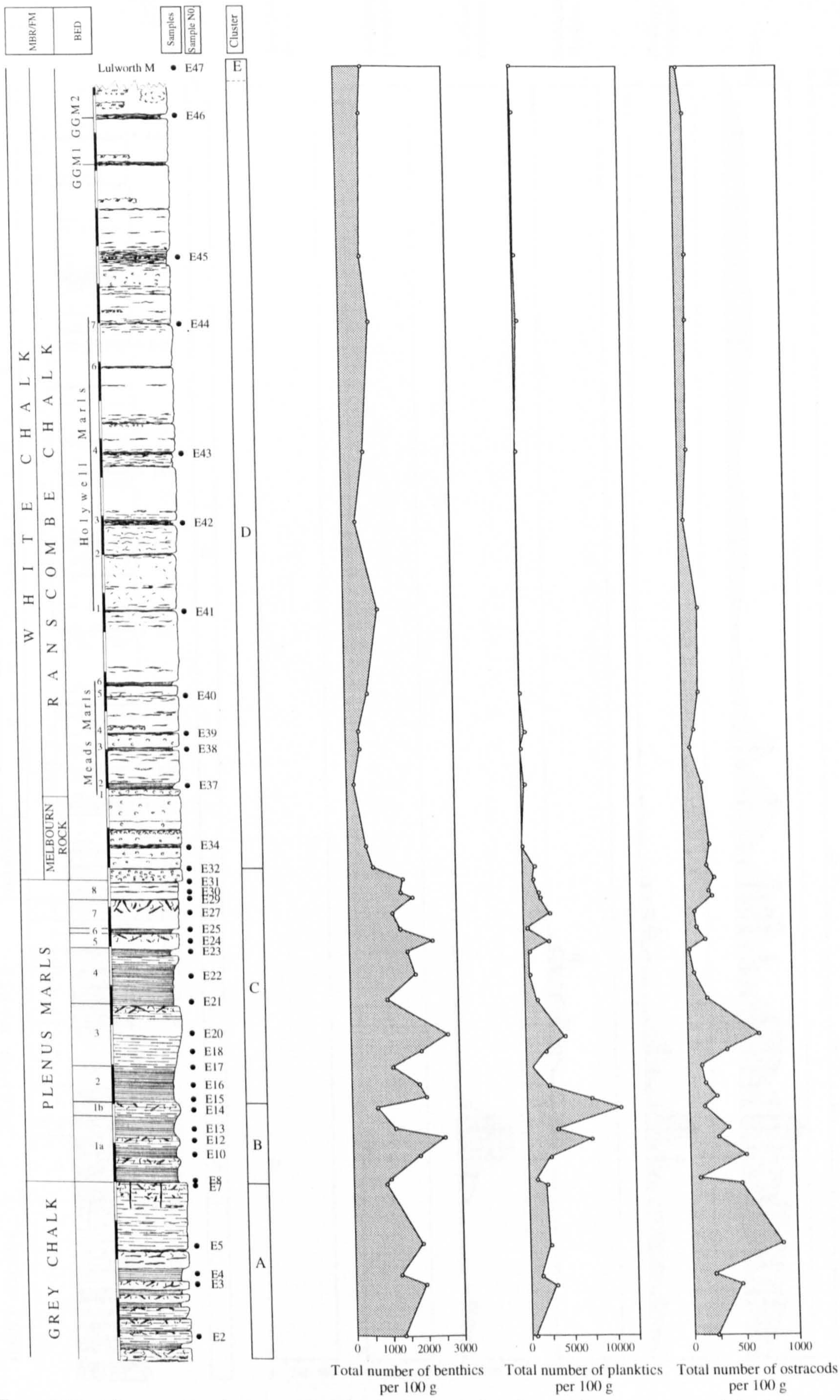


Figure 3.3. Absolute abundance of coarse benthic and planktic foraminifera and ostracods in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

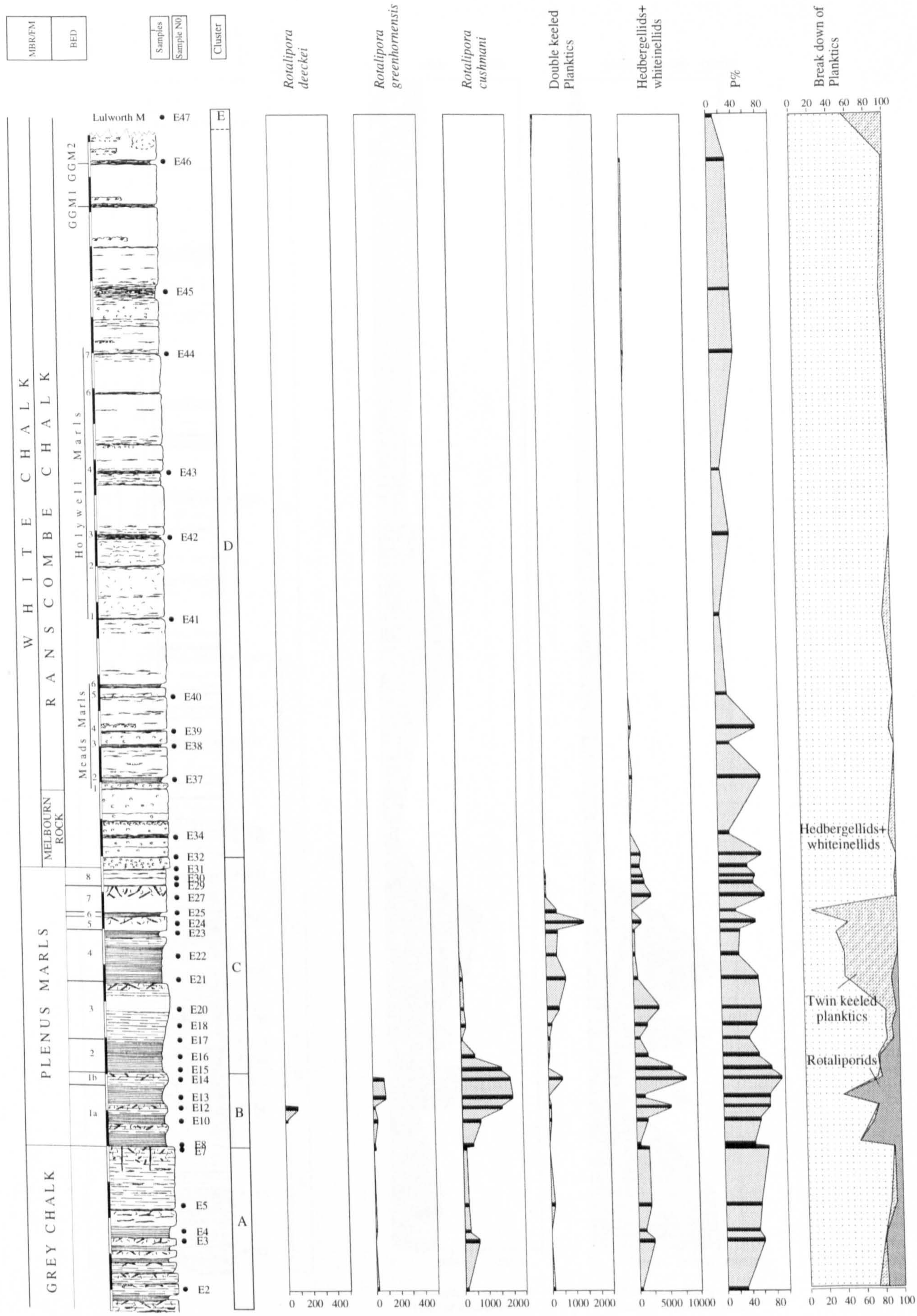


Figure 3.4. Absolute abundance (per 100 g), P% and breakdown of coarse planktic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

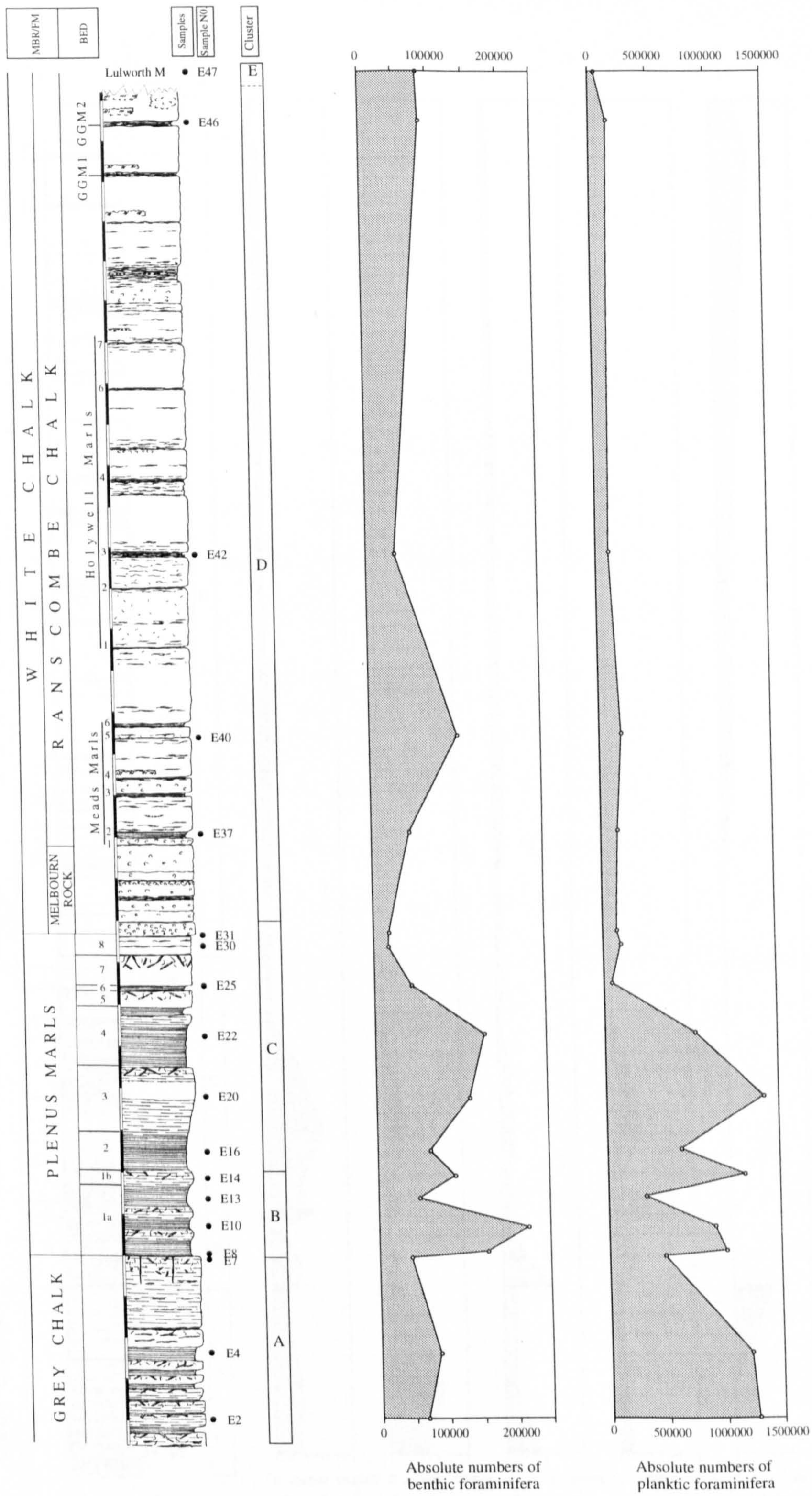


Figure 3.5. Absolute abundance of fine benthic and planktic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

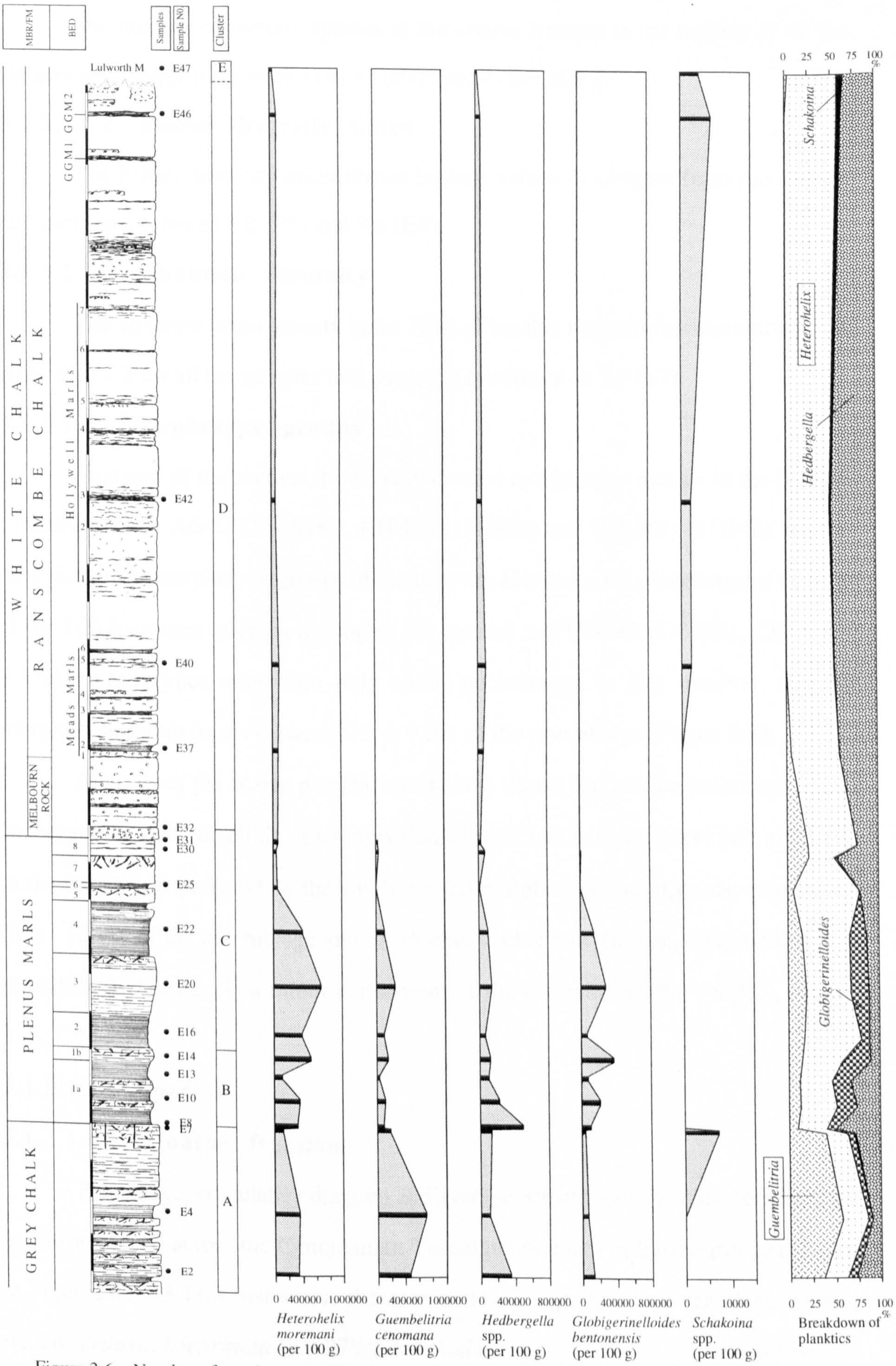


Figure 3.6. Number of specimens and breakdown of fine planktic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

3.1.3.1.2.1. Simple diversity (species richness)

The number of benthic species in the coarse fraction is the highest of all the clusters and ranges from 34 (E5) to 39 (E4) species per 100 g.

3.1.3.1.2.2. Fisher diversity index

The Fisher diversity index shows highest values in samples from this cluster and oscillates between 6.0 (E3) and 7.8 (E4).

3.1.3.1.2.3. Shannon diversity

The Shannon heterogeneity index H(S) of benthic foraminiferal assemblages is more than 2.3 for all the samples and reaches a maximum of 2.9 (E7).

3.1.3.1.3. Morphotype groups

This part of the section shows very diverse morphotype groups in the benthic assemblage and AG-C (33 -61%), CH-B3 (16-29%) and CH-B2 (12-19%) are the most dominant morphotype groups of the interval. However, the percentage of CH-C2 (1.7-11%) increases towards the top of the section and CH-B1 (1-2.8%), CH-A (0-2.5%) morphotypes constitute only small percentages in this interval. CH-B4 morphotype group forms between 0.3 to 9.0% of the assemblage (Figure 3.8).

Analysis of the coarse planktic assemblage shows that non-keeled morphotype, hedbergellids - whiteinellids, is strongly dominant (72-81% in the lower part to 92.1% in the uppermost part), while the single-keeled morphotype, rotaliporids, constitutes 6.1 to 18.7% of the assemblage and the double-keeled morphotype, dicarinellids and praeglobotruncanids, is a minor constituent of the assemblage (0.5 - 9.9%), Figure 3.4.

3.1.3.1.4. Species

3.1.3.1.4.1. Coarse fraction

Percentage, comulative diagram and average percentage of benthic foraminifera in clusters A - E across the Cenomanian-Turonian boundary at Eastbourne are shown in Figures 3.9 - 3.11. Cluster A is characterised by a high diverse assemblage, among which, *Tritaxia tricarinata* (3.9-27%), *Lenticulina* spp. (12-17%), *Gavelinella baltica* (6.9-18.6%) and *Gavelinella cenomanica* (2-19%) are the most important ones.

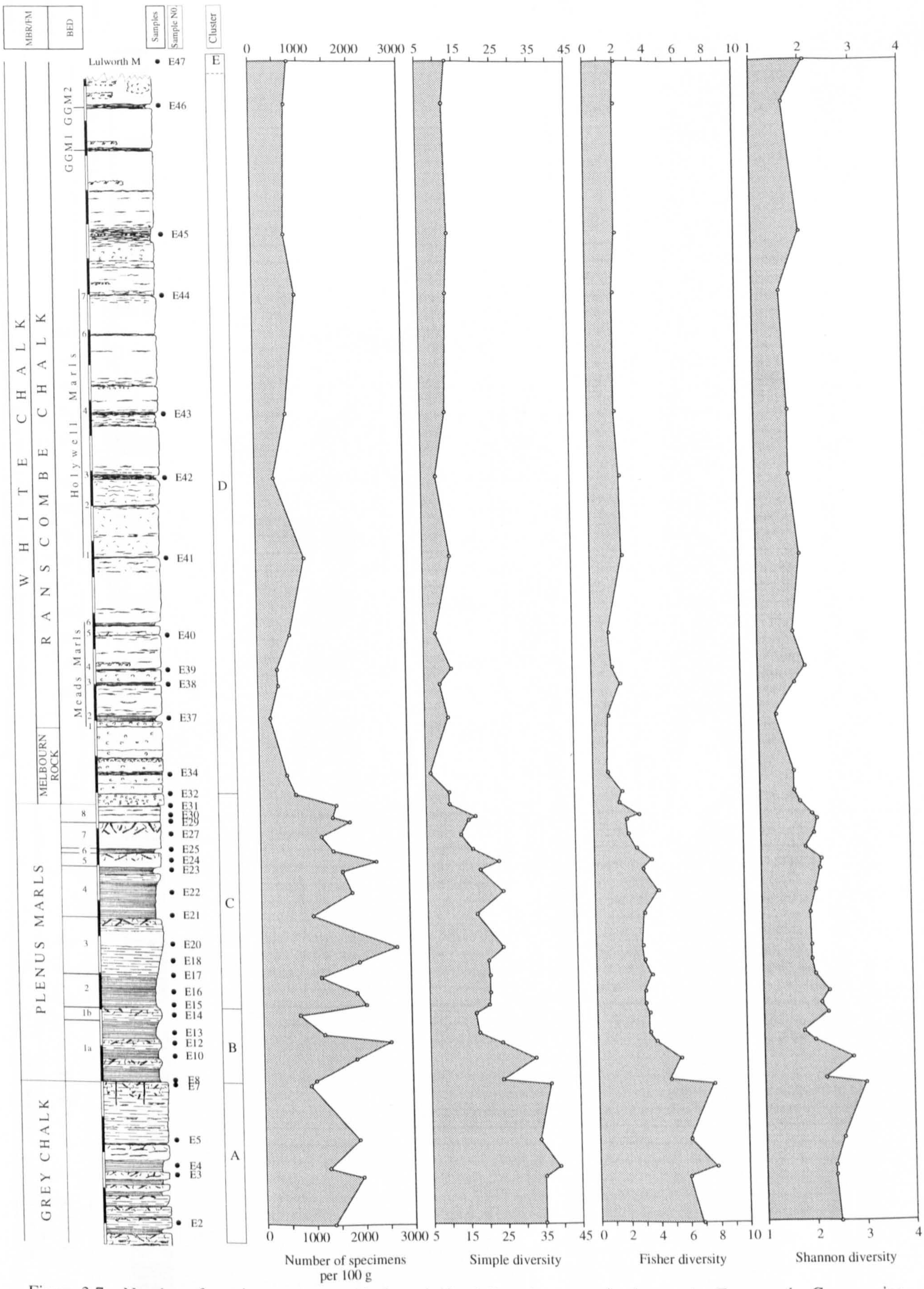


Figure 3.7. Number of specimens and benthic foraminiferal diversity curves in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

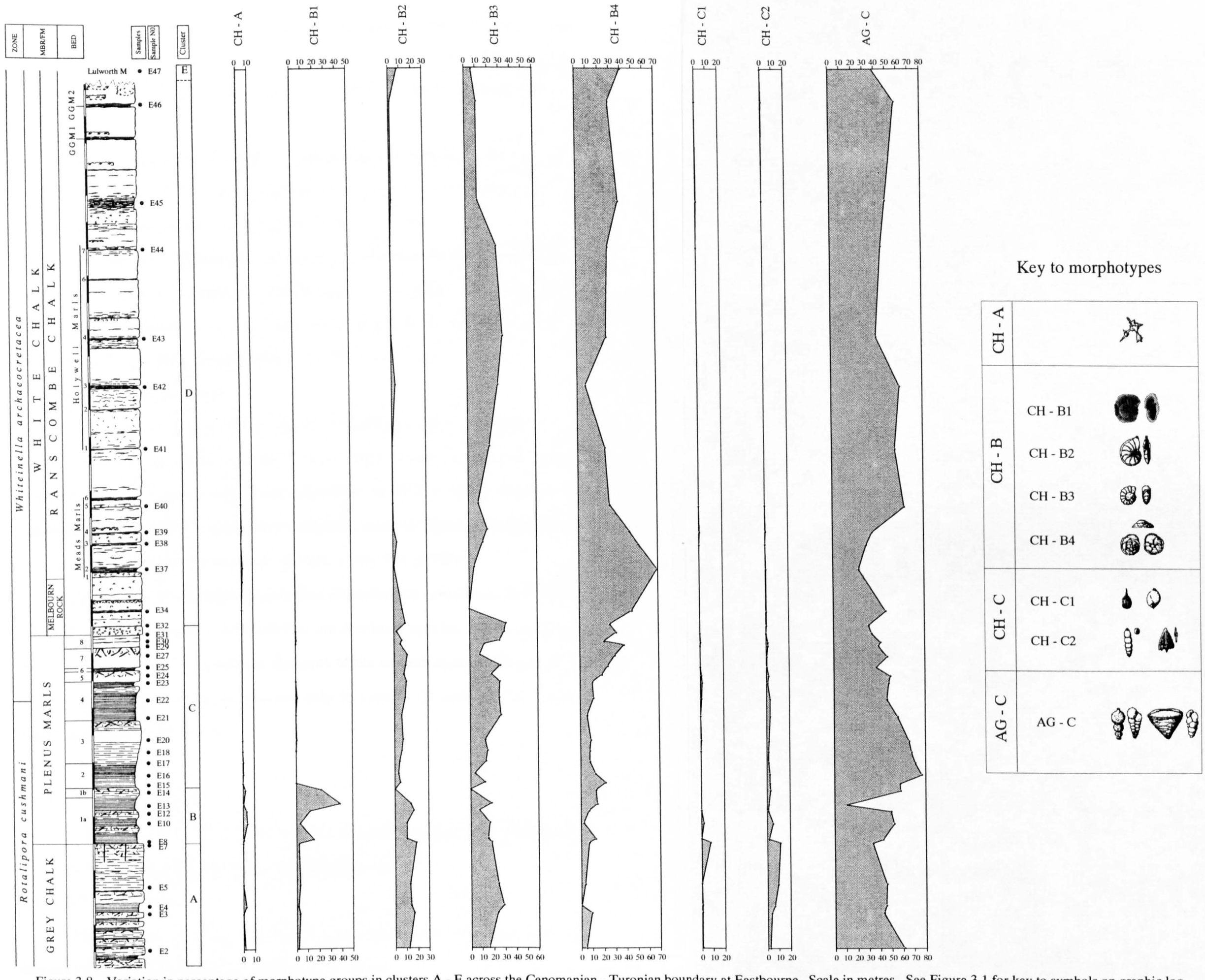


Figure 3.8. Variation in percentage of morphotype groups in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

However, *Tritaxia pyramidata* (0-11%), *Gavelinella reussi* (0.3-9%), *Dorothia gradata* plus *Plectina* spp. (4-10%) are the other elements of the cluster. *Marssonella trochus* var. *turris* (0-5%) and *Gavelinella berthelini* (0-0.8%) are minor constituents of this assemblage.

Although the infaunal, semi-infaunal group is dominant in this interval, a relatively high proportion of the assemblage is occupied by the epifaunal group, the percentage of which ranges from 17.8 to 28.4% (Figure 3.10).

In the planktics, *Hedbergella delrioensis* is the most important element (66.4-86.8%) and *Rotalipora cushmani* occupies from 6.1 to 18.7% of the assemblage. *Rotalipora greenhornensis* (0-1.2%), *Dicarinella algeriana* (0-0.5%), *Dicarinella hagni* (0-4.1%) and *Praeglobotruncana stephani* (0-5.7%) are very rare.

3.1.3.1.4.2. Fine fraction

The dominant species of fine benthic foraminifera are *Praebulimina* sp. A (42.8-69.2%) and *Gyroidinoides* sp. A (30.7-38%). However, in some samples *Osangularia* sp. A is also a significant contributor (0-18.7%). These three species constitute more than 95% of assemblage within this interval, Figure 3.12. *Eggerellina* sp. occurs only in sample E4 and its proportion is very low (4.7%).

Among the fine planktics foraminifera *Guembelitria cenomana* (36.4-57.2%) and *Heterohelix moremani* (24.4%-28.9%) are dominant species. *Hedbergella* spp. (8.7-27.3%) are the other significant elements of the assemblages in this part of the section. *Shackoina cenomana* appears only in sample E7 and only as a minor constituent (1.5%), Figure 3.6.

3.1.3.2. Ostracods

3.1.3.2.1. Total number

The total number of ostracods is high in samples from this interval and ranges from 216 (E4) to 864 (E5) valves per 100 g (Figure 3.13).

3.1.3.2.2. Diversity

The different diversity curves for ostracods are shown in Figure 3.13. The characteristics of each diversity in cluster A is as below.

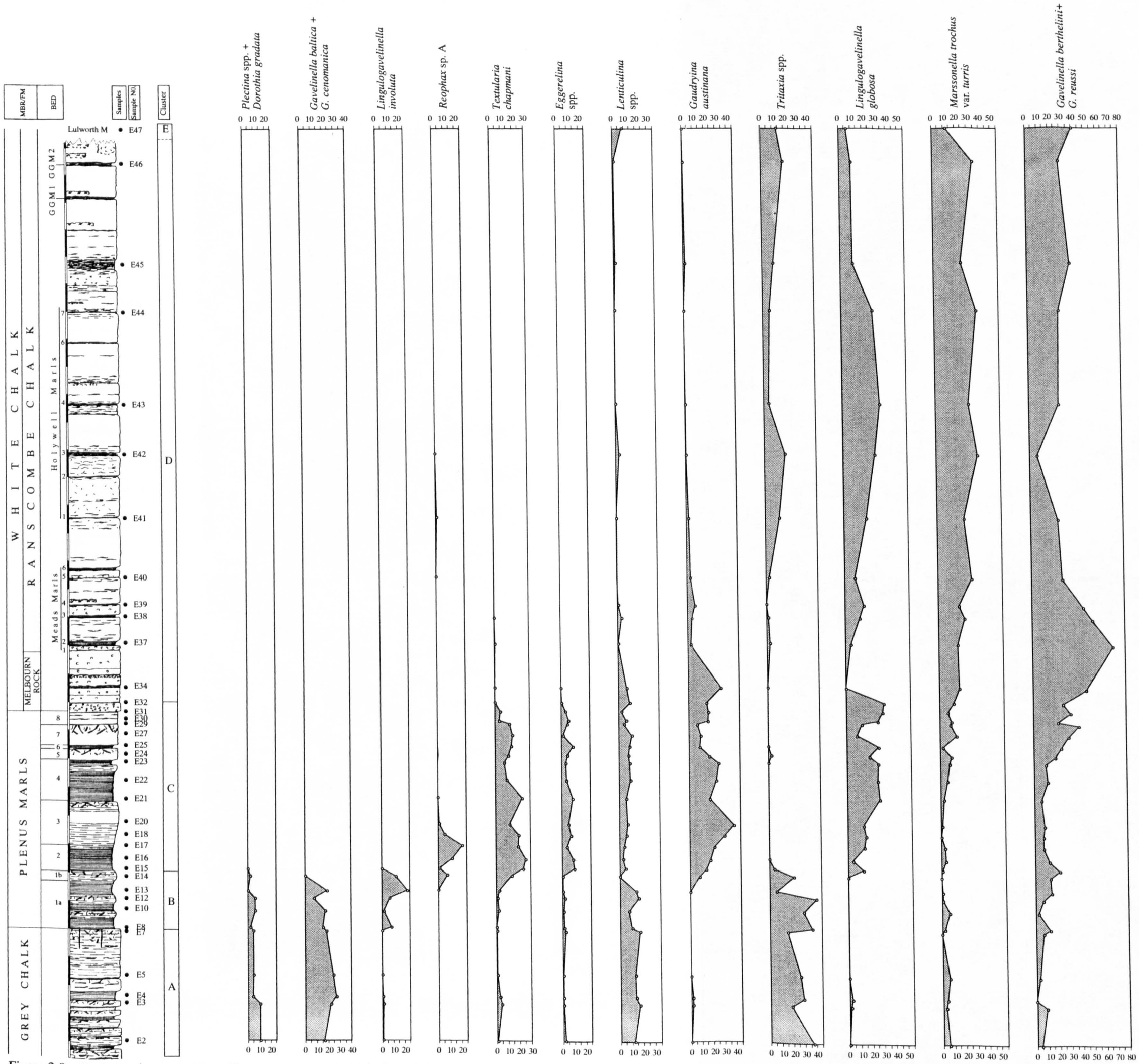


Figure 3.9. Variation in percentage of important coarse benthic foraminifera in clusters A -E across the Cenomanian - Turonian boundary at Eastbourne. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

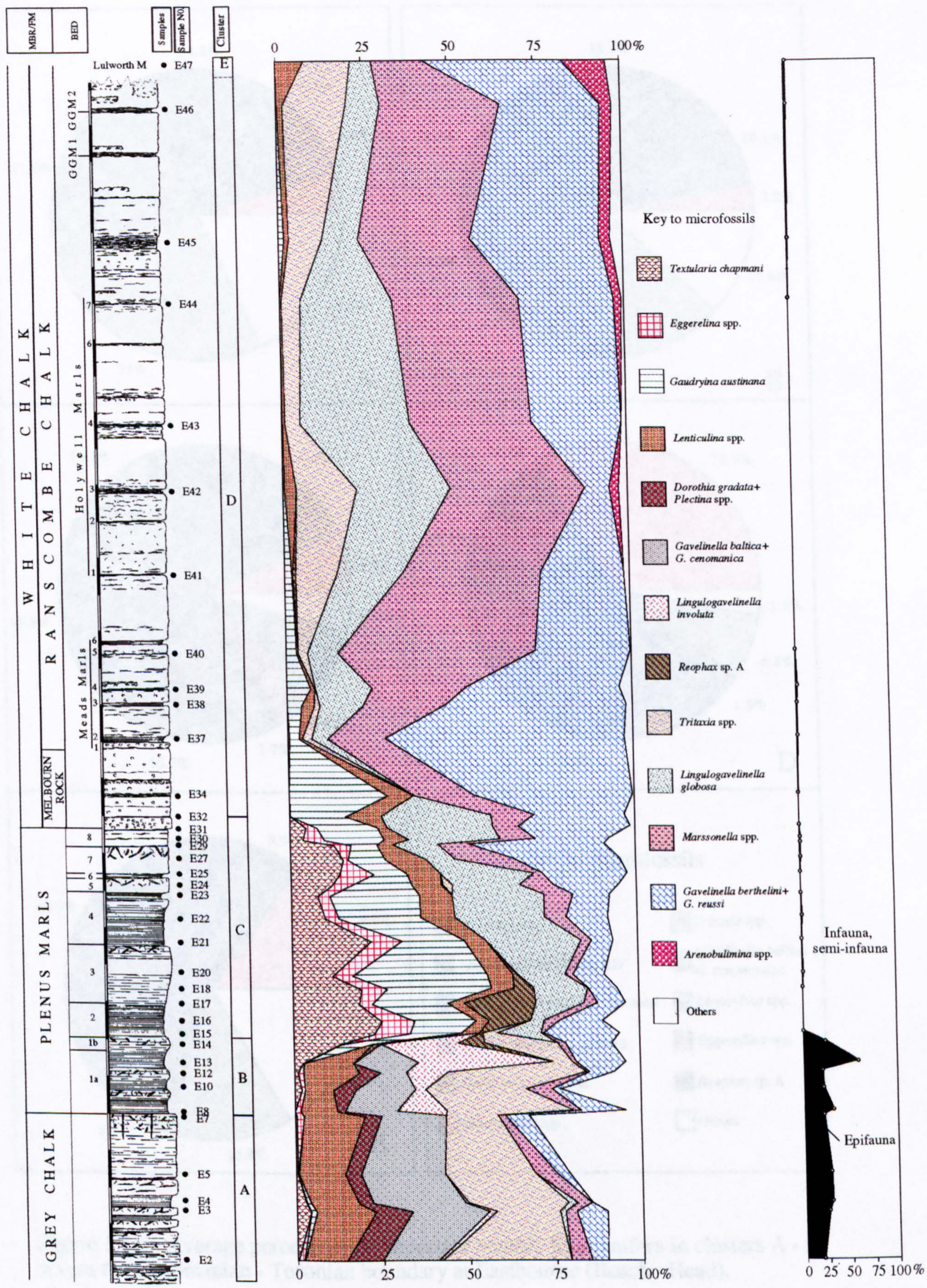


Figure 3.10. Cumulative percent of dominant benthic foraminifera and percentage of epifaunal group in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

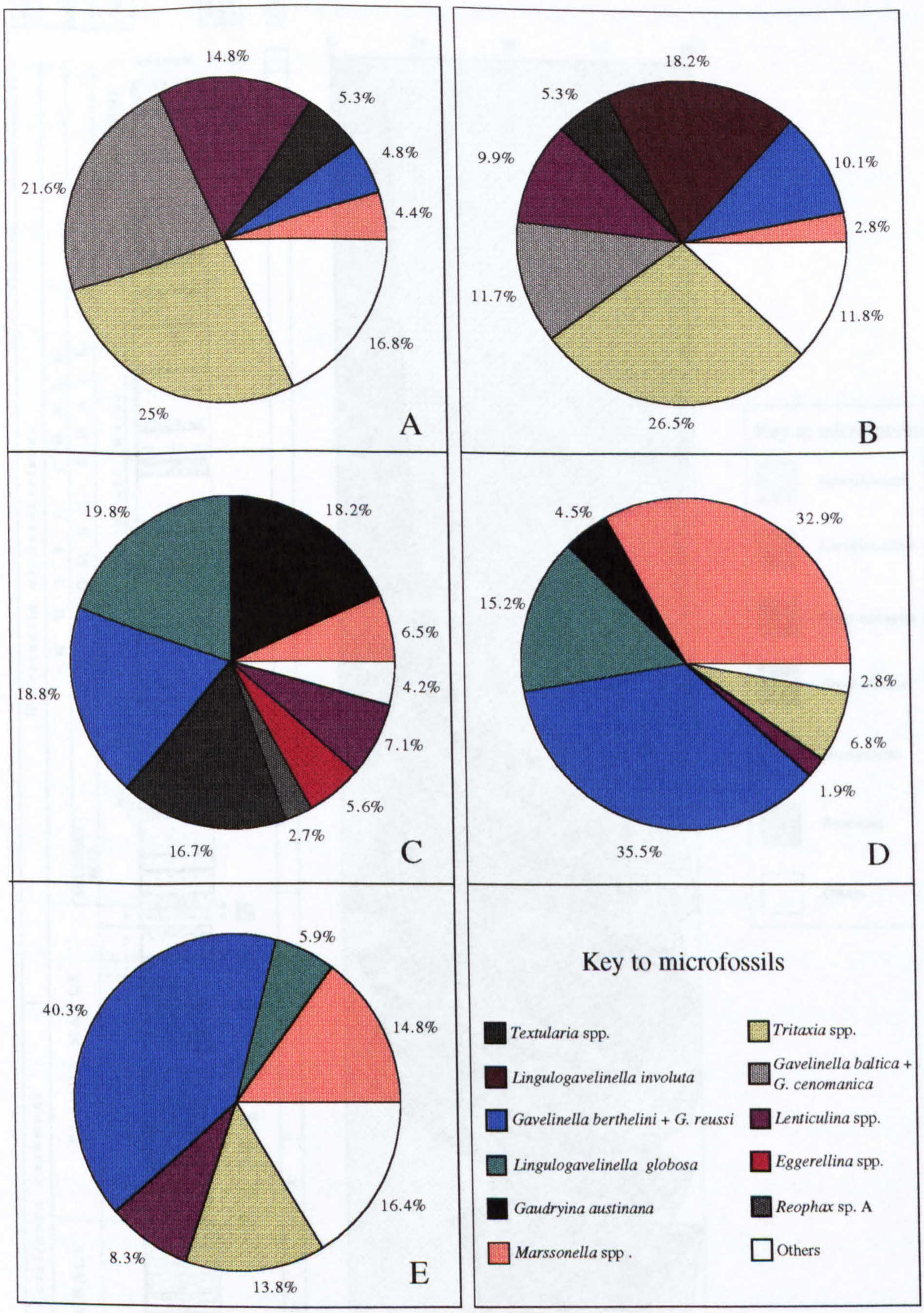
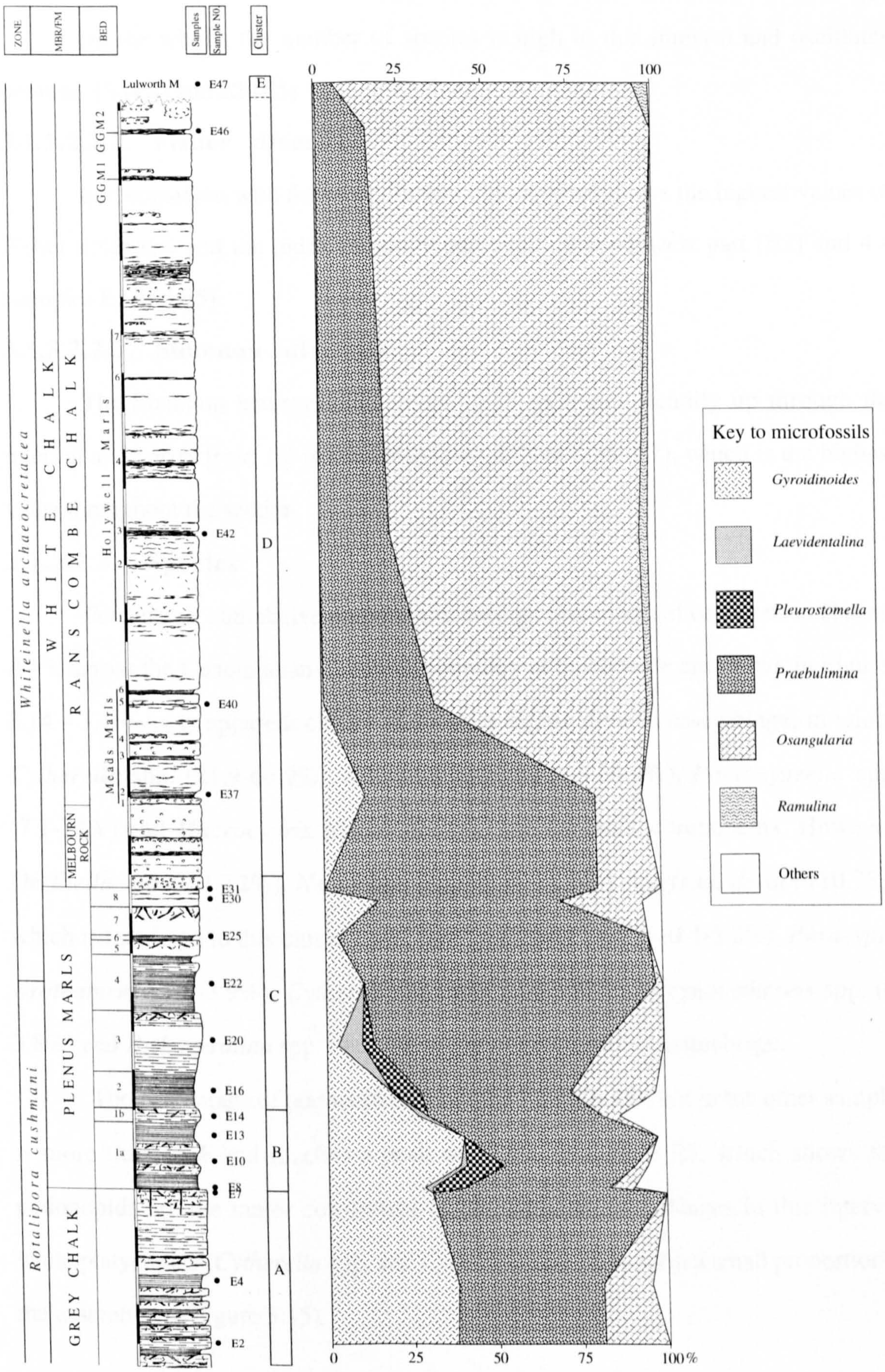


Figure 3.11. Average percentage of important benthic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head).



Figur 3.12. Cumulative percent of dominant fine benthic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

3.1.3.2.2.1. Simple diversity

On the whole, the number of species is high in this interval and oscillates between 13 (E2) and 22 (E5).

3.1.3.2.2.2. Fisher diversity

In comparison with the other clusters, this interval shows the highest values of Fisher diversity, and the index ranges between 3.1 in the lowest part (E2) and 4.4 (samples E3 and E5).

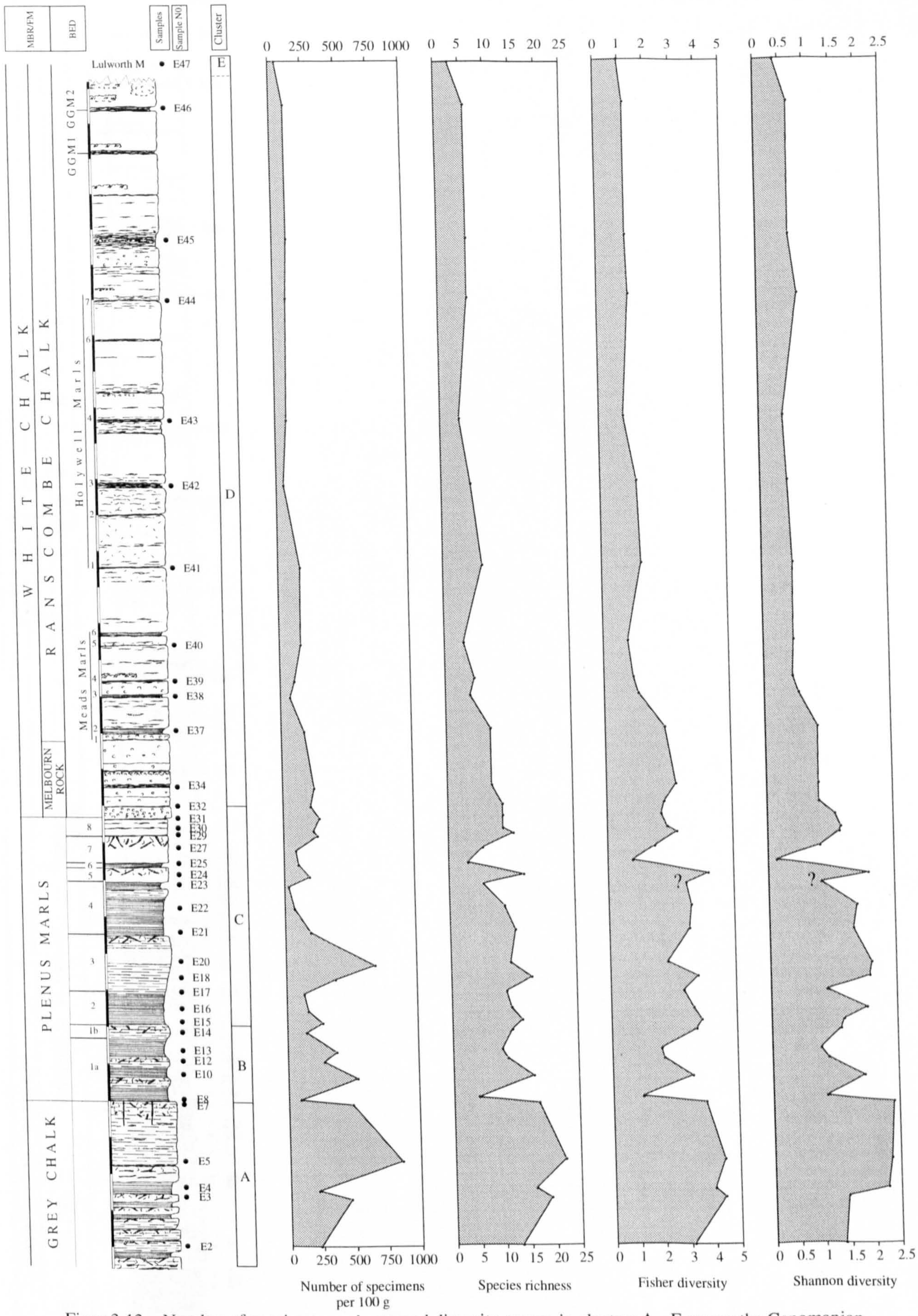
3.1.3.2.2.3. Shannon diversity

The Shannon heterogeneity index H(S), increases steadily up through the interval and varies from 1.3 in the lowest part (E2) to 2.38 (E7), which is the highest value throughout the section.

3.1.3.2.3. Species

Percentage, cumulative diagram and average percentage of ostracods in clusters A - E across the Cenomanian-Turonian boundary at Eastbourne are shown in Figures 3.14 - 3.16. As is apparent cluster A shows a highly diverse assemblage, in which *Cytherella* spp. (21.9-66.9%), *Bairdoppilata* spp., (8-34.3%), *Pontocyprella* spp. (7.1-22%) and *Macrocypris siliqua* (0-26%) are the main components. However, *Oertliella* spp. (0.1-12%), *Neocythereis kayei* (0-11.6%), *Curfsina derooi* (10.7%), which is restricted to this cluster only, *Herrigocythere donzei* (0.4-5.2%), *Paracypris wrothamensis* (0-3.9%), *Cytherelloidea* spp. (0.6-3.8%), *Pterygocythereis* spp. (0-3.8%) and *Bythoceratina* spp. (0-3.5%) are minor elements of assemblage.

The percentage of podocopids in sample E2 is 29.4%, but in the other samples is more than 65% and reaches a peak of 77.4% in sample E5, which shows that podocopids are the major constituent of the ostracod assemblages in this interval, while platycopids (*Cytherella* spp. and *Cytherelloidea* spp.) form a small proportion of the assemblage (Figure 3.15).



Figur 3.13. Number of specimens and ostracod diversity curves in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Question marks indicate the low number of specimens, therefor uncertain diversities. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

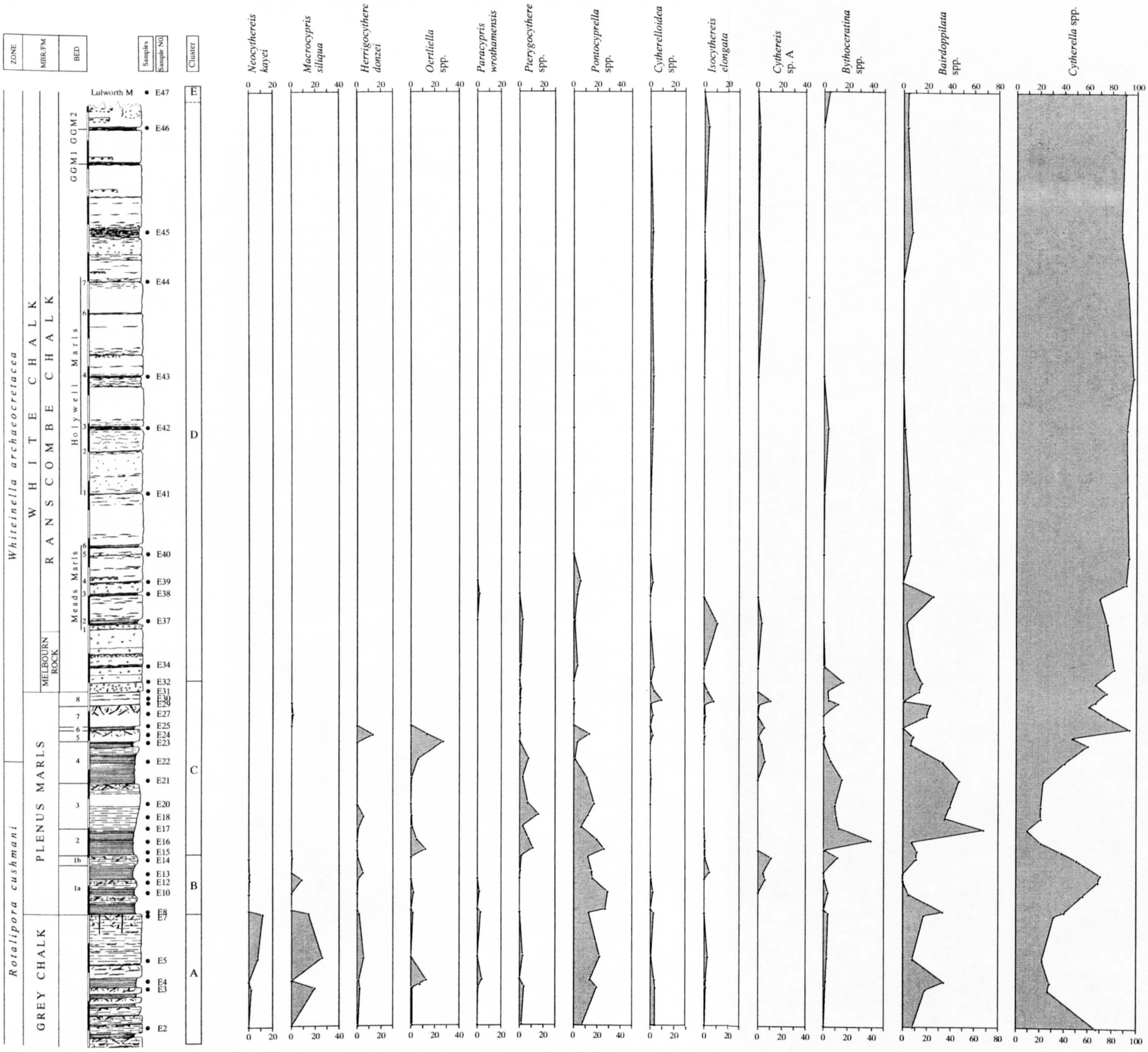
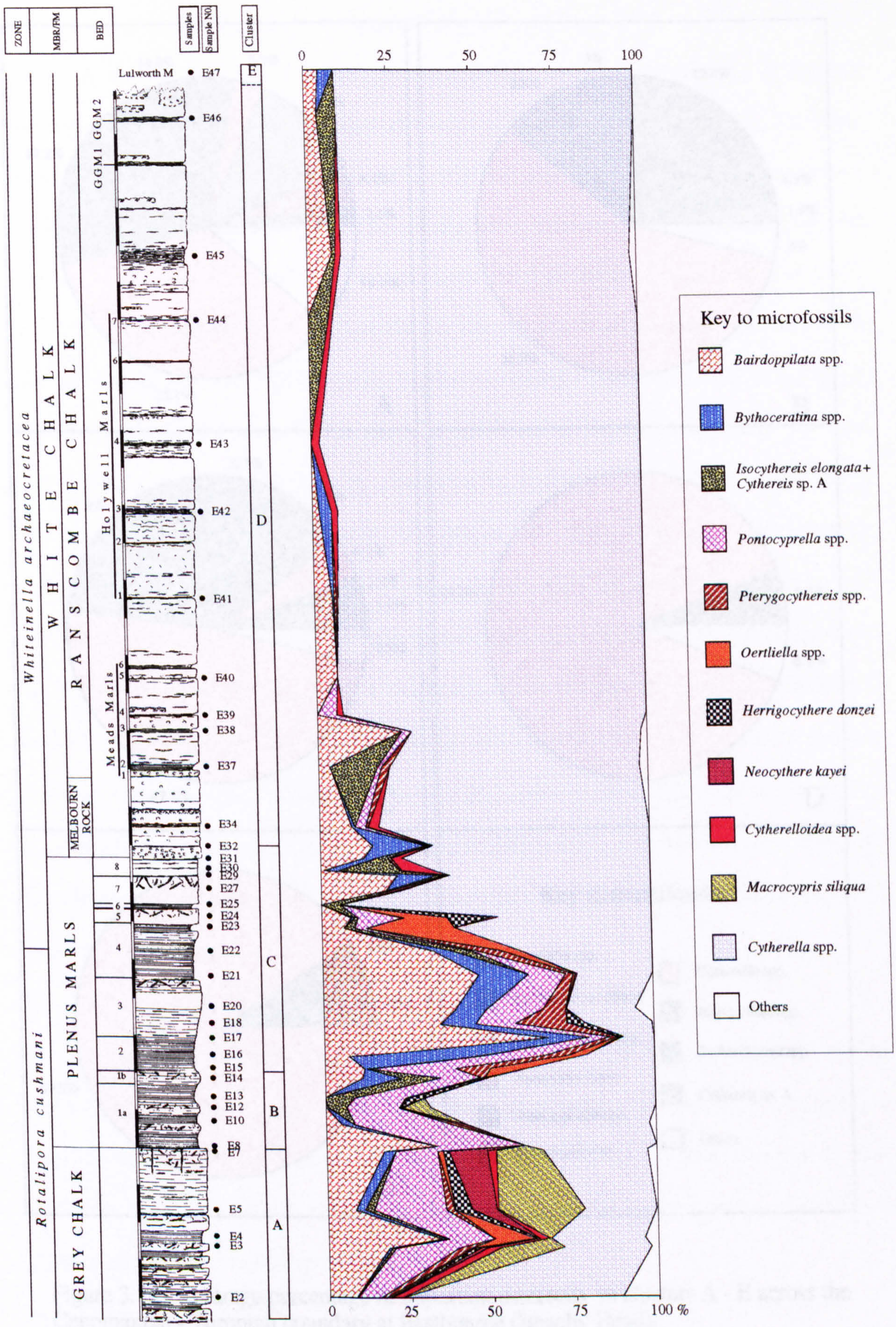


Figure 3.14. Variation in percentage of important ostracods in clusters A -E across the Cenomanian - Turonian boundary at Eastbourne. Scale in metres. See Figure 3.1 for key to symbols on graphic log.



Figur 3.15. Cumulative percent of dominant benthic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

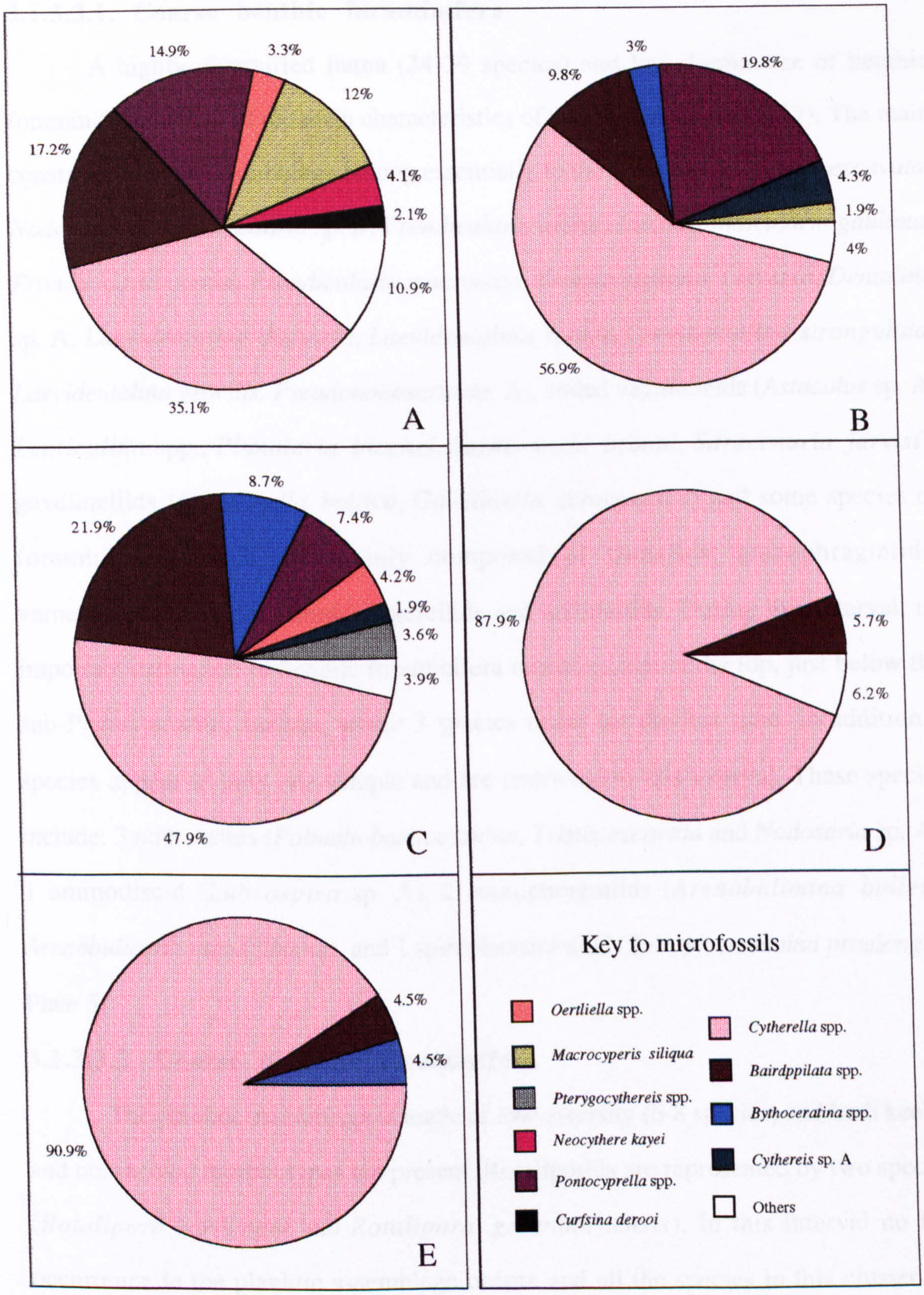


Figure 3.16. Average percentage of important ostracods in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head).

3.1.3.3. Changes in micofossils

3.1.3.3.1. Coarse benthic foraminifera

A highly diversified fauna (34-39 species) and low dominance of benthic foraminifera are two of the main characteristics of this cluster (Figure 3.17). The main constituents of the assemblage belong essentially to the nodosariids (*Tristix excavata, Nodosaria* sp. A, *Nodosaria* sp. B, *Frondicularia archiaciana, Frondicularia gaultina, Frondicularia cordai, Frondicularia mucronata, Frondovaginulina inversa, Dentalina* sp. A, *Laevidentalina distincta, Laevidentalina soluta, Laevidentalina strangulata, Laevidentalina gracilis, Pseudonodosaria* sp. A), coiled vaginulinids (*Astacolus* sp. A, *Lenticulina* spp., *Planularia biochei, Saracenaria bronni, Saracenaria jarvisi*), gavelinellids (*Gavelinella baltica, Gavelinella cenomanica*) and some species of foraminifera, which are mainly composed of tritaxiids, ataxophragmiids, verneuilinids, polymorphinids, eggerellids and textulariids. During this interval, no important extinction of benthic foraminifera occurs except at the top, just below the sub-Plenus erosion surface, where 3 species occur for the last time. In addition 4 species appear in only one sample and are restricted to this interval. These species include: 3 nodosariids (*Palmula baudouiniana, Tristix excavata* and *Nodosaria* sp. A), 1 ammodiscid (*Labrospira* sp. A), 2 ataxophragmiids (*Arenobulimina bulleta, Arenobulimina pseudalbiana*), and 1 spiroplectamminid (*Spiroplectammina praelonga*), Plate 5.

3.1.3.3.2. Coarse planktic foraminifera

The planktic assemblage is made of low diversity (6-8 species) and both keeled and non-keeled morphotypes are present. Rotaliporids are represented by two species (*Rotalipora cushmani* and *Rotalipora greenhornensis*). In this interval no last occurrence in the planktic assemblage occurs and all the species in this cluster are present also in the overlying cluster (Figure 3.18).

3.1.3.3.3. Ostracods

In this interval the ostracod community is characterised by a relatively diversified assemblage (13-22 species), nevertheless only 1 platycopid species occurs

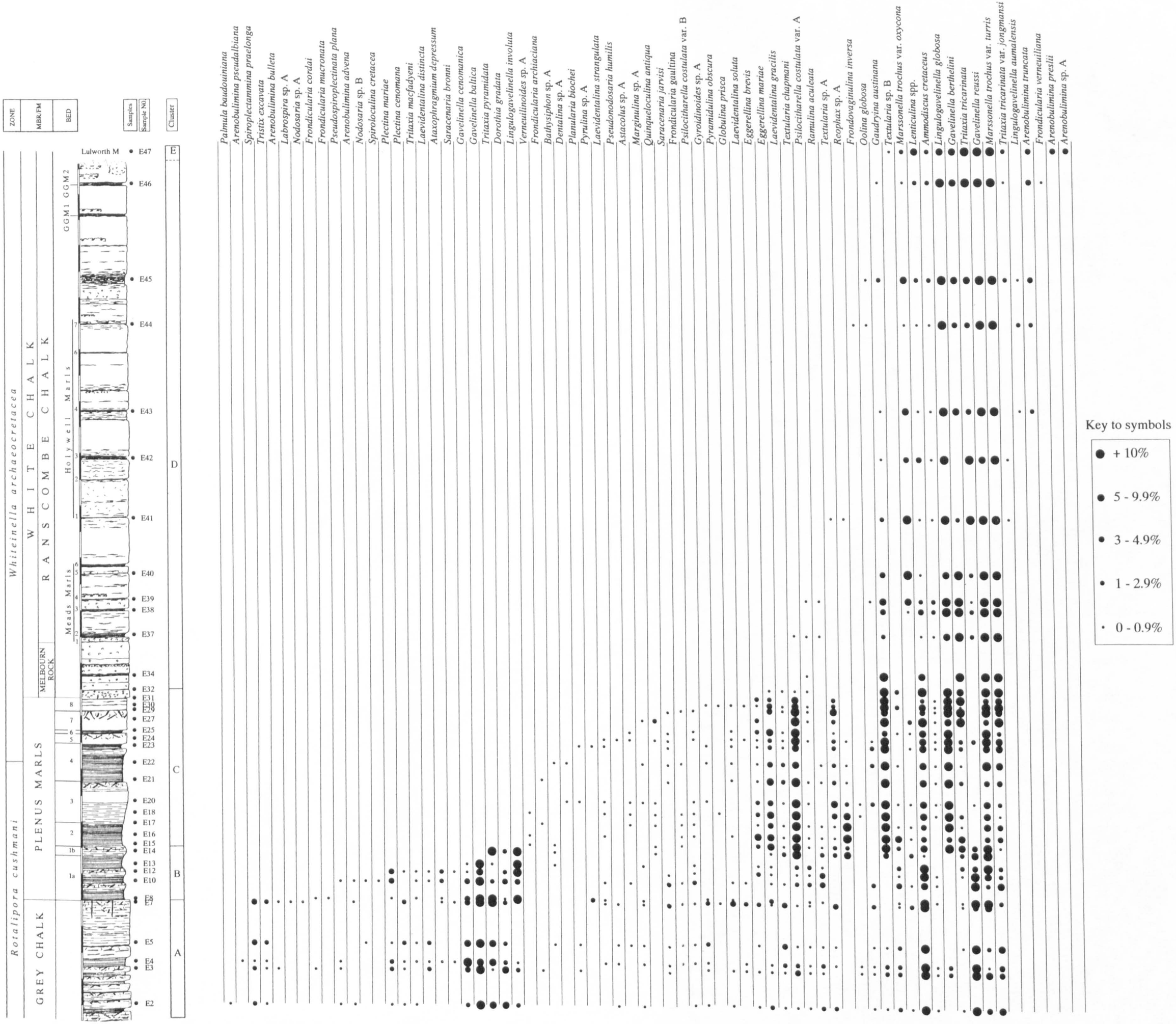


Figure 3.17. Distribution of coarse benthic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. For key to symbols on graphic log see Figure 3.1.

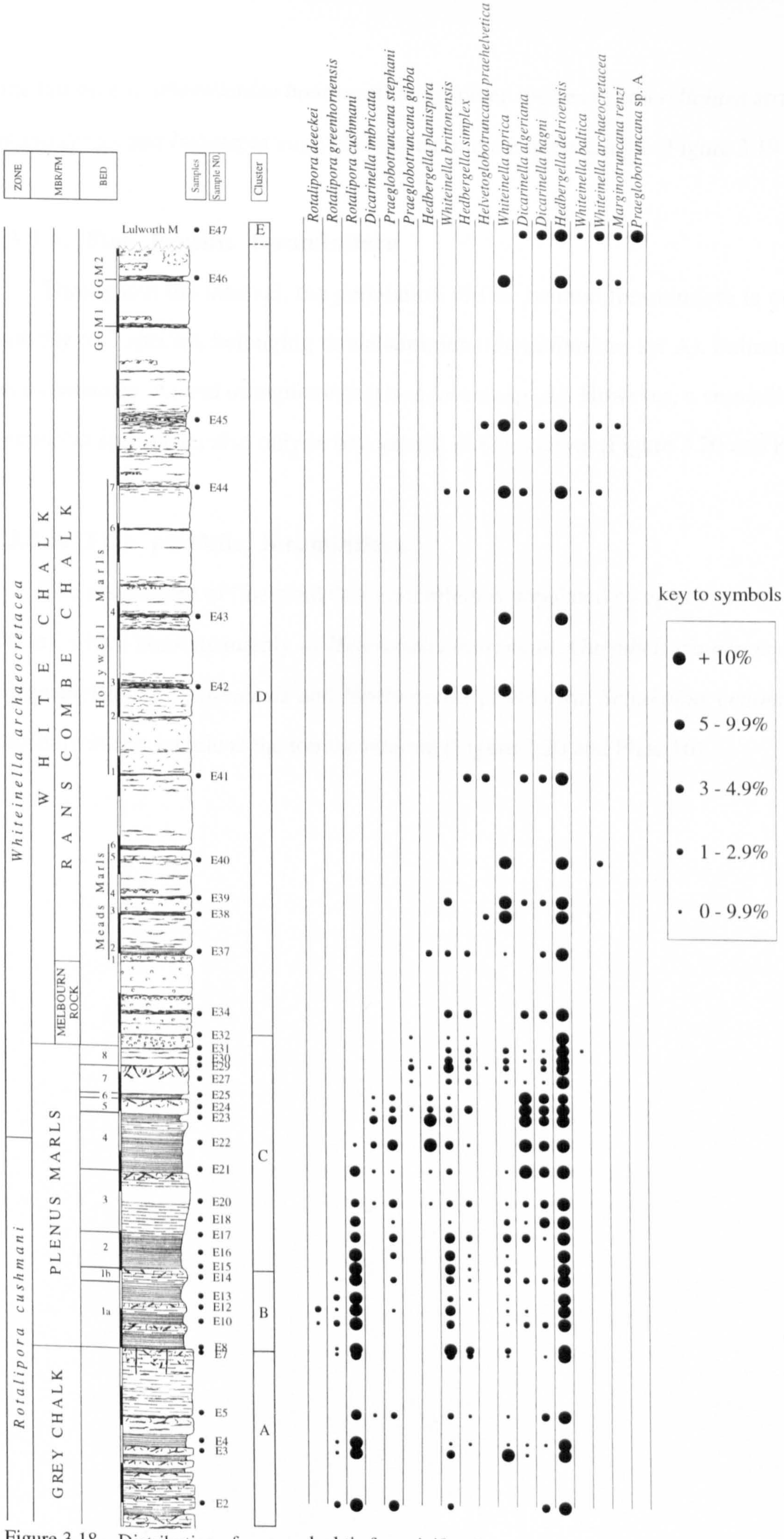


Figure 3.18. Distribution of coarse planktic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. For key to symbols on graphic log see Figure 3.1.

for the last time (*Cytherelloidea bonnemai*) and 3 other species (*Cytherelloidea stricta, Curfsina derooi* and *Imhotepia euglyphea*) occure in a unique sample (Figure 3.19 and Plate 13).

3.1.3.3.4. Fine benthic foraminifera

Throughout the interval, the population of fine benthic foraminifera is made essentially of 3 species, belonging to alabaminids (*Gyroidinoides* sp. A), buliminids (*Praebulimina* sp. A) and osangulariids (*Osangularia* sp. A). However, a verneuilinid (*Eggerellina* sp.) occurs also only in one sample of the interval (Figure 3.20 and Plate 16).

3.1.3.3.5. Fine planktic foraminifera

The assemblage of fine planktic foraminifera is populated by epipelagic species (0-50 m), which consists mainly of *Heterohelix moremani, Guembelitria cenomana, Globigerinelloides bentonensis* and *Hedbergella planispira. Schakoina cenomana* occurs only in one sample at the top the interval (Figure 3.20 and Plate 16).

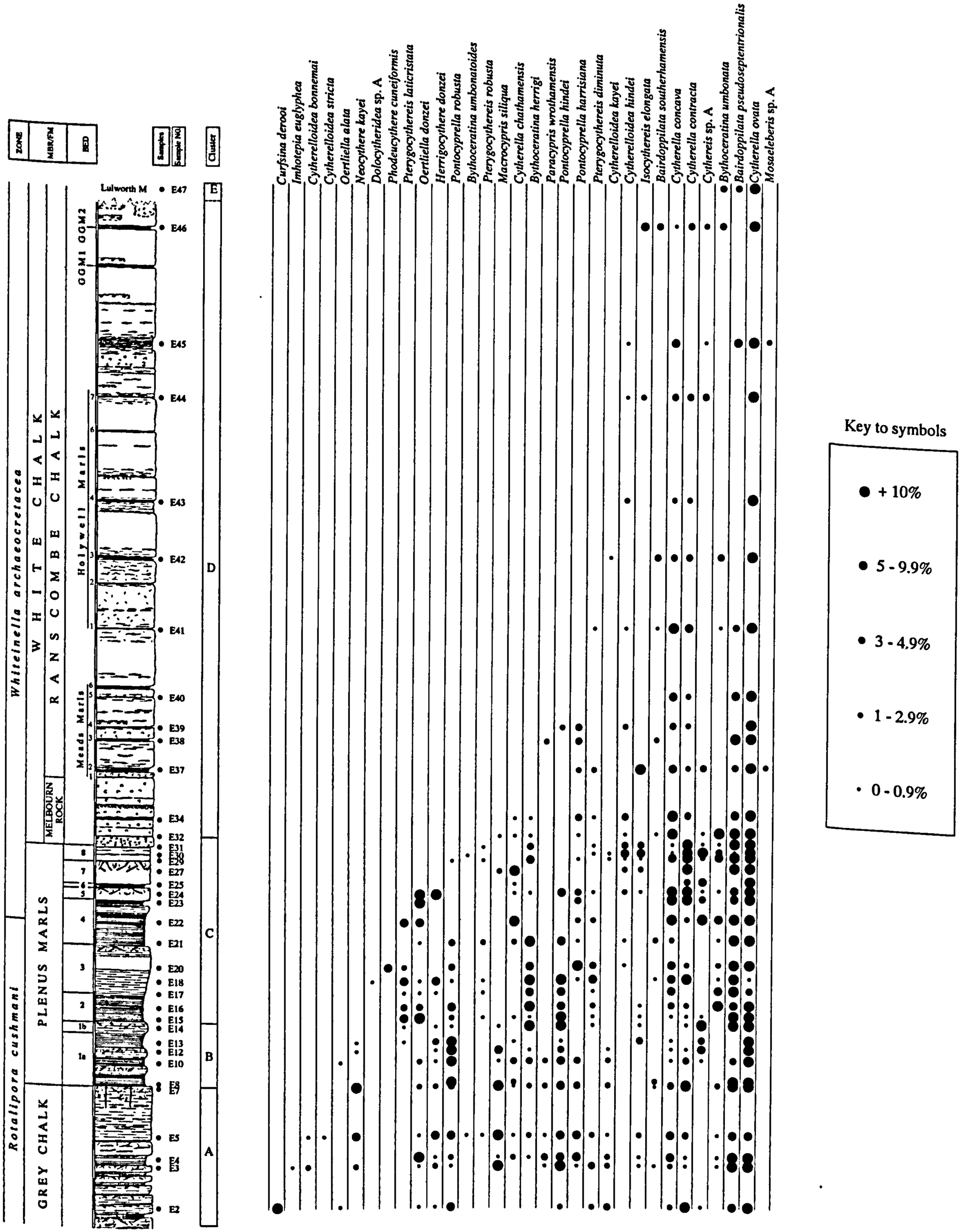


Figure 3.19. Distribution of ostracods in cluster A - E across the Cenomanian - Turonian boundary at Westbury. Scale in metres. For key to symbols on graphic log see Figure 4.1.

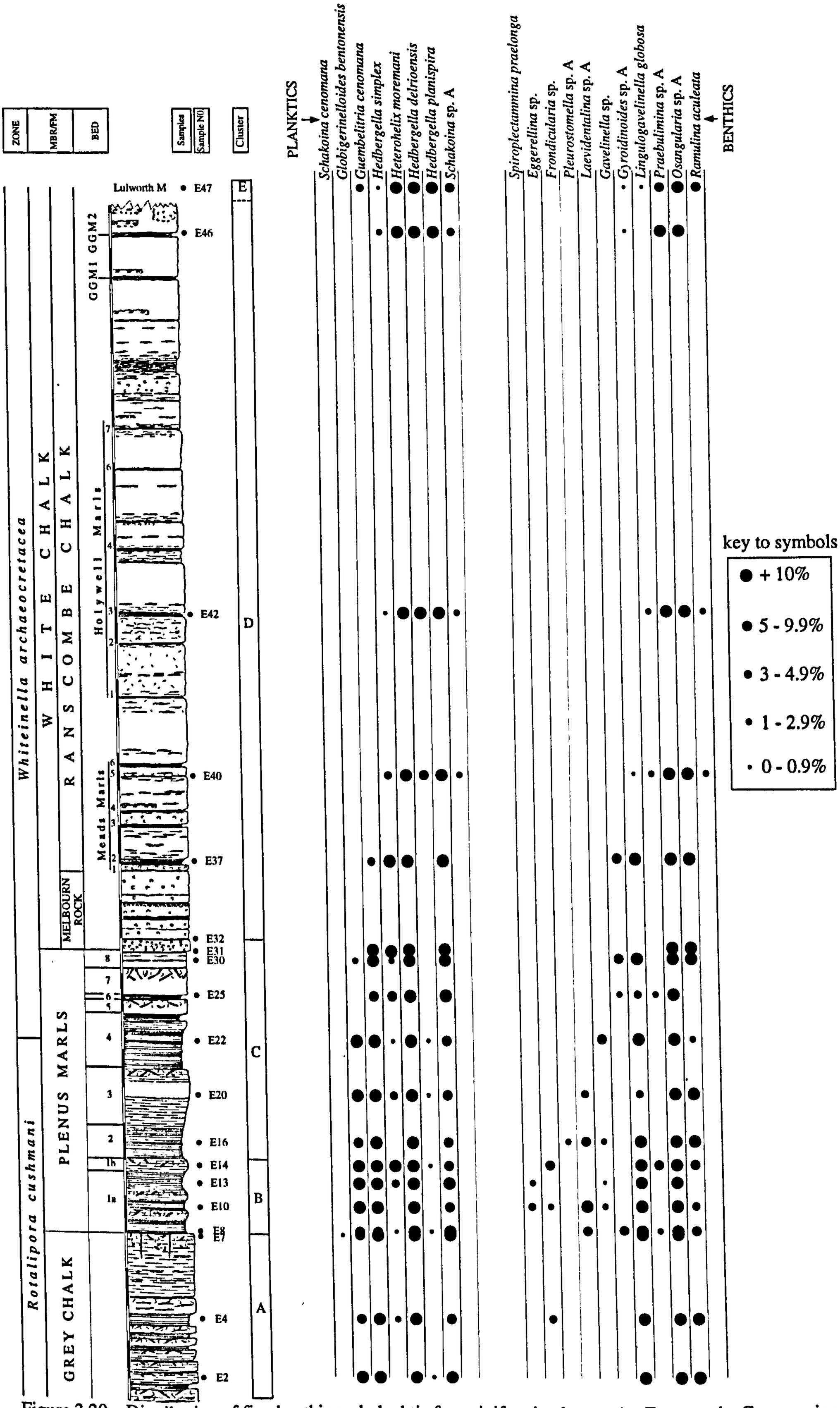


Figure 3.20. Distribution of fine benthic and planktic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. For key to symbols on graphic log see Figure 3.1.

3.2. Cluster B_E (bed 1 of the Plenus Marls)

3.2.1. Lithology and samples

The thickness of the interval is 2 m, which is the thickest bed of the Plenus Marls. It actually consists of two beds, bed 1a, which is more marly and bed 1b which is more chalky (Figure 3.1). These two beds together constitute one of the five couplets which can be recognised in the Plenus Marls and the bed immediately above (Fig.3.21). The bottom and the top of bed 1 are defined by two erosion surfaces, the SPES at the bottom and Sub bed 2 erosion surface of Jefferies (1963a) at the top.

Samples E8-E14 came from this interval, of which the fine (63-90 μm) fraction of samples E8, E10, E13 and E14 has been examined and the coarse fraction of all except samples E9 and E11.

3.2.2. Stable isotopes and acid insoluble residues

Variation in stable isotope curves for carbon and oxygen in different clusters at Eastbourne is shown in Figure 3.2. In this interval, carbon isotope ($\delta^{13}C$) values rise from 2.8‰ PDB to two minor peaks in the middle and top of bed 1a (3.3‰ and 3.5‰ PDB, respectively).

Compared with cluster A, $\delta^{18}O$ curve in this cluster shows slightly more negative values, which begin with a base about -3.1‰ PDB, then fall to -3.4‰ PDB, but become lighter again reaching about -2.9‰ PDB at the top of the interval.

The amount of AIR, which was very low in previous interval, jumps to high values and ranges between 13 and 23%. This reveals less purity for the samples of this cluster.

3.2.3. Microfauna

3.2.3.1. Foraminifera

3.2.3.1.1. Absolute abundance

3.2.3.1.1.1. Coarse fraction

Absolute number of coarse benthic foraminifera in this cluster do not show any significant changes from cluster A. Values vary from 710 to 2554 (Figure 3.3).

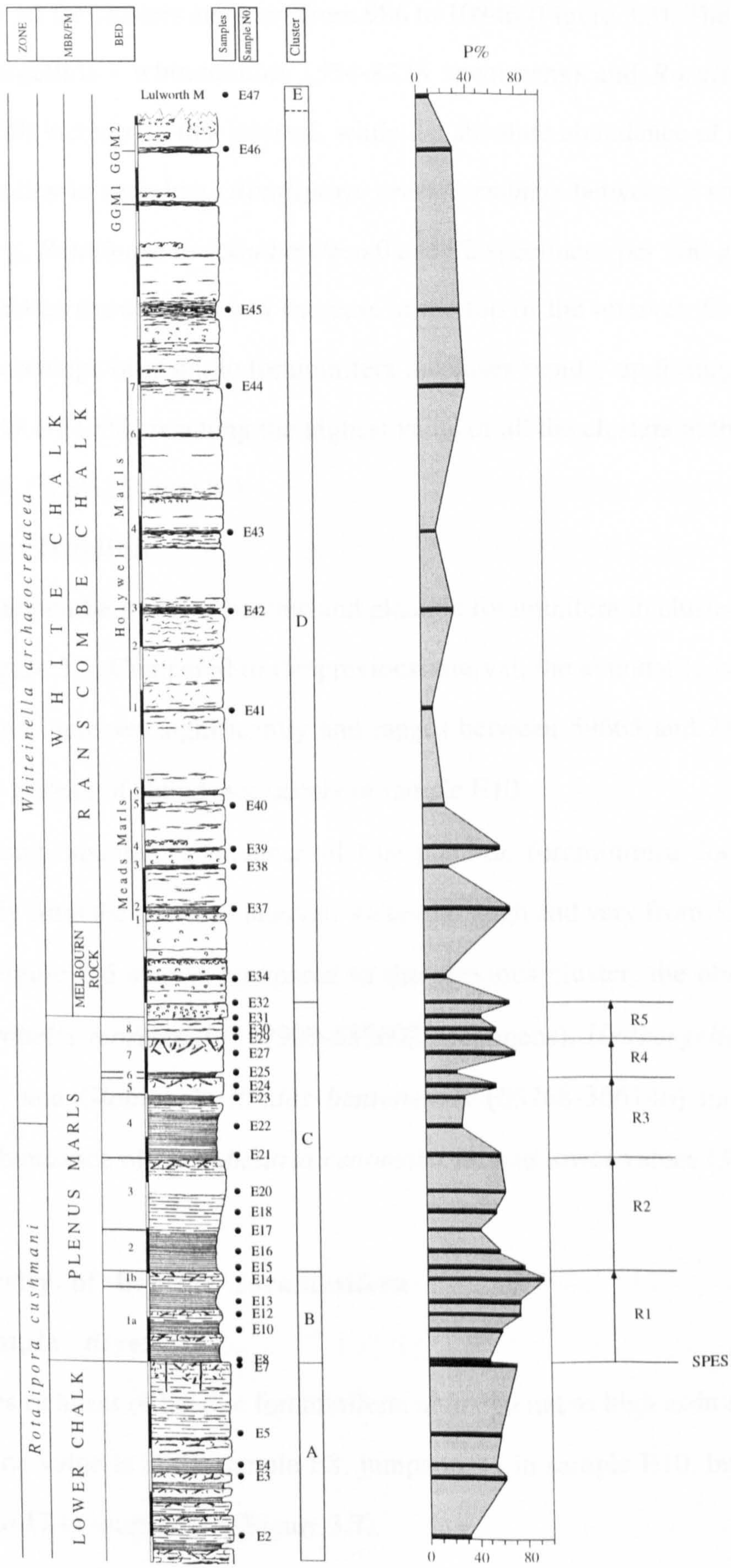


Figure 3.21. Five marl - chalk rhythms in Plenus Marls and the chalk immediately above against P% at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

The total number of planktics increases significantly in this interval. Values show the highest of all the clusters and vary from 986 to 10846 (Figure 3.3). The total numbers of hedbergellids - whiteinellids (554-8238 specimens) and *Rotalipora cushmani* (430-2060) increase in this interval, while the absolute abundance of other single-keeled planktics is very low (*Rotalipora greenhornensis* between 2 and 98 specimens per 100 g, *Rotalipora deeckei* between 0 and 92 specimens per 100 g) and double-keeled planktics show only a low increase at the top of the interval (0-550), Figure 3.4. The percentage of planktic foraminifera increases rapidly up through the interval (E8-E13, 49.1-74.8%) reaching the highest value of all the clusters at the top of the interval (E14, 93.8%) Figure 3.4.

3.2.3.1.1.2. Fine fraction

The absolute numbers of fine benthic and planktic foraminifera in clusters A - E are shown in Figure 3.5. Compared to the previous interval, the abundance of fine benthic foraminifera increases significantly and ranges between 59665 and 217504 specimens per 100 g. Peak of abundance occurs in sample E10.

In this cluster, absolute abundance of fine planktic foraminifera does not change significantly from the previous interval. Values are high and vary from 329579 to 1192244. As Figure 3.6 shows, compared to the previous cluster, the absolute numbers of *Heterohelix moremani* (117909-535602 specimens), *Hedbergella* spp. (105124-495000), and *Globigerinelloides bentonensis* (66768-366146) increase suddenly, while abundance of *Guembelitria cenomana* falls to lower values (39776-166430).

3.2.3.1.2. Diversity of benthic foraminifera

3.2.3.1.2.1. Simple diversity

The species richness of benthic foraminifera, although not as high as in cluster A, is still high. The value is 25 in sample E8, jumps to 33 in sample E10, but then declines steadily to 17 in sample E14 (Figure 3.7).

3.2.3.1.2.2. Fisher diversity

The general trend of Fisher diversity is the same as simple diversity. The values are lower than in cluster A, but are still high and vary from 3.5 to 5.5 (Figure 3.7).

3.2.3.1.2.3. Shannon diversity

The Shannon heterogeneity index, except in sample E13 (1.7), represents the same trend as in the previous interval and ranges from 2.0 to 2.7 (Figure 3.7).

3.2.3.1.3. Morphotype groups

As Figure 3.8 shows, a sudden increase in the percentage of morphotype group CH-B1 is one of the characteristics of this cluster (3.0-39.0%), which together with morphotype group AG-C (10.8-58.1%) represents the dominant groups of the cluster. However, CH-B3 (0-18.7%), CH-B2 (0.2-16.9%) and CH-B4 (2.6-14.4%) are other significant morphotype groups.

Among the planktic foraminifera, the high percentage (18.9-60.8%) of the single-keeled morphotype group is one of the important characteristics of this cluster. However, the percentage of the non-keeled morphotype group is high (39.1-75.9%) as well, but the values for double-keeled morphotype group are very low (0-5.0%).

3.2.3.1.4. Species

3.2.3.1.4.1. Coarse fraction

Figures 3.9 - 3.11 indicate the percentage, cumulative diagram and average percentage of important benthic foraminifera in clusters A - E at Eastbourne. In this cluster, as is apparent *Lingulogavelinella involuta* (3.0-39.0%), together with *Tritaxia tricarinata* (4.1-39.0%), constitutes the dominant taxa of the assemblage. *Gavelinella baltica* plus *Gavelinella cenomanica* (0-18.7%), *Lenticulina* spp. (0.2-16.1%), *Tritaxia pyramidata* (0-14.3), *Textularia chapmani* (0-13.5%), *Gavelinella reussi* (2.6-12.3%) and *Dorothia gradata* plus *Plectina* spp. (0-6.3%) are the other elements of the assemblage.

The percentage of epifaunal group, which was high in cluster A, increases even more in the samples of this cluster and varies between 20.1 and 58.1% (Figure 3.10).

In the planktics, the cluster is characterised by high proportion of *Hedbergella delrioensis* (35.5-70.1%), a sudden increase of *Rotalipora cushmani* (18.2-58%), and very low values for *Rotalipora greenhornensis* (0.1-2.7%), *Rotalipora deeckei* (0-1.2%) and double keeled species (maximum 1.9% for *Dicarinella hagni*).

3.2.3.1.4.2. Fine fraction

Praebulimina sp. A (39.2-57.1%) and *Gyroidinoides* sp. A (27.0-40.4%) are the most important elements of the fine benthic assemblage, while *Pleurostomella* sp. A (0-10.7%), *Osangularia* sp. A (0-7.1%) and *Laevidentalina* sp. (0-2.7%) constitute minor elements of the assemblage (Figure 3.12).

Among the fine planktic foraminiferal assemblage, *Heterohelix moremani* (32.3-44.9%), *Hedbergella planispira* (7.6-44.1%), *Globigerinelloides bentonensis* (9.9-30.7%) and *Guembelitria cenomana* (9.1-13.9%) are major elements of the assemblage (Figure 3.6).

3.2.3.2. Ostracods

3.2.3.2.1. Absolute abundance

On the whole the total number of ostracods is lower than in cluster A and oscillates between 90 (E8) and 530 (E10) valves per 100 g, Figure 3.13.

3.2.3.2.2. Diversity

Three different diversity curves for ostracods assemblage are shown in Figure 3.13 values for cluster B are as below.

3.2.3.2.2.1. Simple diversity

The species richness in sample E8 is 5, jumps to 16 in sample E10 and thereafter does not show any significant changes (E12-14, 10-12).

3.2.3.2.2.2. Fisher diversity

Fisher diversity in this interval shows the same trend as simple diversity and values vary from 1.2 to 3.4

3.2.3.2.2.3. Shannon diversity

The general trend of Shannon diversity is more or less the same as the other diversity indices. The values are lower than in cluster A and range between 0.9 and 1.8.

3.2.3.2.3. Species

Percentage, cumulative diagram and average percentage of important ostracods in cluster B is shown in Figures 3.14 - 3.16, where *Cytherella* spp. show higher percentages than in cluster A (37.7-69.7%) and *Pontocyprella* spp. are still an important element (12.0-29.1%). *Macrocypris siliqua* has much lower percentages than with the previous cluster (0-8.6%). *Bairdoppilata* spp. (0-33.3%) and *Isocythereis elongata* plus *Cythereis* sp. A (0-12.0%) are the other elements of the assemblage.

The proportion of podocopids in this interval changes significantly. The percentage of podocopids decreases steadily up through the section, reaching 29.7% in sample E13, but recovers again at the top (E14, 49.6%), Figure 3.15.

3.2.3.3. Changes in microfossils

3.2.3.3.1. Coarse benthic foraminifera

In this cluster the assemblage is diversified (17-24 species), but a prominent extinction event in the benthic community occurs, when 15 species occur for the last time (Figure 3.17). These species belong to tritaxiids (*Tritaxia macfadyeni, Tritaxia pyramidata*), eggerellids (*Dorothia gradata, Plectina cenomana, Plectina mariae*), gavelinellids (*Gavelinella baltica, Gavelinella cenomanica, Lingulogavelinella involuta*), nodosariids (*Nodosaria* sp. B, *Frondicularia cordai, Laevidentalina distincta*), ataxophragmiids (*Ataxophragmium depressum, Arenobulimina advena*), verneuilinids (*Pseudospiroplectinata plana*), and coiled vaginulinids (*Saracenaria bronni*). Besides, 2 species (*Frondicularia mucronata* and *Spiroloculina cretacea*) occur only in one sample. A major part of the vacated niches is promptly filled by *Lingulogavelinella involuta*, although this species also has its last occurrence at the top of the interval (Plates 5 and 6).

3.2.3.3.2. Coarse planktic foraminifera

In the planktic community diversity is similar to the previous interval (6-9 species), but a successive extinction of *Rotalipora deeckei* (in the middle of bed 1a) and *Rotalipora greenhornensis* (at the top of bed 1a) occurs. In contrast, *Rotalipora cushmani*, constitutes a high proportion of the assemblage (18.2-58%), Figure 3.18 and Plate 11.

3.2.3.3.3. Ostracods

Compared to the previous interval, the ostracod assemblage is less diversified (5-16 species) and extinction is less prominent. In this interval only 2 podocopid species, *Neocythere kayei* and *Oertliella alata*, occur for the last time, while *Pterygocythereis laticristata* appears for the first time, Figure 3.19 and Plate 13.

3.2.3.3.4. Fine benthic foraminifera

This interval shows the most diversified assemblage of the fine benthic foraminifera (4-7 species). In the base of the interval 3 new species, belonging to gavelinellids (*Gavelinella* sp., *Lingulogavelinella globosa*) and pleurostomellids (*Pleurostomella* sp. A) appear for the first time. Higher up in sample E10, 2 other new species, which belong to spiroplectamminids (*Spiroplectammina praelonga*) and nodosariids (*Laevidentalina* sp.) appear, and cause diversity of the benthic foraminifera to recover, Figure 3.20 and Plate 16.

3.2.3.3.5. Fine planktic foraminifera

In this interval diversity of the fine planktic foraminifera is similar to the previous interval (4-6 species) and apart from the absence of *Schakoina cenomana*, the structure of the assemblage does not change from that of the previous cluster, Figure 3.20.

3.3. Cluster C_E (bed 2 to base of Melbourn Rock)

3.3.1. Lithology and samples

The thickness of the interval is 6 m and includes bed 2 of the Plenus Marls to the base of the Melbourn Rock (Figure 3.1). The bottom is defined by sub bed 2 erosion surface of Jefferies (1963a) and the top by the top of bed 9 of Jeans *et al.* (1991). Beside this, three other erosion surfaces have been recognised in this interval and are, sub bed 4, sub bed 6, and sub bed 8, of which the surface beneath bed 4 is the most important one. The beds in this interval comprise 4 other marl-chalk couplets, which are beds 2 and 3, beds 4 and 5, beds 6 and 7, beds 8 and 9. In total there are five couplets in the Plenus Marls and bed 9 (Figure 3.21).

Samples E15-E32 come from this interval, of which the fine (63-90 μm) fraction of samples E10, E12, E22, E30 and E31 has been examined and the coarse fraction of all except samples E19, E26 and E28.

3.3.2. Stable isotopes and acid insoluble residues

The $\delta^{13}C$ signature for this cluster is shown in Figure (3.2), where two main peaks are apparent. Values start at the base around 3.5‰ PDB, but increase quickly to form the first main peak (4.7‰ PDB) in the middle of bed 3 and the second (5.3‰ PDB) at the top of bed 8/base of Melbourn Rock.

As Figure 3.2 shows, one of the most important characteristic of oxygen curve ($\delta^{18}O$) in this cluster is its positive excursion between beds 2 and 4 of the Plenus Marls. Values start about -3.0‰ PDB at the base of bed 2, but become quickly lighter and reach -2.5‰ PDB and -2.3‰ PDB in beds 2 and 4, respectively. However, the $\delta^{18}O$ curve oscillates strongly between chalks and marls in the upper part of the interval (above bed 6).

Acid insoluble residue values are fairly high and range between 10% and 29%, which reveals an increase of mud in the marls of this interval.

3.3.3. Microfauna

3.3.3.1. Foraminifera

3.3.3.1.1. Absolute abundance

3.3.3.1.1.1. Coarse fraction

Compared to the previous interval, the total numbers of benthic foraminifera do not change significantly and oscillate between 700 and 2701 specimens per 100 g. The highest value occurs in bed 3 (sample E20), while the lowest value occurs at the base of Melbourn Rock (sample E32), Figure 3.3.

The total numbers of coarse planktic foraminifera in this interval decrease again. Values fluctuate between 7560 (E15) and 488 (E25) (Figure 3.3). The sudden increase in the total number of double-keeled planktics (0-1560 specimens per 100 g) and very low abundance of *Rotalipora cushmani* (except at the base of the interval, 0-1636) are characteristics of the interval, although the total numbers of hedbergellids - whiteinellids show a small decrease compared with the previous interval (44-5924), Figure 3.4. The percentage of planktic foraminifera is high and ranges between 25.3% and 78.5% (Figure 3.4).

3.3.3.1.1.2. Fine fraction

The total number of fine benthic foraminifera up to sample E25 is high and ranges between 77688 to 159255 specimens, but at the top of the interval falls to low values and varies from 22459 to 55294 specimens per 100 g (Figure 3.5).

The total number of fine planktic foraminifera in this interval oscillates strongly. In the lower part the values are extremely high and range between 640926 and 1372550, but at the top falls to very low values and varies from 74304 to 130424 (Figure 3.5). The total numbers of all fine planktic foraminifera in the lower part of the interval (up to bed 4) are high. Thereafter they fall in bed 6 and remain low to the top of the interval. The total number of fine planktic foraminifera is as follows, *Heterohelix moremani* (43704-683850 specimens), *Guembelitria cenomana* (4320-266750), *Hedbergella* spp. (15552-145500), and *Globigerinelloides bentonensis* (0-276450), Figure 3.6.

3.3.3.1.2. Diversity of benthic foraminifera

Figure 3.7 shows the diversity curves for benthic foraminiferal assemblage. The characteristics of each diversity in cluster C are as below.

3.3.3.1.2.1. Simple diversity

Numbers of species in most part of the section are similar to cluster B (E15-E24, 18-25), but it declines gradually in the upper part to 11 at the top of the interval.

3.3.3.1.2.2. Fisher diversity index

Fisher index values in the lower part of the interval are similar to cluster B (3.1-4.2), while in the upper part they decrease gradually, reaching to 1.9 at the top of the interval.

3.3.3.1.2.3. Shannon diversity index

The Shannon heterogeneity values do not show any great changes compared to cluster B and range from 1.6 to 2.2 in this cluster.

3.3.3.1.3. Morphotypes

Morphotypes AG-C (31.1-71.4%), CH-B4 (6.2-39.1%) and CH-B3 (3.9-32%) are the dominant groups in this cluster, while morphotype group CH-B2 (3.5-11.7%) is a minor constituent of the assemblage (Figure 3.8).

In the planktic assemblage the percentage of both non-keeled (9.0-100%) and single-keeled (0-21.6%) morphotypes decreases up through the section, while the double-keeled morphotype group (0-90.9%) quickly becomes the dominant one. However, by the top of the interval the non-keeled morphotype group becomes dominant again (Figure 3.4).

3.3.3.1.4. Species

3.3.3.1.4.1. Coarse fraction

Gavelinella reussi plus *Gavelinella berthelini* (6.2-39.1%), *Lingulogavelinella globosa* (3.9-32%), *Gaudryina austinana* (7.6-39.0%) and *Textularia chapmani* (0.1-23.5%) are major constituents in this cluster, while *Marssonella* spp (0.7-17.1%), *Lenticulina* spp. (3.5-11.7%), *Reophax* sp. A (0-20.7%) and *Eggerellina* spp. (0.1-10.2%) are the other constituents of the assemblage (Figures 3.9 - 3.11).

A sudden change in the proportion of epifaunal / infaunal, semi-infaunal is one of the characteristics of this interval. Values for epifaunal group fall suddenly and vary from 0 to 1.5% (Figure 3.10).

During this interval, *Hedbergella delrioensis* still has a high proportion in the coarse planktics assemblage (7.3-99.4%), although the percentage of *Dicarinella algeriana* shows a sudden jump (0-82.7%). *Praeglobotruncana gibba* (0-1%), *Dicarinella imbricata* (0-3.2%), *Rotalipora cushmani* (0-21.6%), *Praeglobotruncana stephani* (0-5%), *Whiteinella brittonensis* (0.3-8.8%), *Hedbergella planispira* (0-13.7%), *Dicarinella hagni* (0-9.6%) and *Hedbergella simplex* (0-4.2%) are the other elements of the assemblage.

3.3.3.1.4.2. Fine fraction

In the fine benthics, a sudden change in the proportion of elements occurs, i.e. percentage of *Praebulimina* sp. A increases suddenly in this interval and ranges between 44.4 and 92.1%. *Gyroidinoides* sp. A (0-19.4%) and *Osangularia* sp. A (0-24.3%) are minor elements, while *Pleurostomella* sp. A (0-8.3%) and *Laevidentalina* sp. (0-7.1%) are rare, Figure 3.12.

Fine planktic assemblage does not change significantly from the previous cluster and *Heterohelix moremani* (28-73.2%) is the most important element, while *Guembelitria cenomana* (5.8-23.2%), *Hedbergella planispira* (5.3-29.0%), *Globigerinelloides bentonensis* (0-20.1%) and *Hedbergella simplex* (0-17.0%) are the other species of the assemblage (Figure 3.6).

3.3.3.2. Ostracods

3.3.3.2.1. Absolute abundance

The absolute numbers of ostracods are shown in Figure 3.13. Compared to previous cluster abundance is a little lower (E15-E32, 30-680) and its peak occurs in the middle of bed C.

3.3.3.2.2. Diversity

Three different diversity curves for ostracods assemblage are shown in Figure 3.13. The values for each diversity in cluster C are as below.

3.3.3.2.2.1. Simple diversity

The species richness, is more or less the same as in the previous cluster and ranges between 7 and 16, except in sample E25 which shows a sudden fall to 4.

3.3.3.2.2.2. Fisher diversity index

The Fisher index values are approximately the same as in the previous cluster and oscillate between 1.0 (E25) and 4.0 (E24).

3.3.3.2.2.3. Shannon diversity index

Except for a sudden fall to 0.1 which occurs in sample E25, the values do not vary much from cluster B and range between 1.0 (E23, E27, E32) and 2.0 (E20).

3.3.3.2.3. Species

This interval is characterised by high percentage of *Cytherella* spp. (9.4-94.37%), *Bairdopillata* spp. (0-67.7%), *Bythoceratina* spp. (0-39.2%), *Oertliella* spp. (0-26.6%) and *Pontocyprella hindei* (0-24.4%). *Pterygocythereis* spp. (0-15.6%) and *Herrigocythere donzei* (0-13.1%) are minor constituents of the assemblage (Figures 3.14 - 3.16).

The podocopid percentage, which was relatively low in cluster B, increases again in this cluster and ranges between 5.6 and 90.5%, the highest values occur in the interval from the middle of bed 2 to the base of bed 4 (Figure 3.15).

3.3.3.3. Changes in microfossils.

3.3.3.3.1. Coarse benthic foraminifera

The extinction in the benthic foraminiferal assemblage, which began during clusters A and B, continues through this cluster as well (Figure 3.17). Although the lower part (bed 2 to the base of bed 4) is characterised by last occurrences of only 2 species (*Verneuilinoides* sp. A, *Frondicularia archiaciana*), the upper part (middle of bed 4 to base of Melbourn Rock) marks another significant series of last occurrences in the benthic foraminiferal assemblage, where 19 species occur for the last time. The victims are essentially of coiled vaginulinids (*Astacolus* sp. A, *Planularia biochei*, *Saracenaria jarvisi*), nodosariids (*Dentalina* sp. A, *Laevidentalina soluta*, *Laevidentalina strangulata*, *Laevidentalina gracilis*, *Pseudonodosaria humilis*,

Frondicularia gaultina, Pyramidulina obscura), verneuilinids (*Eggerellina brevis, Eggerellina mariae*), uncoiled vaginulinids (*Marginulina* sp. A, *Psilocytharella costulata* var. B), polymorphinids (*Globulina prisca, Pyrolina* sp. A), bathysiphonids (*Bathysiphon* sp. A), hauerinids (*Quinqueloculina antiqua*) and an alabaminid (*Gyroidinoides* sp. A), Plates 7 and 8.

3.3.3.3.2. Coarse planktic foraminifera

In the planktic community last occurrences of a single-keeled species, *Rotalipora cushmani,* in the middle of bed 4, and 3 double-keeled species, *Dicarinella imbricata* and *Praeglobotruncana stephani* (Plate 11) in bed 6 and *Praeglobotruncana gibba* at the base of the Melbourn Rock are recorded (Figure 3.18). Two new species *Helvetoglobotruncana praehelvetica*, at the base, and *Whiteinella baltica*, at the top of bed 8 appear for the first time.

3.3.3.3.3. Ostracods

In this interval, the diversity of ostracods is similar to previous cluster (4-16 species), but one of the biggest changes in the structure of ostracods occurs. Seven podocopids including *Pterygocythereis laticristata, Pterygocythereis robusta, Oertliella donzei, Bythoceratina umbonatoides, Herrigocythereis donzei, Pontocyprella robusta* and *Macrocypris siliqua* occur for the last time, while 2 new podocopids, *Dolocytheridea* sp. A, *Phodeucythere cuneiformis*, and 1 platycopid, *Cytherelloidea hindei*, appear for the first time, although the two former are present only in one sample (Figure 3.19 and Plates 13 and 14).

3.3.3.3.4. Fine benthic foraminifera

In the fine benthic population diversity decreases up through the section and 1 nodosariid (*Laevidentalina* sp.) and 1 pleurostomellid (*Pleurostomella* sp. A) occur for the last time, although 1 nodosariid (*Frondicularia* sp.) occurs in a unique sample. No first appearance in this interval occurs, Figure 3.20.

3.3.3.3.5. Fine planktic foraminifera

Among the fine planktics, only *Globigerinelloides bentonensis* has its last occurrence. Otherwise the structure of fine planktics is similar to previous cluster, Figure 3.20.

3.4. Cluster D_E (Post Plenus Marls beds)

3.4.1. Lithology and samples

The interval represents the thickest succession of all the clusters. The thickness is about 20 m which includes the Meads Marls, Holywell Marls and Gun Gardens Marls 1 and 2. Except in the marly beds, the rest of the interval consists of very hard chalk, Figure 3.1.

The interval includes samples E34 - E46, of which the fine fraction of samples E37, E40, E42 and E46 has been examined and the coarse fraction of all except samples E35 and E36.

3.4.2. Stable isotopes and acid insoluble residues

The $\delta^{13}C$ curve begins above sample E32 at about 4.9‰ PDB and after a long interval of fluctuations between 4.5‰ and 5.0‰ PDB it reaches to 5.1‰ PDB to form the third peak of the excursion around Meads Marl 6. It then falls rapidly to a low of 3.8‰ PDB in Holywell Marl 2 and after further oscillations forms a blip at Holywell Marl 5. Thereafter it falls gradually, reaching 3.4‰ PDB at the Gun Gardens Marl 2 (Figure 3.2).

The $\delta^{18}O$ curve oscillates strongly between chalks and marls from the base of the interval to Meads Marl 2. Above this level to Meads Marl 6 the values are low, but do not show a clear trend. From Holywell Marl 1 to Gun Gardens Marl 2 the values are very low and oscillate between -3.2‰ and -3.9‰ PDB (Figure 3.2).

The amount of acid insoluble residue for this cluster has not been measured, but at Dover the average percentage has been reported about 4.2% (Lamolda *et al.*, 1994), which shows this cluster is very pure chalk.

3.4.3. Microfauna

3.4.3.1. Foraminifera

3.4.3.1.1. Absolute abundance

3.4.3.1.1.1. Coarse fraction

Compared to previous intervals, the abundance of coarse benthic foraminifera falls to very low values, and varies between 216 and 953 specimens per 100 g (Figure 3.3).

In the planktic assemblage, the values decrease to very low numbers and range between 88 and 628 (Figure 3.3). In this interval, the main constituent of the coarse planktic foraminifera are hedbergellids - whiteinellids (50-486 specimens), while double-keeled species are rare (0-26), Figure 3.4. Percentage of planktic foraminifera in this cluster oscillates strongly between 8.4 and 69.6% (Figure 3.4).

3.4.3.1.1.2. Fine fraction

Compared to previous interval the total number of fine benthic foraminifera in cluster D decreases and ranges from 43554 to 128100 specimens per 100 g (Figure 3.5).

The absolute number of fine planktic foraminifera is similar to the top of the previous interval. Values are very low and range between 116314 to 200550 (Figure 3.5). In this interval, the total numbers of *Heterohelix moremani* (81925-106050 specimens) and *Hedbergella* spp. (57901-92400) do not show any difference from the top of the previous interval. *Guembelitria cenomana* is present only at the base of the interval (7250 specimens), while *Globigerinelloides bentonensis* is completely absent. Total number of a new species, *Schakoina* sp. A, increases up through the section and varies between 0 and 6544 specimens (Figure 3.6).

3.4.3.1.2. Diversity of benthic foraminifera

Variations of three diversity curves for benthic foraminiferal assemblage at Eastbourne are shown in Figure 3.7. The values for cluster D are as below.

3.4.3.1.2.1. Simple diversity

The number of species in this interval is the lowest of all the clusters and ranges between 6 (E34) and 13 (E45).

3.4.3.1.2.2. Fisher diversity index

The general trend of Fisher diversity is more or less the same as that for simple diversity. Values range between 1.0 and 2.2

3.4.3.1.2.3. Shannon diversity index

The Shannon diversity index shows low values which range between 1.3 and 1.9.

3.4.3.1.3. Morphotype groups

Important morphotype groups of this interval include, AG-C (22.6-63.3%), CH-B4 (7.2-69.4%) and CH-B3 (0-31.9%), while CH-B2 (0.2-7.6%) is a minor element of the cluster (Figure 3.8).

In the planktic assemblage, the non-keeled morphotype group which was dominant at the top of the cluster C, is completely dominant throughout this cluster too (90.9-100%), while the double-keeled morphotype group constitutes only a small portion of the assemblage (0-9.0%). The single-keeled morphotype has completely disappeared, Figure 3.4.

3.4.3.1.4. Species

3.4.3.1.4.1. Coarse fraction

In this cluster the structure of coarse benthic assemblage changes significantly from the previous cluster. The dominant benthic species in this interval include, *Marssonella* spp. (16.6-57.3%), *Gavelinella berthelini* plus *Gavelinella reussi* (7.2-69.4%), *Lingulogavelinella globosa* (0-31.9%) and *Tritaxia tricarinata* (0-18.6%), Figures 3.9 - 3.11. However, *Arenobulimina truncata* plus *Arenobulimina* sp. A (0-3.5%), which appear for the first time in this cluster, and *Lenticulina* spp. (0.2-7.6%) only form a low percentage of the assemblage.

As with cluster C, the epifaunal group is very rare in this interval (0-1.7%) and instead the infaunal, semi-infaunal group is strongly dominant (Figure 3.10).

Among the planktic assemblage, a high proportion of *Hedbergella delrioensis* (43.4-93.1%), strong oscillation of *Whiteinella aprica* (0-53.7%) and low abundance of *Whiteinella archaeocretacea* (0-2.0%) and double-keeled species (maximum 4.5% for both *Dicarinella hagni* and *Dicarinella algeriana*) are characteristics of this cluster.

3.4.3.1.4.2. Fine fraction

In the lowest part of the interval *Praebulimina* sp. A is the most important species (E37, 67.9%), but its percentage decreases up through the section (E40-E46, 14.8-32.7%). In contrast *Osangularia* sp. A, which is of minor elements in the lowest part (E37, 14.1%) becomes dominant in the upper part of the interval (E40-E46, 63.1-84.2). *Gyroidinoides* sp. A (0-12.8%) and *Ramulina aculeata* (0-2.3%) are of low importance in the assemblage (Figure 3.12).

Among the planktics, *Heterohelix moremani* (48.4-58.4%) and *Hedbergella planispira* (17.4-41.4%) are dominant species, while *Hedbergella delrioensis* (0-18.8%) and *Shackoina* sp. A (0-4.1%) are the other constituents (Figure 3.6).

3.4.3.2. Ostracods

3.4.3.2.1. Absolute abundance

In the lower part of the interval the values are fairly low (E34-E37, 174-240 valves per 100 g), but higher samples show very low values (E38-E46, 52-168 valves per 100 g) (Figure 3.13).

3.4.3.2.2. Diversity

Three different diversity curves for ostracods assemblage are shown in Figure 3.13. Variation of each diversity in cluster D is as below.

3.4.3.2.2.1. Simple diversity

The number of species for the lower part of the interval is not high (E34-E37, 9), but in the upper part falls to very low values (E38-E46, 4-8).

3.4.3.2.2.2. Fisher Diversity index

The values for the lower samples of the cluster are fairly high (E34-37, 2.4-2.8), but fall in the other samples and oscillates between 1-1.6%.

3.4.3.2.2.3. Shannon diversity index

As with the simple diversity, two parts can be recognised in the interval. First, low values in the lower part (E34-E37, 1.0) and second, very low values in the upper part (E38-E46, 0.4-0.8).

3.4.3.2.3. Species

Cytherella spp. are the most important species in this cluster (69.8-97.5%), among which *Cytherella ovata* has the highest values (50.2-92.6%). *Bairdoppilata* spp. (0-25.3%) and *Isocythereis elongata* plus *Cythereis* sp. A (0-14.2%) are minor elements of the interval, Figures 3.14 - 3.16. The proportion of a new species, *Mosaeleberis* sp. A is very low (0-2.3%).

In this interval, platycopids are strongly dominant and the percentage of podocopids, which was very high in the previous cluster, falls once again and ranges between 0 and 31%.

3.4.3.3. Changes in microfossils.

3.4.3.3.1. Coarse benthic foraminifera

In this interval 8 species have their last occurrences. These species belong to textulariids (*Textularia chapmani*, *Textularia* sp. A), nodosariids (*Psilocytharella costulata* var. A, *Frondovaginolina inversa*), elongate polymorphinids (*Ramulina aculeata)*, hormosinids (*Reophax* sp. A), polymorphinids (*Oolina globosa*) and verneuilinids (*Gaudryina austinana*). However, 4 new species appear for the first time, which belong to tritaxiids (*Tritaxia tricarinata* var. *jongmansi*), gavelinellids (*Lingulogavelinella aumalensis*), ataxophragmiids (*Arenobulimina truncata*) and nodosariids (*Frondicularia verneuiliana)*, Figure 3.17 and Plates 8 and 9.

3.4.3.3.2. Coarse planktic foraminifera

Among the planktic assemblage, 5 species (*Hedbergella planispira*, *Hedbergella simplex*, *Whiteinella brittonensis*, *Helvetoglobotruncana praehelvetica* and *Whiteinella aprica*) have their last occurrences in this interval. Two new species appear, which include a non-keeled species, *Whiteinella archaeocretacea* (Meads Marl 5) and a double-keeled species, *Marginotruncana renzi*, (the marl above the Meads Marl 7), Figure 3.18 and Plates 11 and 12.

3.4.3.3.3. Ostracods

In the ostracod population diversity continues to fall steadily up through the section. During the interval 5 podocopids including, *Bythoceratina herrigi*, *Paracypris wrothamensis*, *Pontocyprella hindei*, *Pontocyprella harrisiana*, *Pterygocythereis*

diminuta, and 3 platycopids including *Cytherella chathamensis*, *Cytherelloidea kayei* and *Cytherelloidea hindei*, occur for the last time (Plate 14). *Isocythereis elongata*, *Bairdoppilata southerhamensis*, *Cytherella concava*, *Cytherella contracta* and *Cythereis* sp. A are absent at the top of the interval, which might be due to sampling. A highly reticulated podocopid, *Mosaeleberis* sp. A, is the only new species to appear in this interval, Figure 3.19 and Plate15.

3.4.3.3.4. Fine benthic foraminifera

In the fine benthic foraminifera, 1 gavelinellid (*Gavelinella* sp.) occurs for last time in Meads Marl 2, while 1 elongate polymorphinid (*Ramulina aculeata*) appears for the first time in Meads Marl 5, Figure 3.20. Dominance of a buliminid (*Praebulimina* sp. A), which began in the base of the cluster B continues also in the lower part of this interval, but in the Meads Marl 5 there is a marked substitution between this species and an osangulariid (*Osangularia* sp. A), which is the dominant species in the rest of the interval.

3.4.3.3.5. Fine planktic foraminifera

Among the fine planktic assemblage the appearance of *Schakoina* sp. A (Plate 16) in Meads Marl 5 is significant. The genus *Schakoina* appeared for the first time at the top of cluster A (*Schakoina cenomana* in only one sample), but disappeared temporarily through clusters B and C. However, it re-appears with a new species (*Schakoina* sp. A) in the lower part of this interval and is present throughout the rest of the interval. *Guembelitria cenomana* occurs only in the lower part of the interval and is absent throughout the interval, Figure 3.20.

3.5. Cluster E_E (Lulworth Marl)

3.5.1. Lithology and samples

The interval includes only a thin marly bed. This is the only sample available representative of higher beds in the section (Figure 3.1). Sample E34 is the only one available and both coarse and fine fractions have been examined.

3.5.2. Stable isotopes and acid insoluble residues

Compared to previous interval, $\delta^{13}C$ value in the unique sample of this cluster falls to a low value (2.9‰ PDB), Figure 3.2.

In contrast to previous interval, $\delta^{18}O$ value in the unique sample of this cluster jumps to a significantly less negative value (-2.3‰ PDB), Figure 3.2.

The amount of acid insoluble residue for this sample has not been measured, but at Dover the average percentage for the chalks below this sample has been reported about 4.2% (Lamolda *et al.*, 1994).

3.5.3. Microfauna

3.5.3.1. Foraminifera

3.5.3.1.1. Absolute abundance (total number per 100 g)

3.5.3.1.1.1. Coarse fraction

The total number of coarse benthic foraminifera is low (780 specimens per 100 g), which is similar to previous interval (Figure 3.3).

The total number of coarse planktic foraminifera falls to 83 specimens, which is the lowest of all the intervals (Figure 3.3). In this cluster, the absolute number of hedbergellids - whiteinellids falls to a very low value (33 specimens per 100 g), whereas double-keeled species show a slight recovery compared to the previous interval (26), Figure 3.4. In this sample, the percentage of planktic foraminifera is also lowest of all the samples (9.6%), Figure 3.4.

3.5.3.1.1.2. Fine fraction

The absolute abundance of fine benthic and planktic foraminifera is shown in Figure 3.5. The absolute number of fine benthic foraminifera is 86630 specimens which does not show any great change from the top of the cluster D.

In this sample, the absolute number of fine planktic foraminifera falls to 53692 specimens, which is the lowest of all the intervals. Apart from the re-appearance of some specimens of *Guembelitria cenomana* (1804), the total numbers of *Heterohelix moremani* (29328) and *Hedbergella* spp. (18499) are very low and *Schakoina* sp. A (4060) has also lower value than with previous interval (Figure 3.6).

3.5.3.1.2. Diversity of benthic foraminifera

Figure 3.7 shows different diversity curves for benthic foraminiferal assemblage. Characteristics of each curve in cluster E are as below.

3.5.3.1.2.1. Simple diversity

The number of species is 13, which indicates a slight recovery compared to the uppermost part of cluster D.

3.5.3.1.2.2. Fisher diversity index

Like simple diversity, only a low recovery can be distinguished. The value is 2.1 for the unique sample of this cluster.

3.5.3.1.2.3. Shannon diversity

The Shannon diversity index is 2.1 in this sample, which represents a higher value than cluster D.

3.5.3.1.3. Morphotype groups

CH-B4 (40.3%) and AG-C (38.5%) are the most important morphotypes of the assemblage, while CH-B2 (8.3%) and CH-B3 (5.9%) are minor morphotypes of the assemblage (Figure 3.8).

In the planktic foraminifera, double-keeled morphotype reaches one of the highest values (44%), while non-keeled morphotype falls to 55.9%.

3.5.3.1.4. Species

3.5.3.1.4.1. Coarse fraction

As with pervious cluster, *Gavelinella reussi* plus *Gavelinella berthelini* (40.3%) are dominant elements of the assemblage. *Marssonella* spp. (14.8%) and *Lingulogavelinella globosa* (5.9%) have lower proportion than in cluster D. *Tritaxia tricarinata* (13.8%) does not show any significant change compared to the top of cluster D, but the proportion of *Arenobulimina* spp. increases (12.7%) and *Lenticulina* spp. (8.33%) remain as a minor element of the assemblage (Figures 3.9 - 3.11).

In the unique sample of this cluster, the epifaunal group is very rare (2.3%) and the infaunal, semi-infaunal group is still strongly dominant (Figure 3.10).

Analysis of the planktic assemblage shows that *Hedbergella delrioensis*, although its proportion falls to 47.4%, is still the important element of the assemblage and a new species, *Praeglobotruncana* sp. A, forms about 30.5% of the percentage. However, *Marginotruncana renzi* (3.3%), *Dicarinella hagni* (6.7%), *Dicarinella algeriana* (3.3%) and *Whiteinella archaeocretacea* (6.7%) are minor elements of the assemblage.

3.5.3.1.4.2. Fine fraction

Among the benthic foraminifera, *Osangularia* sp. A is the dominant species (89.0%), while the other species occupy only a small portion of the assemblage (*Praebulimina* sp. A, 5.2% and *Ramulina aculeata* , 4.6%), Figure 3.12.

In the planktic foraminifera, *Heterohelix moremani* (54.6%) and *Hedbergella planispira* (22.6%) are still the most important species. *Shackoina* sp. A shows its highest percentage in this cluster (7.5%) and *Guembelitria cenomana* is rare (3.3%), Figure 3.6.

3.5.3.2. Ostracods

3.5.3.2.1. Absolute abundance

Compared to the other intervals the absolute number of ostracods is very low and falls to 46 valves per 100 g (Figure 3.13).

3.5.3.2.2. Diversity

3.5.3.2.2.1. Simple diversity

The number of species, which at the top of the cluster D was 7 falls to 3 in this sample, which is lowest of all the clusters (Figure 3.13).

3.5.3.2.2.2. Fisher diversity index

In this sample, the Fisher diversity is very low and falls to 1.0 (Figure 3.13).

3.5.3.2.2.3. Shannon diversity index

The heterogeneity index shows one of its lowest values, 0.4, in this sample (Figure 3.13).

3.5.3.2.3. Species

Like cluster D, *Cytherella ovata* is the dominant species and forms 91% of the sample, while both *Bairdoppilata pseudoseptentrionalis* and *Bythoceratina umbonata,* with 4.5% each, are rare (Figures 3.14 - 3.16).

In the unique sample of this cluster, the percentage of podocopids is still very low (9.0%), and does not show any significant change from the upper part of cluster D (Figure 3.15).

3.5.3.3. Changes in microfossils.

3.5.3.3.1. Coarse benthic foraminifera

With appearance of 2 ataxophragmiids (*Arenobulimina preslii* and *Arenobulimina* sp. A) and the re-appearance of a textulariid (*Textularia* sp. B) diversity of benthic foraminifera in this cluster improves a little compared to the previous cluster. However, the unique sample of this cluster, includes only 13 benthic foraminifera, belonging mainly to gavelinellids (*Gavelinella berthelini, Gavelinella reussi, Lingulogavelinella globosa*), eggerellids (*Marssonella* spp.) and tritaxiids (*Tritaxia tricarinata*), Figure 3.17 and Plates 9 and 10.

3.5.3.3.2. Coarse planktic foraminifera

The recovery in the planktic foraminiferal assemblage, which began from the middle of cluster D, continues also in this sample and a new species, *Praeglobotruncana* sp. A, appears for the first time (Figure 3.18). In this sample 7 species are present, among which 4 species are keeled-morphotypes (*Dicarinella*

algeriana, *Dicarinella hagni*, *Marginotruncana renzi* and *Praeglobotruncana* sp. A), Plate 12.

3.5.3.3.3. Ostracods

In the ostracod community diversity falls to its lowest level, so that only three species are present in this sample. About 90% of the assemblage is *Cytherella ovata*, while *Bairdoppilata pseudoseptentrionalis* and *Bythoceratina umbonata* are of minor importance (Figure 3.19 and Plate 15).

3.5.3.3.4. Fine benthic foraminifera

In this sample the fine benthic foraminiferal community is made of 5 species, which do not show any significant difference from cluster D (Figure 3.20).

3.5.3.3.5. Fine planktic foraminifera

In the planktic community only the re-appearance of some specimens of *Guembelitria cenomana* is noteworthy. Otherwise the assemblage is similar to the upper part of cluster D (Figure 3.20).

CHAPTER 4

CHAPTER 4

CENOMANIAN-TURONIAN BOUNDARY AT WESTBURY

4.1. Cluster A_W (pre Plenus Marls)

Based on statistical data (cluster analysis) four clusters at Westbury were recognised, labelled A_W - D_W. Characteristics of cluster A_W are as below.

4.1.1. Lithology and samples

The thickness of the measured interval is about 110 cm and in contrast to cluster A_E, which shows alternation of marl and chalk, consists only of very hard chalk, characterised by *Chondrites*-type burrow systems within the upper part (Figure 4.1).

At Westbury only coarse fractions (> 250 μm) were analysed and no fine fraction was investigated. However, in this cluster only one sample was taken, which belongs to the *Chondrites* interval (W1).

4.1.2. Stable isotopes

The $\delta^{13}C$ curve in three samples of this cluster, taken for geochemical analysis, shows low values which vary from 2.5‰ to 2.6‰ PDB (Figure 4.2).

The values for $\delta^{18}O$ start around -3.5‰ PDB, reaching -2.7‰ PDB in the *Chondrites* interval and fall again to -3.2‰ PDB by the top of the interval (Figure 4.2).

4.1.3. Microfauna

4.1.3.1. Foraminifera

4.1.3.1.1. Absolute abundance of coarse fraction (total number per 100 g)

The absolute abundance of coarse benthic and planktic foraminifera is shown in Figure 4.3. As is apparent, the absolute number of coarse benthic foraminifera in the unique sample of this cluster (W1) is fairly high (1123 specimens per 100 g).

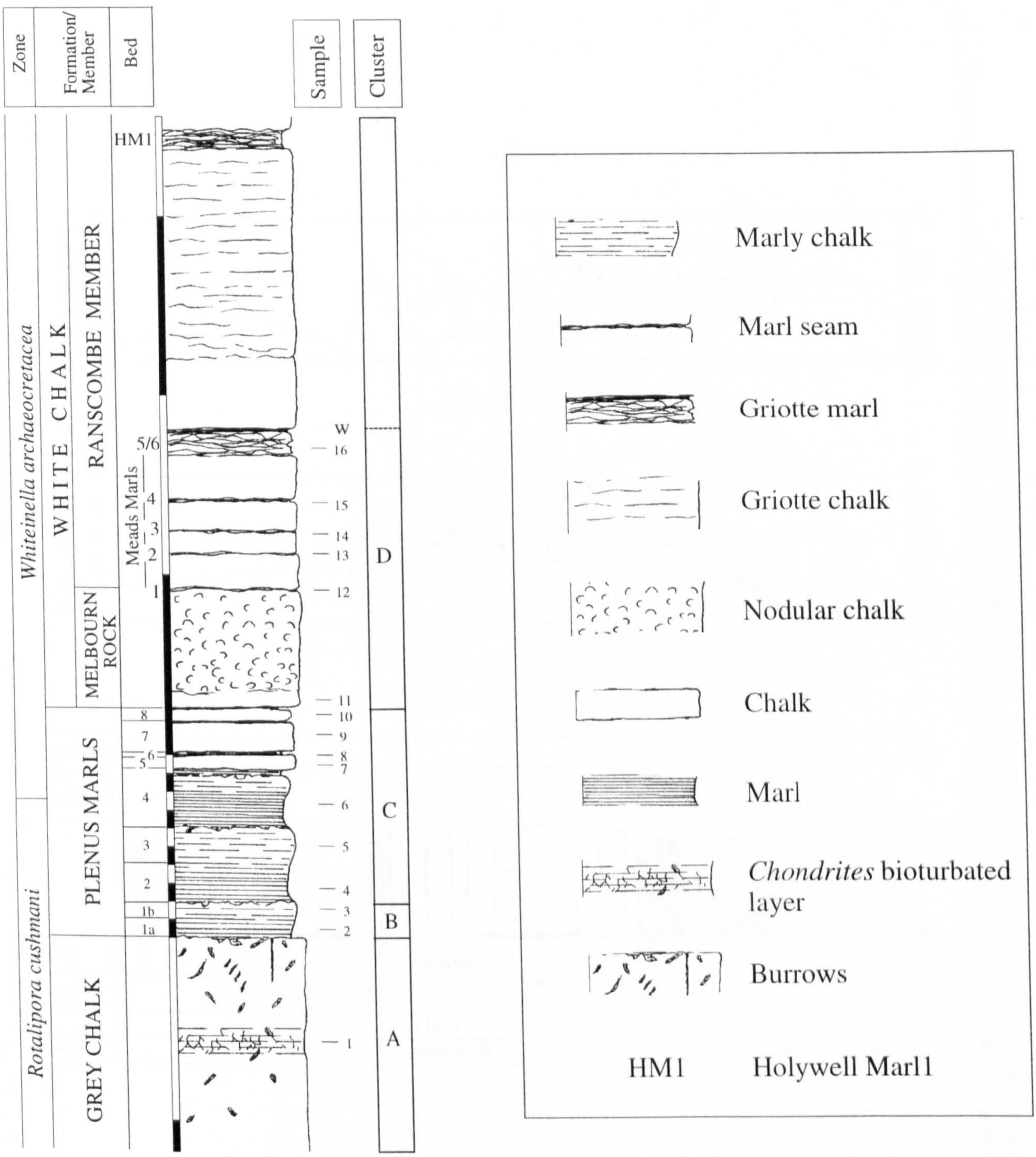


Figure 4.1. Lithostratigraphy of the Upper Cenomanian - Lower Turonian at Westbury.

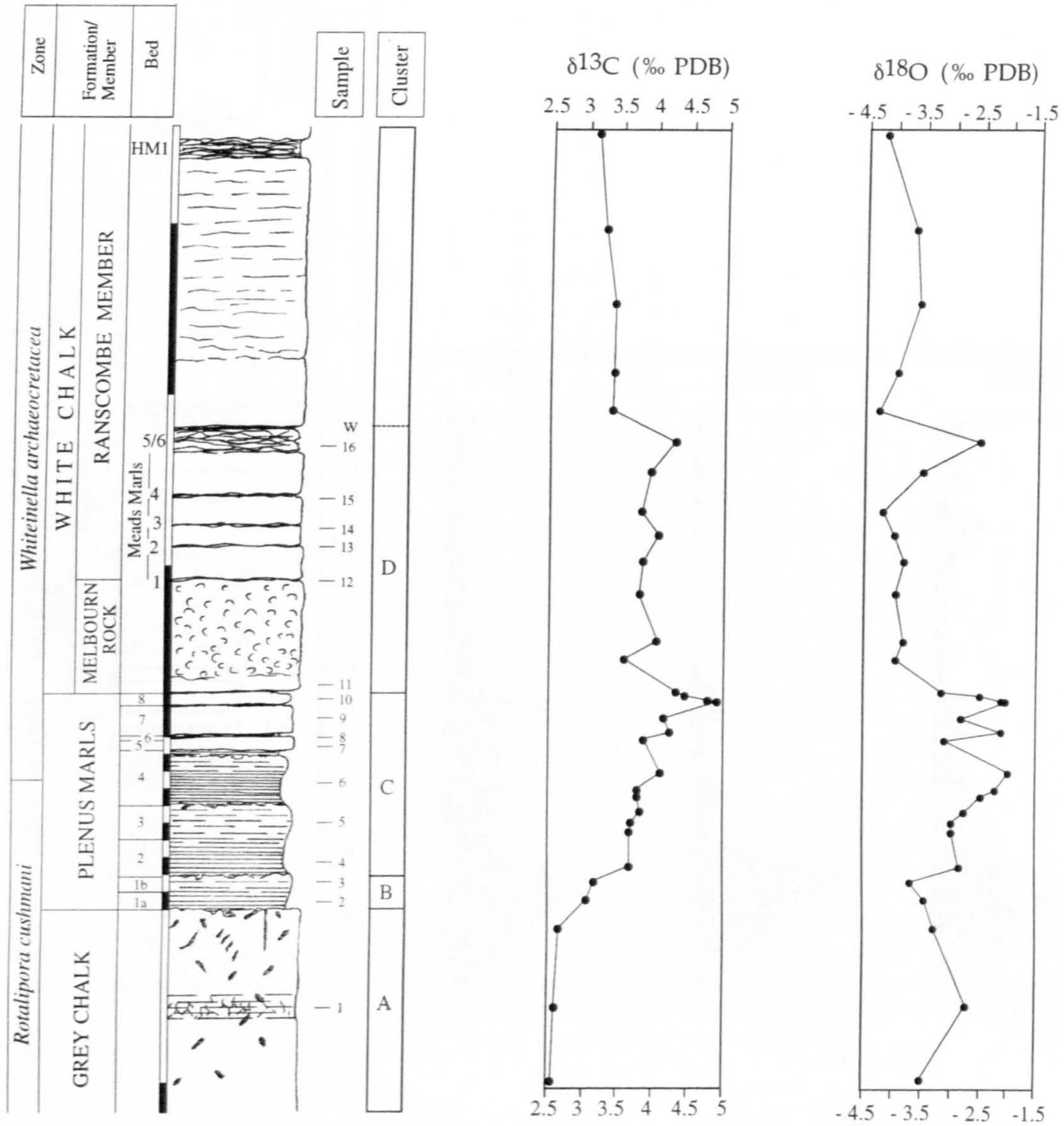


Figure 4. 2. Stable isotope curves for carbon and oxygen in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

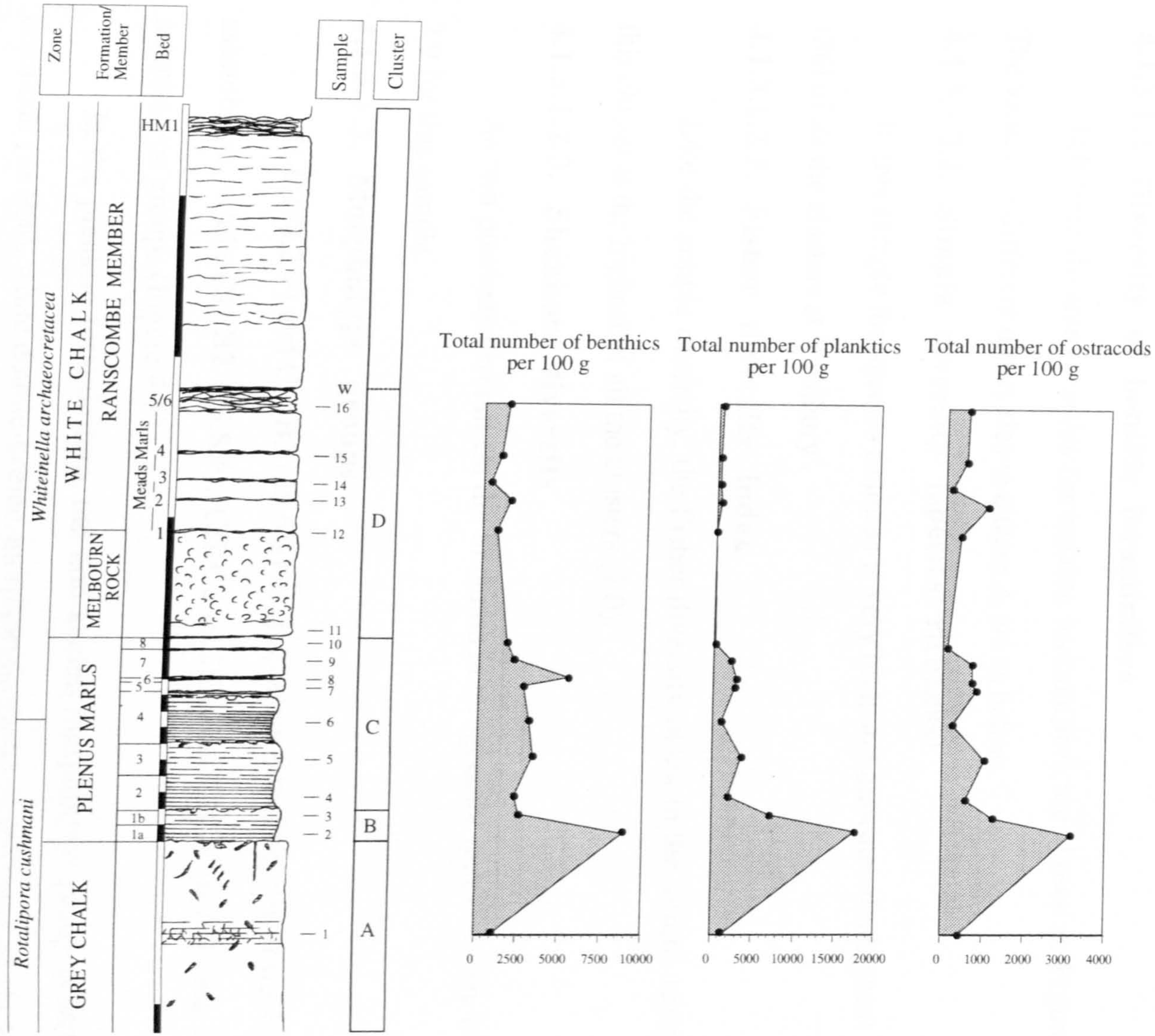


Figure 4. 3. Absolute abundance of coarse benthic and planktic foraminifera and ostracods in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

The total number of planktic foraminifera is also fairly high, 1298 specimens per 100 g. In this interval, the abundance of hedbergellids - whiteinellids is high (1066 specimens), while double-keeled planktics (108) and *Rotalipora cushmani* (24) constitute minor elements of the assemblage (Figure 4.4).

Percentage of planktic foraminifera is high at 53.6% (Figure 4.4).

4.1.3.1.2. Diversity of benthic foraminifera

Different diversity curves for benthic foraminifera are shown in Figure 4.5. The values for different diversities in cluster A are as below.

4.1.3.1.2.1. Simple diversity (species richness)

In this sample the species richness is very high and indicates the highest value (36) of all the clusters at Westbury .

4.1.3.1.2.2. Fisher diversity index

Like the simple diversity, the Fisher diversity index in the unique sample of this cluster is the highest of all the clusters (7.0).

4.1.3.1.2.3. Shannon diversity

As two previous diversities, the Shannon heterogeneity index is very high at 2.9 for this sample.

4.1.3.1.3. Morphotype groups

AG-C (43.2%) and CH-B3 (20.6%) are important morphotypes of the benthic assemblage, while CH-B2 (13.8%), CH-C2 (9.2%) and CH-A (6.2%) are minor morphotype groups (Figure 4.6).

In the planktic foraminifera, the non-keeled morphotype group is strongly dominant (88.9%), while double-keeled-morphotype group (9.0%) and single-keeled morphotype group (2.0%) are minor constituents of the assemblage (Figure 4.4).

4.1.3.1.4. Coarse fraction species

Percentage, cumulative diagram and average percentage of benthic foraminifera in clusters A - D across the Cenomanian-Turonian boundary at Westbury are shown in Figures 4.7 - 4.9. As is apparent, this sample is characterised by a highly diverse benthic assemblage, among which *Tritaxia* spp.(23.4%), *Gavelinella baltica* plus

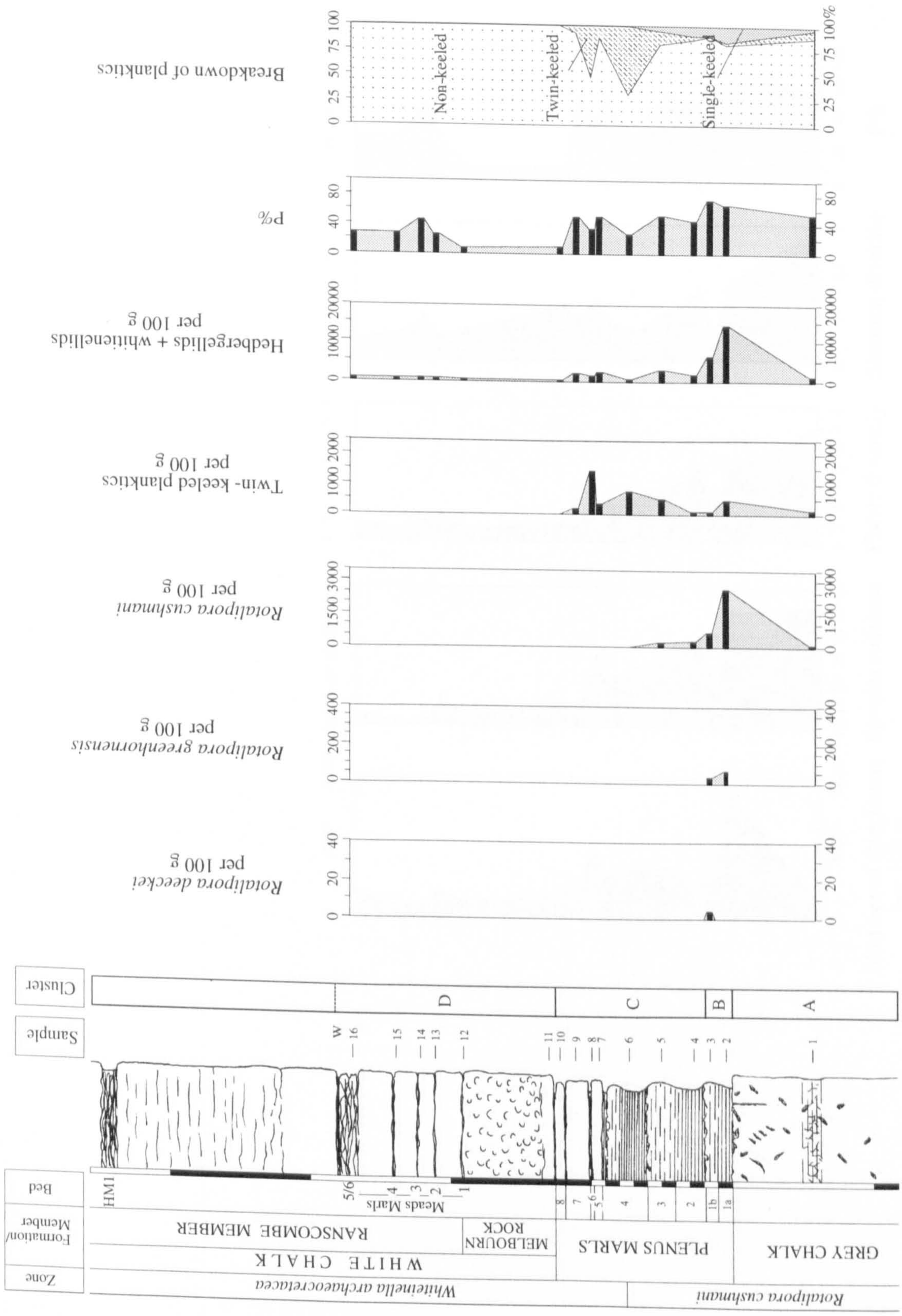


Figure 4.4. Absolute abundance, P% and breakdown of planktic assemblage in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scales in metres. See Figure 4.1 for key to symbols on graphic log.

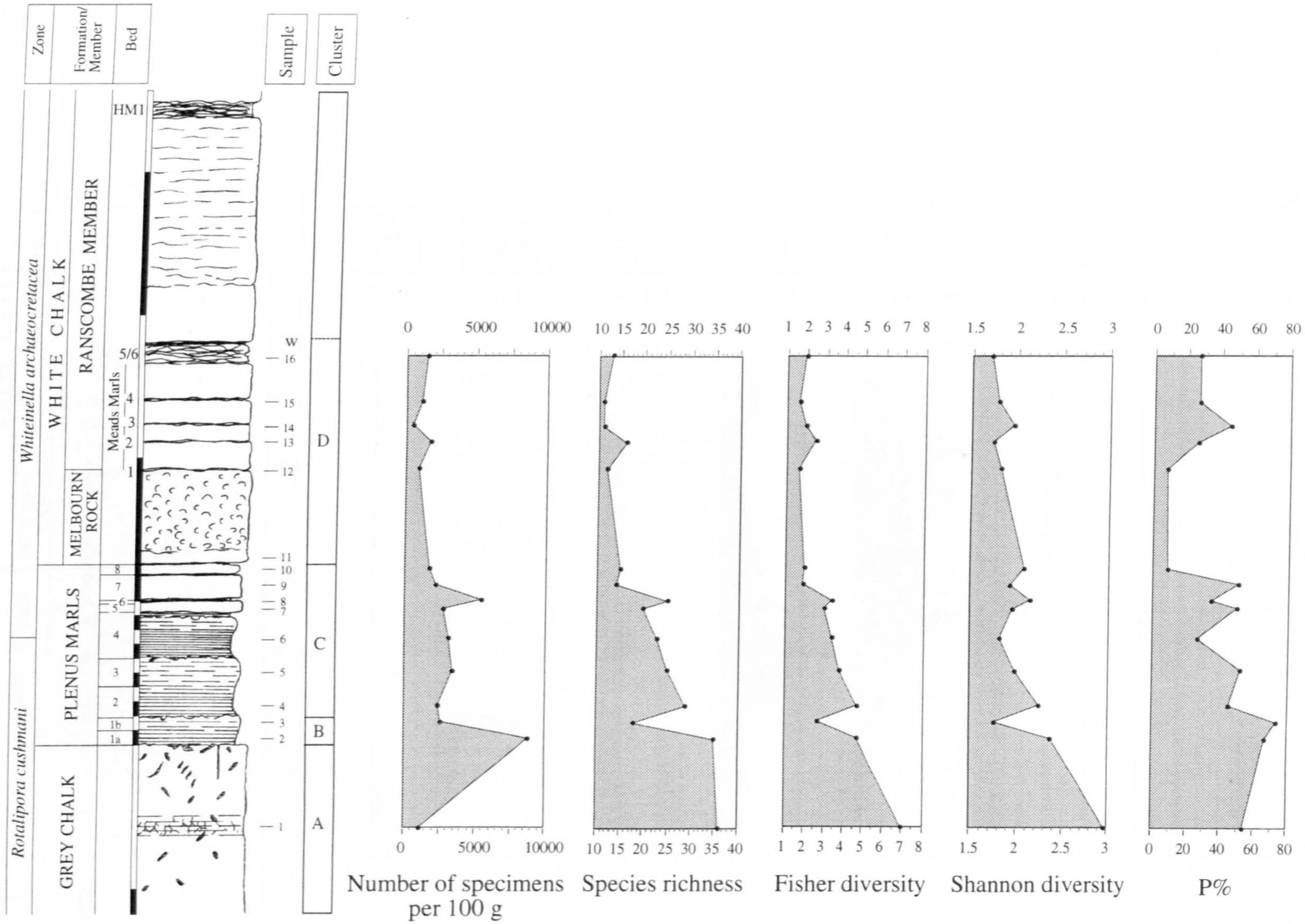


Figure 4. 5. Number of specimens and benthic foraminifera, diversity curves and p% in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

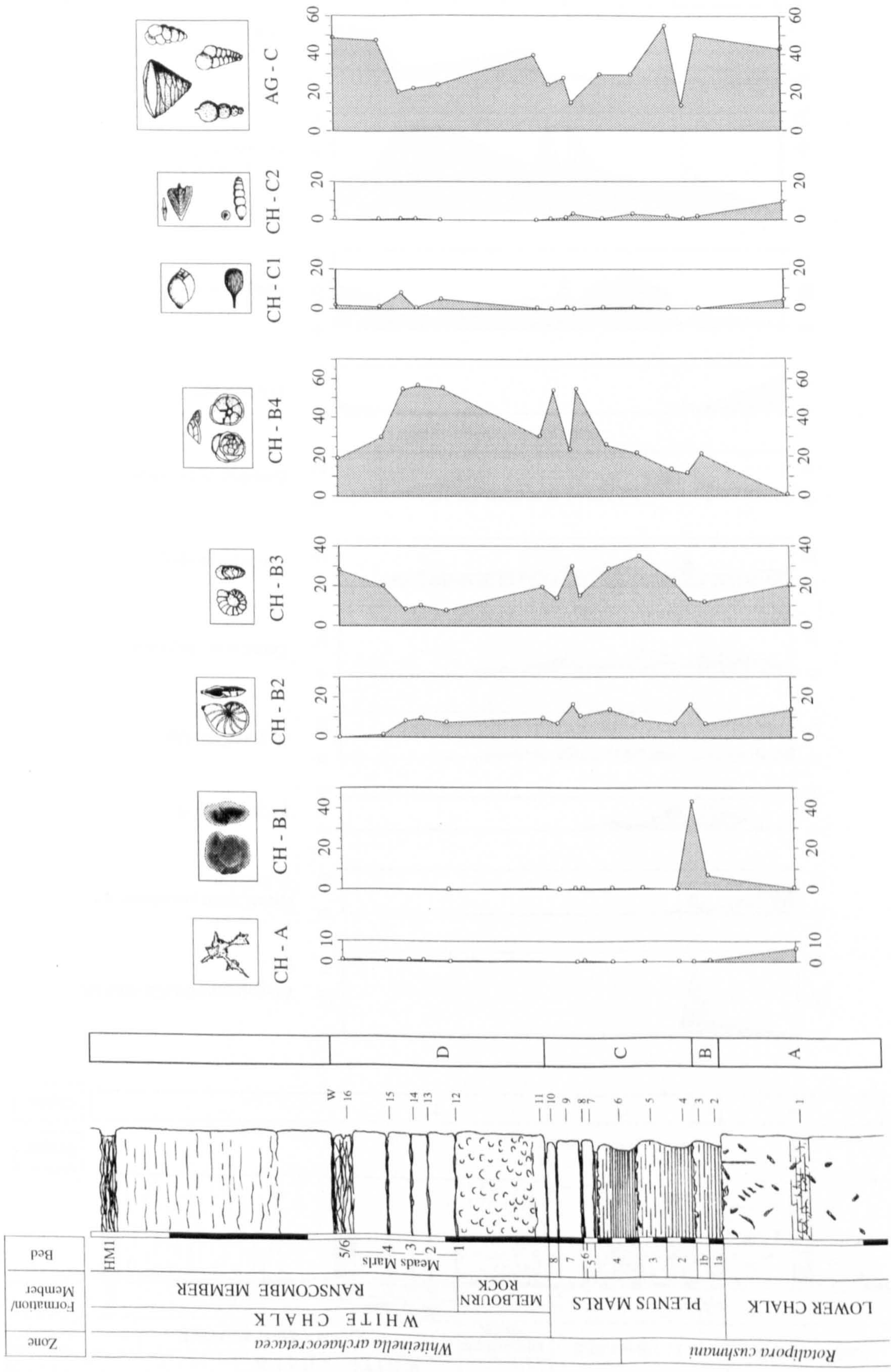


Figure 4. 6. Variation in morphotype groups in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

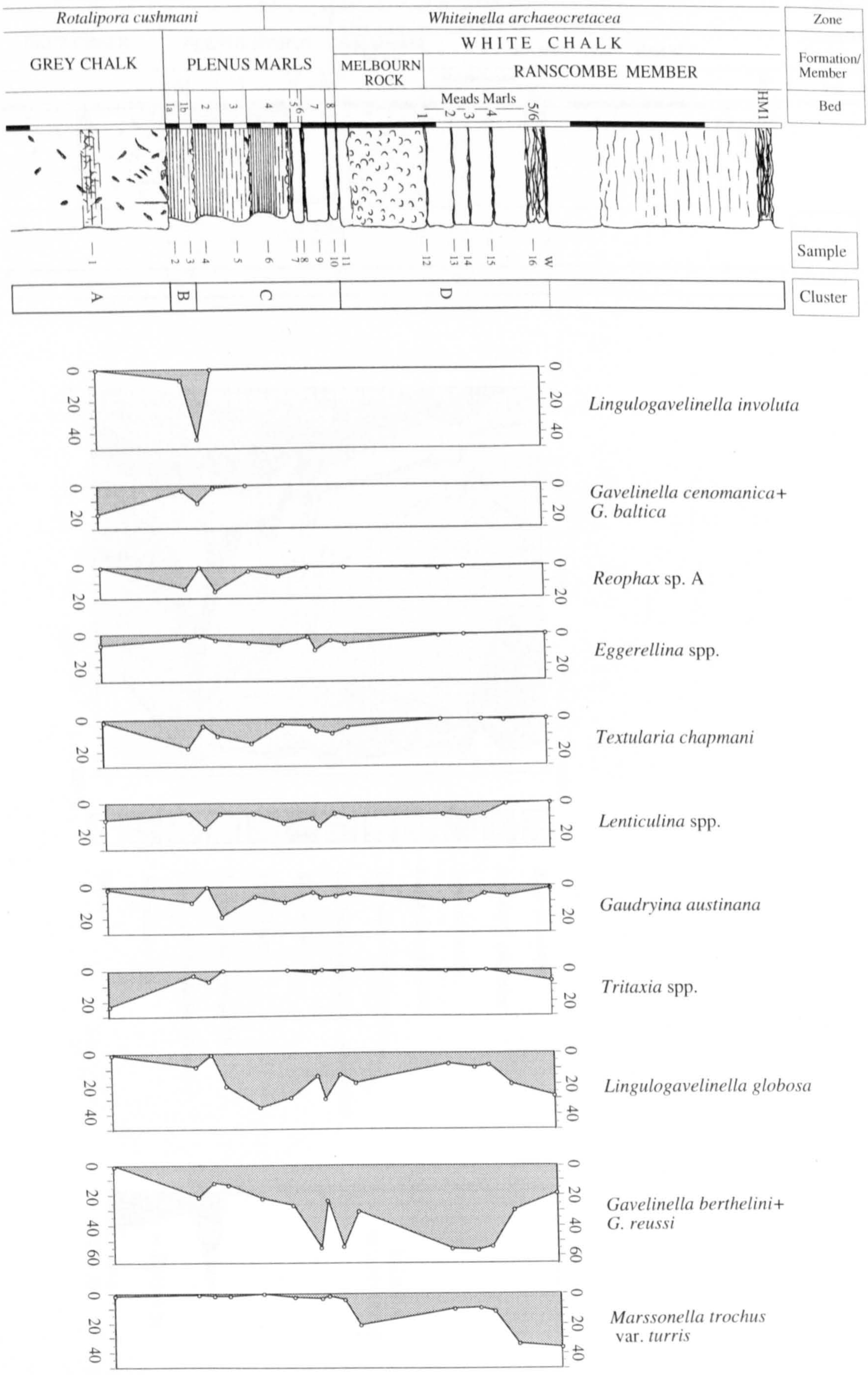


Figure 4.7. Variation in percentage of important benthic foraminifera in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

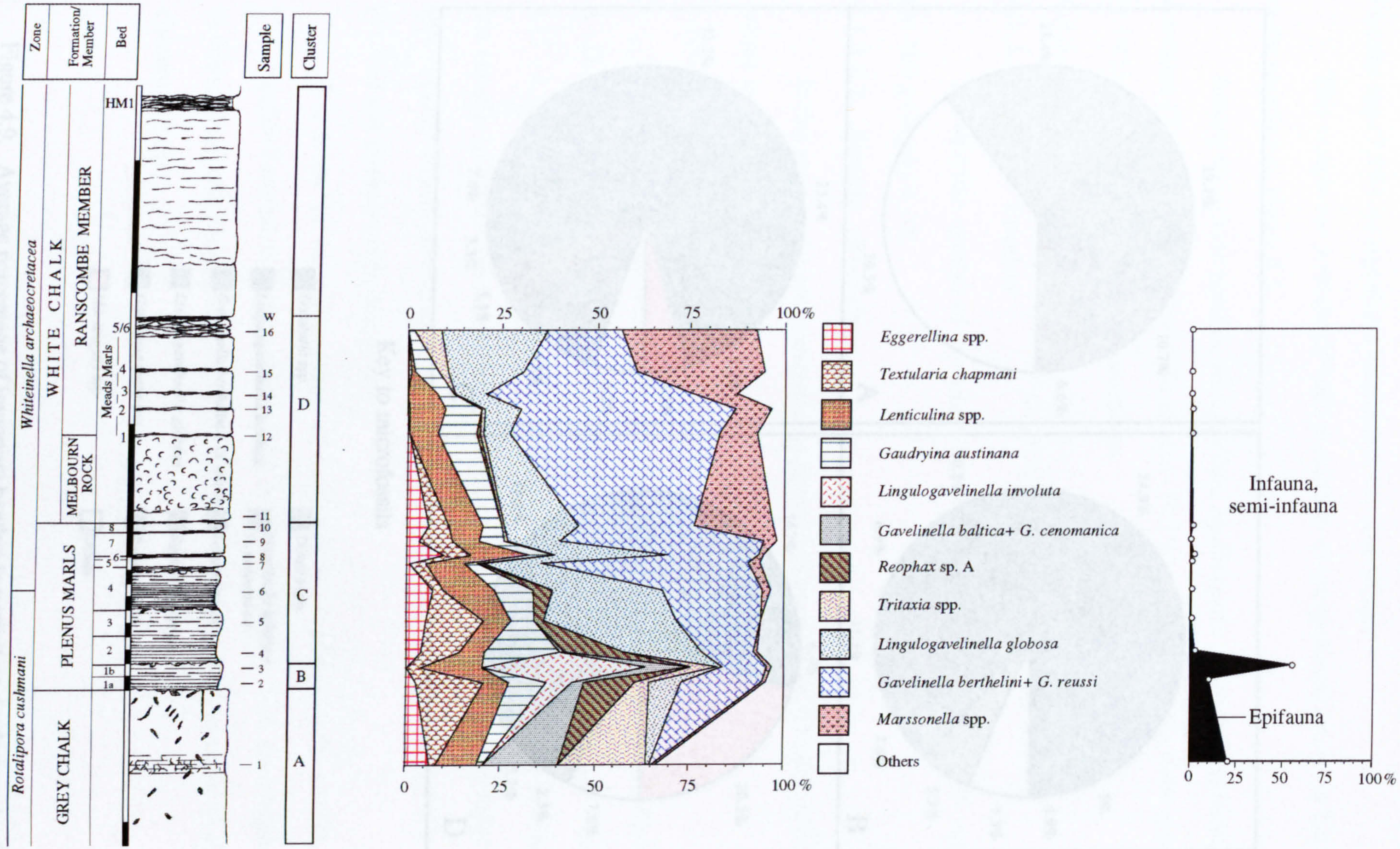
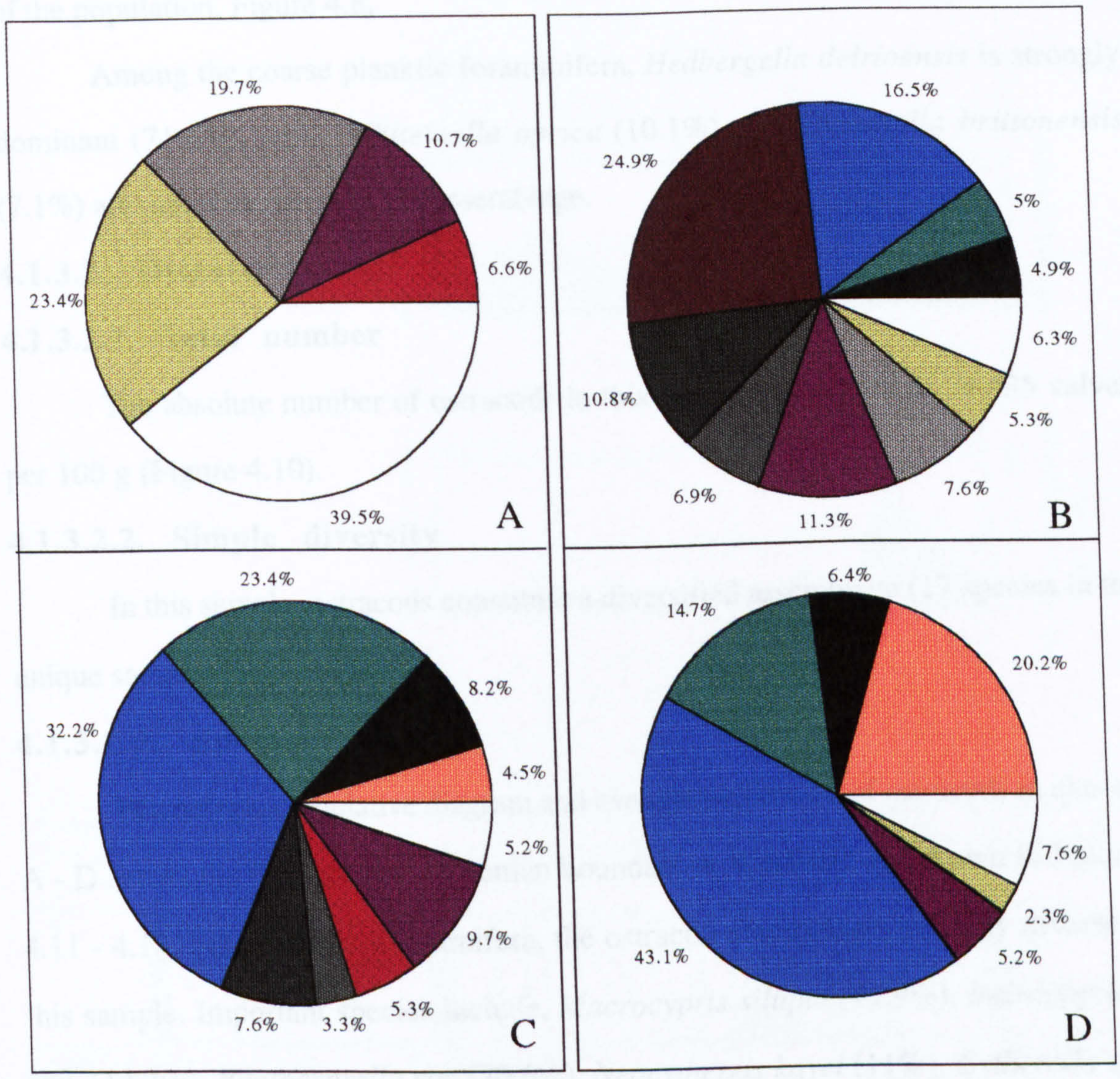


Figure 4. 8. Cumulative percent of dominant benthic species and percentage of the epifaunal group in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.



Key to microfossils

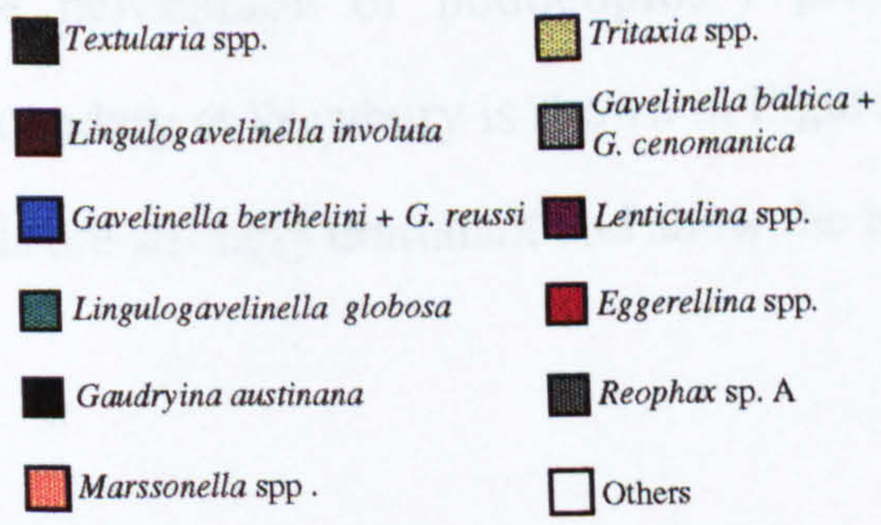


Figure 4.9. Average percentage of important benthic foraminifera in clusters A - D across the Cenomanian - Turonian boundary at Westbury.

Gavelinella cenomanica (19.7%), *Lenticulina* spp. (10.7%), and *Dorothia gradata* plus *Plectina* spp.(7.5%) are significant elements of the assemblage.

This sample has a relatively high proportion of the epifaunal group, at 20.5% of the population, Figure 4.8.

Among the coarse planktic foraminifera, *Hedbergella delrioensis* is strongly dominant (71.6%), while *Whiteinella aprica* (10.1%) and *Whiteinella brittonensis* (7.1%) are minor elements of the assemblage.

4.1.3.2. Ostracods

4.1.3.2.1. Total number

The absolute number of ostracods in this sample is fairly high, at 435 valves per 100 g (Figure 4.10).

4.1.3.2.2. Simple diversity

In this sample, ostracods constitute a diversified assemblage (17 species in the unique sample), Figure 4.10.

4.1.3.2.3. Species

Percentage, cumulative diagram and average percentage of ostracods in clusters A - D across the Cenomanian-Turonian boundary at Westbury are shown in Figures 4.11 - 4.13. Like benthic foraminifera, the ostracod assemblage is highly diverse in this sample. Important species include, *Macrocypris siliqua* (17.9%), *Bairdoppilata* spp. (14.2%), *Pontocyprella* spp.(20.6%), *Neocythereis kayei* (11%), *Cytherella* spp. (15.6%) and *Bythoceratina* spp. (7.3%).

Variation in the percentage of podocopids / platycopids across the Cenomanian-Turonian boundary at Westbury is shown in Figure 4.12. As is apparent, in this sample podocopids are strongly dominant and show the highest value of all the clusters (82.2%).

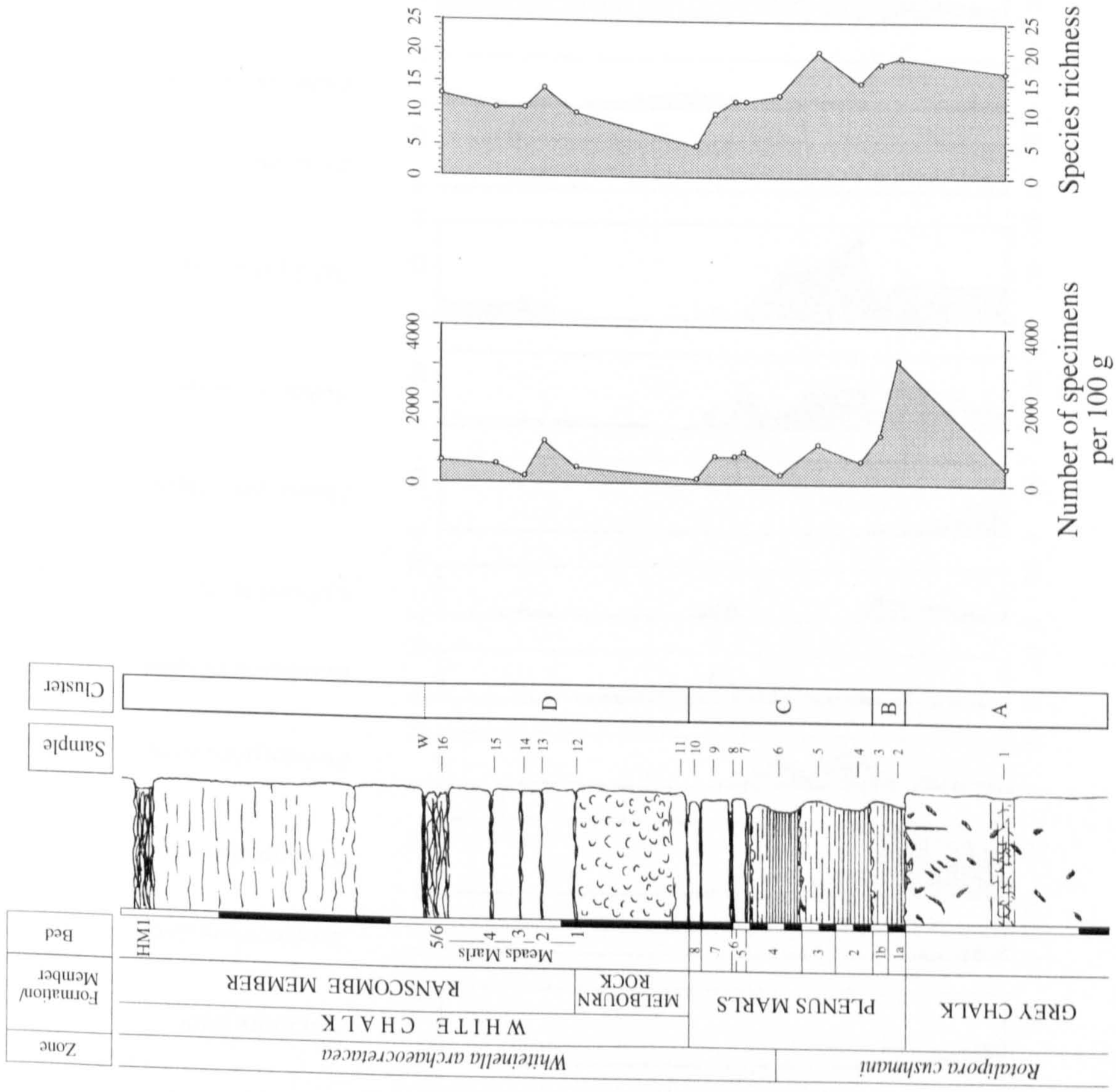


Figure 4.10. Absolute abundance and species richness for ostracods in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

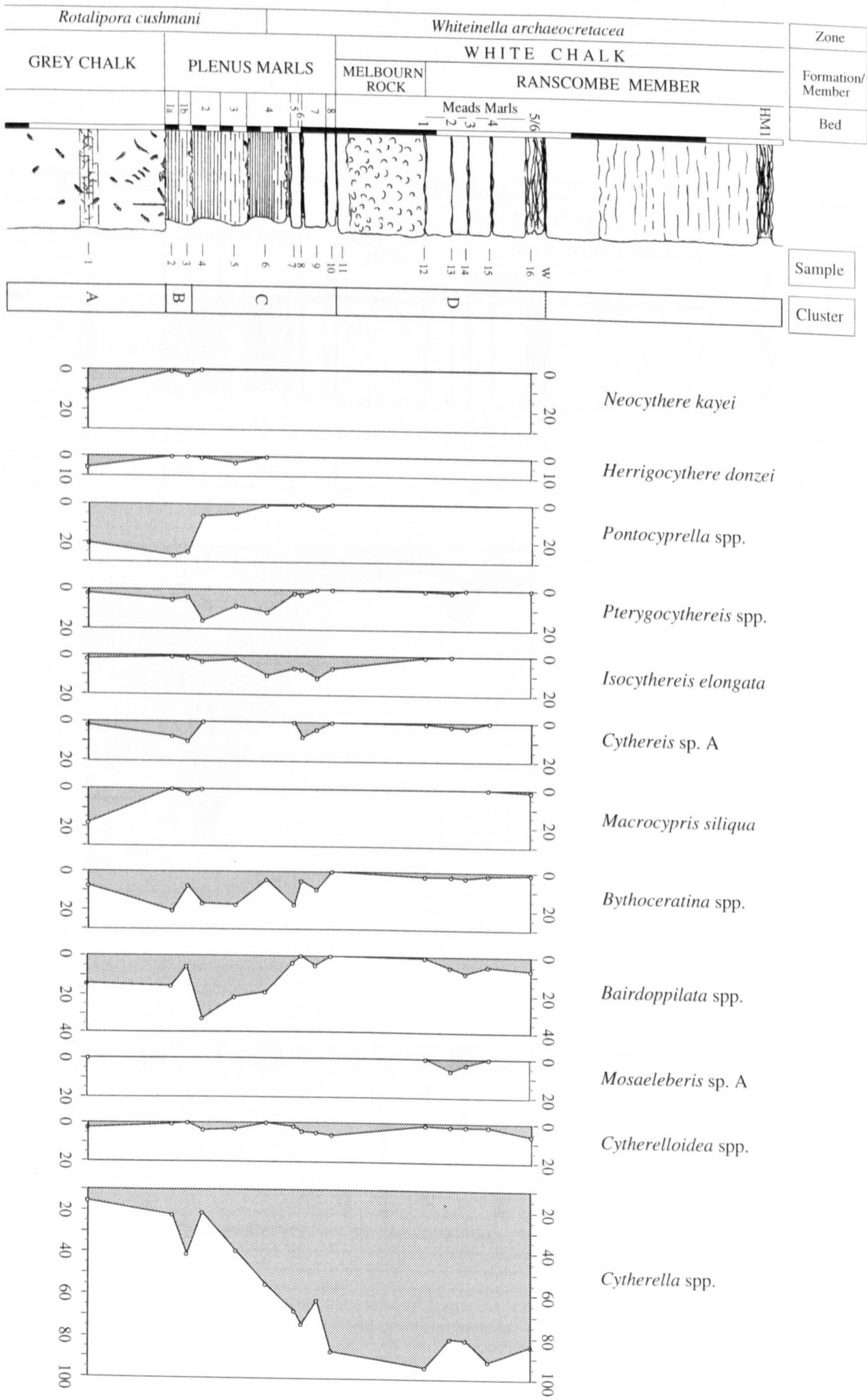


Figure 4. 11. Variation in percentage of important ostracods in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

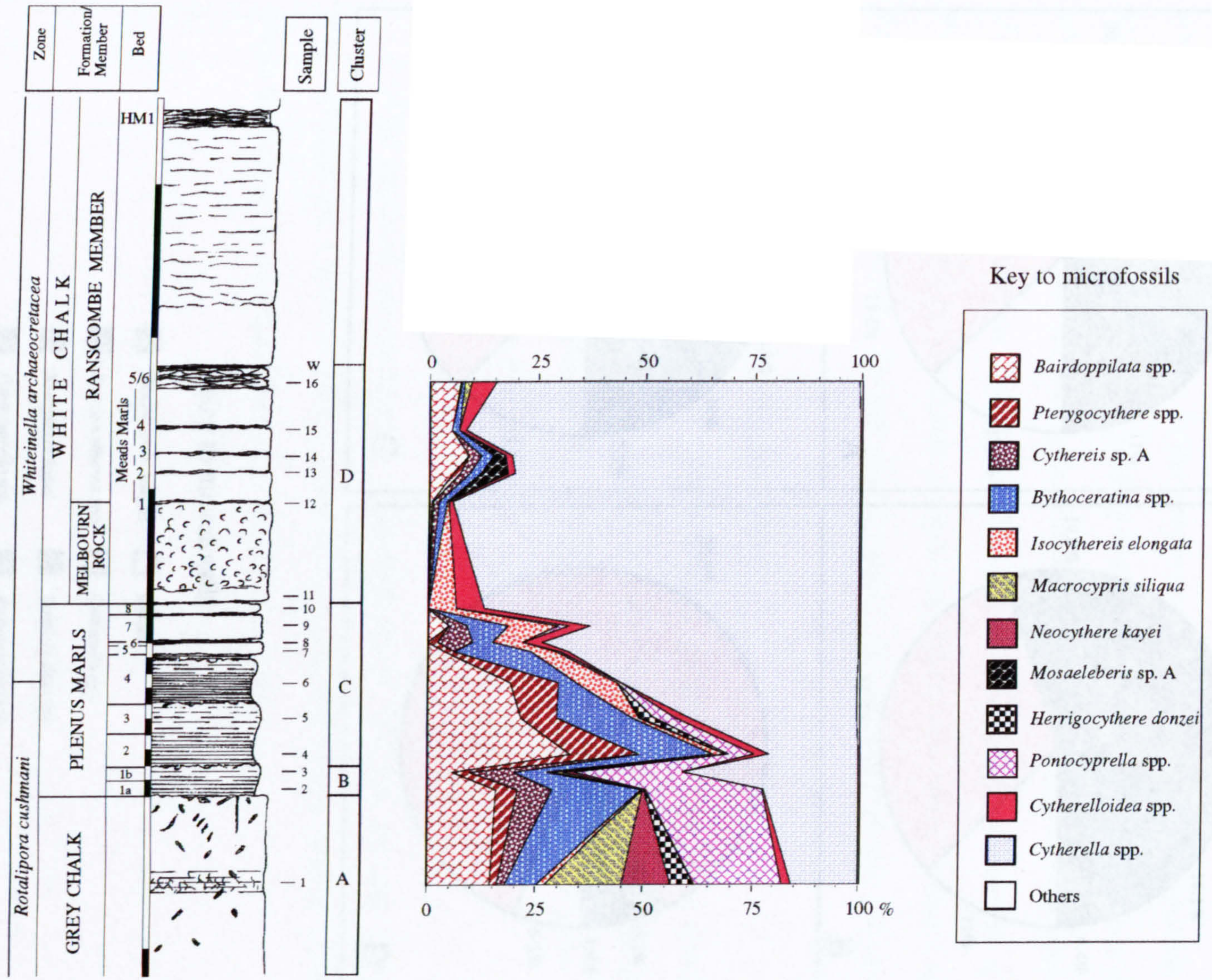


Figure 4. 12. Cumulative percent of dominant ostracods in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

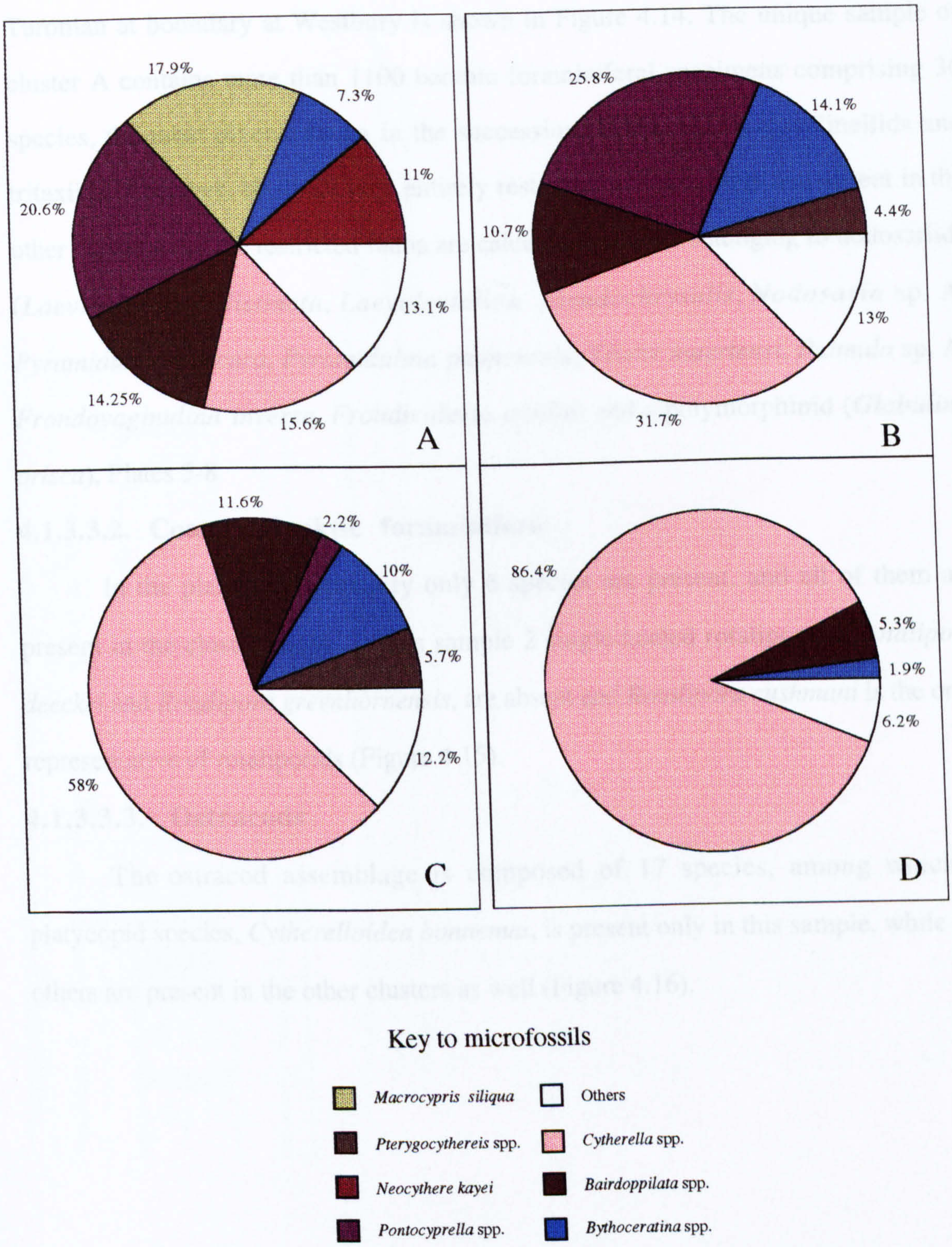


Figure 4. 13. Average percentage of important ostracods in clusters A - D across the Cenomanian - Turonian boundary at Westbury.

4.1.3.3. Changes in microfossils

4.1.3.3.1. Coarse benthic foraminifera

Distribution of benthic foraminifera in clusters A-D across the Cenomanian-Turonian at boundary at Westbury is shown in Figure 4.14. The unique sample of cluster A contains more than 1100 benthic foraminiferal specimens comprising 36 species, the most diverse fauna in the succession, dominated by gavelinellids and tritaxiids. However, 10 species are entirely restricted to this sample and absent in the other clusters. All the restricted fauna are calcareous species belonging to nodosariids (*Laevidentalina distincta*, *Laevidentalina pseudochrysalis*, *Nodosaria* sp. A, *Pyramidulina obscura*, *Pyramidulina paupercula*, *Tristix maertensi*, *Palmula* sp. A, *Frondovaginulina inversa*, *Frondicularia cordai*) and a polymorphinid (*Globulina prisca*), Plates 5-8.

4.1.3.3.2. Coarse planktic foraminifera

In the planktic community only 6 species are present, and all of them are present in the cluster above. In this sample 2 single-keeled rotaliporids, *Rotalipora deeckei* and *Rotalipora greenhornensis*, are absent and *Rotalipora cushmani* is the only representative of rotaliporids (Figure 4.15).

4.1.3.3.3. Ostracods

The ostracod assemblage is composed of 17 species, among which 1 platycopid species, *Cytherelloidea bonnemai*, is present only in this sample, while the others are present in the other clusters as well (Figure 4.16).

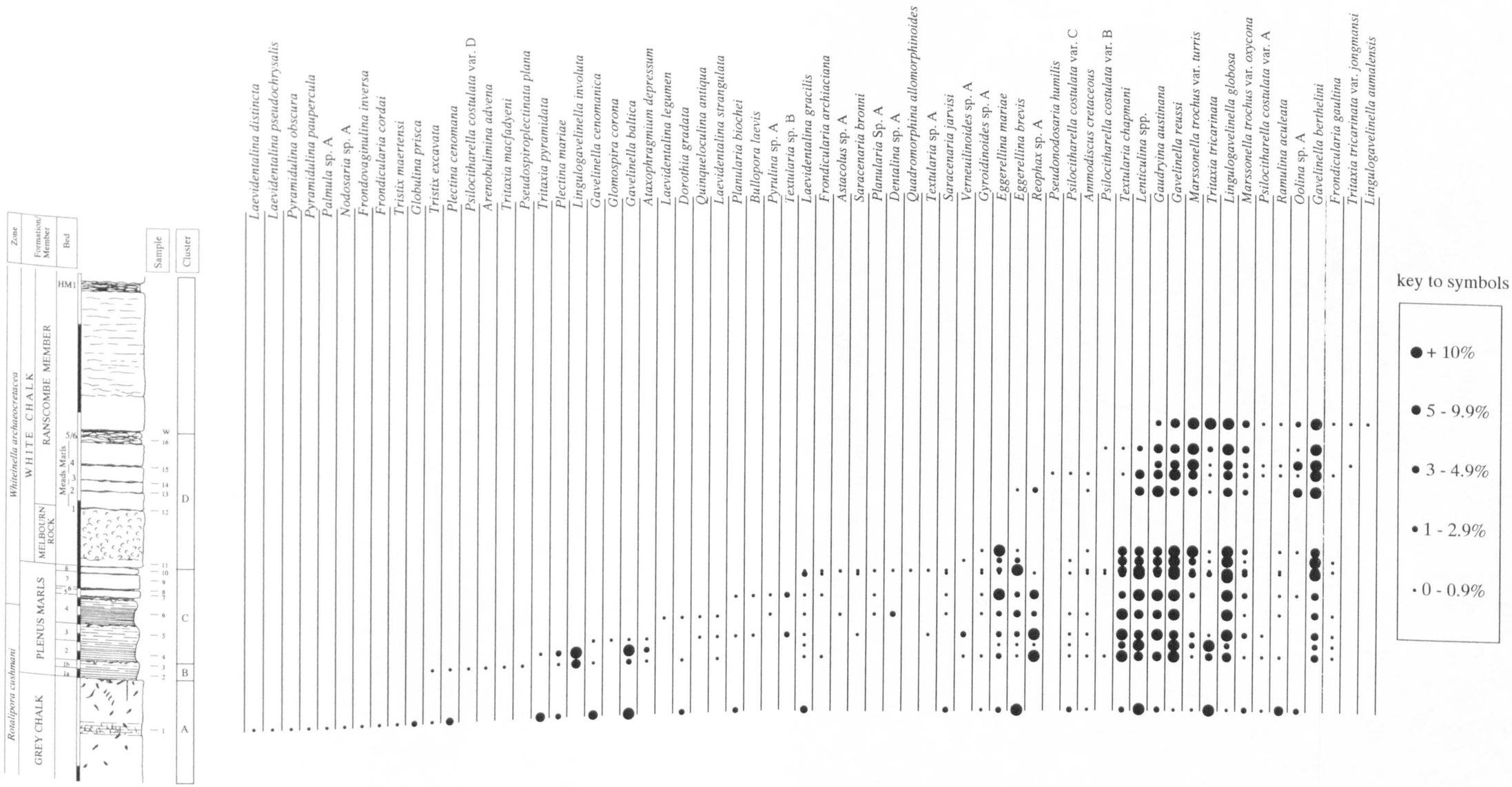


Figure 4.14. Distribution of coarse benthic foraminifera in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. For key to symbols on log see Figure 4.1.

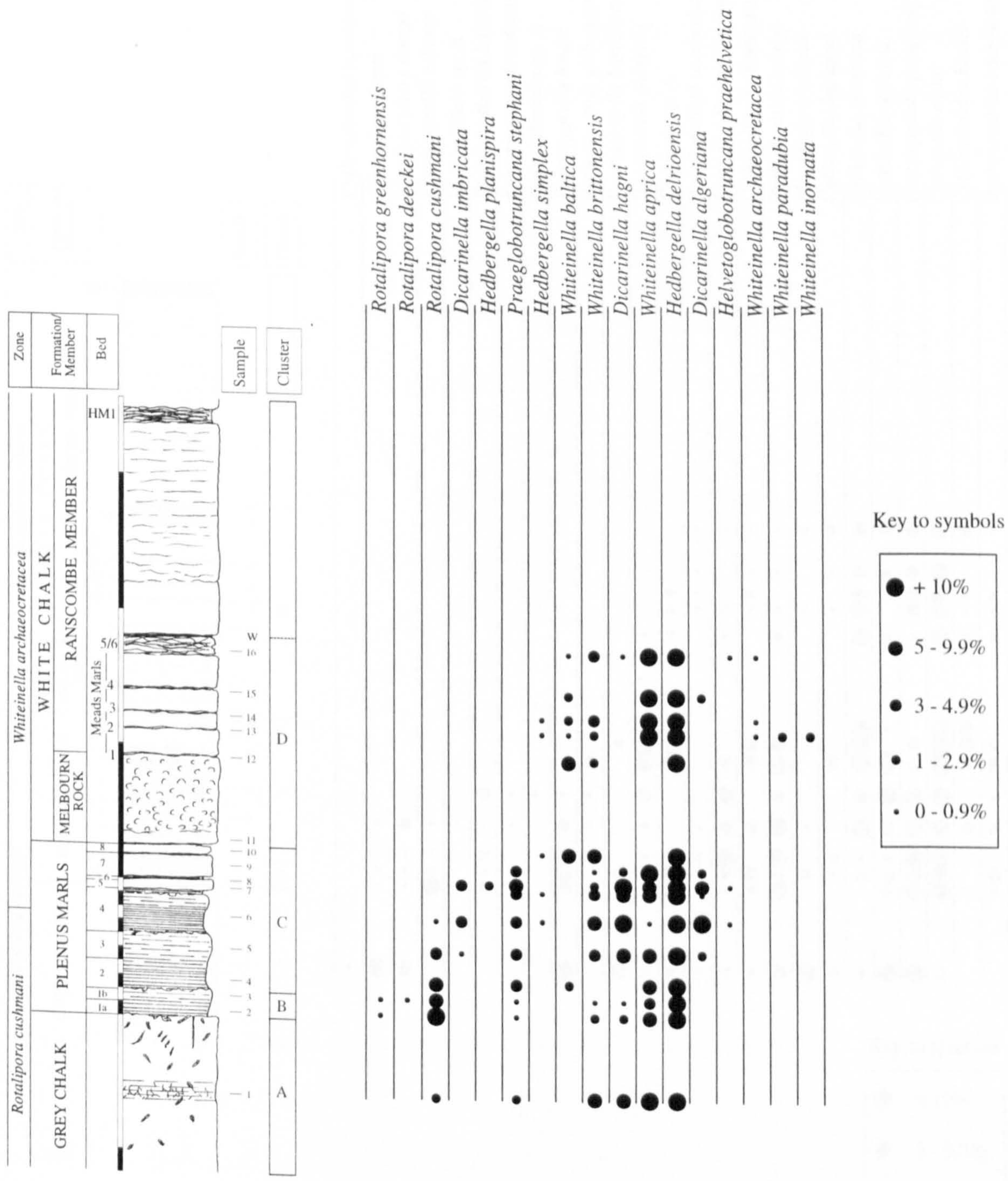


Figure 4.15. Distribution of coarse planktic foraminifera in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. For key to symbols on log see Figure 4.1.

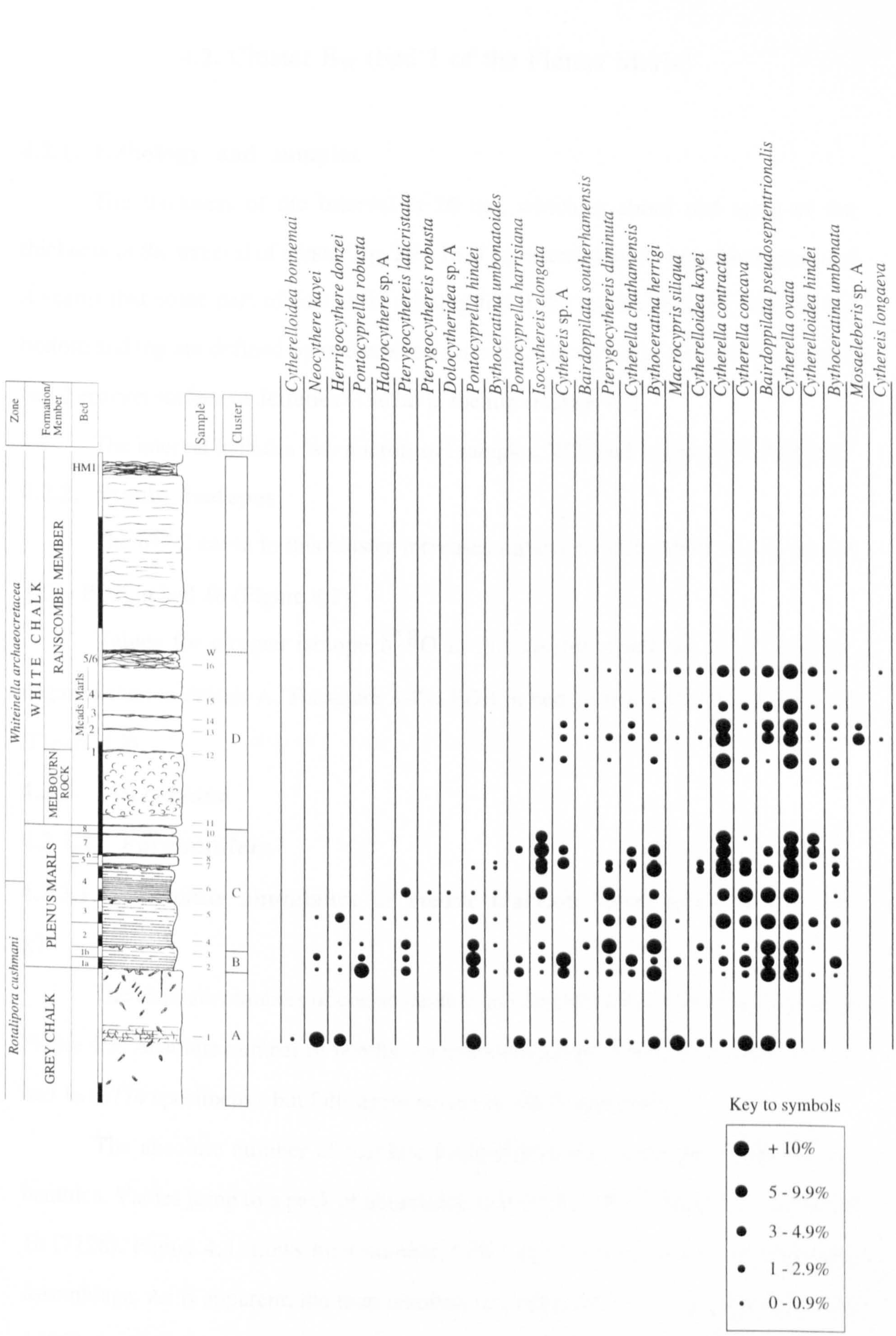


Figure 4.16. Distribution of ostracods in clusters A - D across the Cenomanian - Turonian boundary at Westbury. Scale in metres. For key to sumbols on log see Figure 4.1.

4.2. Cluster B_W (bed 1 of the Plenus Marls)

4.2.1. Lithology and samples

The thickness of the interval is 20 cm, which is about one tenth of the thickness of the interval of cluster B_E. Bed 1a is represented by its uppermost part and it seems that some part of bed 1b is missing too. Like the Eastbourne section, the bottom and top are defined by two erosion surfaces. The SPES at the bottom and sub bed 2 erosion surface of Jefferies (1963a) at the top (Figure 4.1).

The interval includes two microfossil samples, W2 (bed 1a) and W3 (bed 1b).

4.2.2. Stable isotopes

The $\delta^{13}C$ curve in this cluster increases rapidly to 3.0‰ PDB in bed 1a and 3.1‰ PDB in bed 1b (Figure 4.2).

Values for oxygen isotope $\delta^{18}O$ in this cluster, continue to fall to more negative than in cluster A. These are 3.4‰ PDB in bed 1a and 3.6‰ PDB in bed 1b (Figure 4.2).

4.2.3. Microfauna

4.2.3.1. Foraminifera

4.2.3.1.1. Absolute abundance of coarse fraction (total number per 100 g)

The absolute numbers of coarse benthic and planktic foraminifera are shown in Figure 4.3. Absolute number of benthic foraminifera jumps to a peak of abundance in bed 1a (8774 specimens), but falls again in bed 1b (2627 specimens).

The absolute number of planktic foraminifera shows the same trend as the benthics. Values jump to a peak of abundance in bed 1a (17436), but fall again in bed 1b (7128). Figure 4.4 shows total number, "P%" and breakdown of coarse planktic assemblage. As is apparent, the total numbers of hedbergellids - whiteinellids (6348-14052 specimens) and *Rotalipora cushmani* (616-2592) jump to high values in this cluster, although two new rotaliporids, *Rotalipora greenhornensis* (32-64) and

Rotalipora deeckei (0-4) are rare. The values for double-keeled species increase only in bed 1a compared to cluster A_W (64-448).

The percentage of planktic foraminifera (P/B ratio) in this interval is the highest of all the clusters, at 66.5% in bed 1a (W2) and 73.0% in bed 1b (W3).

4.2.3.1.2. Diversity of benthic foraminifera

Figure 4.5 shows three different diversity curves for benthic foraminifera. Values for each diversity in cluster B are as below.

4.2.3.1.2.1. Simple diversity (species richness)

The species richness in bed 1a is very high (W2, 35), but almost halves in bed 1b (W3, 18).

4.2.3.1.2.2. Fisher diversity index

Fisher diversity index shows the same trend as simple diversity. It is very high in bed 1a (W2, 4.7), but falls in bed 1b (W3, 2.7).

4.2.3.1.2.3. Shannon diversity

The Shannon heterogeneity index in bed 1a shows a high value (W2, 2.3), then falls in bed 1b (W3, 1.7).

4.2.3.1.3. Morphotype groups

AG-C (13.6-49.9%) is the major element of the assemblage, while a sudden increase in the percentage of morphotype group CH-B1 (6.6-43.1%) in bed 1b (W3) is noteworthy. CH-B4 (11.8-21.3%), CH-B3 (12.0-13.2%) and CH-B2 (6.5-16.1%) constitute the other morphotype groups of the assemblage (Figure 4.6).

In the planktic foraminiferal assemblage the non-keeled morphotype group is dominant (81-89.8%), and the proportion of the single-keeled morphotype group increases compared with sample W1 (9.2-15.4%). The double-keeled morphotype group is rare in this interval (0.9-2.6%), Figure 4.4.

4.2.3.1.4. Coarse fraction species

The cluster is characterised by sudden increase in the percentage of the *Lingulogavelinella involuta* (6.5-43.3%) and a high proportion of *Textularia chapmani*

(3.8-17.8%), *Gavelinella reussi* (10.6-17.2%), *Lenticulina* spp.(6.5-16.1%), *Reophax* sp. A (0.1-13.6%) and *Gavelinella baltica* (2.5-11.8%), Figures 4.7 - 4.9.

The proportion of the epifaunal group in bed 1a is low (10%), but jumps to a peak in bed 1b (55.1%), Figure 4.8.

Among the coarse planktics, as with previous cluster, *Hedbergella delrioensis* is strongly dominant (74.7-84.7%). The percentage of *Rotalipora cushmani* increases compared with the previous cluster (8.7-15.1%), while *Whiteinella aprica* has a lower proportion (4.6-5.2%).

4.2.3.2. Ostracods

4.2.3.2.1. Total number

As with benthic and planktic foraminifera, there is a sudden jump in the total number of ostracods in bed 1a (3174 specimens per 100 g), and then a fall in bed 1b (1254), Figure 4.10.

4.2.3.2.2. Simple diversity

In this interval, simple diversity increases a little from that in cluster A_W. The values vary from 18 to 19 (Figure 4.10).

4.2.3.2.3. Species

Cytherella spp. (22.4-41.1%), *Pontocyprella* spp. (24.8-26.8%) and *Bythoceratina* spp. (7.6-20.6%) show higher values than in sample W1 and are major elements of the assemblage, while *Bairdoppilata* spp. (5.7-15.7%) and *Cythereis* sp. A. (8.0-10.2%) are other constituents of the assemblage.

The percentage of podocopids, although lower than cluster A, is still very high and ranges between 58.7% and 77.3%, (Figures 4.11-4.13).

4.2.3.3. Changes in microfossils

4.2.3.3.1. Coarse benthic foraminifera

In this interval benthic foraminiferal diversity varies significantly (18-35 species). During the interval 5 species occur for the last time and include: a nodosariid (*Tristix excavata*), a tritaxiid (*Tritaxia pyramidata*), 2 verneuilinids (*Plectina mariae*, *Plectina cenomana*), and a gavelinellid (*Lingulogavelinella involuta*). Also 4 species

occur in a unique sample, which include: a vaginulinid (*Psilocytharella costulata* var. D, Plate 8), a ataxophragmiid (*Arenobulimina advena*), a tritaxiid (*Tritaxia macfadyeni*) and a verneuilinid (*Pseudospiroplectinata plana*), Figure 4.14.

4.2.3.3.2. Coarse planktic foraminifera

In the planktic assemblage, *Rotalipora greenhornensis* appears in bed 1a, although it becomes extinct in bed 1b. *Rotalipora deeckei* occurs only in bed 1b and shows a coeval extinction with *Rotalipora greenhornensis*. Otherwise, the structure of the planktic foraminifera is similar to the previous interval, Figure 4.15.

4.2.3.3.3. Ostracods

In this interval, the ostracod assemblage is similar to the previous sample and is diverse (18-19 species). No species occurs for the last time, instead 4 podocopid species including, *Pontocyprella robusta*, *Pterygocythereis laticristata*, *Bythoceratina umbonatoides*, *Bythoceratina umbonata*, and a platycopid species, *Cytherelloidea hindei*, appear for the first time, Figure 4.16.

4.3. Cluster C_W (beds 2-8 of Plenus Marls)

4.3.1. Lithology and samples

The thickens of the interval is about 110 cm, which is approximately one fifth of the thickness of the cluster C_E. As at Eastbourne, the bottom is defined by the sub-bed 2 erosion surface (Jefferies, 1963a) and the top by bed 9 of Jeans *et al.* (1991), Figure 4.1. In this interval, bed 8 is more marly than bed 8 of the Eastbourne section, and more typical of bed 8 throughout the Anglo-Paris Basin (Jefferies, 1963a).

Samples W4-W10 belong to this cluster, i.e. one sample was taken from each bed.

4.3.2. Stable isotopes

As Figure 4.2 shows, $\delta^{13}C$ values start about 3.6‰ PDB and then with some oscillation increase rapidly up through the section to reach a single peak at the top of bed 8 (4.9‰ PDB)

The $\delta^{18}O$ curve in this cluster increase rapidly and form a peak (-2.0‰ PDB) in the middle of bed 4, then after strong oscillation reaches a second peak (-2.0‰ PDB) at the base of bed 8 (Figure 4.2).

4.3.3. Microfauna

4.3.3.1. Foraminifera

4.3.3.1.1. Absolute abundance of coarse fraction

The total abundances of benthic and planktic foraminifera are shown in Figure 4.3. The total number of benthic foraminifera does not show any significant changes from the top of the previous interval (bed 1b). Values are relatively high and vary between 1727 and 5428.

Compared to the previous interval, the total number of planktic foraminifera falls to lower values and range from 161 to 3608. As Figure 4.4 shows the absolute abundance of double-keeled planktics increases in this interval (0-1428 specimens), but hedbergellids - whiteinellids show lower values (161-2752). *Rotalipora cushmani* (0-190) is restricted to lower part of the interval and is rare (Figure 4.4).

The percentage of planktic foraminifera is high ranging from 26.7 to 51.2% except at the top of the interval (bed 8), which is very low (8.5%) Figure 4.4.

4.3.3.1.2. Diversity of benthic foraminifera

Variations of three different benthic diversity curves in clusters A - D at Westbury are shown in Figure 4.5. Characteristics of each diversity in cluster C are as below.

4.3.3.1.2.1. Simple diversity (species richness)

The number of species decreases from 14 to 29 up through the section.

4.3.3.1.2.2. Fisher diversity index

Fisher α index shows the same trend as species richness. The values range between 1.9 and 4.7

4.3.3.1.2.3. Shannon diversity

The Shannon heterogeneity index declines from beds 2 to bed 4 and ranges between 2.2 and 1.8, but oscillates in the rest of the interval and varies from 1.9 to 2.1.

4.3.3.1.3. Morphotype groups

AG-C (14.8-54.7%) and CH-B3 (13.8-35.4%) are the dominant benthic morphotype groups. The CH-B4 morphotype increases towards the top of the interval (13.6-54%), but the CH-B2 morphotype does not show any significant changes and is a relatively minor element of the assemblage (6.7-16.0%), Figure 4.6.

In the planktic foraminifera, the non-keeled morphotype group is the most significant constituent of the assemblage (30.6-100%), but the single keeled morphotype decreases up through the section (0-9.7%) and occurs for the last time in bed 4. However, the double-keeled morphotype group, becomes an important elements of the assemblage (0-68.9%) at expense of the single-keeled morphotype group, Figure 4.4.

4.3.3.1.4. Coarse fraction species

As Figures 4.7 - 4.9 show, in this interval the proportion of *Gavelinella berthelini* plus *Gavelinella reussi* increases up through the section (13.6-54.9%). The

other constituents of the assemblage include *Lingulogavelinella globosa* (13.8-35.4%), *Lenticulina* spp., (6.6-15.0%), *Gaudryina austinana* (3.7-19.5%), *Textularia chapmani* (3-15.2%), *Eggerellina* spp. (0.9-10.2%) and *Reophax* sp. A (0-15.7%).

In this interval, the percentage of the epifaunal group falls suddenly to very low values (0-2.1%), while the infaunal, semi-infaunal group is strongly dominant, Figure 4.8.

Among the planktics, *Hedbergella delrioensis* constitutes a high proportion of the assemblage (21.8-82.4%). The double-keeled planktics, *Dicarinella hagni* (0-32.8%) and *Dicarinella algeriana* (0-28.1%) have higher values compared with previous clusters. *Whiteinella aprica* (0-14.1%) and *Whiteinella brittonensis* (0-9.9%) are the other elements of the interval.

4.3.3.2. Ostracods

4.3.3.2.1. Total number

Compared to previous interval, the total number of ostracods falls. Values oscillate between 244 and 1027 from bed 2 to 7, but fall to 125 in bed 8 (Figure 4.10).

4.3.3.2.2. Simple diversity

Although at the base of the interval diversity does not change significantly compared to previous intervals (W4-W5, 15-20), it falls to low values in the upper part of the interval (W6-W10, 5-13), Figure 4.10.

4.3.3.2.3. Species

Compared to previous intervals, the percentages of *Cytherella* spp. (20.9-87.2%), *Isocythereis elongata* (1.5-11.3%) and *Bairdoppilata* spp. (0-32.8%) increase in this interval, but the proportion of *Bythoceratina* spp. (0-17.6%) does not change significantly (Figures 4.11 - 4.13). *Herrigocythere donzei* (0-3.1%) and *Pontocyprella* spp. (0-6.2%) have their last occurrences in this interval.

Although podocopids are dominant in beds 2 and 3 (57.7-75.5%), their values decline rapidly up through the section (beds 4-7, 21.5-45%) and eventually fall to a very low figure in bed 8 (6.4%), Figure 4.12.

4.3.3.3. Changes in microfossils

4.3.3.3.1. Coarse benthic foraminifera

In this interval, the benthic foraminiferal assemblage undergoes a significant change and shows a progressive decline in the diversity (Figure 4.14). Through the interval 21 species occur for the last time. These species include 2 gavelinellids (*Gavelinella baltica, Gavelinella cenomanica*) 5 nodosariids (*Laevidentalina strangulata, Laevidentalina gracilis, Frondicularia archiaciana, Dentalina* sp. A, *Bullopora laevis*), 5 coiled vaginulinids (*Astacolus* sp. A, *Planularia biochei, Planularia* sp. A, *Saracenaria bronni, Saracenaria jarvisi*), 1 polymorphinid (*Pyrolina* sp. A), 2 textulariids (*Textularia* sp. A, *Textularia* sp. B), 2 verneuilinids (*verneuilinoides* sp. A, *Eggerellina mariae*), 1 alabaminid (*Gyroidinoides* sp. A), 1 eggerellinid (*Dorothia gradata*), 1 hauerinid (*Quinqueloculina antiqua*) and 1 ataxophragmiid (*Ataxophragmium depressum).* Also 3 species occur in a unique sample and include: 1 quadrimorphinid (*Quadrimorphina allomorphinoides*, Plate 7) 1 nodosariid (*Laevidentalina legumen*, Plate 7) and 1 ammodiscid (*Glomospira corona*).

4.3.3.3.2. Coarse planktic foraminifera

In the planktic foraminiferal assemblage, *Whiteinella baltica* appears in bed 2 and *Dicarinella algeriana* in bed 3 (Figure 4.15). *Rotalipora cushmani* occurs for the last time in the middle of bed 4, while *Hedbergella simplex* and *Helvetoglobotruncana praehelvetica* appear for the first time in this bed. *Dicarinella imbricata* occurs for the last time in bed 6 and *Praeglobotruncana stephani* in bed 7.

4.3.3.3.3. Ostracods

This interval also marks a major change in the composition of ostracod assemblage, with a severe drop in diversity, which results from the disappearance of 8 species (Figure 4.16). These species include: *Neocythere kayei, Herrigocythere donzei, Pontocyprella robusta* (all in bed 3), *Pterygocythereis robusta* and *Pterygocythereis laticristata* (both in bed 4), *Pontocyprella hindei* (bed 5), *Bythoceratina umbonatoides* (bed 6) and *Pontocyprella harrisiana* (bed 7). Also 2 species occur in a unique sample and includ: *Habrocythere* sp. A (bed 3) and *Dolocytheridea* sp. A (bed 4).

4.4. Cluster D_W (post Plenus Marls)

4.4.1. Lithology and samples

The thickness of the measured interval is about 200 cm and consists of hard nodular chalk in the lower part and hard chalk with marl seams in the upper part. The button is defined by bed 9 of Jeans *et al.* (1991) and the top by a griotte marl (Meads Marls 5/6), Figure 4.1. Due to difficulties in processing of hard chalks only marls were sampled.

Samples W11-W16 belong to this interval, although sample W11 was not processed.

4.4.2. Stable isotopes

The $\delta^{13}C$ curve is shown in Figure 4.2, where a sudden decrease in the values is apparent. The values oscillate between 3.5‰ and 4.3‰ PDB up to Meads Marls 5/6, but above this level fall even more and range from 3.1 to 3.4‰ PDB.

The $\delta^{18}O$ curve falls to very low values and ranges between -3.5 and -4.2‰ PDB except at the top of the Meads Marls 5/6, which shows a high value (-2.5‰ PDB).

4.4.3. Microfauna

4.4.3.1. Foraminifera

4.4.3.1.1. Absolute abundance of coarse fraction

The total number of benthic and planktic foraminifera are shown in Figure 4.3, where a major decline in abundance of both groups is apparent. The total number of benthic foraminifera ranges between 934 and 1717 specimens per 100 g, while absolute abundance of planktic foraminifera varies from 77 to 591 specimens. Figure 4.4 shows the absolute abundance and percentage of planktic foraminifera. The population of coarse planktic foraminifera is made essentially of hedbergellids - whiteinellids, although compared to previous interval their abundance falls to very lower values (77-591 specimens).

In this interval, percentage of planktic foraminifera is lower than other clusters. The value in the lowest sample is very low (W12, 7.5%), but values increase in the upper part and oscillate between 25.6 and 45.1%.

4.4.3.1.2. Diversity of benthic foraminifera

4.4.3.1.2.1. Simple diversity (species richness)

Compared to other intervals, the species richness values are very low and range between 11 and 16 (Figure 4.5).

4.4.3.1.2.2. Fisher diversity index

Similar to species richness, Fisher diversity values are low and vary from 1.7 to 2.5 (Figure 4.5).

4.4.3.1.2.3. Shannon diversity

Compared to cluster C, the values are low and vary from 1.7 to 1.9 (Figure 4.5).

4.4.3.1.3. Morphotype groups

In this interval, dominant morphotype groups are CH-B4 (19.3-56.6%), AG-C (20.1-48.7%) and CH-B3 (7.2-28.3%), while CH-B2 (0-9.5%) and CH-C1 (0-8.2%) are rare (Figure 4.6).

Among the planktic foraminifera, the non-keeled morphotype is strongly dominant (99.7-100%), while the double-keeled morphotype constitutes extremely low percentages of the assemblage (0-0.3%) and the single-keeled morphotype group is absent (Figure 4.4).

4.4.3.1.4. Coarse fraction species

The dominant species of the cluster are *Gavelinella berthelini* plus *Gavelinella reussi* (19.3-56.5%), *Marssonella trochus* var. *turris* (9.5-36%) and *Lingulogavelinella globosa* (7.2-28.3%). *Gaudryina austinana* (1.5-10.1%), *Lenticulina* spp. (0-9.5%) and *Tritaxia tricarinata* (0.4-7.1%) constitute only minor percentage in the interval, Figures 4.7 - 4.9.

In this cluster, the epifaunal group is very rare (0-0.4%), while the infaunal, semi-infaunal group constitutes the whole assemblage (Figure 4.8).

Among the planktic foraminifera, *Hedbergella delrioensis* is still the dominant species and occupies between 66.8 to 93.5% of the assemblage. *Whiteinella aprica* shows higher values than with previous clusters (0-29.7%).

4.4.3.2. Ostracods

4.4.3.2.1. Total number

In this cluster the total number of ostracods is relatively low and ranges between 144 and 1041 valves per 100 g (Figure 4.10).

4.4.3.2.2. Simple Diversity

Compared to other intervals, the number of species is low and ranges from 10 to 14 (Figure 4.10).

4.4.3.2.3. Species

Cytherella spp. are strongly dominant in the interval and constitute between 80.4 and 94.5% of the assemblage (Figures 4.11 - 4.13). The rest of assemblage is composed of *Bairdoppilata* spp. (0.5-9%), *Mosaeleberis* sp. A (0-6.1%), *Cytherelloidea* spp. (1-5.8%), *Bythoceratina* spp. (0.9-2.7%) and *Pterygocythereis* spp. (0-1.5%).

In this interval, the proportion of podocopids falls to lowest of all the clusters (4.4-17.9%), while platycopids are strongly dominant (Figure 4.12).

4.4.3.3. Changes in microfossils

4.4.3.3.1. Coarse benthic foraminifera

During this interval 7 other species occur for the last time and this causes diversity to fall to low values (11-16), Figure 4.14. Disappead species belong to uncoiled vaginulinids (*Psilocytharella costulata* var. B and *Psilocytharella costulata* var. C), coiled vaginulinids (*Lenticulina* spp.), textulariids (*Textularia chapmani*), hormosinids (*Reophax* sp. A), verneuilinids (*Eggerellina brevis*) and ammodiscids (*Ammodiscus cretaceus*), also 1 nodosariid (*Pseudonodosaria humilis*) occurs in a unique sample. Two new species appear for the first time, which includ a textulariid (*Textularia tricarinata* var. *jongmansi*) and a gavelinellid (*Lingulogavelinella aumalensis*).

4.4.3.3.2. Coarse planktic foraminifera

In the planktic assemblage, 3 new species, *Whiteinella archaeocretacea*, *Whiteinella paradubia* and *Whiteinella inornata* appear for the first time, of which the later two occur in a unique sample (Figure 4.15). Nevertheless at the top, the assemblage is poor and planktic foraminifera are essentially represented by surface-water dwelling species including, *Hedbergella* spp., *Whiteinella* spp. and a few specimens of a double-keeled species, *Dicarinella hagni.*

4.4.3.3.3. Ostracods

In the ostracod assemblage 2 other podocopids, *Isocythereis elongata* and *Cythereis* sp. A, have their last occurrences in this interval. The vacated niches are occupied by 2 other new podocopid species, *Mosaeleberis* sp. A and *Cythereis longaeva* (broken specimens), Figure 4.16.

CHAPTER 5

CHAPTER 5

CENOMANIAN-TURONIAN BOUNDARY AT SOUTH FERRIBY

In this chapter the results from the South Ferriby section (north-east England) will be discussed. The section is very condensed and incomplete, therefore it is difficult to cluster the benthic foraminiferal assemblages, so the results are discussed generally for the whole section as below.

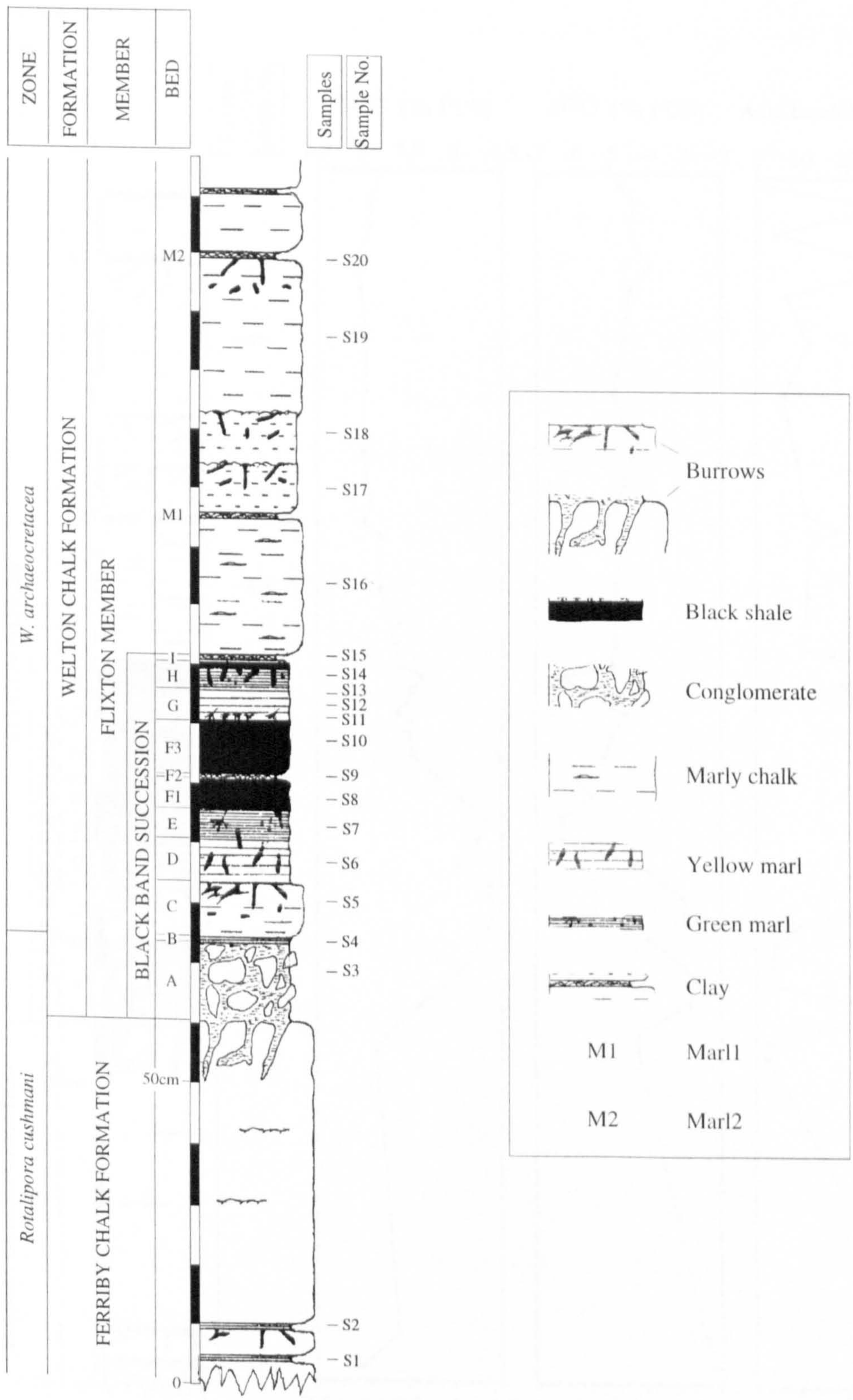
5.1. Lithology and samples

The thickness of the measured interval is about 230 cm and consists of three distinctive units (Figure 5.1). The lower unit is the topmost part of the Ferriby Chalk Formation, consisting of 60 cm very hard chalk and two marl seams. The middle unit, the Black Band succession, consists of about 60 cm of marly-chalk and marl facies with pebbles of conglomerate at the base and finally the upper unit, part of Flixton Member, consists 110 cm of marly chalk facies with marls seams. The interval includes samples S1 to S20, of which the 63-90 μm fraction of samples S2, S5, S6, S8, S9, S12, S13, S15, S16, S17, S19 and S20 has been examined and the coarse fraction (> 250 μm) of all.

5.2. Stable isotopes and acid insoluble residues

Variation in stable isotope values for carbon and oxygen across the Cenomanian-Turonian boundary at South Ferriby is shown in Figure 5.2.

The $\delta^{13}C$ curve begins with a high value in the upper part of the Ferriby Chalk at a base level of 3.0 ‰ PDB. It rapidly rises above the erosion surface at the base of the Welton Chalk Formation to a peak of 4.3 ‰ in the base of bed D. It falls a little in the middle of bed D (4.0‰) and recovers again to a level of 4.3 ‰ at the base of bed F1, where the second peak occurs. Values then decrease rapidly and fall to 3.4‰ in bed F_3. The values in bed G increase to a peak (3.6 ‰) in bed H, but drop (3.3‰)



Figur 5.1. Lithostratigraphy of the upper Cenomanian - Lower Turonian at South Ferriby.

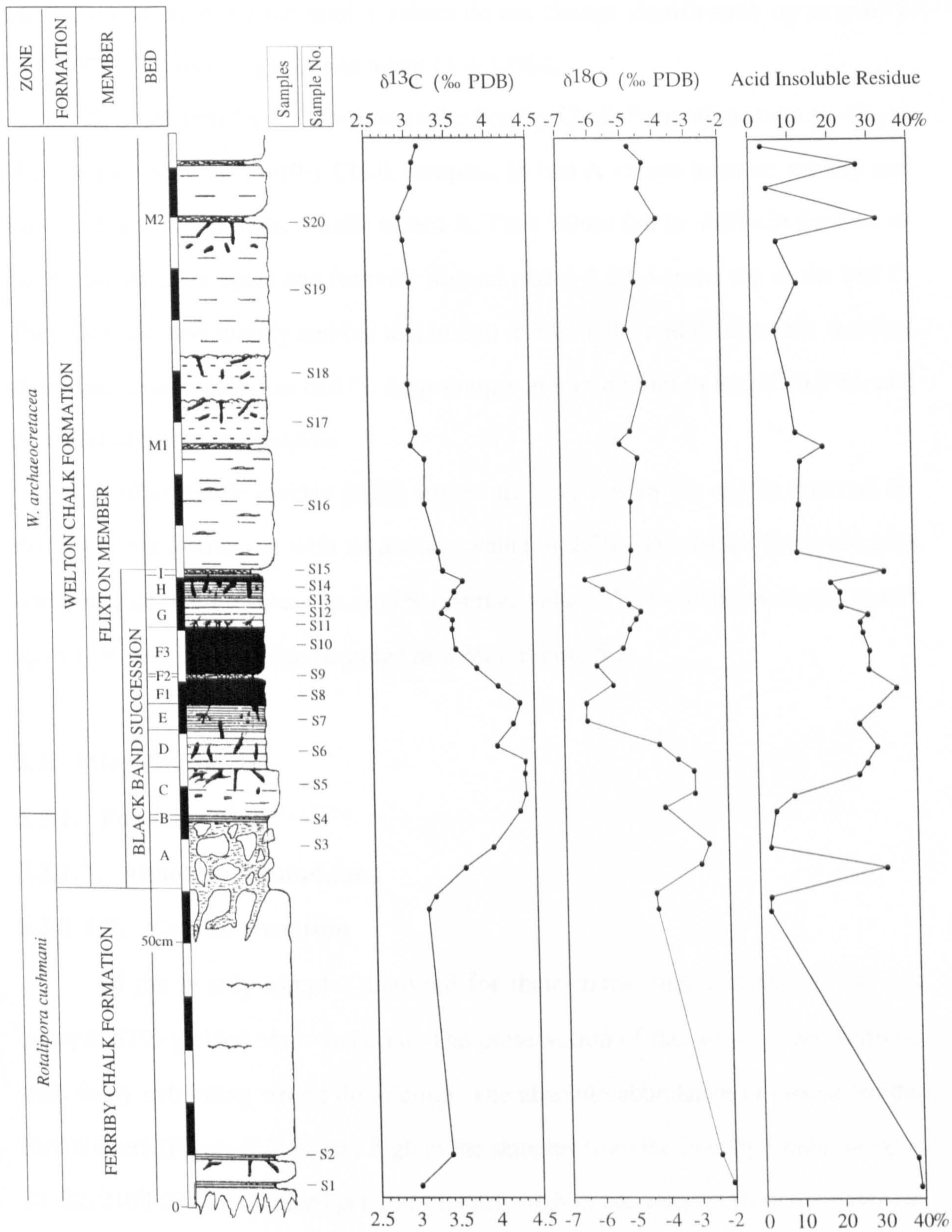


Figure 5.2. Stable isotope curves for carbon and oxygen across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

again in bed I. Then they decline and fall to a trough (3.0‰) in marl 1. This level might be regarded as the end of recovery phase in the carbon excursion. In the Welton Chalk Formation above the marl 1 values do not change significantly up to marl 2 (2.9-3.0‰), but then begin to rise again (3.0-3.1‰).

At South Ferriby $\delta^{18}O$ values in the Ferriby Chalk Formation starts at -2‰ to -4.2‰ in the topmost Ferriby Chalk samples. In bed A values increase rapidly and form a peak (-2.5‰) in the middle of bed A. Then values fall to -3.8‰ in the base of bed C, but increase again and form the second peak (-2.9‰) at the top of the bed C. They then decrease sharply and fall to a trough -6.3‰ in the middle of bed E, increase to another peak (-4.5‰) in bed G, drop sharply at a minimum in bed H (6.3%), and thereafter oscillate about -4.6‰

Acid insoluble residue (AIR) values are very low in the chalky parts of the Ferriby Chalk Formation with an average value of 2.5%. The Black Band contains acid insoluble residue values up to 37% (average value, 25%) and the overlying chalks up to 12% insoluble residue (average of 8.3%), Figure 5.2.

5.3. Microfauna

5.3.1. Foraminifera

5.3.1.1. Absolute abundance

5.3.1.1.1. Coarse fraction

Of the twenty samples analysed for their coarse microfossils, all but one (sample S10) yielded some material. The preservation of the tests is very variable, with many exhibiting strong dissolution. The absolute abundance of coarse benthic foraminifera (Figure 5.3) is very high in the samples from the Ferriby Chalk (samples S1-S2, 2100-2247 specimens per 100 g), fairly high in the samples from the basal part of the Black Band succession (samples S3-S7, 60-721 specimens per 100 g). It falls to extremely low values in the upper part of the Black Band succession (samples S8-S15, 0-38 specimens per 100 g) before recovering in the Flixton Member above the Black Band succession (samples S16-S20, 136-461 specimens per 100 g). The major

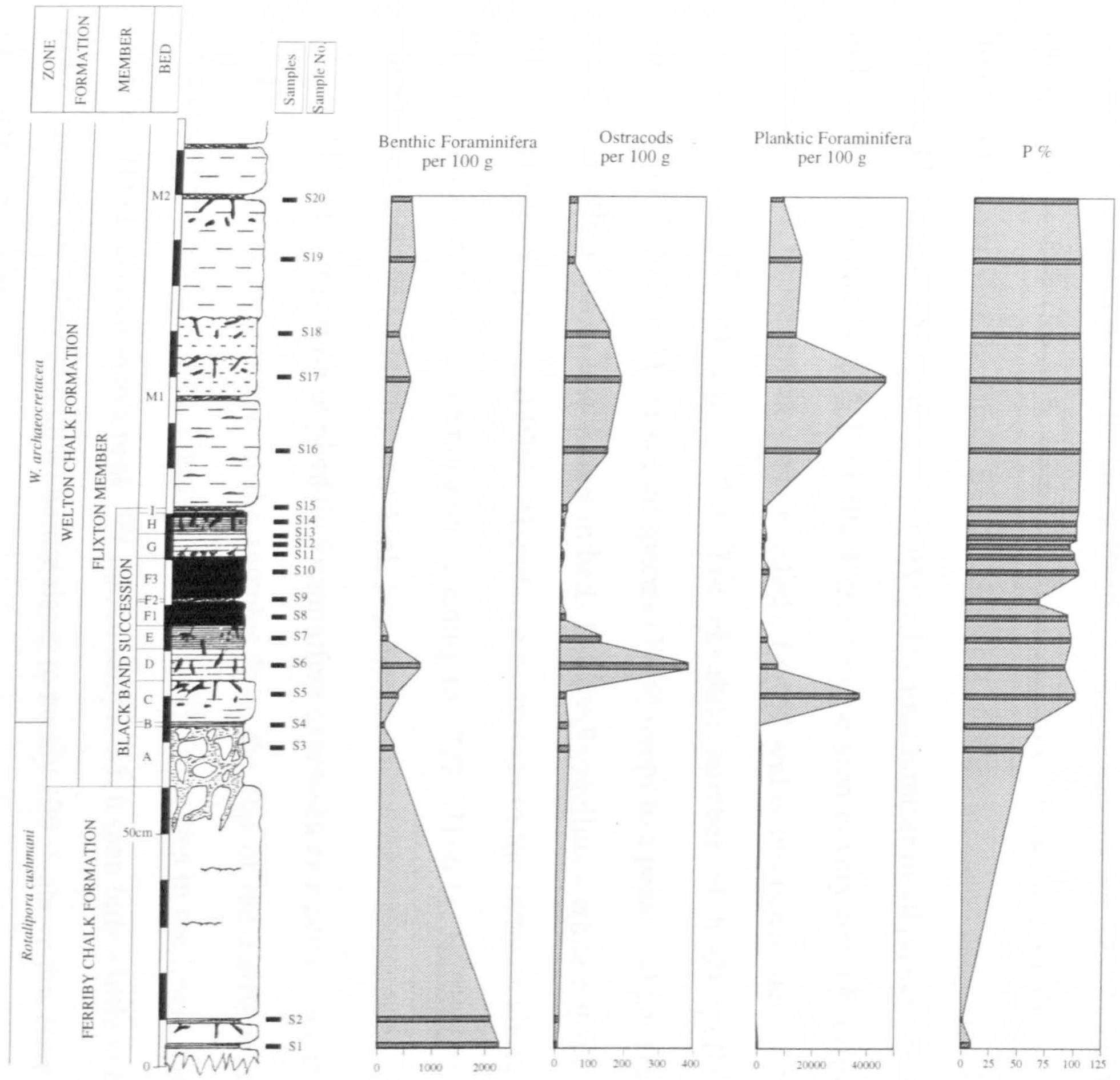


Figure 5.3. Absolute number of coarse benthic and planktic foraminifera and ostracods and P% across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

decline in the absolute numbers of the benthic foraminifera corresponds mainly to the interval during which black shales were deposited.

The absolute abundance of coarse planktic foraminifera also varies considerably throughout the succession (Figure 5.3). The number of specimens from the Ferriby Chalk Formation and lower part of Black Band succession (bed A-B) is low (S1-S4, 26-295 specimens per 100 g). It jumps to a peak of abundance in the limestone in the lower part of the Black Band succession (sample S5, 35922), but falls again in beds D-I (S6-S15, 60-6123). The absolute abundance in the chalks immediately overlying the Black Band (samples S16-S20) increases again, reaching between 4751 and 43558 specimens per 100 g. The total number of all planktic species in Ferriby Chalk and beds A-B of Black Band succession is very low (*Rotalipora cushmani*, 0-12, hedbergellids - whiteinellids, 18-152 and twin-keeled species, 0-88 specimens per 100 g), Figure 5.4. The absolute number of hedbergellids - whiteinellids (21842) and twin-keeled species (3956) jumps to a peak of abundance in bed C, but falls again to low values in beds D-I (hedbergellids - whiteinellids, 16-4314, twin-keeled species, 0-978). Abundance of species in the samples above the Black Band succession recovers again, reaching to 1222-27166 for hedbergellids - whiteinellids and 1654-7248 for twin-keeled species.

P % (the proportion of planktic foraminifera expressed as a percentage of the total assemblage) is very low in the samples from the top of the Ferriby Chalk Formation (S1-S2, 1.2-9.0%), Figure 5.4. P % rapidly increases in the lower part of the Black Band succession to a peak (99.1%) in sample S5, it then falls a little in beds D-F2 (samples S6-S9, 65.9-94.8%) before rising to nearly 100 % above this (samples S10 - S20, 92.1-100%).

5.3.1.1.2. Fine fraction

Absolute number of fine benthic foraminifera in Ferriby Chalk Formation (S2) and bed C (S5) is relatively high and varies between 39928 and 40320 specimens per 100 g (Figure 5.5). It jumps to a peak in bed D (S6, 100408), but falls to a very low

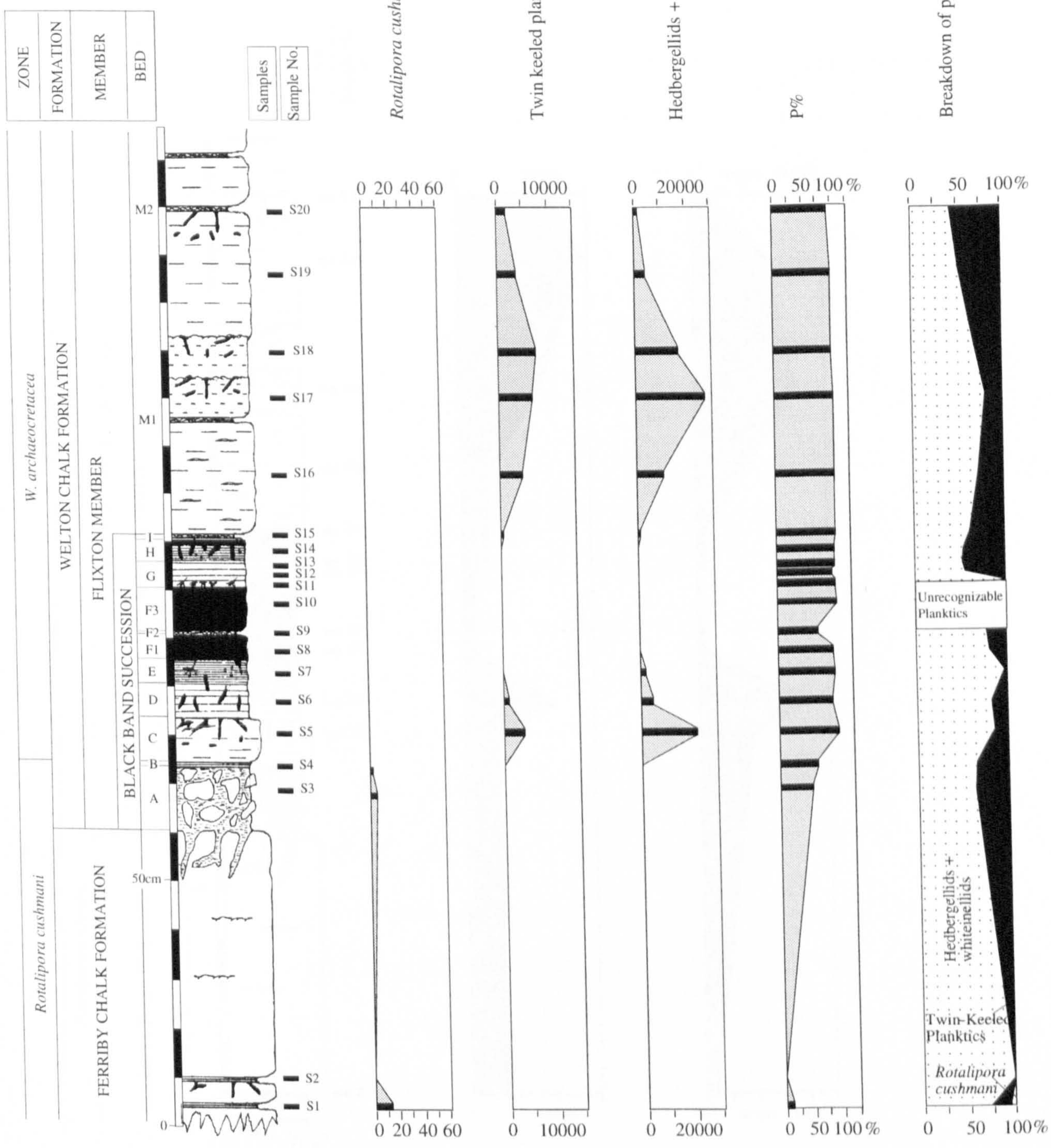


Figure 5.4. Absolute abundance, P% and breakdown of coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

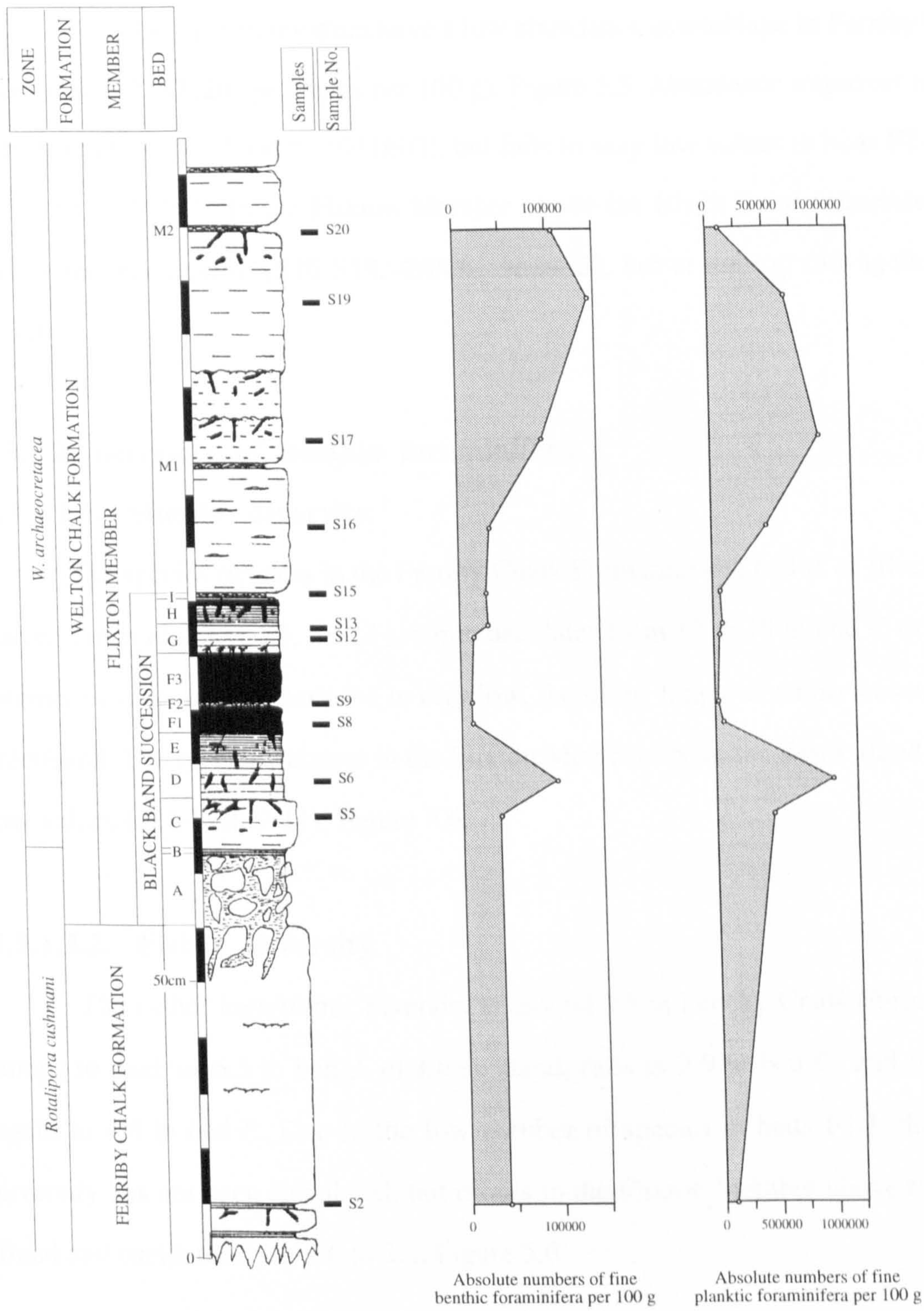


Figure 5.5. Absolute abundance of fine benthic and planktic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

value in bed F1 (S8, 10534) and remains low up to middle of bed G (S9-S12, 9918 13392). Values from the top of bed G recover rapidly and oscillate between 29003 and 143298.

Fine planktic foraminifera have a low abundance assemblage in Ferriby Chalk Formation (S2, 80220 specimens per 100 g), Figure 5.5. Abundance improves rapidly in beds C-D (S5-S6, 503440-1011603), but falls to very low values in beds F1-I (S8-S15, 15312-71280). In the Flixton Member above the Black Band succession, the values recover rapidly (S16-S19, 490061 962483), but at the top fall again (S20, 105264).

5.3.1.2. Diversity of benthic foraminifera

5.3.1.2.1. Simple diversity

The species richness in the Ferriby Chalk Formation and bed A of Black Band succession is high (S1-S3, 21-23), while oscillates from 12 to 18 in bed C to E. The number of specimens in beds F-I is very low, therefore simple diversity has not been calculated. The species richness in the Flixton Member above the Black Band falls to low values (S16-S20, 9-11), Figure 5.6.

5.3.1.2.2. Fisher diversity

The Fisher logarithmic diversity is around 3.5 in Ferriby Chalk Formation, it jumps to peak of 6.5 in bed A of Black Band, falls to 2.9 in bed C, and increases again to 4.6 in bed E. Due to the low number of species in beds F1-I, the Fisher diversity has not been calculated, but it falls in the Flixton Member above the Black Band and oscillates from 1.6 to 2.8, Figure 5.6.

5.3.1.2.3. Shannon diversity

The Shannon heterogeneity index in the Ferriby Chalk Formation and bed A of Black Band succession is high (S1-S3, 2.3-2.6), but falls in beds C-E of Black Band

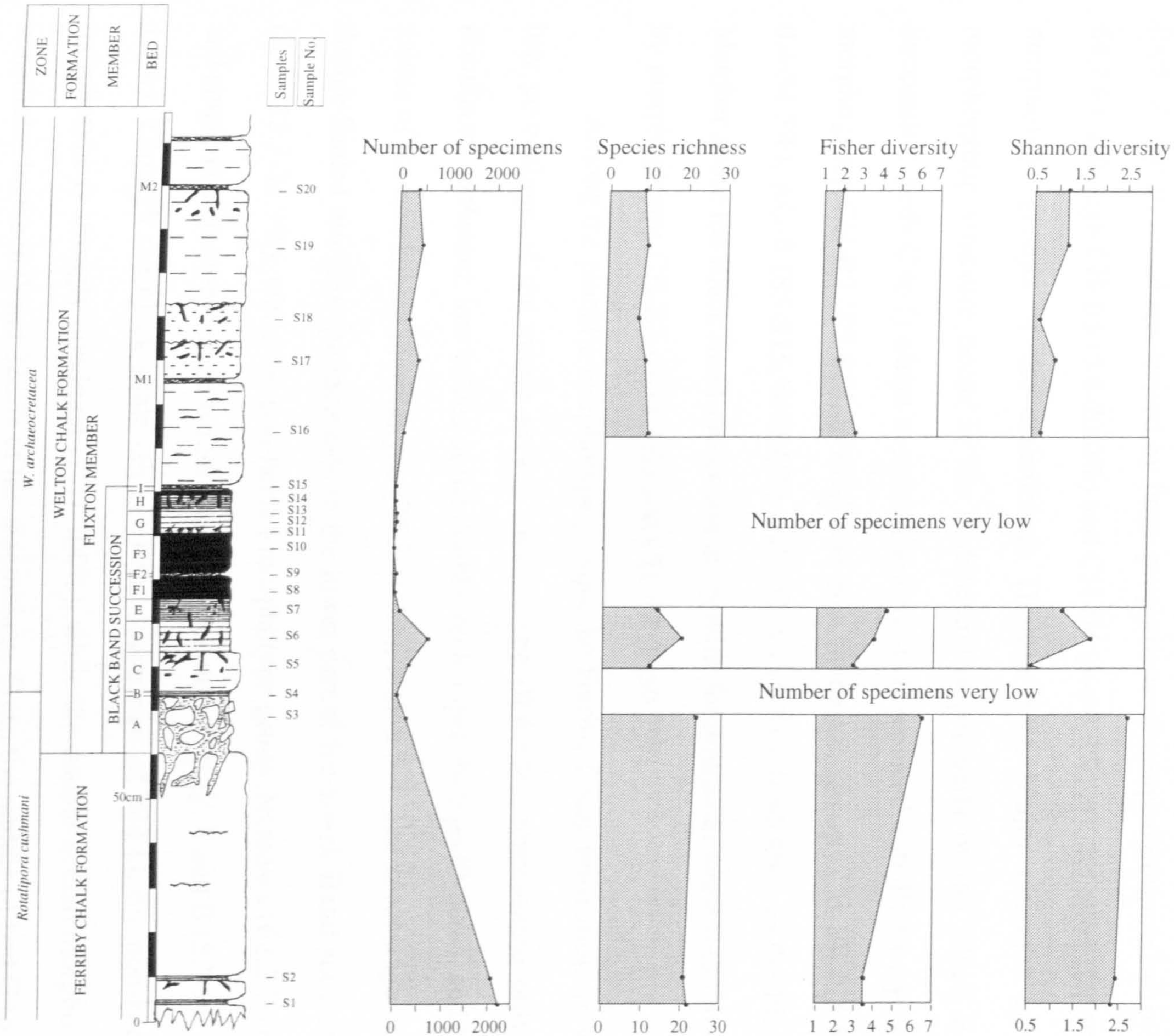


Figure 5.6. Number of specimens and benthic foraminifera diversity curves across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

succession and the overlying marl seams in the hard chalk of the Flixton Member, where it oscillates between 0.5 and 1.8, Figure 5.6.

5.3.1.3. Morphotype groups

The Ferriby Chalk Formation and the basal part of the Black Band succession (beds A and B) are characterised by large proportions of morphogroup AG-C (45.3-64.7%), although CH-B3 (5.6-20.0%) and CH-B4 (4.4-9.8%) are the other important morphotype groups of the assemblage (Figure 5.7). Major changes in the morphogroup structure occur in the middle and upper parts of the Black Band Succession (beds C to I) where morphogroup AG-C is replaced initially by a peak of morphogroup CH-B2 (S5-S15, 0-95%) and then by morphogroups CH-B4 (S5-S15, 0.4-54.5%), AG-B (S5-S15, 0-41.6%) and AG-A (S5-S15, 0-45.4%). In the Flixton Member above the Black Band succession the benthic foraminiferal fauna is dominated by morphogroups CH-B2 (0-73.3%) and CH-B4 (9-59.2%).

Among the planktic morphotype groups, the Ferriby Chalk Formation shows a low percentage of the single keeled morphotype (0-6.6%), represented only by *Rotalipora cushmani*, low values of the double-keeled morphotype (0-20%), and high values of the non keeled morphotype (73.3-100%), Figure 5.4. The percentage of the double keeled morphotype increases in the lower part of the Black Band succession (A-D, 15.3-35,9%), while the non-keeled morphotype group decreases (62.2-84.6%) and single-keeled morphotype is rare and restricted only to beds A and B (S3-S4, 1.3-1.7%). Through the black shale (F_1 - F_3) and lower part of bed G, the non-keeled morphotype is strongly dominant (77.7-100%), while the double-keeled morphotype constitutes between 0 and 22.2% of the assemblage. From the middle of bed G to bed I and Flixton Member above the Black Band succession, the proportion of the double-keeled morphotype increases again (19.5-57.5%), while the proportion of the non-keeled morphotype ranges between 42.4 and 80.4%.

5.3.1.4. Species

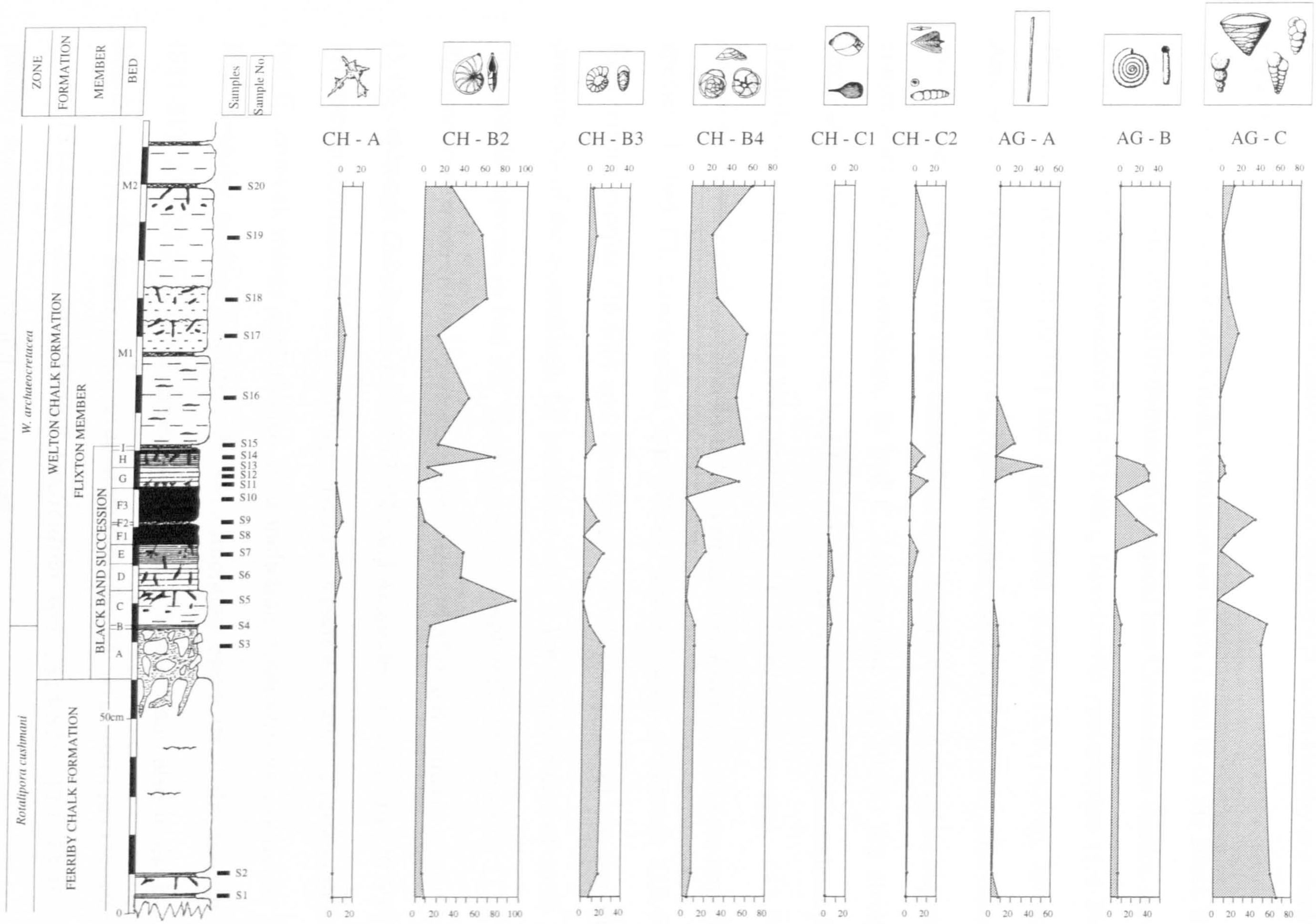


Figure 5.7. Variation in percentage of important morphotype groups across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

5.3.1.4.1. Coarse fraction

Variation in percentage and comulative diagram of important coarse benthic foraminifera across the Cenomanian-Turonian boundary at South Ferriby are shown in Figures 5.8 - 5.9.

The top of the Ferriby Chalk Formation and beds A and B of the Black Band succession are characterised by dominance of typical late Cenomanian benthic species including: *Tritaxia pyramidata* (7.4-32.4%), *Gavelinella cenomanica* (1.4-20%), *Plectina cenomana* (0-10.3%) and *Eggerellina mariae* (5.9-14.4%), although *Ammodiscus cretaceus* (6.4-7.6%), *Hyperammina gaultina* (1.6-7.3%), *Marssonella trochus* var. *turris* (0.4-19.7%), *Lenticulina* spp. (6.7-12.6%) are the other important constituents of the assemblage. In bed C, *Lenticulina* spp. (95%) are strongly dominant in the assemblage. In bed D *Lenticulina* spp. (41.2%) accompanied by *Textularia chapmani* (19.3%) and in bed E, *Lenticulina* spp. (43.5%), *Lingulogavelinella globosa* (19.3%) and *Gavelinella berthelini* (19.3%) are important species. In bed F1, *Lenticulina* spp. (25%), *Ammodiscus cretaceus* (16.6%), *Eggerellina mariae* (16.6%) and *Gavelinella berthelini* (16.6%) are important constituents of the assemblage. Of particular note is the reappearance of some late Cenomanian species in bed F2. These include: *Gavelinella cenomanica* (13.7%), *Plectina cenomana* (6.8%), *Tritaxia tricarinata*, (6.8%) and *Tritaxia pyramidata* (3.4%), although *Gavelinella reussi* (13.7%) and *Ammodiscus cretaceus* (20.6%) are the other constituents of the assemblage. Bed F3 is barren of benthic foraminifera. In bed G, non-calcareous agglutinated taxa including *Ammodiscus cretaceus* plus *Hyperammina gaultina* constitute the most important elements of the assemblage, (S11-S13, 33.3-72,7%). In the upper part of bed H to bed I and also in the Flixton Member above the Black Band succession, *Gavelinella berthelini* plus *Gavelinella reussi* (S14-S20, 20.8-59.2%) and *Lenticulina* spp. (S14-S20, 17.6-73.3%) are strongly dominant species of the assemblage.

In the planktic Foraminiferal assemblage, the Ferriby Chalk shows a high values of *Whiteinella brittonensis* (13.3-100%), *Hedbergella delrioensis* (0-26.6),

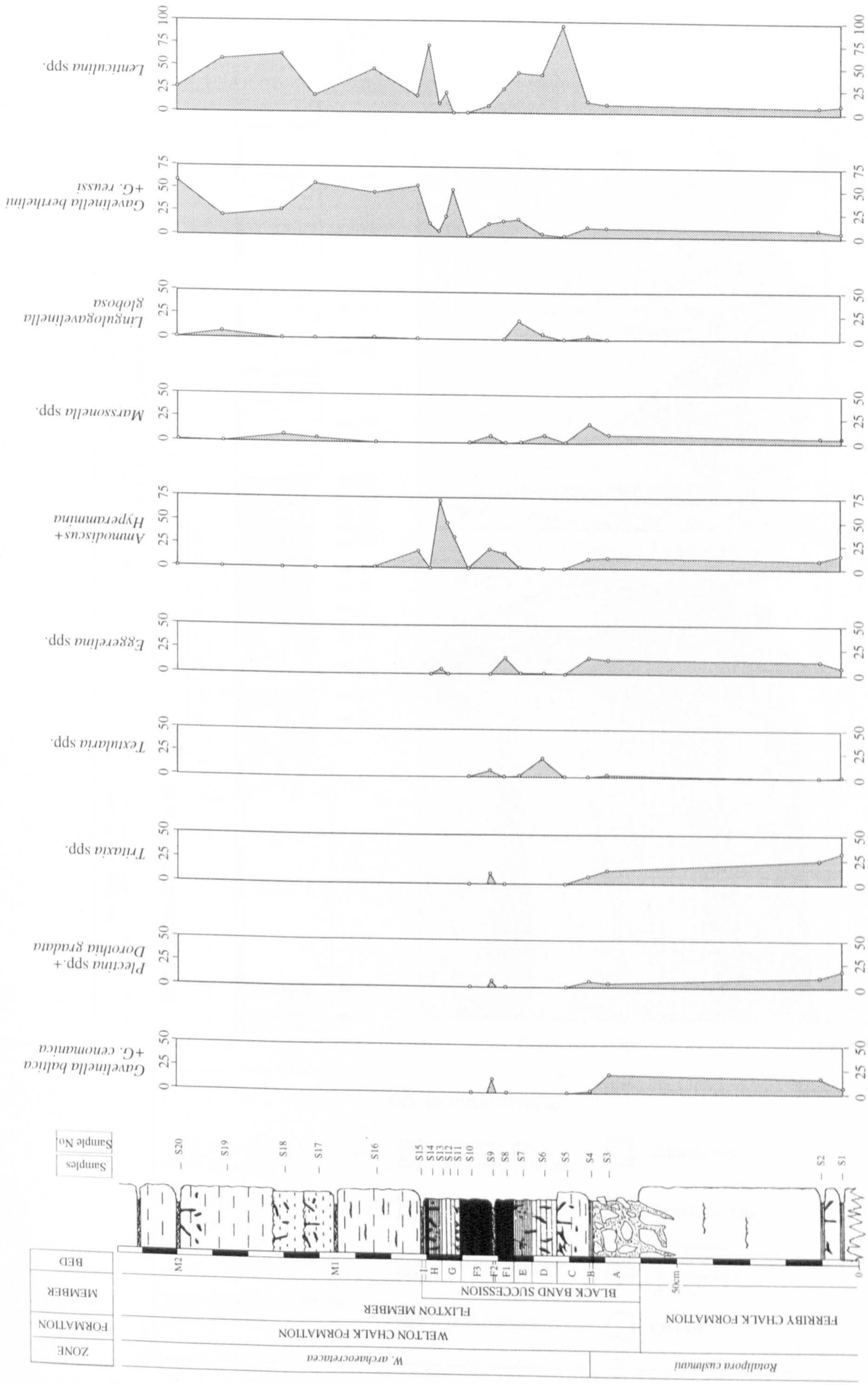


Figure 5.8. Variation in percentage of important coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

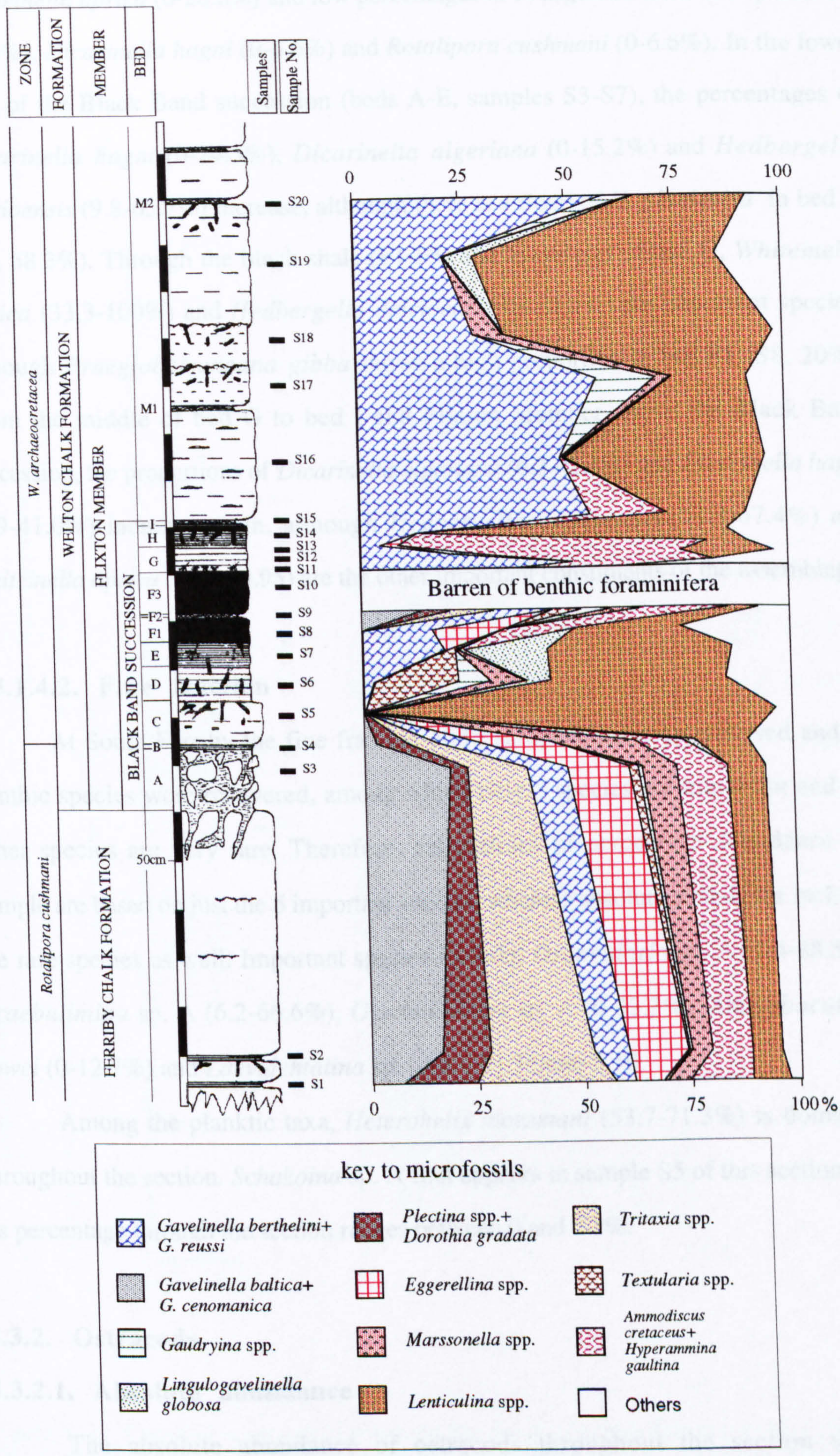


Figure 5.9. Comulative percent of dominant coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

Whiteinella aprica (0-26.6%) and low percentages of *Praeglobotruncana stephani* (0-13.3%), *Dicarinella hagni* (0-6.6%) and *Rotalipora cushmani* (0-6.6%). In the lower part of the Black Band succession (beds A-E, samples S3-S7), the percentages of *Dicarinella hagni* (0-24.5%), *Dicarinella algeriana* (0-15.2%) and *Hedbergella delrioensis* (9.8-65.7%) increase, although there is a flood of *H. planispira* in bed D (S6, 58.3%). Through the black shale (F1-F3) and lower part of bed G, *Whiteinella aprica* (33.3-100%) and *Hedbergella delrioensis* (0-33.3%) are important species, although *Praeglobotruncana gibba* shows a high proportion in bed F1 (S8, 20%). From the middle of bed G to bed I and Flixton Member above the Black Band succession, the proportions of *Dicarinella algeriana* (6.3-41.3%) and *Dicarinella hagni* (1.9-41.0%) increase again, although *Hedbergella delrioensis* (11.9-67.4%) and *Whiteinella aprica* (11.7-39.95) are the other important constituents of the assemblage.

5.3.1.4.2. Fine fraction

At South Ferriby the fine fraction of 12 samples has been analysed and 14 benthic species were recovered, among which only 5 species are important and the other species are very rare. Therefore, calculations of percentage abundance per sample are based on just the 5 important species, whereas absolute abundance includes the rare species as well. Important species include; *Osangularia* sp. A (7.4-88.5%), *Praebulimina* sp. A (6.2-66.6%), *Gyroidinoides* sp. A (0-33.3%), *Ammobaculites rowei* (0-12.7%) and *Laevidentalina* sp. (0-8.6%), Figure 5.10.

Among the planktic taxa, *Heterohelix moremani* (53.7-71.3%) is dominant throughout the section. *Schakoina* sp. A first appears in sample S5 of this section and its percentage through the section ranges between 0 and 5.1%.

5.3.2. Ostracods

5.3.2.1. Absolute abundance

The absolute abundance of ostracods throughout the section varies significantly. Ostracods are rare throughout the top of the Ferriby Chalk and basal part

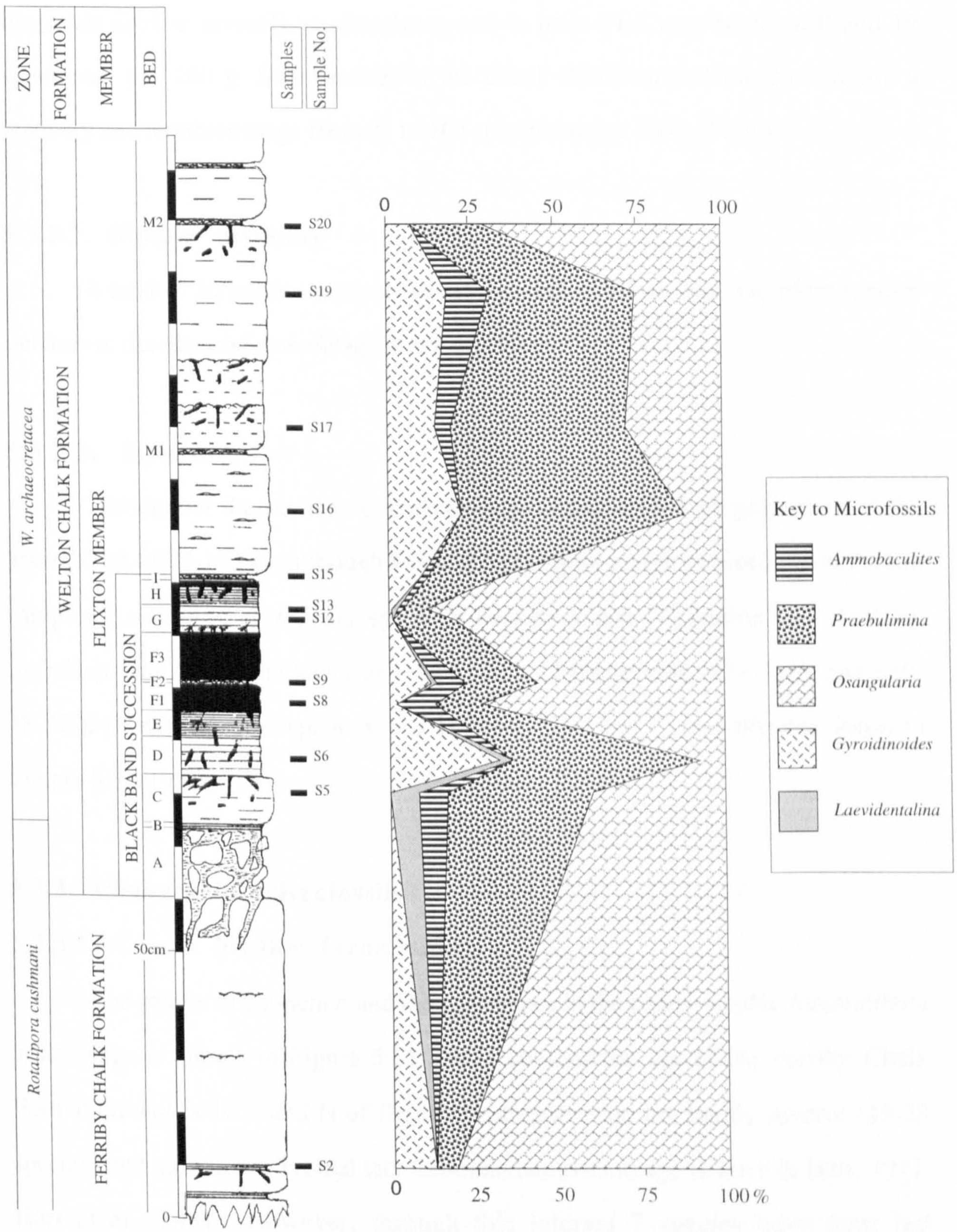


Figure 5.10. Cumulative percent of dominant fine benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to sumbols on graphic log.

of the Black Band succession (samples S1-S5, 9-30 valve per 100 g). A peak of abundance occurs in bed D (S6, 375), but numbers fall in bed E (S7, 121). Above this ostracods decline severely in abundance and in beds F1-I vary between 0 and 18 specimens per 100 g. Samples above the Black Band succession show again a recovery and numbers range from 21 to 165 specimens per 100 g, Figure 5.3.

5.3.2.2. Simple diversity

A total of 10 species was recovered throughout the section, therefore species richness in the ostracod assemblage is not important.

5.3.2.3. Species

Throughout the section, *Cytherella* spp. constitute a high proportion of the assemblage (42.8-100%), although some species show a high proportions in certain samples, including: *Cythereis* sp. A in Ferriby Chalk Formation (S1, 16.6%), *Bairdoppilata* spp. in the lower and upper parts of the section (S2-33.3% and S19-38.8%), *Cornicythereis* sp. A in bed H (S14, 25%) and *Cytherelloidea kayei* in sample S19 (19%).

5.3.3. Changes in microfossils

5.3.3.1. Coarse benthic foraminifera

The pattern of extinction and the appearance in the coarse benthic foraminiferal assemblage is shown in Figure 5.11. As is obvious the top of the Ferriby Chalk Formation and beds A and B of Black Band succession are highly diverse (19-23 species) and comprise a typical late Cenomanian assemblage (Carter & Hart, 1977; Hart *et al.*, 1981). However, through this interval 7 species have their last occurrences, including: 2 ataxophragmiids (*Arenobulimina pseudalbiana* and *Arenobulimina advena*), 1 gavelinellid (*Gavelinella baltica*), 2 eggerellids (*Plectina mariae*, *Dorothia gradata*), 1 verneuilinoides (*Eggerellina brevis*), 1 spiroplectamminids (*Spiroplectammina praelonga*) and 5 species occur in a unique

sample, which include: 2 ataxophragmiids (*Arenobulimina elongata, Arenobulimina bulleta*), 1 tritaxiid (*Tritaxia macfadyeni*) 1 coiled vaginulinid (*Planularia* sp. A) and 1 eggerellid (*Marssonella trochus* var. *oxycona*). Bed C is characterised by no last occurrences in the benthic assemblage, while 1 verneuilinid (*Gaudryina stephensoni*), 1 coiled vaginulinid (*Psilocytharella costulata* var. C), 1 quadrimorphinid (*Quadrimorphina allomorphinoides*) and 2 nodosariids (*Frondovaginulina inversa, Frondicularia archiaciana*) appear for the first time although, 1 nodosariid (*Pseudonodosaria humilis*) occurs only in this bed.

A marked decline in the diversity of the benthic foraminiferal community occurs in bed D, where 5 other species have their last occurrences. These species belong to coiled vaginulinids (*Saracenaria jarvisi, Psilocytharella costulata* var. C) polymorphinids (*Globulina prisca*), quadrimorphinids (*Quadrimorphina allomorphinoides*) and nodosariids (*Frondovaginulina inversa*), although 1 alabaminid (*Gyroidinoides* sp. A) and 1 coiled vaginulinid (*Saracenaria bronni*) appear only in this bed. From beds E to I, the population of benthic foraminifera shows progressive last occurrences, when 12 other species occur for the last time. The disappearing species include: 2 textulariids (*Textularia chapmani, Textularia* sp. B), 1 nodosariid (*Frondicularia gaultina*), 1 coiled vaginulinid (*Planularia biochei*), 1 gavelinellid (*Gavelinella* sp.), 1 verneuilinid (*Eggerellina mariae*), 1 polymorphinid (*Oolina globosa*), 1 hippocerepinid (*Hyperammina gaultina*), 2 tritaxiids (*Tritaxia tricarinata, Tritaxia pyramidata*), 1 gavelinellid (*Gavelinella cenomanica*) and 1 eggerellid (*Plectina cenomana*), although 1 ammodiscid (*Glomospira corona*) and 1 nodosariid (*Frondicularia lanceola*, Plate 8) occur in a unique sample. During this interval, origination of only 1 gavelinellid (*Lingulogavelinella aumalensis*) occurs.

Of particular interest at this interval is the re-appearance of some late Cenomanian fauna in bed F2, where 2 tritaxiids (*Tritaxia tricarinata* and *Tritaxia pyramidata*), 1 gavelinellid (*Gavelinella cenomanica*), 1 eggerellinid (*Plectina cenomana*), which had disappeared temporarily in beds A and B, appear again.

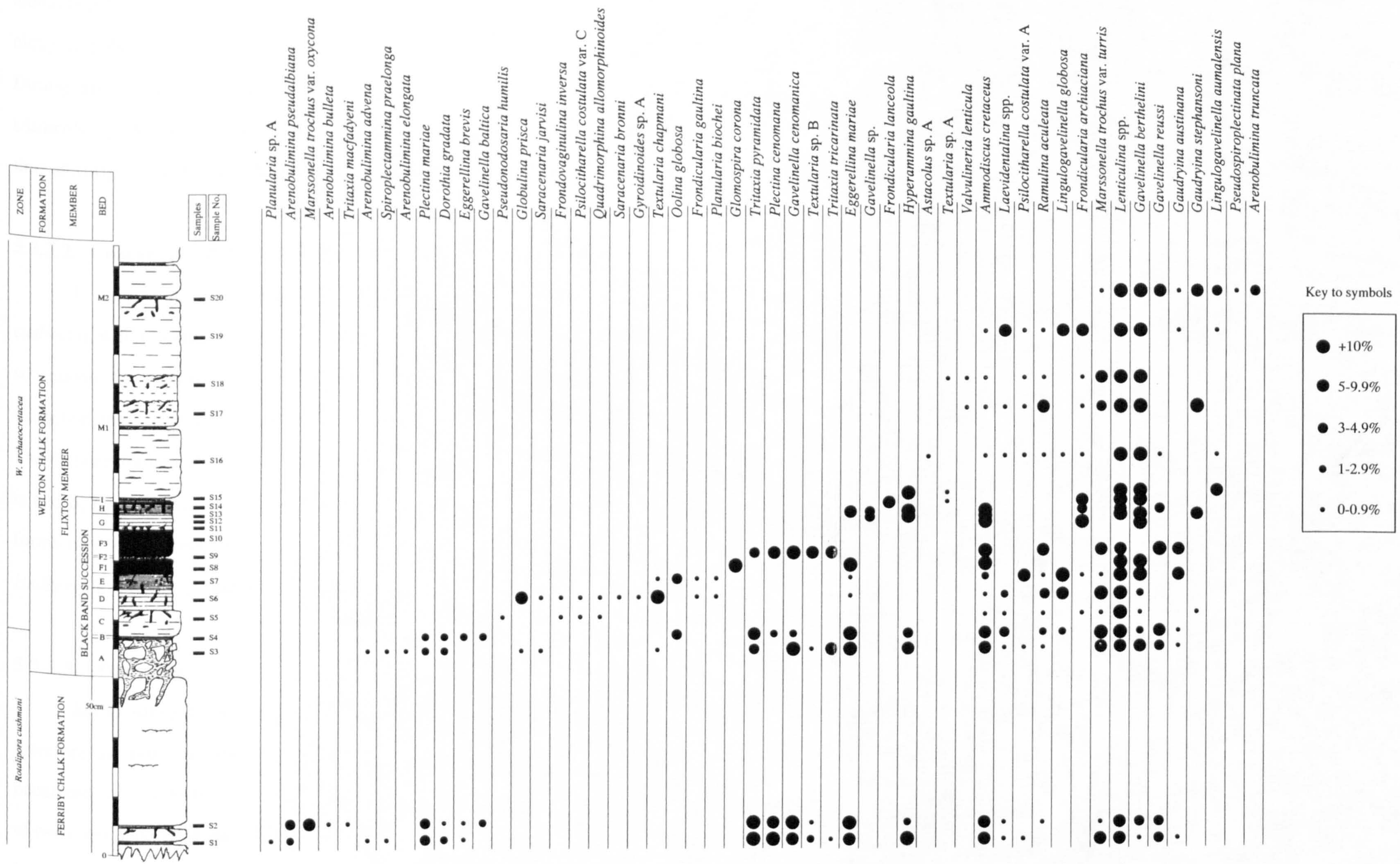


Figure 5.11. Distribution of coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

Through the Flixton Member above the Black Band succession 8 other species occur for the last time (6 species in sample S19 alone, which might be due to sampling). These species include: 2 nodosariids (*Laevidentalina* sp., *Frondicularia archiaciana*), 2 coiled vaginulinids (*Lenticulina* sp., *Psilocytharella* var. A), 1 ammodiscid (*Ammodiscus cretaceus*), 1 gavelinellid (*Lingulogavelinella globosa*), 1 elongate polymorphinid (*Ramulina aculeata*) and 1 textulariid (*Textularia* sp. A). During this interval, 1 bagginid (*Valvulineria lenticula*, Plate 9), 1 coiled vaginulinid (*Astacolus* sp. A) and 1 verneuilinid (*Pseudospiroplectinata plana*) appear for the first time and origination of 1 ataxophragmiid (*Arenobulimina truncata*) occurs.

5.3.3.2. Coarse planktic foraminifera

In the planktic assemblage, rotaliporids, are represented only by *Rotalipora cushmani*, which occurs in Ferriby Chalk Formation and beds A and B of Black Band succession. This species occurs for the last time at the top of bed B. Apart from this extinction, the appearance of new species is more significant than their disappearance. The first occurrences of *Helvetoglobotruncana praehelvetica* and *Dicarinella algeriana* in bed B, *Dicarinella imbricata* in bed D, *Praeglobotruncana gibba* in bed F_1, early forms of *Marginotruncana renzi* in bed G, *Whiteinella archaeocretacea* and *Hedbergella simplex* in bed H can be mentioned (Figure 5.12).

5.3.3.3. Ostracods

In the ostracod assemblage, totalling 10 species occur throughout the section, therefore the last occurrences of species are less prominent. Except for the last occurrence of a podocopid species (*Cythereis* sp. A) in bed A and unique occurrences of two other podocopid species (*Isocythereis elongata* and *Bythoceratina umbonata*) in bed D, the other species more or less are present in all the samples. Throughout the section, only one podocopid species, *Cornicythereis* sp. A, appears in bed C and is present up through the section (Figure 5.13).

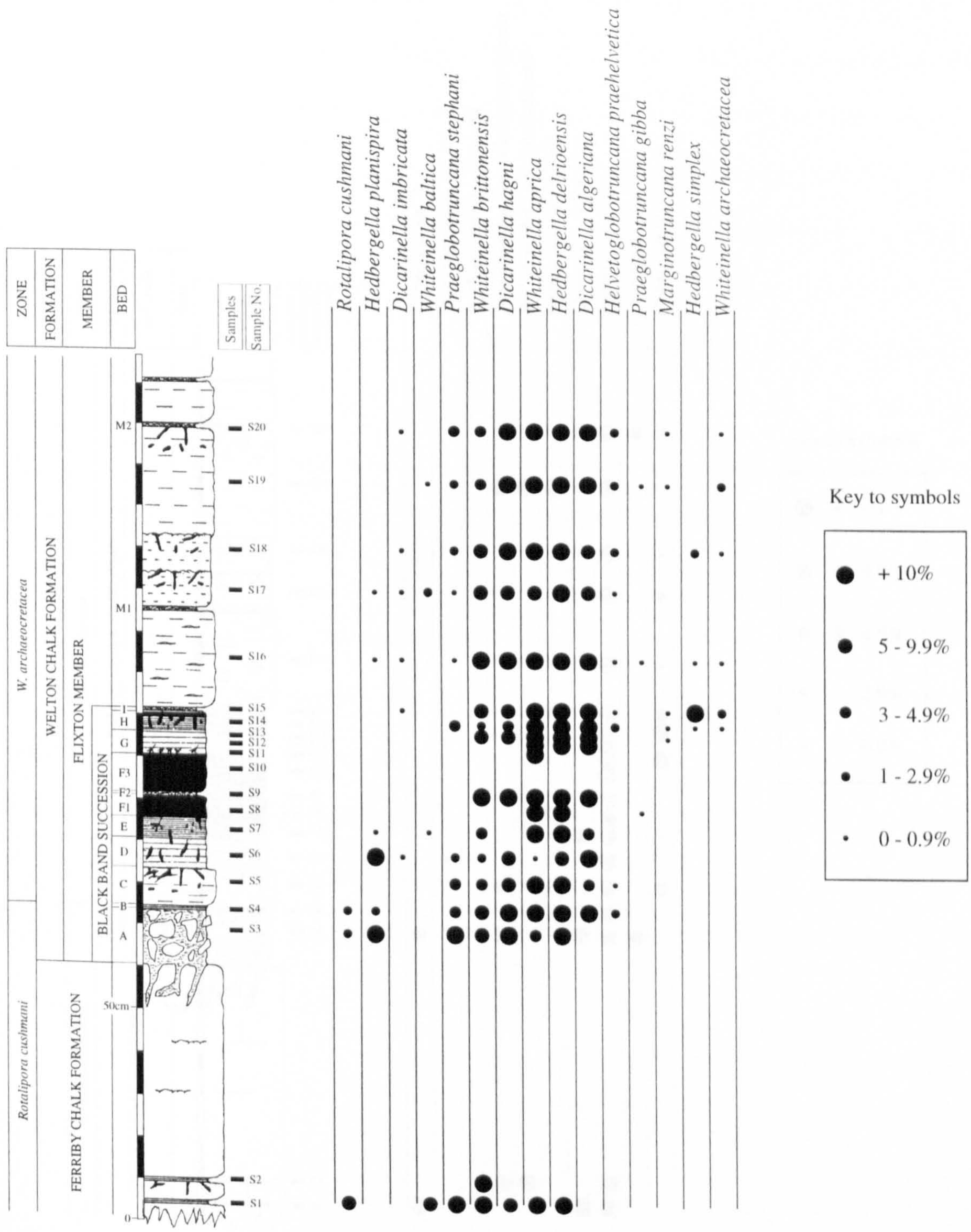


Figure 5.12. Distribution of coarse planktic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

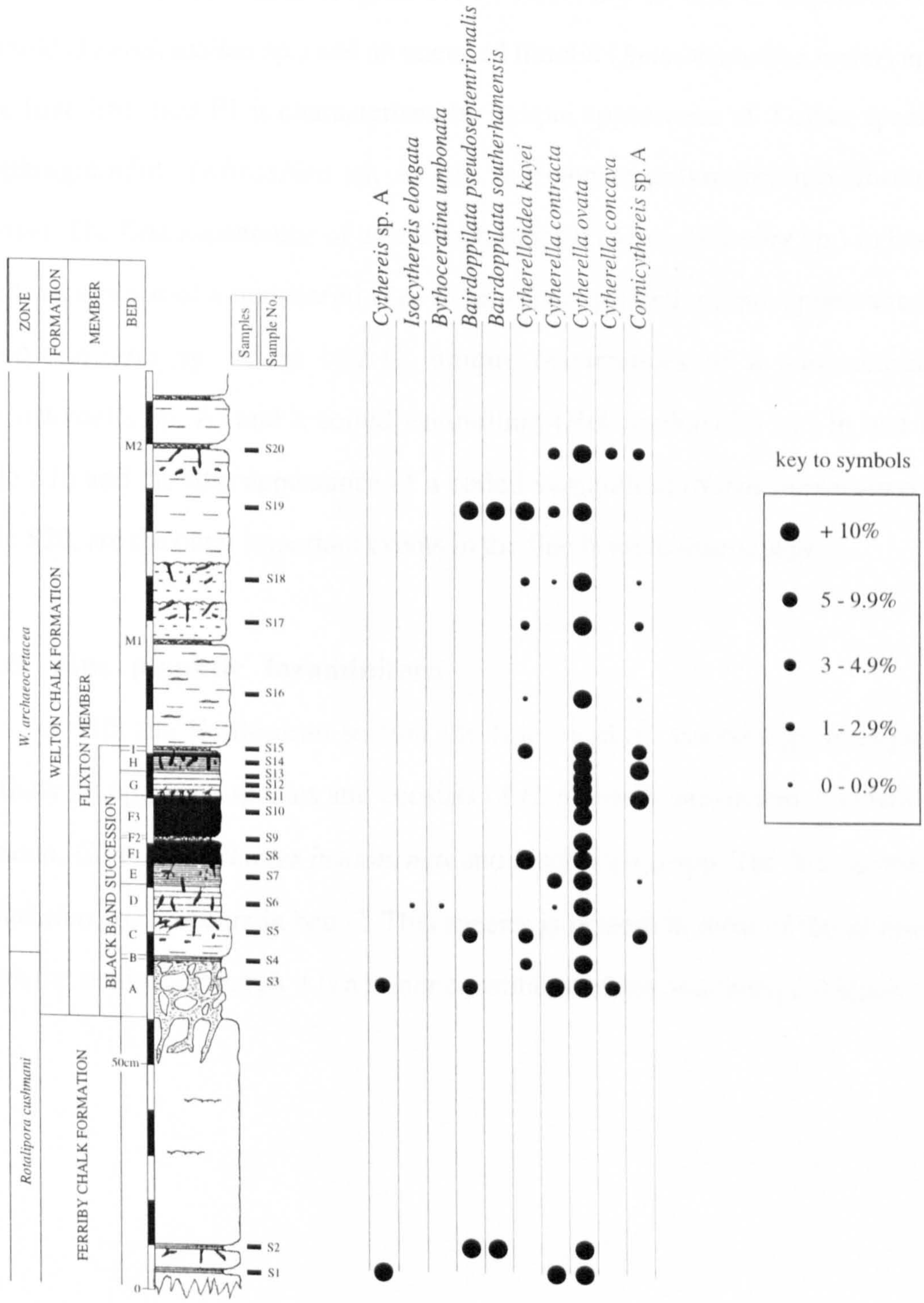


Figure 5.13. Distribution of ostracods across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

5.3.3.4. Fine benthic foraminifera

In the Ferriby Chalk, diversity of fine benthics is poor and only an osangulariid (*Osangularia* sp. A), an alabaminid (*Gyroidinoides* sp. A) and a buliminid (*Praebulimina* sp. A) occur (Figure 5.14). Diversity in bed C improves and a nodosariid (*Laevidentalina* sp.) and an uncoiled lituolid (*Ammobaculites rowei*) appear for the first time. Bed F1 is characterised by unique appearance of 2 other species, a haplophragmoidid (*Labrospira* sp. A) and an elongate polymorphinid (*Ramulina aculeata*). The first appearance of an ataxophragmiid (*Arenobulimina* sp.) in bed F2, the last occurrence of a nodosariid (*Laevidentalina* sp.) and unique appearance of a laginid (*Lagena* sp. A) in bed G, unique occurrences of a pleurostomellid (*Pleurostomella* sp. A) and a coiled vaginulinid (*Psilocytharella* sp.) in bed I and sample S16 and the first appearance of a coiled vaginulinid (*Saracenaria jarvisi*) in sample S20, are the other important events in the fine benthic assemblage.

5.3.3.5. Fine planktic foraminifera

As with the Eastbourne section the fine planktic assemblage is populated essentially by epiplagic species and consists of *Heterohelix moremani*, *Guembelitria cenomana*, *Globigerinelloides bentonensis* and *Hedbergella* spp. The first appearance of *Schakoina* sp. A occurs in bed C. This species is present in most of the samples up through the section, although it is a minor constituent of the assemblage (Figure 5.14).

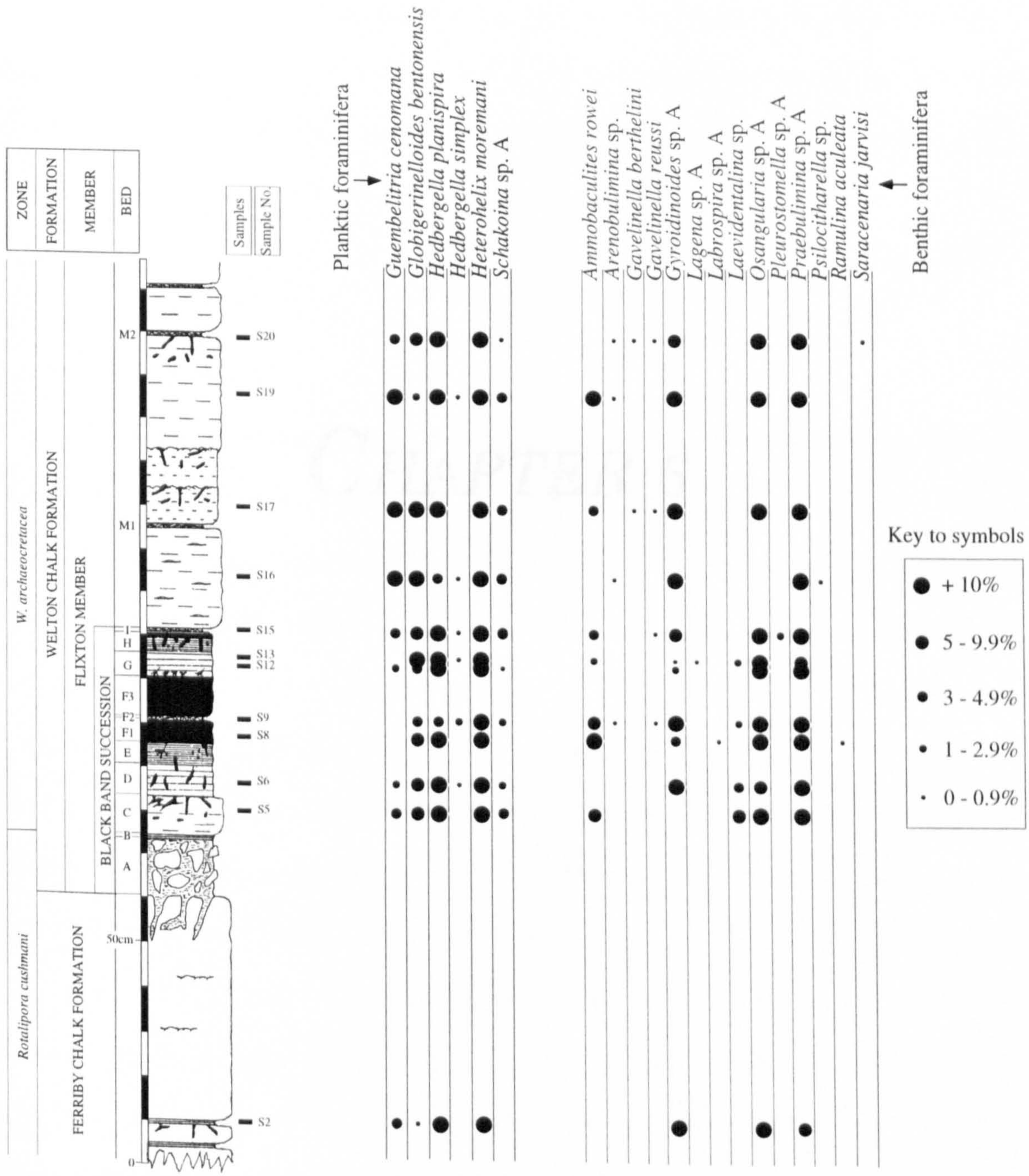


Figure 5.14. Distribution of fine benthic and planktic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

CHAPTER 6

CHAPTER 6

CORRELATION BETWEEN MICROFAUNAL ASSEMBLAGES AND CHANGING ENVIRONMENT

The studied sections reveal that through the Cenomanian-Turonian boundary some factors, such as lithology, $\delta^{13}C$, $\delta^{18}O$ and microfossil faunas change. Study of which factors change and the pattern of these changes are essential to suggest possible causes of the Cenomanian-Turonian boundary event.

6.1. Changes

6.1.1. Lithology

In all three sections there is a broadly similar pattern of lithological change from pure chalks (AIR with an average value of 7% at Eastbourne and 2.5% at South Ferriby) to more marly sediments, the Plenus Marls at Eastbourne and Westbury; the Black Band at South Ferriby (AIR up to 29% at Eastbourne and 37% at South Ferriby), and back to pure chalks again (AIR with an average value of 4% at Eastbourne and 8% at South Ferriby). The section at Eastbourne is thickest and will be used as a reference section. It starts with the top 5 m of the Grey Chalk, which is weakly rhythmic at Eastbourne, but not at Westbury. There follows a pronounced facies change to bed 1 of the Plenus Marls, with a marked increase in siliclastic content (AIR rises from 13 to 23% at Eastbourne). The Plenus Marls rest on an erosion surface, the "sub Plenus erosion surface" of Jefferies (1963a), (Figure 3.1), with evidence of erosion in the form of coated chalk pebbles, and they consist of alternations of marls (beds 1a, 2, 4, 6) and chalks (beds 1b, 3, 5, 7). The Plenus Marls are succeeded by the pure nodular chalks of the Melbourn Rock and then the Ranscombe Chalk facies (AIR less than 4%) in which a number of named marls have been recognised at Eastbourne. These are, in ascending order, Meads Marls 1-6, Holywell Marls 1-7, Gun Gardens Marls 1-2, and the Lulworth Marl, which is the

highest marl level sampled for this research. The Westbury section differs mainly in being thinner (e.g. the Plenus Marls are 1.3 m thick at Westbury as opposed to nearly 8 m at Eastbourne). Nevertheless, all beds of the Plenus Marls can be recognised, but the precise correlation of the marl seams in the Ranscombe Chalk facies is still uncertain. The South Ferriby section is very condensed; the Black Band succession is just over 60 cm thick and almost certainly represents much more time than the Plenus Marls in southern England. The Black Band succession rests on a clear erosion surface at the top of the Ferriby Chalk Formation with pebbles of chalk in unit A (Figure 5.1) and also differs in containing units with a significant organic carbon content (TOC up to 1.5%, Schlanger *et al.*, 1987). The Black Band is succeeded by pure chalk within the Welton Chalk Formation.

6.1.2. $\delta^{13}C$ values

Studied sections reveal a great change in the $\delta^{13}C$ values across the Cenomanian-Turonian boundary. At Eastbourne the Grey Chalk, below the SPES shows very little change in the $\delta^{13}C$ values which average 2.7 ‰, but at the base of bed 1 the values begin to increase gradually and form two minor peaks in the middle (3.3‰) and top (3.5‰) of the bed (Figure 3.2). From the base of bed 2 values increase more rapidly and form the first major peak in the middle of bed 3 (4.7‰). Thereafter they decline gradually and form a trough in the middle of bed 4 (4.1‰), but increase again to form the second major peak at the top of bed 8 (around 5.2‰). Then values decline slightly in the base of Melbourn Rock (around 4.8‰), but are still high up to Meads Marl 6 (around 4.7‰), which represents the plateau phase of the carbon excursion. Thereafter values decline to a minimum between Holywell Marl 3 and 4, increase slightly in Hollywell Marl 5 and then decrease more slowly up to Gun Gardens Marl 2 (Holywell 7 can be considered as the end of recovery phase in the carbon excursion). The value in the Lulworth Marl is very low and falls to 2.9‰.

At Westbury, as at Eastbourne, the Grey Chalk Formation does not show any significant change in the $\delta^{13}C$ values (average value 2.5‰), but the $\delta^{13}C$ excursion begins in bed 1, then with some oscillations increases rapidly up through the section (Figure 4.2) to reach a single major peak at the base of bed 8 (4.9‰). Values then decline a little in the base of Ranscombe Chalk (3.5‰), but are still high up to the griotte marl 1 (Meads Marls 5/6); this interval forms the plateau phase of the curve. From the top of the griotte marl 1 to the top of the section (griotte marl 2) the values decline gradually (3.1-3.4‰) and form the recovery phase of the excursion. Therefore the main differences between this section and that at Eastbourne are the absence of the first major peak in the middle of bed 3 and the trough between the two major peaks.

At South Ferriby due to the condensed nature of the section, the pattern of change in the $\delta^{13}C$ values is quite different from those the Eastbourne and Westbury (Figure 5.2) and, in comparison to them, the values in Ferriby Chalk (before the event) start considerably higher (average, 3.1‰). From the base of bed A the values increase rapidly and form the first major peak (4.0‰) in the base of bed D and after a sudden drop in the middle of the bed increase again to the base of bed F_1, where the second peak occurs (4.3‰). Values then decrease rapidly and fall to 3.4‰ in bed F_3. The values in bed G increase to a peak (3.6 ‰) in bed H, but drop (3.3‰) again in bed I. Then they decline and fall to a trough (3.0‰) in marl 1. This level might be regarded as the end of recovery phase in the carbon excursion. In the Welton Chalk Formation above the marl 1 values do not change significantly up to marl 2 (2.9-3.0‰), but then begin to rise again (3.0-3.1‰).

6.1.3. $\delta^{18}O$ values

In all three sections the $\delta^{13}C$ excursion is accompanied by changes in stable oxygen isotope values as well. At Eastbourne, samples from the Grey Chalk and bed 1 fluctuate slightly around an average of -3.0‰ (Figure 3.2). From the base of bed 2 the values gradually become less negative and after a minor oscillation form a peak (-

2.3‰) in the middle of bed 4, then decline rapidly to a minimum (-3.2‰) in bed 6. Thereafter up to Meads Marl 2 they oscillate strongly between chalks and marls with marl values about 1‰ less negative than chalk values. Above this level up to Meads Marl 6 the values are low, but do not show a clear trend. From Holywell Marl 1 to Gun Gardens Marl 2 the values are very low and oscillate between -3.2 and -3.9‰. However, in the Lulworth Marl there is a sudden jump to -2.3‰ in the $\delta^{18}O$ value.

At Westbury $\delta^{18}O$ values started at -3.5‰ rise to -2.7‰ in the *Chondrites* level and decline again to -3.6 ‰ in bed 1 of the Plenus Marls (Figure 4.2). However, from the base of bed 2 values increase rapidly to a peak of -1.9‰ in the middle of bed 4, then after strong oscillations they reach a second peak at the base of bed 8 (-2.0‰). Then they become rapidly more negative and fall to -3.9‰ at the base of nodular chalk above the Plenus Marls, but do not change significantly up through the section and remain low, except in Meads Marls 5/6 where there is a significant less negative value (-2.5‰).

At South Ferriby $\delta^{18}O$ values in the Ferriby Chalk Formation started at -2‰ to -4.2% in the topmost Ferriby Chalk samples (Figure 5.2). In bed A values increase rapidly and form a peak (-2.5‰) in the middle of bed A. Then values fall to -3.8‰.in the base of bed C, but increase again and form the second peak (-2.9‰) at the top of the bed C. They then decrease sharply and fall to a trough -6.3‰in the middle of bed E, increase to another peak (-4.5‰) in bed G, drop sharply at a minimum in bed H (-6.3), and thereafter oscillate about -4.6‰

6.1.4. Faunal composition

6.1.4.1. Coarse benthic foraminifera

At Eastbourne, the Grey Chalk is characterised by an abundant and diverse fauna (34-39 species), with no important extinction of benthic foraminifera except at the top, just below the sub Plenus erosion surface, where 3 species occur for the last

time (Figure 3.17). In addition 4 species appear in only one sample and are restricted to this interval. Bed 1 is one of the most significant levels of extinction of benthic foraminifera, where 17 species are recorded for the last time. Among them are some typical late Cenomanian benthic foraminifera which include *Pseudospiroplectinata plana*, *Arenobulimina advena*, *Plectina mariae*, *Plectina cenomana*, *Tritaxia macfadyeni*, *Ataxophragmium depressum*, *Gavelinella baltica*, *Gavelinella cenomanica*, *Tritaxia pyramidata*, *Dorothia gradata* and *Lingulogavelinella involuta*. Two species (*Spiroloculina cretacea*, *Frondicularia mucronata*) occur only in one sample. Only 2 species become extinct in the interval from bed 2 to the base of bed 4, but the second significant extinction level occurs from the middle of bed 4 up to the lower part of the Melbourn Rock, in which 19 species including many Nodosariacea have their last occurrences. From Meads Marl 1 to the Lulworth Marl the rate of extinction becomes low again with only 8 last occurrences. Significant origination in the benthic assemblage takes place in this interval (*Tritaxia tricarinata* var. *jongmansi* first appears in Holywell Marl 1, *Arenobulimina truncata* and *Lingulogavelinella globosa* in Holywell Marl 4, *Arenobulimina preslii* and *Arenobulimina* sp. A in the Lulworth Marl).

At Westbury, the number of species of benthic foraminifera in the Grey Chalk is high (36 species), but a relatively large number of them (10 species) are restricted to the *Chondrites* interval within the Grey Chalk and are absent in the other intervals (Figure 4.14). In bed 1, 5 species occur for the last time and 4 species are present in a unique sample. Most of these species are typical late Cenomanian benthic foraminifera (*Tristix excavata*, *Plectina cenomana*, *Arenobulimina advena*, *Tritaxia macfadyeni*, *Psilocytharella costulata* var. D, *Pseudospiroplectinata plana* in bed 1a and *Tritaxia pyramidata*, *Plectina mariae* and *Lingulogavelinella involua* in bed 1b). In beds 2-4, 11 species occur for the last time and 1 species is present in a unique sample. Last occurrences of some typical late Cenomanian benthic foraminifera including, *Gavelinella baltica*, *Gavelinella cenomanica* and *Ataxophragmium depressum* in bed 2,

are noteworthy, because at Eastbourne these species occur for the last time in bed 1. In bed 5 no last occurrence is recorded, but a large number of benthic foraminifera (9 species) occur for the last time in bed 6. From bed 7 up to the Meads Marl 2 in the Ranscombe Chalk the rate of extinction is also high (8 species, of which 1 species occurs in a unique sample), but between Meads Marl 3 and Meads Marls 5/6 (the last marls, which has been sampled) the number of species which occur for the last time is very low (3 species) and origination of 2 new species takes place (*Tritaxia tricarinata* var. *jongmansi* in Meads Marl 3 and *Lingulogavelinella aumalensis* in Meads Marls 5/6).

At South Ferriby the number of species in Ferriby Chalk Formation is high (21-22 species), but a few of them (5 species) are restricted to this interval (Figure 5.11). Beds A to the top of bed G show successive disappearances, during which 23 species occur for the last time and 4 species are present in a unique sample. Of particular interest is the re-appearance in bed F2 of 3 typical late Cenomanian benthic foraminifera, *Tritaxia pyramidata*, *Plectina cenomana* and *Gavelinella cenomanica*. Previously these species were recorded for the last time in bed B. From bed H to the top of the section 9 species have their last occurrences and 2 species are present in a unique sample, while origination of 4 new species occurs. In this section *Tritaxia tricarinata* var. *jongmansi* is apparently absent and appearance of new species begins with *Lingulogavelinella aumalensis* in bed I. *Valvulineria lenticula* appears in sample S17 and *Pseudospiroplectinata plana* appears with *Arenobulimina truncata* in marl 2 above the Black Band succession.

6.1.4.2. Fine benthic foraminifera

At Eastbourne and South Ferriby, the fine fraction benthic foraminiferal have been examined as well. At Eastbourne in the Grey Chalk the number of species is low (2-4) and no last occurrence is recorded (Figure 3.20). Bed 1 is the most diversified level and 5 new species appear for the first time, including *Gavelinella* sp.,

Lingulogavelinella globosa, *Pleurostomella* sp. A, *Laevidentalina* sp. and *Spiroplectammina* sp. The later last occurs in the middle of bed 1 and *Eggerellina* sp., which is also present in the Grey Chalk, occurs for the last time at the top of bed 1. In beds 2 and 3 there are no last occurrences, instead *Frondicularia* sp. appears in bed 2. At the top of bed 4, *Laevidentalina* sp. occurs for the last time. From bed 6 (bed 5 has not been sampled) up to the top of the section 1 species, *Gavelinella* sp. last occurs in Meads Marl 2, while *Ramulina aculeata* appears in Meads Marl 5 and is present thereafter up to top of the section.

At South Ferriby the number of fine benthic species in Ferriby Chalk is low (3 species), but recovers in bed C (beds A and B have not been sampled), where *Ammobaculites rowei* appears for the first time (Figure 5.14). Higher up 6 new species appear, which include *Ramulina aculeata* and *Labrospira* sp. in bed F_1 (both of which are restricted to this bed). *Arenobulimina* sp. and *Gavelinella reussi* appear in bed F_2 and *Lagena* sp. A in bed G. The last occurrence of *Laevidentalina* sp. is in bed G and *Pleurostomella* sp. A appears in bed I. In the Welton Chalk above the Black Band succession, there are successive appearances of new species, including *Psilocitharella* sp. in sample S16, *Gavelinella berthelini* in sample S17 and *Saracenaria jarvisi* in sample S20 (marl 2).

6.1.4.3. Coarse planktic foraminifera

At Eastbourne, in the Grey Chalk no planktic species disappear, but in bed 1 two rotaliporids occur for the last time, *Rotalipora deeckei* in the middle and *Rotalipora greenhornensis* at the top (Figure 3.18). In beds 2 and 3 there are no last occurrences, but *Hedbergella planispira* appears in the middle of bed 3. The last surviving species of rotaliporids, *Rotalipora cushmani*, disappears in bed 4. In bed 5 no species disappears, instead *Praeglobotruncana gibba* appears. Higher up, in bed 6 two keeled species, *Praeglobotruncana stephani* and *Dicarinella imbricata* have their last occurrences. From the base of Melbourn Rock up to the top of the section 5 species

disappear, but they are replaced by 3 new species and the re-appearance of another. The changes include; the last occurrence of *Praeglobotruncana gibba* in the base of Melbourn Rock, the last occurrence of *Hedbergella simplex* in Meads Marl 2, the first appearances of *Whiteinella archaeocretacea* and *Schakoina* sp. A in Meads Marl 5, the last occurrences of *Whiteinella brittonensis*, *Hedbergella simplex* and re-appearence of *Whiteinella baltica* in Holywell Marl 7, the last occurrence of *Helvetoglobotruncana praehelvetica* and also the first appearance of *Marginotruncana renzi* above Holywell Marl 7, and finally, the first appearance of *Praeglobotruncana* sp. A in Lulworth Marl.

At Westbury all three rotaliporids are present, but unlike the situation in Eastbourne, the two largest ones (*Rotalipora deeckei* and *Rotalipora greenhornensis*) are last recorded together at the top of bed 1 (Figure 4.15). In beds 2 and 3 no species disappear, but *Whiteinella baltica* appears in bed 2 and *Dicarinella algeriana* in bed 3. The last occurrence of *Rotalipora cushmani* is in bed 4, while *Hedbergella simplex* and *Helvetoglobotruncana praehelvetica* appear in this bed as well. In bed 5 no change occur, but in bed 6, *Dicarinella imbricata* and *Hedbergella planispira* and, in bed 7 *Praeglobotruncana stephani* have their last occurrences. From bed 8 up to top of the section 2 species disappear and 3 species appear. These changes include, the first appearance of *Whiteinella archaeocretacea*, *Whiteinella paradubia* and *Whiteinella inornata* and also the last occurrence of *Hedbergella simplex* in the second marl above the Plenus Marls and the last occurrence of *Dicarinella algeriana* in the fourth marl above the Plenus Marls.

At South Ferriby, appearance of new species of planktic foraminifera is more significant than disappearance. In two samples of the Ferriby Chalk Formation there are 7 species in total and no last occurrences (Figure 5.12). In the Black Band only *Rotalipora cushmani* became extinct (last occurrence in bed B), but up through the sequence successive appearance of new fauna occurs, including *Helvetoglobotruncana praehelvetica* and *Dicarinella algeriana* in bed B, *Dicarinella imbricata* in bed D,

Praeglobotruncana gibba in bed F1, *Marginotruncana renzi* in bed G, *Whiteinella archaeocretacea* and *Hedbergella simplex* in bed H. In the chalk above the Black Band no new planktic species occur, but 4 species disappear. These include, *Hedbergella planispira* in sample S17, *Hedbergella simplex* in sample S18, *Whiteinella baltica* and *Praeglobotruncana gibba* in sample S19.

6.1.4.4. Fine planktic foraminifera

The planktic foraminifera of the fine fraction have been investigated in two sections and also in the Westbury section a search was made for the genus *Schakoina.* At Eastbourne 8 species occurs and *Heterohelix moremani, Guembelitria cenomana* and *Hedbergella* spp. are the most dominant (Figure 3.20). All the species are present throughout the section, except *Schakoina cenomana* and *Globigerinelloides bentonensis.* The former appears in one sample at the top of the Grey Chalk and re-appears as *Schakoina* sp. A in Meads Marl 5 and is then present up to top of the section, while the later last occurs in bed 8 of the Plenus Marls. It should be mentioned that the genus *Schakoina* has not been recorded at Westbury despite a special search for it.

At South Ferriby 6 species occur in the fine planktic assemblage and, as at Eastbourne, *Heterohelix moremani, Guembelitria cenomana* and *Hedbergella planispira* are dominant and present throughout the section. *Schakoina* sp. A occurs in bed C and is then present up through the section (Figure 5.14).

6.1.4.5. Ostracods

At Eastbourne, the number of species in the Grey Chalk is fairly high (13-22 species) and only 1 platycopid species, *Cytherelloidea bonnemai* is recorded for the last time, although 3 others *Curfsina derooi, Imhotepia euglyphea* and *Cytherelloidea stricta* are restricted to this interval (Figure 3.19). From bed 1 up to the top of the section there is a succession of the last record of the ostracods. Generally one or two

species disappear in each bed of the Plenus Marls . In bed 1, *Oertliella alata* and *Neocythere kayei* have their last occurrences, while *Pterygocythere laticristata* appeared for the first time. In beds 2 and 3 there are no last records, but 3 species appeared for the first time in bed 3, *Dolocytheridea* sp. A, *Phodeucythere cuneiformis* and *Cytherelloidea hindei*, although the former two are restricted to bed 3. In bed 4 the last occurrence of *Pterygocythere laticristata* is recorded and in bed 5 *Oertliella donzei* and *Herrigocythere donzei* occurred for the last time. In beds 6 and 7 there are no last records, but in bed 8, 3 species have their last occurrences, including *Pontocyprella robusta* in the base, *Bythoceratina umbonatoides* in the middle and *Pterygocythere robusta* in the top. From the base of Melbourn Rock up to marl above the Holywell Marl 7 (sample E45), 9 species have their last occurrences, but only 1 new species is recorded. These changes include, the last occurrence of *Macrocypris siliqua* in the base of Melbourn Rock, last occurrence of *Cytherella chathamensis* and *Bythoceratina herrigi* in the middle of Melbourn Rock, the first appearance of *Mosaeleberis* sp. A in Meads Marl 2 and the last occurrences of *Paracypris wrothamensis* in Meads Marl 3, *Pontocyprella hindei* and *Pontocyprella harrisiana* in Meads Marl 4, *Pterygocythere diminuta* in Holywell Marl 1, *Cytherelloidea kayei* in Holywell Marl 3, and *Cytherelloidea hindei* in the marl above the Holywell Marl 7. However, 5 species occur for the last time in Gun Gardens Marl 2; *Isocythereis elongata*, *Bairdoppilata southerhamensis*, *Cytherella concava*, *Cytherella contracta* and *Cythereis* sp. A. In Lulworth Marl only 3 species remain; *Cytherella ovata*, *Bairdoppilata pseudoseptentrionalis* and *Bythoceratina umbonata.*

At Westbury, the number of ostracod species in the Grey Chalk is high (17 species) and no changes are recorded except that *Cytherelloidea bonnemai* is restricted to this interval (Figure 4.16). In beds 1 and 2 of the Plenus Marls no changes occurred. The last occurrences of *Neocythere kayei*, *Herrigocythere donzei*, *Pontocyprella robusta* are recorded in bed 3, although *Habrocythere* sp. A is restricted to this bed. In bed 4, *Pterygocythere laticristata* and *Pterygocythere robusta* have their

last occurrences and *Dolocytheridea* sp. A is restricted to this bed. From bed 5 up to top of the section 5 species occur for the last time and 2 new species appear. These changes include; the last occurrences of *Pontocyprella hindei* in bed 5, *Bythoceratina umbonatoides* in bed 6, *Pontocyprella harrisiana* in bed 7, and *Isocythereis elongata* in Meads Marl 1, the first appearances of *Mosaeleberis* sp. A and *Cythereis longaeva* in Meads Marl 2 and the last occurrenc of *Cythereis* sp. A in Meads Marl 3 (marl 3).

At South Ferriby the diversity of ostracods is very low (10 species) and throughout the section *Cytherella ovata* is the dominant species (Figure 5.13). In this section appearance of new species seems to be more important than disappearance. In the Ferriby Chalk 5 species are present, including *Cythereis* sp. A, *Bairdoppilata pseudoseptentrionalis*, *Bairdoppilata southerhamensis*, *Cytherella contracta* and *Cytherella concava*. Only 1 podocopid species, *Cythereis* sp. A, occurs for the last time in bed A, while up through the section new species appear successively, including, *Cytherelloidea kayei* in bed B, *Cornicythereis* sp. A in bed C, and *Isocythereis elongata* and *Bythoceratina umbonata* in bed D (both of which are restricted to this bed). However, in sample S19, 3 species, *Bairdoppilata pseudoseptentrionalis*, *Bairdoppilata southerhamensis* and *Cytherelloidea kayei*, occur for the last time and at the top of the section (sample S20) only *Cytherella contracta*, *Cytherella concava*, *Cytherella ovata* and *Cornicythereis* sp. A are present.

As it is apparent at least 4 major factors change through the Cenomanian-Turonian boundary. Each factor on its own or in combination with the others can affect the pattern of extinction and origination in the microbiota, therefore one of the main aims of this project is to seek correlation between pattern of extinction and origination and each factor.

6.2. Possible causes

6.2.1. Lithology

As discussed earlier in the south and north of England the sections consist of three major parts, starting in pure chalks (Grey Chalk and Ferriby Chalk Formation), then marls (Plenus Marls and Black Band succession) and back again to pure chalks (Melbourn Rock and Ranscombe Chalk above the Plenus Marls and Welton Chalk Formation above the Black Band). These changes in lithology have been related to a fall and rise in eustatic sea level. The effect of a rapid sea-level fall is represented by the erosion surface at the base of the Plenus Marls (the sub-Plenus erosion surface of the Jefferies, 1963, or SPES) and re-exposure of the source areas of clastic material that had been buried or subdued throughout the upper Cenomanian (Mitchell, 1993). This resulted in renewed influx of clay and led to the deposition of the marls of the Plenus Marls. At South Ferriby the SPES is represented by the conglomerate layer at the base of the Black Band succession. However, it should be mentioned that the effect of other minor sea level falls including, sub bed 2, sub bed 4 and sub bed 6 erosion surfaces (Jefferies, 1963) are also present in the Plenus Marls Formation. Sea level appears to have risen rapidly above the last erosion surface and the clastic input was cut off. Clastic accumulation rates are probably inversely proportional to sea level, as sea level rose, clastic supply declined and *vice versa* (Paul and Mitchell, 1994). Since AIR (Acid Insoluble Residue) values are even lower in the Melbourn Rock, Ranscombe Chalk and Welton Chalk Formation above the Plenus Marls and Black Band than in the Grey Chalk and Ferriby Chalk Formation, it is inferred that sea level after the event was higher than before the event. Thus of possible cause of the faunal changes seen in three sections studied may be a response to changing lithology induced by rapid changes in the static sea level.

6.2.2. $\delta^{13}C$ values

In all three sections, a positive excursion in the $\delta^{13}C$ values is apparent. Paul and Mitchell (1994) recognised three major parts to the $\delta^{13}C$ excursion, the build-up,

plateau and recovery phases. At Eastbourne and Westbury these three phases are quite obvious especially in the more detailed curve for Eastbourne, but at South Ferriby the three phases are not clearly recognisable. It is argued that the high $\delta^{13}C$ values in the Cenomanian-Turonian indicate an enrichment of the global oceanic $\delta^{13}C$ (e.g. Jenkyns, 1980; Arthur *et al.*, 1987). The widespread burial of organic carbon recognised across the Cenomanian-Turonian boundary interval is likely to have been the main driving force for the $\delta^{13}C$ excursion. Increased $\delta^{13}C$ values result from the preferential extraction of ^{12}C from sea water by marine phytoplankton photosynthesis and subsequent burial in marine deposits. The build-up phase of the excursion is interpreted as an unstable time during which the proportion of organic carbon being buried increased. The plateau phase represents the development of a new steady-state system. Berger and Loutre (1989) have argued that the precession cycle was shorter in the past and may would have been 20 000 years in the Cretaceous. Therefore plateau phase lasted may be 120 kyr (i.e. about 6 precession cycles according to Gale's (1996) timescale for the Turonian). The recovery phase of the excursion is interpreted as a time of decreasing burial rates of organic carbon which led to the development of a new steady state system in the Early Turonian. The balance between organic production and recycling and the permanent burial of organic matter controlled $\delta^{13}C$ values in marine carbonates. Jarvis *et al.* (1988) argued that changes in $\delta^{13}C$ values were a response to high productivity in surface water due to strong upwelling. Pratt (1985) argued that the combination of high productivity and enhanced preservation of organic carbon was a probable cause of the positive $\delta^{13}C$ excursion at the Cenomanian-Turonian boundary event. However, a positive $\delta^{13}C$ excursion can also occur due to increased burial of organic carbon and need not necessarily be accompanied by high productivity in surface water (Paul and Mitchell, 1994).

6.2.3. $\delta^{18}O$ values

The main reasons for changes in $\delta^{18}O$ values are: (1) a primary temperature change in the water of the photic zone where the coccoliths were secreting calcite; (2) a

change in the isotopic composition of the water mass (Ditchfield and Marshall, 1989); or (3) post-depositional diagenesis such as precipitation of carbonate cement. However, it seems that the effect of the former is very significant.

Primarily temperature changes would result in systematic variations in $\delta^{18}O$ values, assuming equilibrium precipitation, with an increase in temperature of four degree centigrade corresponding to a negative shift of one per mil in $\delta^{18}O$.

The $\delta^{18}O$ composition of a different water mass is controlled by kinetic fractionation related to evaporative processes. High evaporation would result in the build up of the heavier isotope of oxygen in the water mass (leading to more positive $\delta^{18}O$ values), while increased precipitation would result in the addition of light meteoric water to the water mass (lower (more negative) $\delta^{18}O$ values).

Both the carbon and oxygen stable isotope values are prone to diagenetic alteration. Such alteration commonly occurs during early diagenesis in sediments composed metastable mineralogies (aragonite or Mg-calcite). Carbon isotopic compositions tend to be less affected by diagenetic alteration than oxygen values. This is because the volume of carbon in carbonate sediments vastly exceeded that in solution within their coexisting pore waters, and the fractionation of carbon isotopes between calcium carbonate and dissolved bicarbonate is relatively small at near surface temperatures (Emrich *et al.*, 1970). Also the temperature-controlled fractionation effect is much less for carbon isotopes than it is for oxygen isotopes at near-surface burial temperatures (Emrich *et al.*, 1970). However, cementation or replacement reactions can also change carbon values significantly (Marshall, 1992). Breakdown of the sedimentary organic matter has a great effect on the alteration of the carbon isotopic composition of the sediments. Organic matter is very unstable and has a $\delta^{13}C$ 25% more negative that contemporaneous inorganic bicarbonate (Marshall, 1992). Therefore the incorporation of a component of organic-derived carbon will have important effects on the carbon stable isotope values of sediments and will produce a lighter carbon isotope signal. Precipitation of carbonate by bacterial methanogenesis

might be also a possible cause for a diagenetic increase in $\delta^{13}C$ in organic-rich sediments below the sulphate reduction zone. However, the oxygen isotope ratios are more prone to be altered than $\delta^{13}C$ values during diagenesis, partly due to the fact that oxygen isotopes show large temperature-related diagenetic effects. The effect of the geothermal gradient and hence temperatures reached during burial on the degree of recrystallization of chalk is fundamental (Land, 1980; Wetzel, 1989). $\delta^{18}O$ values decrease with increasing burial depth and more elevated temperatures.

6.2.4. Biotic interactions

All three sections indicate that the microfossils undergo tremendous change across the Cenomanian-Turonian boundary. The turnover in microfossils occurs in both the benthic and planktic foraminiferal populations and in the ostracod assemblage as well. The possible causes for this turnover include; sediment type (and therefore sea level), $\delta^{13}C$ changes (productivity vs. burial), $\delta^{18}O$ changes (temperature), biotic interactions (competition and migration), or the combination of some factors with each other.

The effect of competition between different taxa seems to be a significant factor in the changes in the faunal composition. Competition is apparent between different genera or even between different species of the same genus. It seems that in both benthic and planktic foraminifera the size of the test was a crucial factor in this competition and consequently in their survival. Among the fauna as a whole, larger species are those which succumb first, while the smaller species survive e.g. in the benthic assemblage *Spiroplectammina praelonga*, *Nodosaria* spp., *Plectina* spp., *Laevidentalina distincta*, *Laevidentalina pseudochrysalis*, *Gavelinella baltica*, *Gavelinella cenomanica*, *Dorothia gradata*, *Tritaxia macfadyeni* and *Tritaxia pyramidata* are those which succumb either in the Grey Chalk or early beds of the Plenus Marls. With the extinction of these large species, vacated niches become promptly occupied by a smaller one i.e. among tritaxiids, two larger species, *Tritaxia macfadyeni* and

Tritaxia pyramidata succumb first, while *Tritaxia tricarinata* characterised by a small, sub-triangular test survives and specimens of *Tritaxia tricarinata* from the Plenus Marls are much smaller than pre-event specimens or the early Turonian form *Tritaxia tricarinata* var. *jongmansi*. Within nodosariids, this trend is clearer in the *Laevidentalina* group. At Westbury *Laevidentalina distincta* and *Laevidentalina pseudochrysalis*, the two largest species in this group, succumb first in the Grey Chalk, although at Eastbourne the latter is absent and the former becomes extinct in bed 1. These are followed by the extinction of *Laevidentalina legumen* in bed 3 at Westbury (absent in Eastbourne), *Laevidentalina strangulata*, (bed 5, at Eastbourne), *Laevidentalina soluta* (bed 8, at Eastbourne), and eventually *Laevidentalina gracilis* (above bed 8, at Eastbourne). Similarly in the gavelinellids, size seems to be prominent. The forms of that survive, *Gavelinella reussi-Gavelinella berthelini* are characterised by trochospiral, plano-convex tests, which are in marked contrast to the trochospiral, inflated tests of the pre-event, *Gavelinella cenomanica* and *Gavelinella baltica*. In the *Lingulogavelinella* group this size trend is obvious as well, i.e. a large conical, epifaunal species *Lingulogavelinella involuta* becomes promptly replaced in bed 1 of the Plenus Marls, (where the stress condition was developing), by a low trochospiral, inflated, smaller one, *Lingulogavelinella globosa*. The Turonian species of this group, *Lingulogavelinella aumalensis*, which appears in the uppermost part of the sections is even smaller and characterised by low trochospiral test with less inflated chambers than the previous species of this genus. In *Eggerellina*, although a squat form, *Eggerellina brevis* disappears before a larger one (*Eggerellina mariae*), the latter shows dwarfism and the test becomes smaller promptly after the extinction of the former.

In the planktic assemblage, there is a successive extinction in rotaliporids, which is well documented at Eastbourne, where the extinction of *Rotalipora deeckei* (Middle of bed 1) is followed by extinction of *Rotalipora greenhornensis* (top of bed 1) and eventually that of *Rotalipora cushmani* (middle of bed 4). In Westbury two

Rotalipora species (*Rotalipora greenhornensis* and *Rotalipora deeckei*) go out together. This difference is probably due to the fact that bed 1 is so thin at Westbury. After the extinction of *Rotalipora cushmani* there is a brief proliferation in the intermediate sized keeled planktics, dicarinellids and praeglobotruncanids.

Competition in ostracods assemblage occurs between two major groups, podocopids and platycopids. The effect of environmental changing on ostracods composition is well documented in Eastbourne section, which will be discussed later.

Migration among the taxa, also occurs in the studied sections and affected the faunal composition and consequently the population structure. There are some examples of this strategy in some groups of microfauna in the studied sections. Perhaps the most prominent example in the benthic foraminifera is the genus *Arenobulimina*. At Eastbourne this genus starts with three species (*Arenobulimina pseudalbiana*, *Arenobulimina bulleta* and *Arenobulimina advena*), which disappear gradually in the Grey Chalk and bed 1a before the main event, but it re-appears again with 3 new species (*Arenobulimina truncata*, *Arenobulimina preslii* and *Arenobulimina* sp. A) in Holywell Marl 4 and the Lulworth Marl, when the conditions were fairly favourable again i.e. it is a Lazarus genus in the Harries model (1993). Also *Pseudospiroplectinata plana* is present at Eastbourne in the Grey Chalk and bed 1a of the Plenus Marls (latest Cenomanian), but then disappears and is absent throughout the section. At South Ferriby this species is absent initially, but suddenly appears at the top of the studied section in the Welton Chalk Formation (early Turonian). Thus although *Pseudospiroplectinata plana* becomes locally extinct in bed 1a at Eastbourne, it clearly survived somewhere (i.e. it is a Lazarus species of the Harries model). At South Ferriby some typical late Cenomanian benthic foraminifera disappear in bed A, but re-appear in bed F2. This may indicate migratory behaviour of these taxa.

6.3. Pattern of extinction

6.3.1. Benthic foraminifera

The pattern of extinction in benthic foraminifera was step-wise across the Cenomanian-Turonian boundary. This pattern is very clear at Eastbourne, where two major extinction events are separated by a significant period during which very little happened. One of the main extinction steps is concentrated at the top of the Grey Chalk as well as bed 1 of the Plenus Marls. In bed 1 alone about 25 % of species occur for the last time, but from bed 2 to base of bed 4 the changes in the benthic fauna are not significant. From the middle of bed 4 to Meads Marl 1 about 32% of the species occur for the last time. The long interval between Meads Marl 2 up to top of the section is characterised by a few minor last occurrences of the fauna. However, at Westbury this trend is not as clear and there is only continuous gradual decline in diversity, which is mainly the result of the spacing of the samples. At South Ferriby the Ferriby Chalk Formation and beds A to G of Black Band succession show, as at Westbury, a continuous gradual decline in diversity, but from bed H to marl 2 there are only a few minor last occurrences, except in sample 19, where 6 species have their last occurrences.

In both the Eastbourne and Westbury sections the extinctions can be grouped into three major intervals, where each interval is characterised by extinction of some specific groups of benthic foraminifera. The first interval is characterised by the extinction of some Nodosariacea and large infaunal species, while in the second interval epifaunal species and more large infaunal species become extinct. In the third interval extinction of many more Nodosariacea occurs. After the third interval extinction mostly affects agglutinated species, including *Eggerellina* spp., *Textularia* spp, *Reophax* sp. A and also *Quadromorphina allomorphinoides* and some more Nodosariacea.

6.3.2. Planktic foraminifera

In contrast to benthic foraminifera, the number of planktic foraminifera is small and special care is needed in interpreting the extinction pattern. At Eastbourne 18 planktic species occur, among which only one species occurs in a uniqe sample. In bed 1 of the Plenus Marls 2 species have their last occurrence, which means about 12% of species occur for the last time. The percentage of last occurrences in beds 2 and 3 is nil. The main step in the faunal change occurs in the interval between the middle of bed 4 and Meads Marl 1, in which about 23.5% of species occur for the last time. During the long interval from Meads Marl 2 to the top of the section only a few minor last occurrences take place. Therefore as with the benthic foraminifera, there are two significant extinction steps; (1) bed 1 of the Plenus Marls and (2) the interval between the middle of bed 4 and Meads Marl 1. These two steps are separated by a significant interval during which nothing happened. At Westbury, in bed 1 about 7.6% species occur for the last time. The percentage of last occurrences in beds 2 and 3 is nil, but from the bed 4 to bed 7 about 23% of the species occur for the last time. From bed 8 to griotte marl 1 (Meads Marls 5/6) two species appear only in one sample and only 2 species have their last occurrences. At South Ferriby the appearance of species is more important than disappearance. Therefore it is difficult to describe the extinction pattern there.

6.3.3. Ostracods

At Eastbourne in the Grey Chalk only one ostracod disappears, therefore the percentage of the species, which occur for the last time is very low (3.7%), but about 7.5% of the species have their last occurrences in bed 1 the of the Plenus Marls. In beds 2 to base of bed 4 the percentage of species which have their last occurrences is not significant, but from the middle of bed 4 to Meads Marl 1 about 33% of the species have their last occurrences. Between Meads Marls 2 to the marl above the Holywell Marl 7 there are only a few minor extinctions, but in Gun Gardens Marl 2 about 22% of the species occur for the last time. This may be only a result of the spacing of samples. Therefore, there are two significant extinction step in the ostracod

assemblage; bed 1 of the Plenus Marls and the interval between middle of bed 4 to Meads Marl 1. At Westbury, there is a gradual decline in the diversity of ostracods, which is a result of the spacing of the samples, although from bed 3 to bed 8 about 33% of the species have their last occurrences. At South Ferriby due to small number of species the interpretation of extinction pattern seems difficult.

The pattern of extinction in the three taxonomic groups in the studied sections reveals that, in contrast to Cretaceous - Tertiary boundary, the benthic foraminifera are more affected than planktic foraminifera and also ostracods are less affected than benthic foraminifera. There are two main extinction steps in the benthic foraminifera; (1) in bed 1 of the Plenus Marls and (2) in the interval between the middle of bed 4 and Meads Marl 1. These two steps are separated by a significant interval (probably 30, 000 years) during which very little happened. In the planktic assemblage the first interval is of minor significant, while the second interval is the main extinction step. In the ostracod assemblage also the second interval is the main extinction step, although at Westbury the second interval in the ostracod assemblage begins from bed 3 of the Plenus Marls, which could be due to sampling.

The stepped disappearance of the taxonomic groups in the studied sections is in marked contrast with a single catastrophic extinction pattern. It has, however recently been suggested that comet showers may have produced not a single catastrophic extinction but a series of less dramatic events, (Hut *et al.*, 1987) the so-called stepwise mass extinction (Kauffman, 1986). Hut *et al.* (1987) argued the Cenomanian-Turonian boundary event was an example of such a phenomenon. They hypothesised that comet showers may have caused stepwise mass extinction through multiple impacts within a short period of time. As discussed earlier the benthic foraminifera, ostracods and planktic foraminifera reveal a stepped extinction pattern, that suggest impacts of two comets cannot be ruled out. Kaiho (1994) has suggested an origin from a mafic to ultra-mafic rock for the iridium anomalies at the Cenomanian-Turonian boundary.

6.4. Correlations

6.4.1. Influence of substrate

In all three sections there is a broadly similar pattern of lithological change from pure chalks (AIR with an average value of 7% at Eastbourne and 2.5% at South Ferriby) to more marly sediments, the Plenus Marls at Eastbourne and Westbury; the Black Band at South Ferriby (AIR up to 29% at Eastbourne and 37% at South Ferriby), and back to pure chalks again (AIR with an average value of 4% at Eastbourne and 8% at South Ferriby).

6.4.1.1. Benthic foraminifera

The distribution of benthic foraminifera through the studied sections reveals that some species are more related to high clay content substrate (group 1), but the majority show no relation to any particular substrate (group 2). In the first group hauerinids (*Quinqueloculina antiqua*), hormosinids (*Reophax* sp. A) and verneuilinids (*Verneuilinoides* sp. A) are more important which at Eastbourne constitute about 4.5% of the assemblage. It is noteworthy that some taxa in the fine fraction (63-90 μm) have also a clear substrate controlled distribution, e.g. *Laevidentalina* sp. and *Pleurostomella* sp. A (at Eastbourne), although the later is absent in coarse fraction.

6.4.1.2. Planktic foraminifera

Although there is not a direct correlation between planktic foraminifera and substrate, nevertheless the structure of planktic foraminiferal populations differ to some extent in chalks compared with marls. P% (planktic foraminifera as a percentage of the total foraminifera in the >250 μm fraction) shows a consistent relationship with the five major marl-chalk rhythms in the Plenus Marls recognised by Jefferies (1962). In general p% is higher in the chalks than in the marls, for instance at Eastbourne P % in chalks ranges from 45 to 93%, while in the marls it varies between 25 and 78%.

6.4.1.3. Ostracods

Ostracods seem to show a considerable tolerance concerning the grain size and nature of the sediment (Neale, 1964). However, a relationship between species and substrate occurs also in ostracods, although it is not as clear as with benthic foraminifera. Among the studied ostracods a podocopid species, *Pterygocythere laticristata* shows a clear relationship with high clay content substrates, although at Eastbourne this taxon constitutes only about 3% of the assemblage.

Thus, substrate may influence the pattern of distribution of the fauna but it is not a major factor in controlling the distribution of the taxa through the sequence, because the percentage of benthic foraminifera and ostracods, which have substrate controlled distribution is very low and also in the upper part of the sections, where the substrate returns to carbonate rich facies, many taxa which disappear do not occur again.

6.4.2. Influence of changes in $\delta^{13}C$

The geochemical analysis reveals that there are different phases to the $\delta^{13}C$ excursion in each section. At Eastbourne, the most expanded section, 5 different phases can be recognised (Figure 6.1), which include: pre-excursion phase (Grey Chalk Formation, 2.6-2.8‰ PDB), build up phase [can be divided into first build up phase (beds 1 to middle of bed 3, 2.8-4.7‰), trough interval (middle of bed 3 to middle of bed 4, 4.1-4.5‰) and second build up phase (top of bed 4 to top of bed 8/base of Melbourn Rock, 4.2-5.3‰)], plateau phase (base of Melbourn Rock to top of Meads Marl 6, around 4.7‰), recovery phase (above Meads Marl 6 to probably Holywell Marl 7, 3.7-5.1‰) and post-recovery phase (above Holywell Marl 7 to top of the section, 2.9-3.5‰). It should be mentioned that first build-up phase embraces three minor parts, including lower part (bed 1), middle part (bed 2) and upper part (base to middle of bed 3). At Westbury four phases are recognisable (Figure 6.2), including: pre-excursion phase (Grey Chalk Formation, 2.5-2.6‰), a single build up

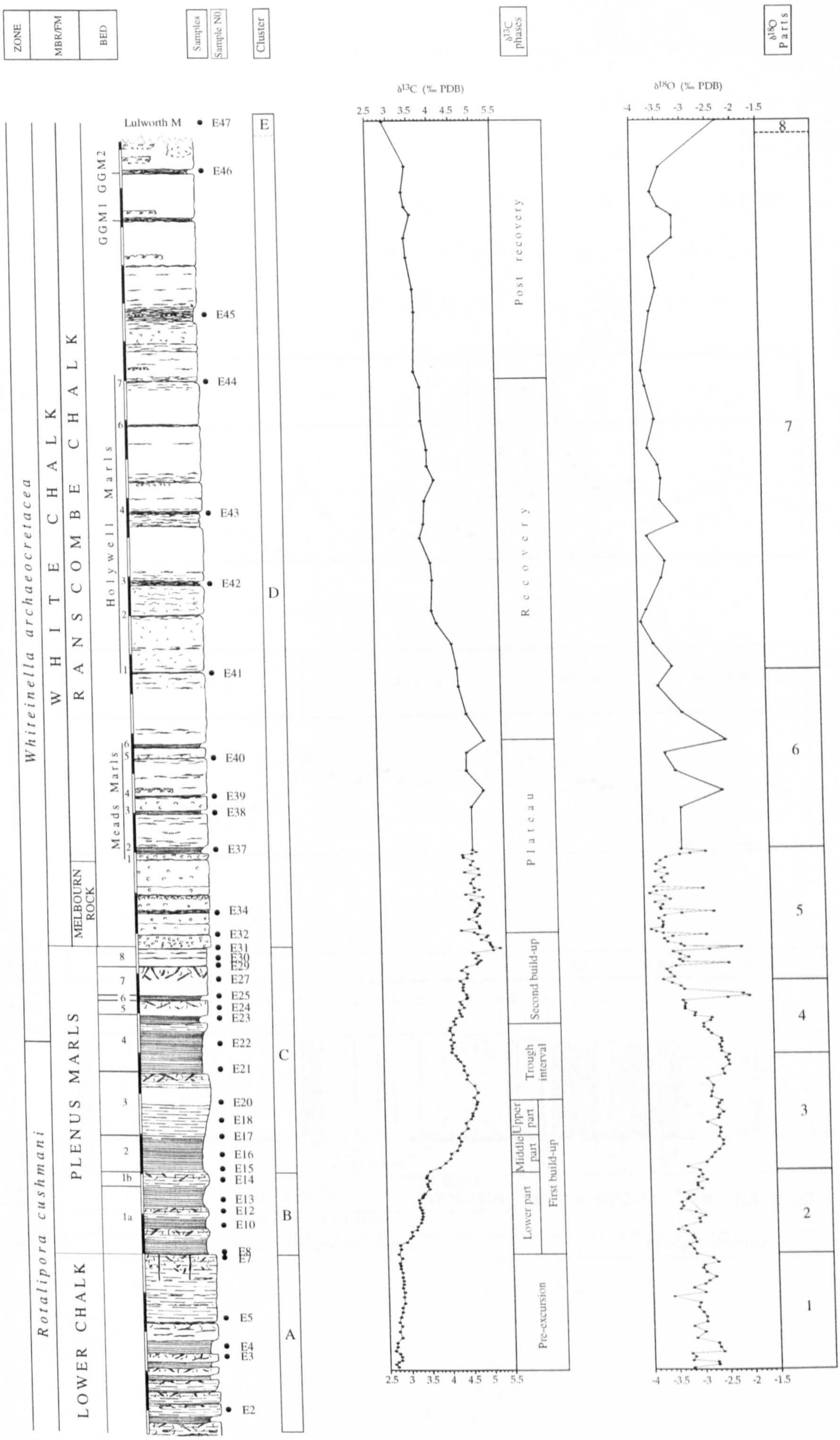


Figure 6.1. Different phases and parts of the δ13C and δ18O curves across the Cenomanian - Turonian boundary at Easrbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

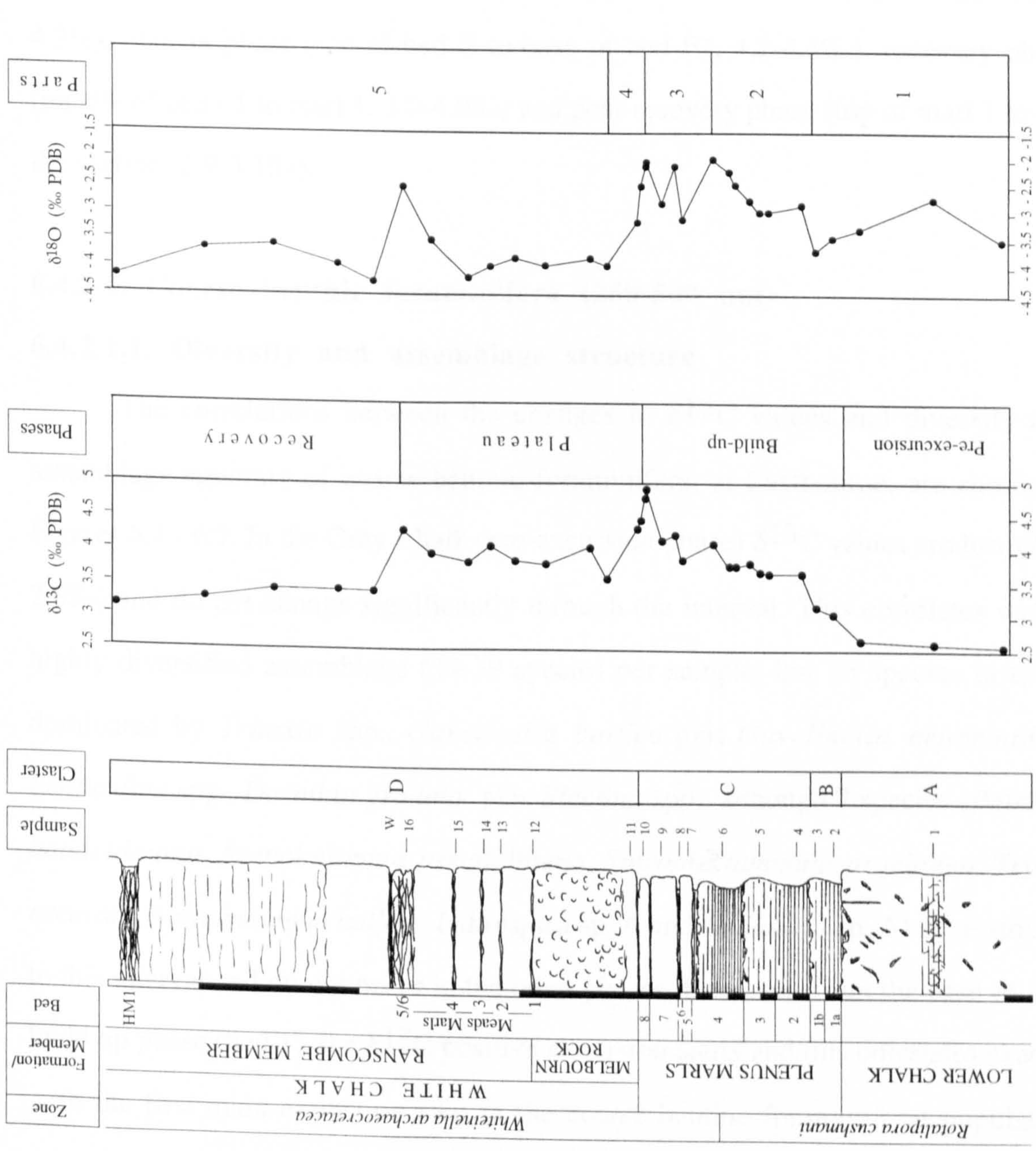


Figure 6. 2. Different phases and parts of the δ13C and δ18O curves across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See figure 4.1 for key to stratigraphic log.

phase (bed 1 to bed 8, 3.0-4.9‰), plateau phase (base of Melbourn Rock to Meads Marls 5/6, 3.5-4.3‰) and post recovery phase (above Meads Marls 5/6 to top of the section, 3.1-3.4‰). Due to condensed and incomplete section at South Ferriby the distinction between some phases is doubtful. However, in this thesis five phases at South Ferriby have been recognised (Figure 6.3), which include: pre-excursion phase (Ferriby Chalk Formation, 3.0-3.3%), build up phase (bed A to middle of bed E, 3.1-4.3%), plateau phase (top of bed E to base of bed F1, 4.2-4.3‰), recovery phase (middle of bed F1 to marl 1, 3.0-4.0‰) and post-recovery phase (top of marl 1 to top the section, 2.9-3.1‰).

6.4.2.1. Coarse benthic foraminifera (250-500 μm)

6.4.2.1.1. Diversity and assemblage structure

The correlations between the changes in $\delta^{13}C$ values and diversity and assemblage structure of coarse benthic foraminifera, at Eastbourne, are shown in Figures 6.4 - 6.7. In the Grey Chalk (pre-excursion phase) $\delta^{13}C$ values are low (2.6-2.8‰) and do not change significantly through the interval. This correlates with a highly diversified assemblage (34-39 species per sample, but 55 species in total) dominated by *Tritaxia* spp., *Gavelinella baltica* plus *Gavelinella cenomanica*, *Lenticulina* spp., *Dorothia gradata* plus *Plectina* spp., although 7 species (*Palmula baudouiniana*, *Arenobulimina pseudalbiana*, *Spiroplectammina praelonga*, *Tristix excavata*, *Arenobulimina bulleta*, *Labrospira* sp. A and *Nodosaria* sp. A) are restricted to this interval and do not occur in the other phases. However, from the base of first build up phase (bed 1), the $\delta^{13}C$ positive excursion starts and this correlates exactly with the first main extinction step in the coarse benthic foraminiferal population (shaded area in Figure 6.7), when 17 species are recorded for the last time, of which 2 species (*Frondicularia mucronata* and *Spiroloculina cretacea*) have a unique occurrence. However, during this interval the assemblage is diversified (17-33 per sample, but 46 species in total) and its structure remains nearly the same as in the Grey Chalk, except that *Lingulogavelinella involuta* constitutes a major proportion of the

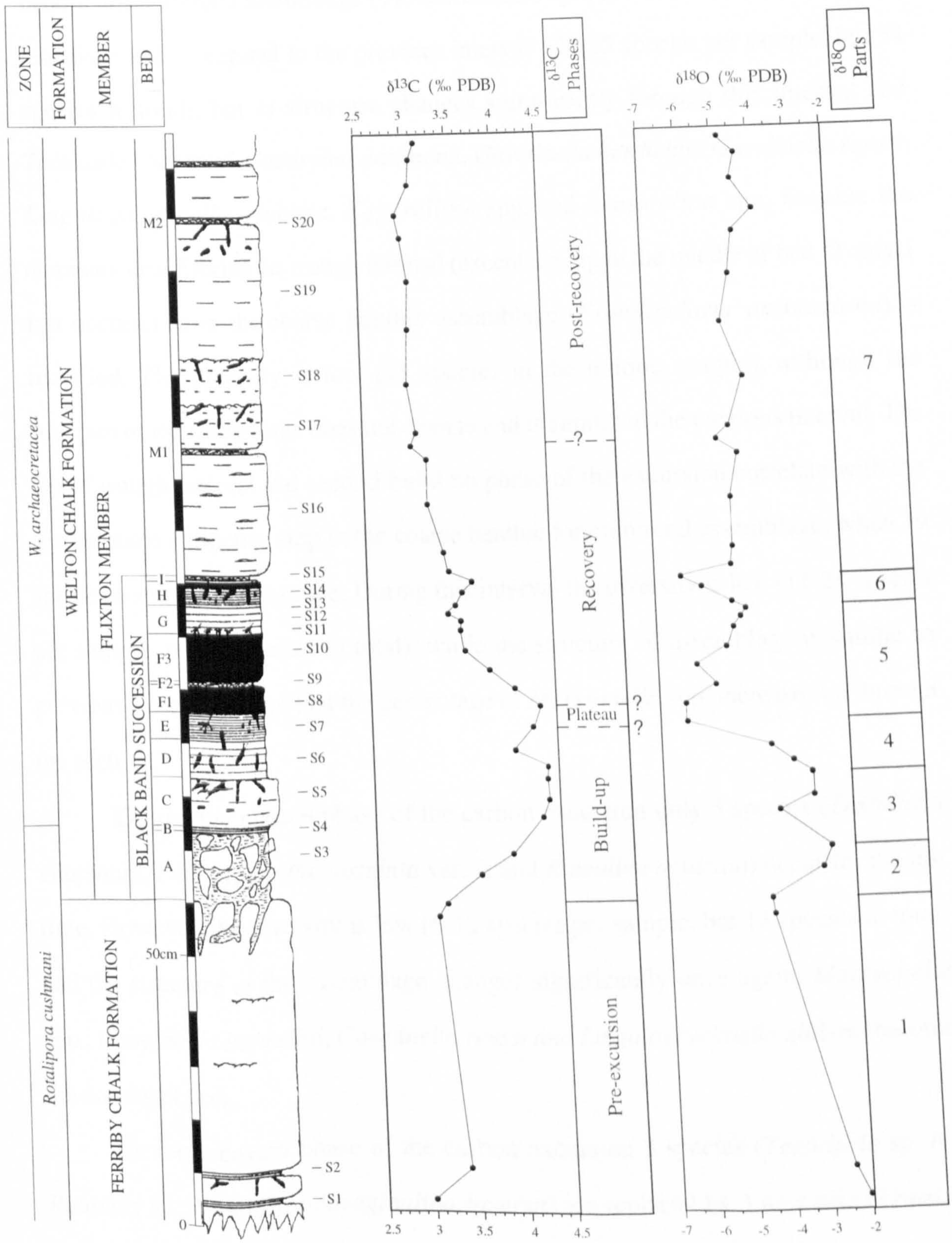


Figure 6. 3. Different phases and parts of the $\delta^{13}C$ and $\delta^{18}O$ curves across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 4.1 for key to stratigraphic log.

assemblage. Despite the fact that $\delta^{13}C$ values continue to increase through bed 2 and form the first main peak in the middle of bed 3, only 1 last occurrence in the coarse benthic foraminiferal assemblage (*Verneuilinoides* sp. A) occurs. The assemblage is less diversified compared to the previous interval (20-25 species per sample, but 34 species in total), but its structure changes significantly through this interval and *Textularia chapmani, Gaudryina austinana, Gavelinella berthelini, Gavelinella reussi, Lingulogavelinella globosa, Eggerellina* spp. and *Lenticulina* spp. become the dominant taxa. During the trough interval (except the top in the middle of bed 4) only 1 last occurrence in the coarse benthic assemblage (*Frondicularia archiaciana*) is recorded. The diversity is low (18 species in the unique sample), although the structure of the assemblage does not change and is similar to the previous interval. The top of trough interval and second build up phase of the excursion correlate with the second main extinction step in the coarse benthic foraminiferal assemblage, when 19 species occur for the last time. During this interval the diversity is low (11-24 species per sample, but 35 species in total), while the structure of assemblage is similar to previous interval, except that the percentage of *Marssonella* spp. increases up through the section.

During the plateau phase of the carbon excursion only 3 species (*Textularia chapmani, Psilocytharella costulata* var. A and *Ramulina aculeata*) occur for the last time. However, the diversity is low (6-12 species per sample, but 13 species in total) and the structure of the assemblage changes significantly once again. *Marssonella* spp., *Gavelinella berthelini, Gavelinella reussi and Lingulogavelinella globosa* become the dominant taxa.

In the recovery phase of the carbon excursion 3 species (*Textularia* sp. A , *Reophax* sp. A and *Frondovaginulina inversa*) are replaced by 3 new taxa (*Tritaxia tricarinata* var. *jongmansi, Arenobulimina truncata* and *Lingulogavelinella aumalensis*). The diversity is low (9-12 species per sample, but 15 species in total) and the structure of the assemblage does not change significantly compared with the previous phase, except that *Tritaxia tricarinata* along with 4 previous species (*Marssonella* spp.,

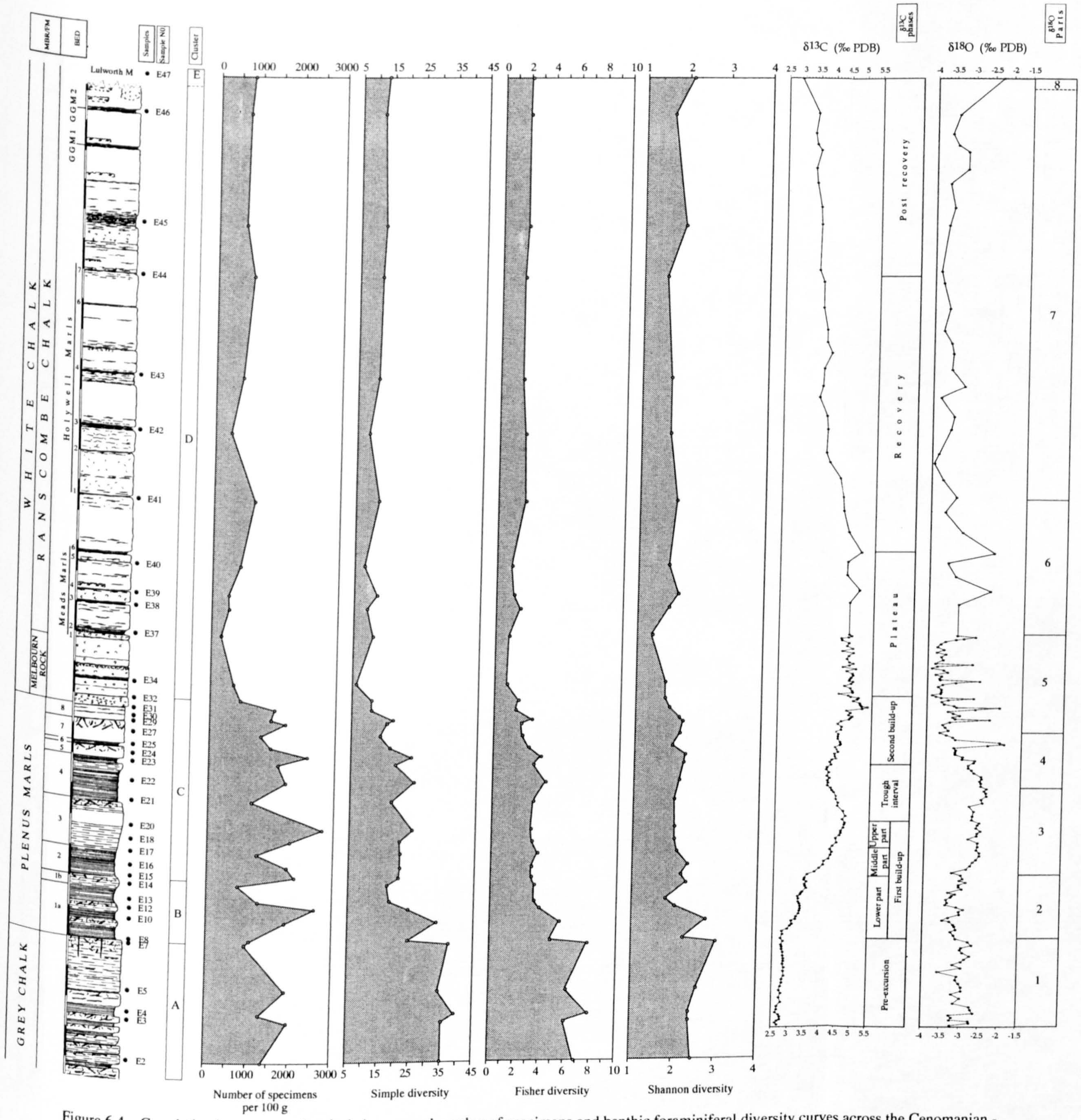


Figure 6.4. Correlation between geochemical changes and number of specimens and benthic foraminiferal diversity curves across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

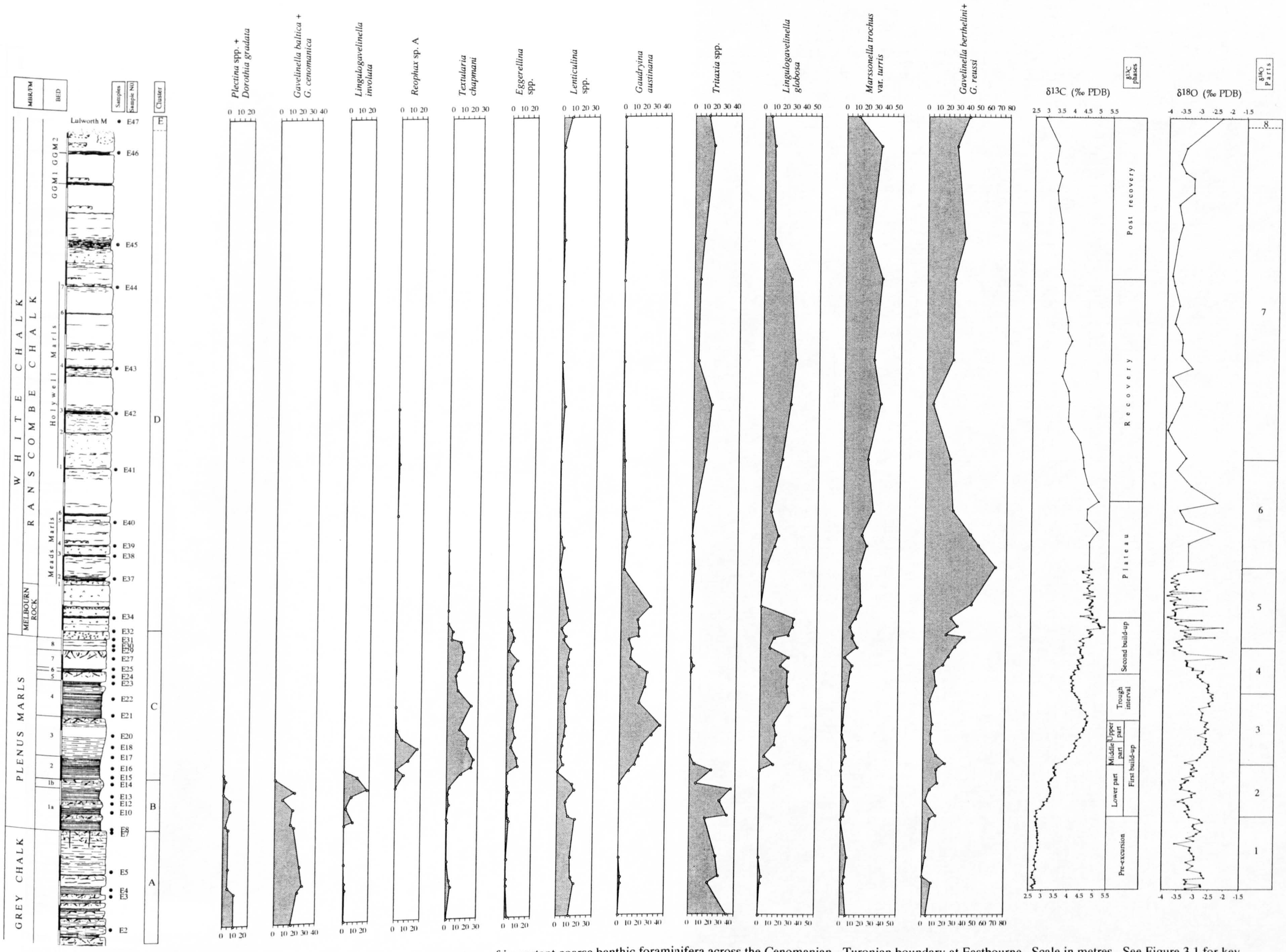


Figure 6.5. Correlation between geochemical changes and variation in percentage of important coarse benthic foraminifera across the Cenomanian - Turonian boundary at Eastbourne. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

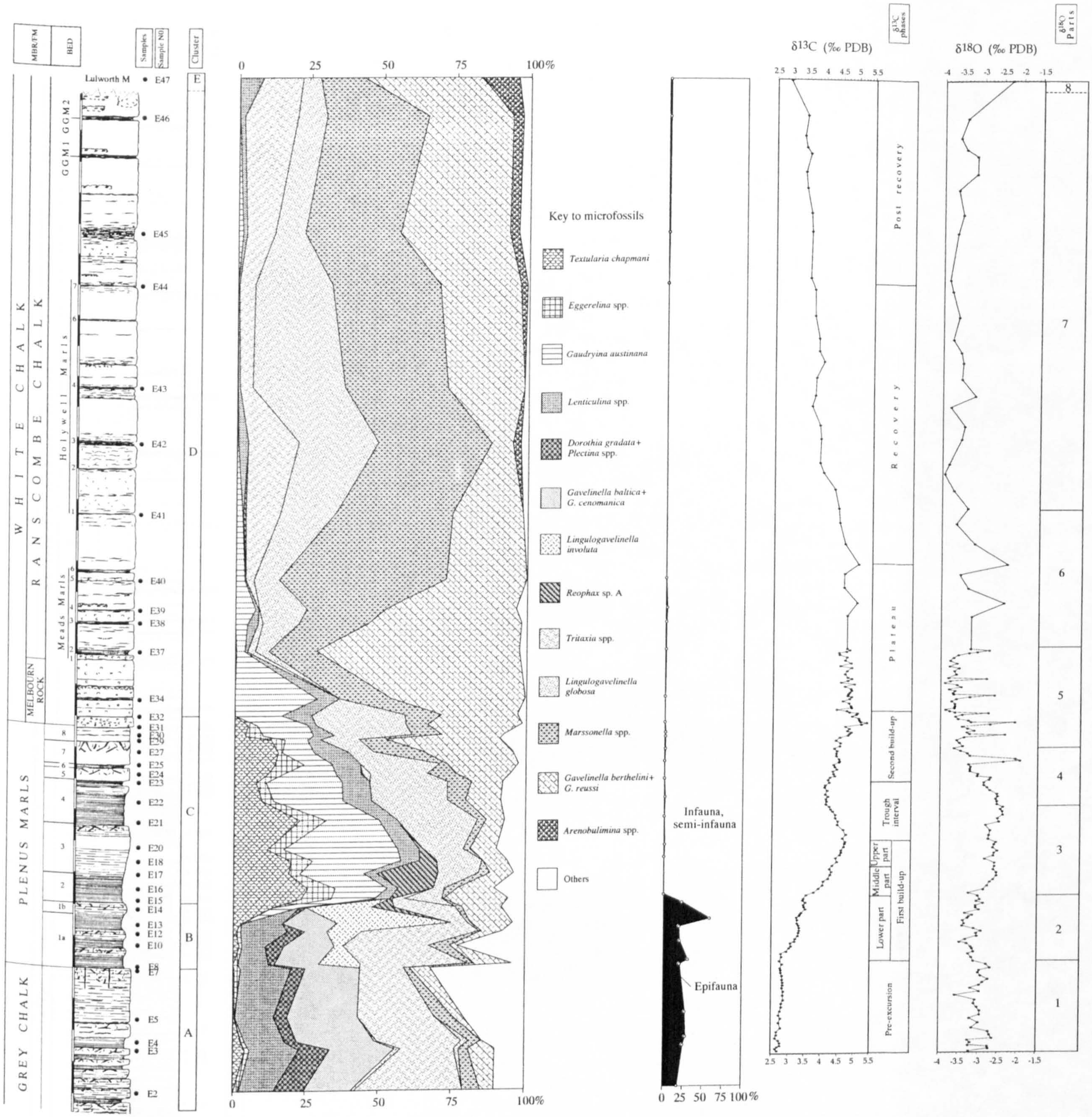


Figure 6.6. Correlation between geochemical changes and cumulative percent of dominant benthic foraminifera and percentage of epifaunal group across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log and 3.10 for colour vision.

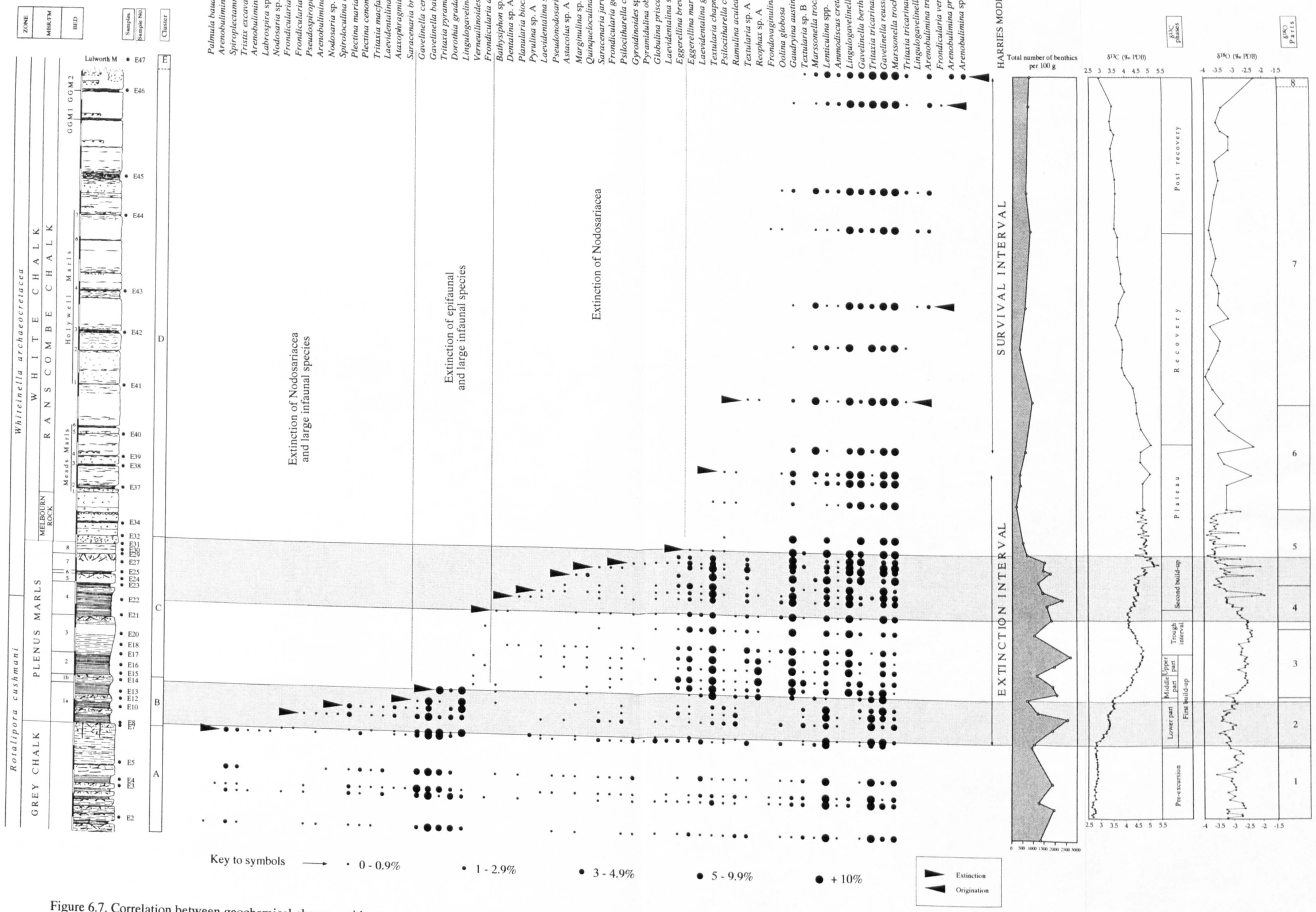


Figure 6.7. Correlation between geochemical changes with coarse benthic foraminifera in clusters A - E across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. For key to symbols on graphic log see Figure 3.1.

Gavelinella berthelini, Gavelinella reussi, Lingulogavelinella globosa) constitute the dominant taxa of the assemblage.

In the post- recovery phase (above the Holywell Marl 7) 2 other species (*Oolina globosa* and *Gaudryina austinana*) have their last occurrences and are replaced by 3 new species (*Frondicularia verneuiliana, Arenobulimina preslii* and *Arenobulimina* sp. A). As with the previous phase, the assemblage is dominated by *Marssonella* spp., *Gavelinella berthelini* plus *Gavelinella reussi, Lingulogavelinella globosa, Tritaxia tricarinata* together with *Arenobulimina* spp. and *Lenticulina* spp. (at the top of the phase).

At Westbury the $\delta^{13}C$ values in the Grey Chalk are low (2.5-2.6‰) and do not change significantly through the interval. This correlates with a highly diversified assemblage (36 species) dominated by *Tritaxia* spp., *Gavelinella baltica, Gavelinella cenomanica* and *Lenticulina* spp (Figures 6.8 - 6.11). Through the build up phase, there is a continuous gradual decline in the diversity from 35, in the base of bed 1a to 15 in bed 8, which correlates with increasing $\delta^{13}C$ values. The structure of the assemblage in bed 1 is different from that in the Grey Chalk. *Lingulogavelinella involuta* is the dominant species, while *Gavelinella baltica, Gavelinella cenomanica, Tritaxia* spp., *Lenticulina* spp., *Marssonella* spp. *Textularia chapmani* and *Reophax* sp. A are the other important elements of the assemblage. However, from bed 2 to the top of bed 8 the assemblage of coarse species changes significantly once again and *Gavelinella berthelini, Gavelinella reussi, Lingulogavelinella globosa, Lenticulina* spp., *Gaudryina austinana, Textularia chapmani* and *Marssonella* spp. (only in bed 8) become the dominant species of the assemblage. In the plateau phase 9 species have their last occurrences (3 species in marl 4 alone, which might be due to sampling) and 1 species (*Pseudonodosaria humilis*) occurs in a unique sample. Origination of 2 new taxa occurs in the upper part of the plateau phase; *Tritaxia tricarinata* var. *jongmansi* and *Lingulogavelinella aumalensis* appear for the first time. The structure of the assemblage is similar to that at the top of the bed 8 and *Gavelinella berthelini*

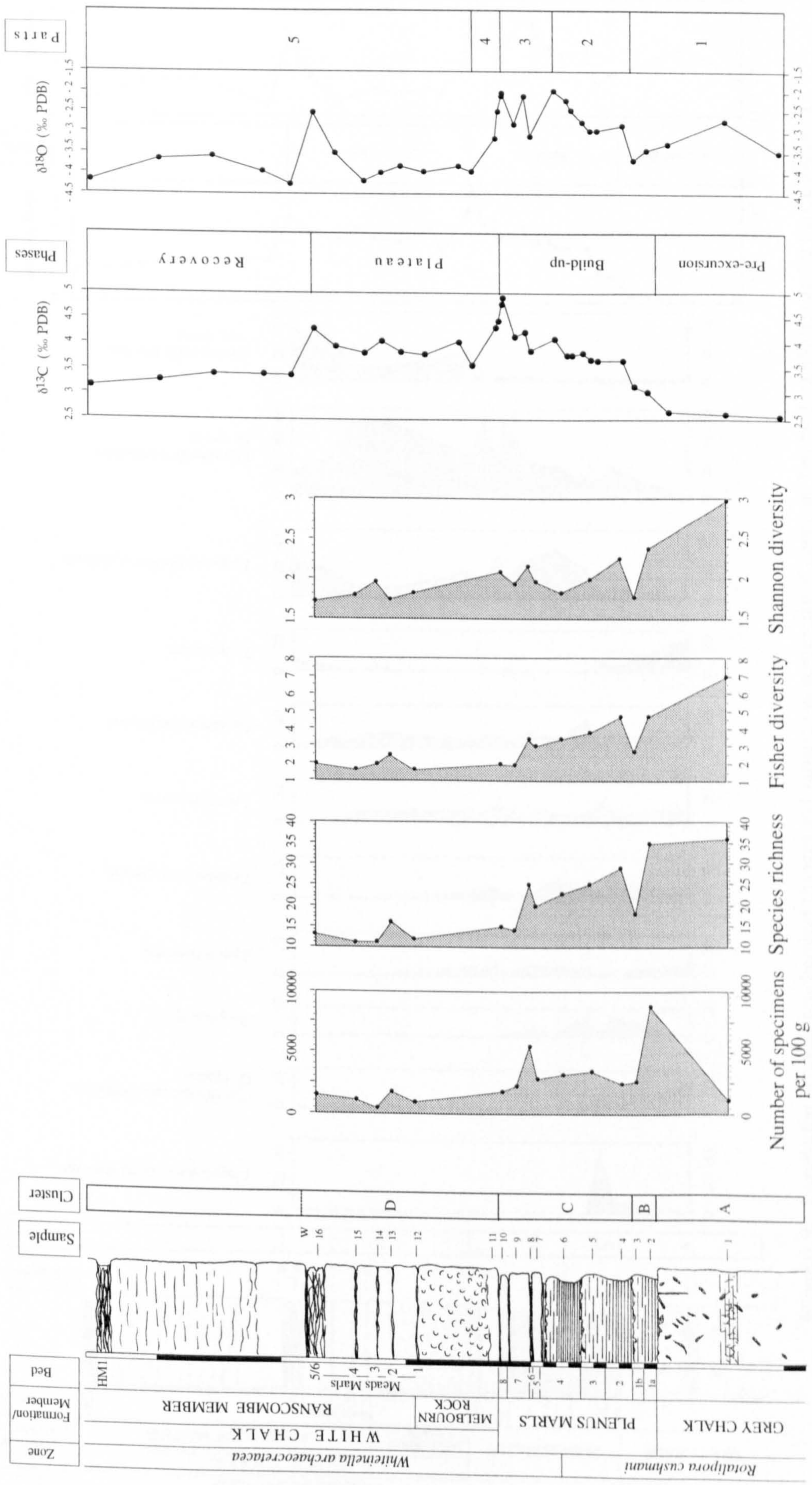


Figure 6. 8. Correlation between geochemical changes and total number and diversity curves of benthic foraminifera across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

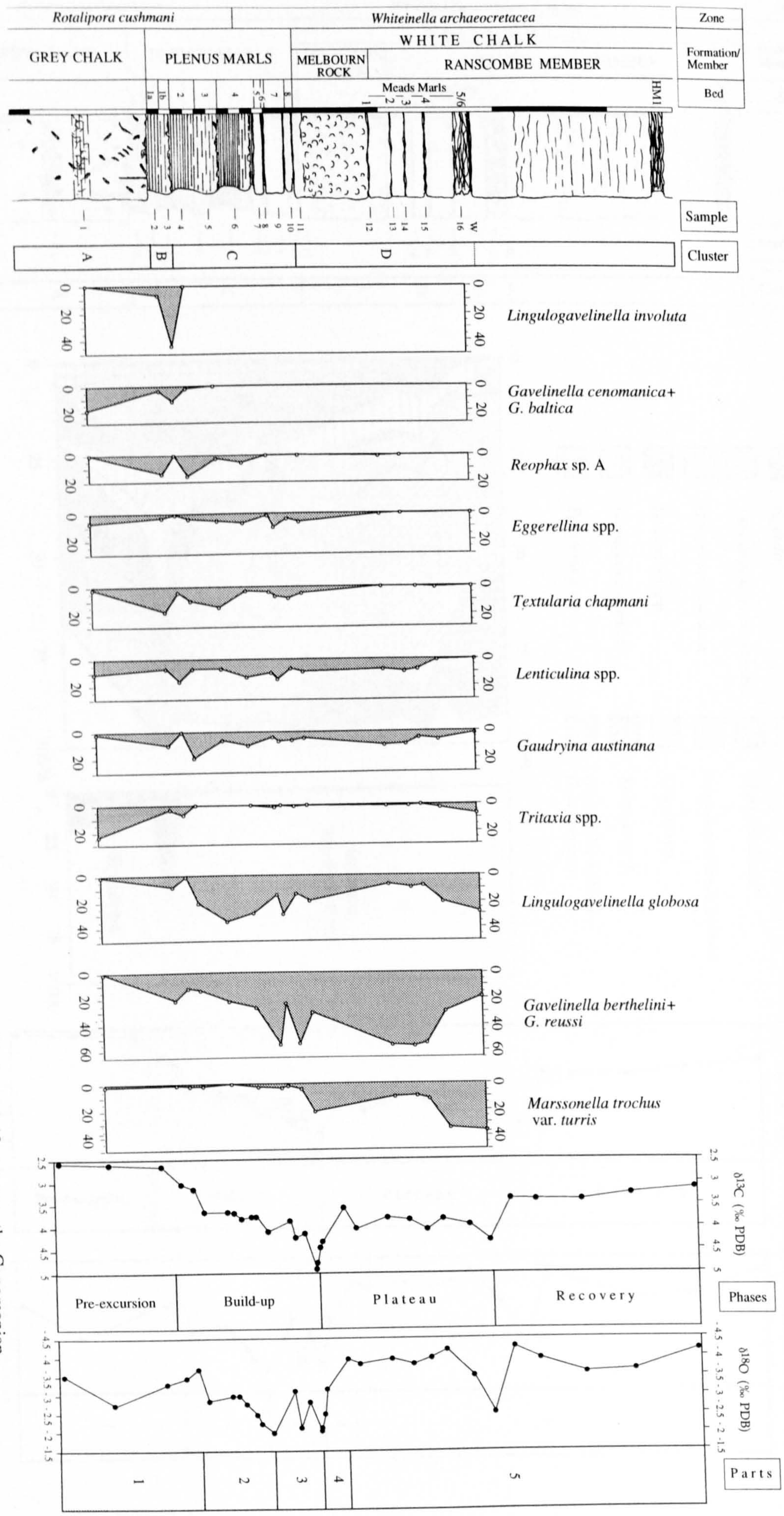


Figure 6. 9. Correlation between geochemical changes and variation in percentage of important benthic foraminifera across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

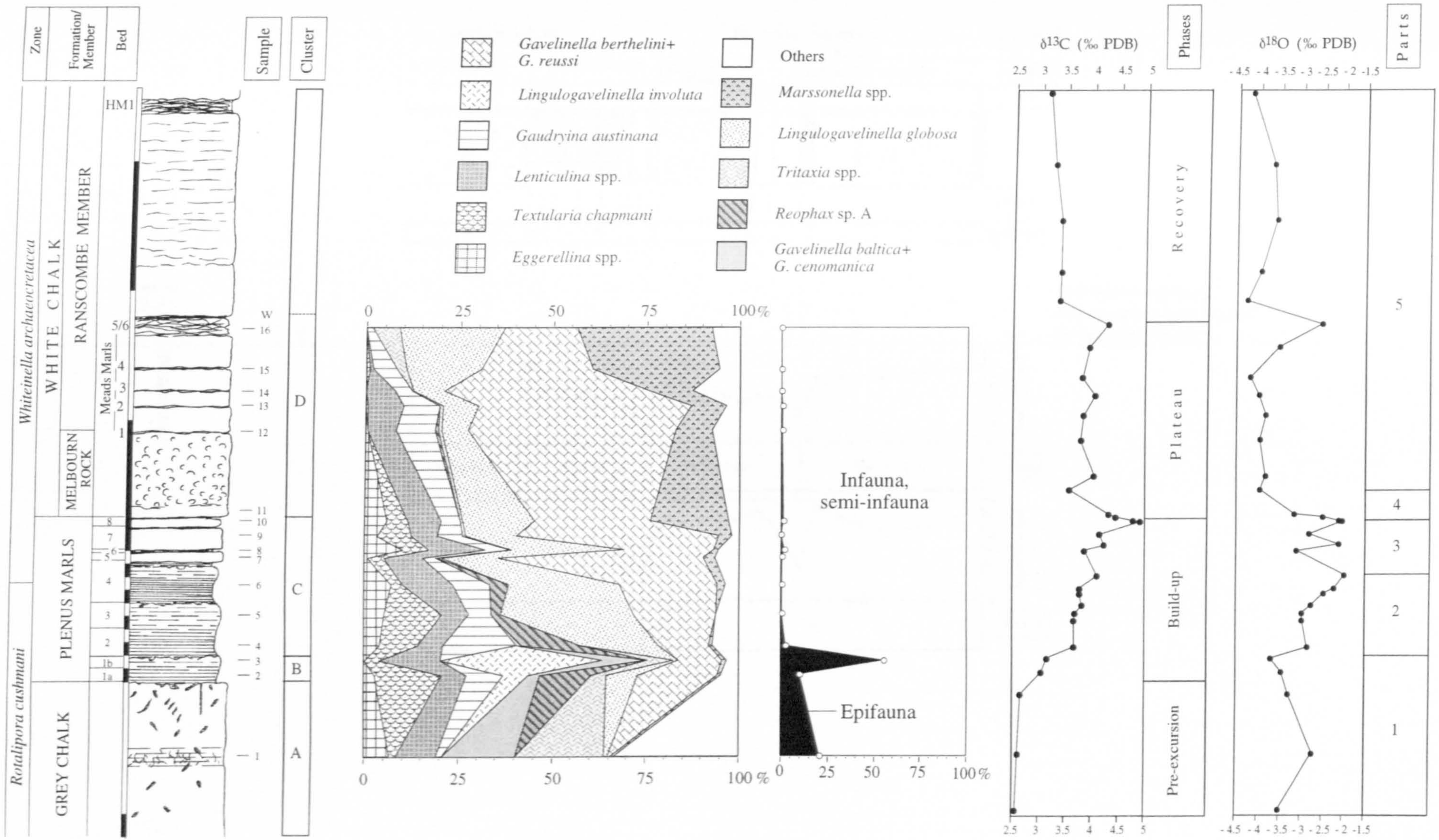


Figure 6. 10. Correlation between geochemical changes and cumulative percent of dominant benthic species and percentage of the epifaunal group across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log and 4.8 for colour vision.

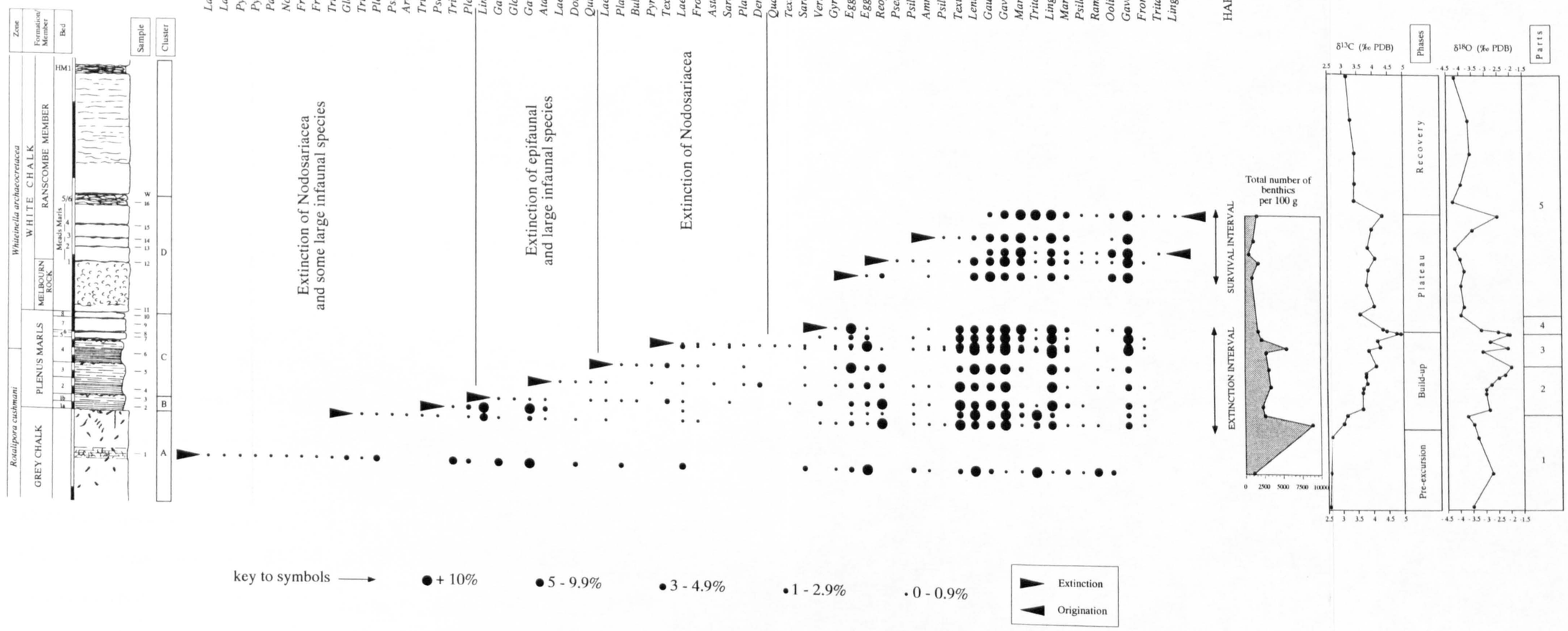


Figure 6.11. Correlation between geochemical changes and distribution of coarse benthic foraminifera across the Cenomanian - Turonian boundary at Westbury. Scale in metres. For key to symbols on log see Figure 4.1.

together with *Gavelinella reussi*, *Marssonella* spp. and *Lingulogavelinella globosa* are the dominant species, although *Lenticulina* spp., and *Gaudryina austinana* are other important elements of the assemblage.

At South Ferriby $\delta^{13}C$ values in the Ferriby Chalk Formation (samples S1 and S2) are fairly high (3.0-3.9‰) compared with the other sections and only 1 species (*Arenobulimina pseudalbiana*) occurs for the last time in sample S2, although 4 species (*Planularia* sp. A, *Marssonella trochus* var. *oxycona*, *Arenobulimina bulleta* and *Tritaxia macfadyeni*) occure in a uniqe sample. The assemblage is diversified, consisting of *Tritaxia* spp., *Plectina* spp. plus *Dorothia gradata*, *Ammodiscus cretaceus* and *Hyperammina gaultina*, *Gavelinella baltica*, *Gavelinella cenomanica* and *Lenticulina* spp (Figures 6.12 - 6.15). The $\delta^{13}C$ values start to increase rapidly at the base of bed A and through the interval between top of bed C to base of bed F1 form two peaks with a trough between them. During this interval (bed A to base of bed F1) successive last occurrences of 19 species are recorded and 1 species (*Gyroidinoides* sp. A) occurs in a unique sample. The structure of the coarse assemblage in beds A and B is similar to that in the Ferriby Chalk Formation, but changes significantly in bed C, where *Lenticulina* spp. constitute about 90% of the assemblage. In bed D *Lenticulina* spp. and *Textularia chapmani* dominate, while in bed E *Lingulogavelinella globosa*, *Gavelinella berthelini* and *Gavelinella reussi* constitute important elements of the assemblage. In bed F1 and F2, 6 other species occur for the last time, among which are 4 typical late Cenomanian species *Tritaxia tricarinata*, *Tritaxia pyramidata*, *Plectina cenomana* and *Gavelinella cenomanica* (in bed F_2). The assemblage in beds F1 and F2 (bed F3 is barren of benthic foraminifera) consists of *Ammodiscus cretaceus*, *Hyperammina gaultina*, *Gavelinella berthelini*, *Gavelinella reussi*, *Gavelinella baltica*, *Gavelinella cenomanica* (only in bed F2) and *Lenticulina* spp. The $\delta^{13}C$ values increase from bed G to a peak in bed H (3.6‰), but drop again in bed I (3.3‰). The interval is characterised by last occurrences of 3 species (*Eggerellina mariae*, *Gavelinella* sp. and *Hyperammina gaultina*), unique appearence of 1 species

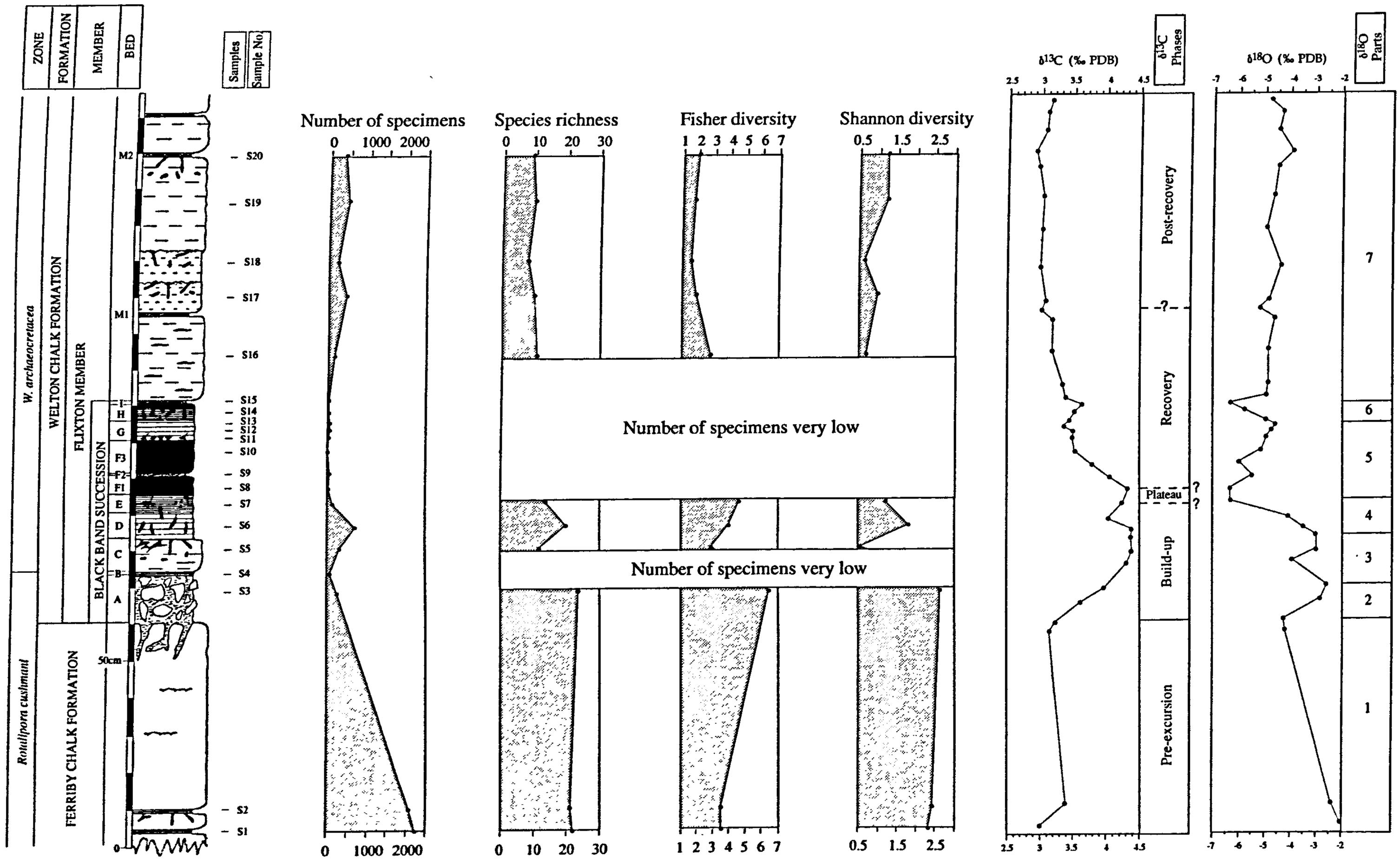


Figure 6.12. Correlation between geochemical changes and number of specimens and benthic foraminifera diversity curves across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

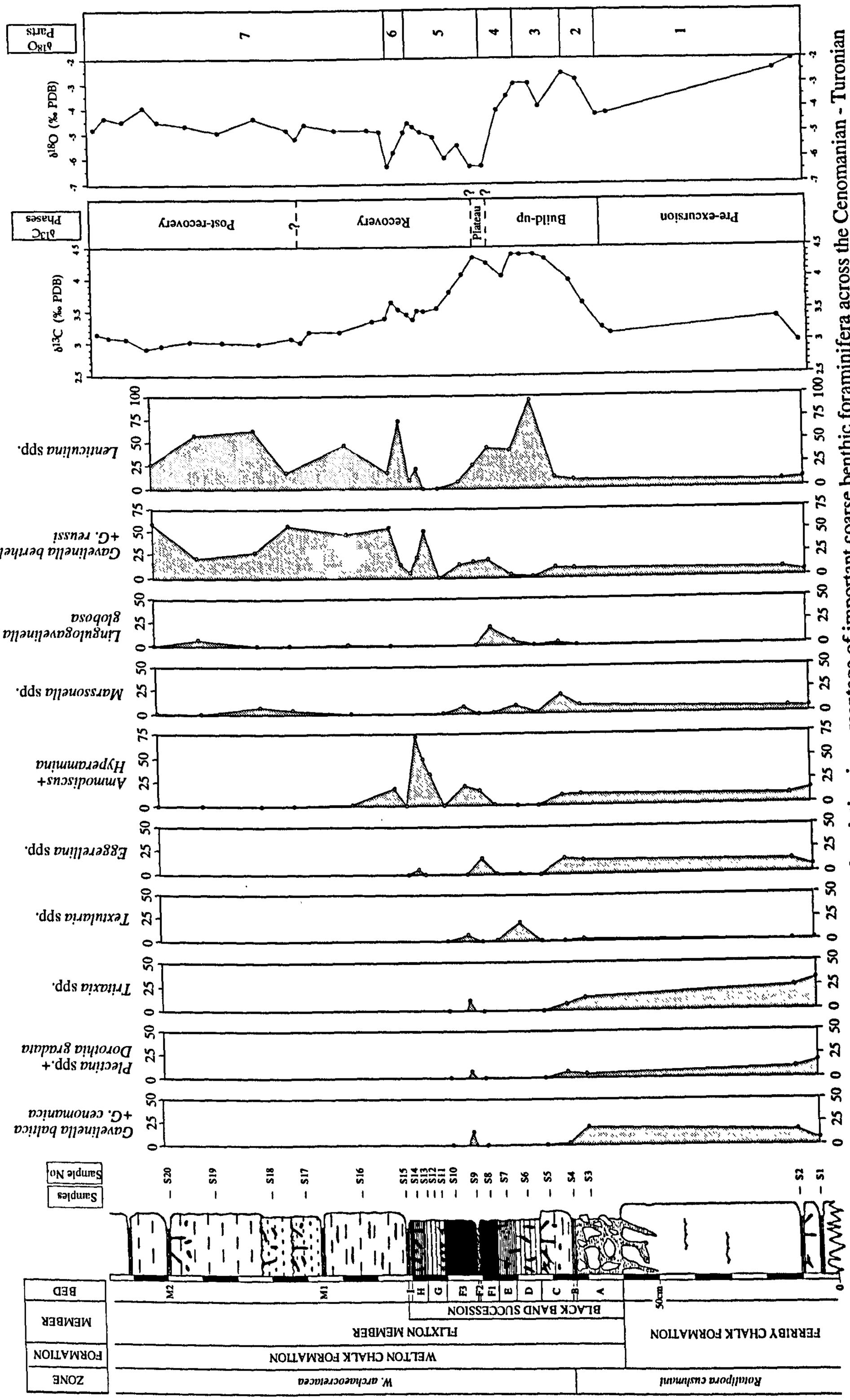


Figure 6.13. Correlation between geochemical changes and variation in percentage of important coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

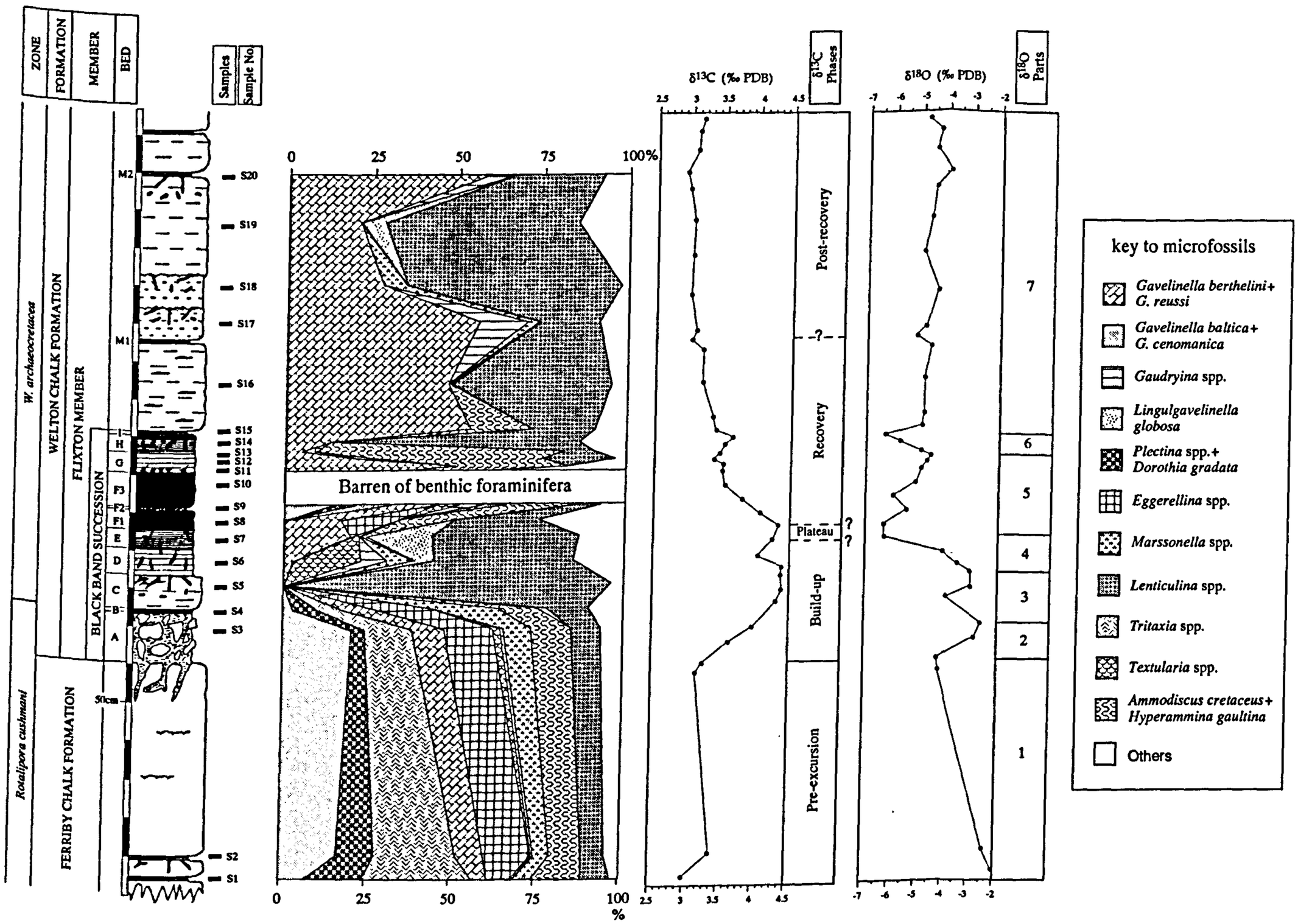


Figure 6.14. Correlation between geochemical changes and comulative percent of dominant coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log and 5.9 for colour vision.

Figure 6.15. Correlation between geochemical changes and abundance and distribution of coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

(*Frondicularia lanceola*) and finally origination of 1 species (*Lingulogavelinella aumalensis*). The structure of the assemblage during this interval is quite different from that in the other intervals and *Lenticulina* spp., *Ammodiscus cretaceus*, *Hyperammina gaultina, Gavelinella berthelini, Gavelinella reussi* constitute the major elements of the assemblage. The $\delta^{13}C$ values decline thereafter and fall to a trough (3.0‰) in marl 1, which might be regarded as the end of the recovery phase. Through this interval only 1 species (*Astacolus* sp. A) appears for the first time (only in sample S16). In the Welton Chalk Formation above the marl 1, $\delta^{13}C$ values do not change significantly up to marl 2 (2.9-3‰), but then begin to rise again (3.0-3.1‰). The structure of the assemblage remains unchanged, but 8 species occur for the last time, which could be due to sampling and 2 new species appear for the first time as well (*Pseudospiroplectinata plana* and *Arenobulimina truncata*).

As is apparent, rapid increase in $\delta^{13}C$ values correlates with a major decline in diversity, particularly during the lower part of first build-up phase and the second build-up phase of Eastbourne. The diversity of species in the recovery and post-recovery phases at Eastbourne is about 25% of diversity in the pre-excursion phase. The structure of the fauna changes more frequently, but also correlates with the phases of the $\delta^{13}C$ excursion.

6.4.2.1.2. Morphotype groups

The correlation between $\delta^{13}C$ values and changes in the morphotype groups at Eastbourne is shown in Figure 6.16. Morphotype AG-C is dominant in the pre-excursion phase of the carbon excursion (33.8-61.1%), although CH-B_3 (16.2-29.2%) and CH-B_2 (12.2-19.0%) are the other elements of the assemblage and CH-C_2 (1.7-11.1%) and CH-B_4 (0.3-9.0%) constitute only minor percentage of the assemblage. In the lower part of the first build up phase (bed 1) AG-C morphotype is still the major constituent of the assemblage (10.8-58.1%), although the percentage of CH-B_1 increases suddenly (3.0-39.0%) and along with CH-B_3 (0-18.7%), CH-B_2

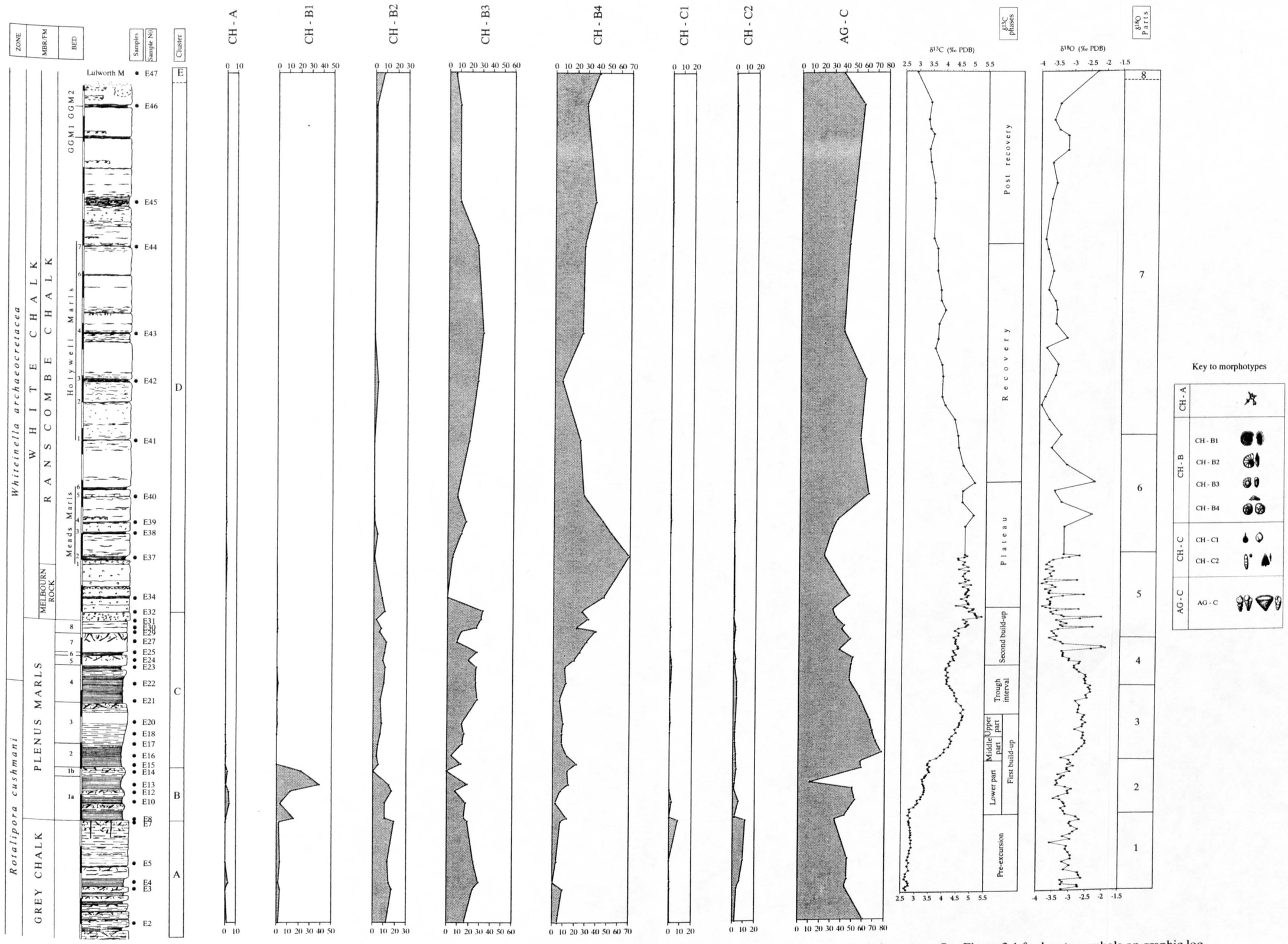


Figure 6.16. Correlation between geochemical changes and morphotype groups across the Cenomanian - Turonian boundary at Eastbourne. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

(0.2-16.9%) and CH-B4 (2.6-14.4%) constitutes the morphotype groups of the assemblage. However, through the rest of the build up phase AG-C (34.0-76.9%) and CH-B_3 (3.9-30.8%) are the dominant morphotypes, although from the second build up phase (top of bed 4) the percentage of CH-B4 morphotype increases rapidly (10.6-39.1%). In the lower part of the plateau phase CH-B_4 (26.2-46.0%) and AG-C (31.1-46.0%) morphotypes are dominant. CH-B_3 (0-32%) and CH-B_2 (7.6-10.2%) are the other important morphotypes of the assemblage. In the middle part the percentage of morphotype AG-C decreases (22.6-29.8%) and CH-B_4 is the dominant morphotype (52.3-69.4%), although CH-B_3 constitutes the other main morphotype of the assemblage (4.6-12.5%). In the upper part of the plateau phase, the recovery and post-recovery phases of the carbon excursion the assemblage is composed essentially of morphotypes AG-C (34.6-63.3%), CH-B_4 (7.2-44.6) and CH-B_3 (5.9-31.9%), although morphotype CH-B_2 is the other constituent of the assemblage (0.2-8.3%).

At Westbury AG-C is the dominant morphotype in the pre-excursion phase (43.2%), although CH-B_3 (20.6%) and CH-B_2 (13.8%) are the other important morphotypes of the assemblage, while CH-C_2 (9.2%), CH-A (6.2%) and CH-C_1 (4.4%) are minor elements of the assemblage (Figure 6.17). In the base of the build-up phase (bed 1) the percentage of morphotype CH-B_1 increases suddenly from 6.6% (in bed 1a) to 43.3% (in bed 1b) and along with AG-C (13.6-49.9%), CH-B4 (11.8-21.3%), CH-B_2 (6.5-16.1%) and CH-B_3 (12.0-13.2%) constitutes an important morphotype group of the assemblage. In the rest of the build-up phase the percentage of morphotype CH-B_4 increases rapidly (13.6-54.9%) and along with AG-C (14.8-54.7), CH-B_3 (13.8-35.4%) and CH-B_2 (6.7-16.0%) constitutes the morphotype groups of the assemblage. In the plateau phase of the carbon excursion, CH-B_4 (19.3-56.6%), AG-C (20.1-48.7%) and CH-B_3 (7.2-28.3) are the dominant morphotypes, while CH-B_2 (0-9.5%) and CH-C_1 (0.9-8.2%) are less important morphotype groups of the assemblage.

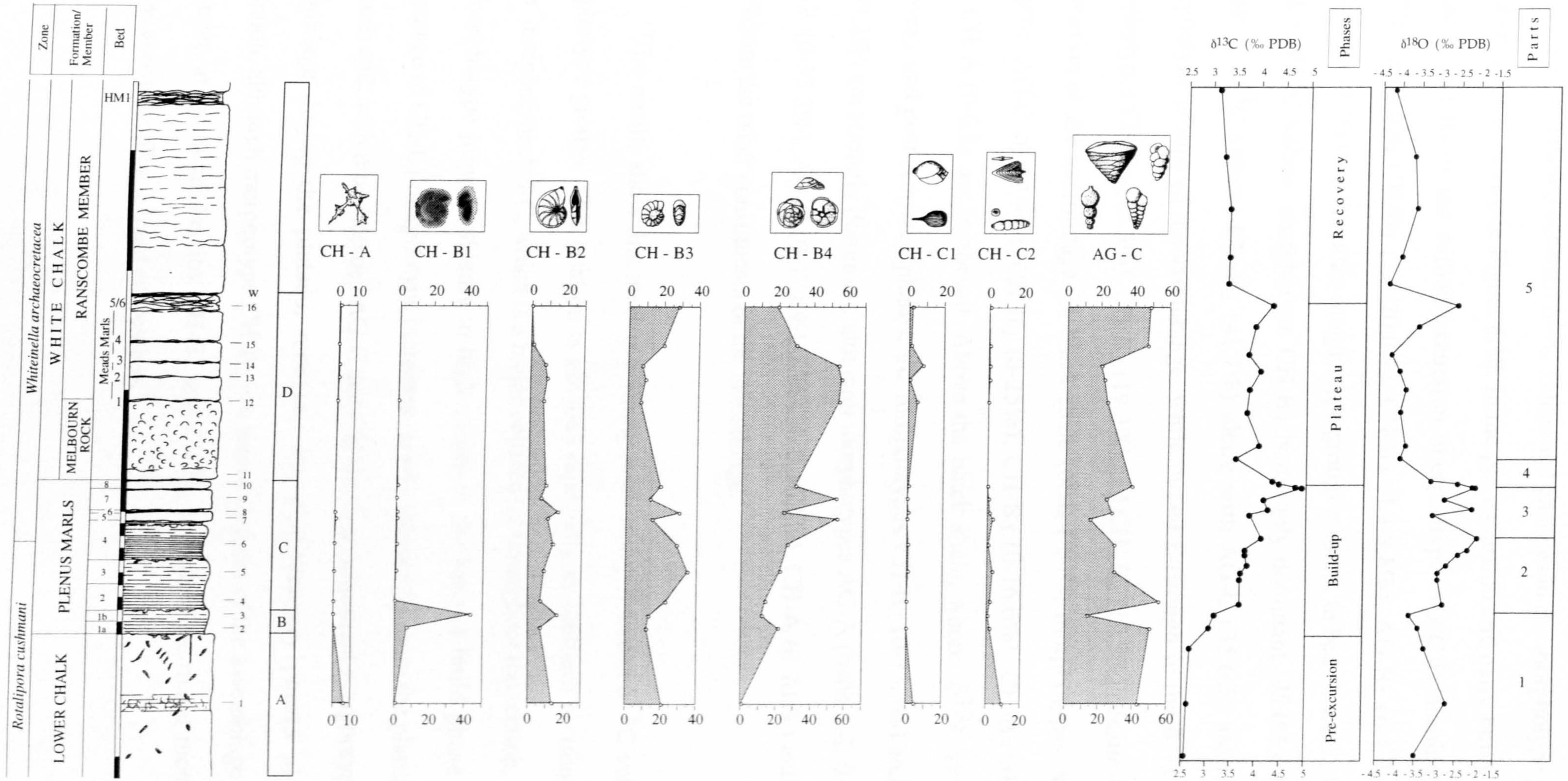


Figure 6. 17. Correlation between geochemical changes and variation in morphotype groups across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

The correlation between $\delta^{13}C$ values and changes in the morphotype groups at South Ferriby is shown in Figure 6.18. In the pre-excursion and early build-up phase (beds A and B) of the carbon excursion, morphotype AG-C is dominant (45.3-64.7%), although CH-B_3 (5.6-20.0%), CH-B_4 (4.4-9.8%), AG-B_2 (6.4-7-6%) and AG-A (1.6-7.3%) are the other morphotype groups present. In bed C, where there is a peak in $\delta^{13}C$ values, morphotype CH-B_2 is strongly dominant (95.0%). In bed D (peak of $\delta^{13}C$ values) CH-B_2 (41.7%) along with AG-C (35.6%) are important morphotype groups of the assemblage, while in bed E (trough in the $\delta^{13}C$ curve), morphotypes CH-B_2 (44.3%), CH-B_3 (19.3%) and CH- B_4 (19.3%) constitute a high proportion of the assemblage. In black shale (beds F1-F3) morphotypes AG-B (0-41.6%), AG-C (0-37.9%), CH-B_2 (0-25%), CH-B_4 (0-16.6%), CH-B_3 (0-13.7%) and CH-A (0-6.8) are important. Above the black shale, where $\delta^{13}C$ curve is in recovery and post-recovery phases, the morphotypes CH-B_2 (0-73.3%) and CH-B_4 (9-59.2%) are strongly dominant, although morphotypes AG-A (beds G-I, 0-45.4%), AG-B (0-33.3%), AG-C (0-17.6%), CH-C_2 (0-16.6%), CH-A (0-7.0%) and CH-B_3 (0-9%) are the other constituents of the assemblage.

The results show that there is a strong relationship between $\delta^{13}C$ values and morphotype groups. This relation is obvious especially in southern sections. Apart from morphotype AG-C, which is a major constituent throughout the section, the CH-B_1 morphotype jumps suddenly to high values in the base of build phase and the percentage of CH-B_4 morphotype increases rapidly (especially from the plateau phase upward) and, with morphotypes AG-C and CH-B_3, is an important morphotype of the assemblage during the plateau, recovery and post-recovery phases of carbon excursion, although morphotype CH-B_2 is a minor element of the assemblage as well. However, at the South Ferriby CH-B_4 and CH-B_2 constitute the major morphotype groups above the Black Band succession.

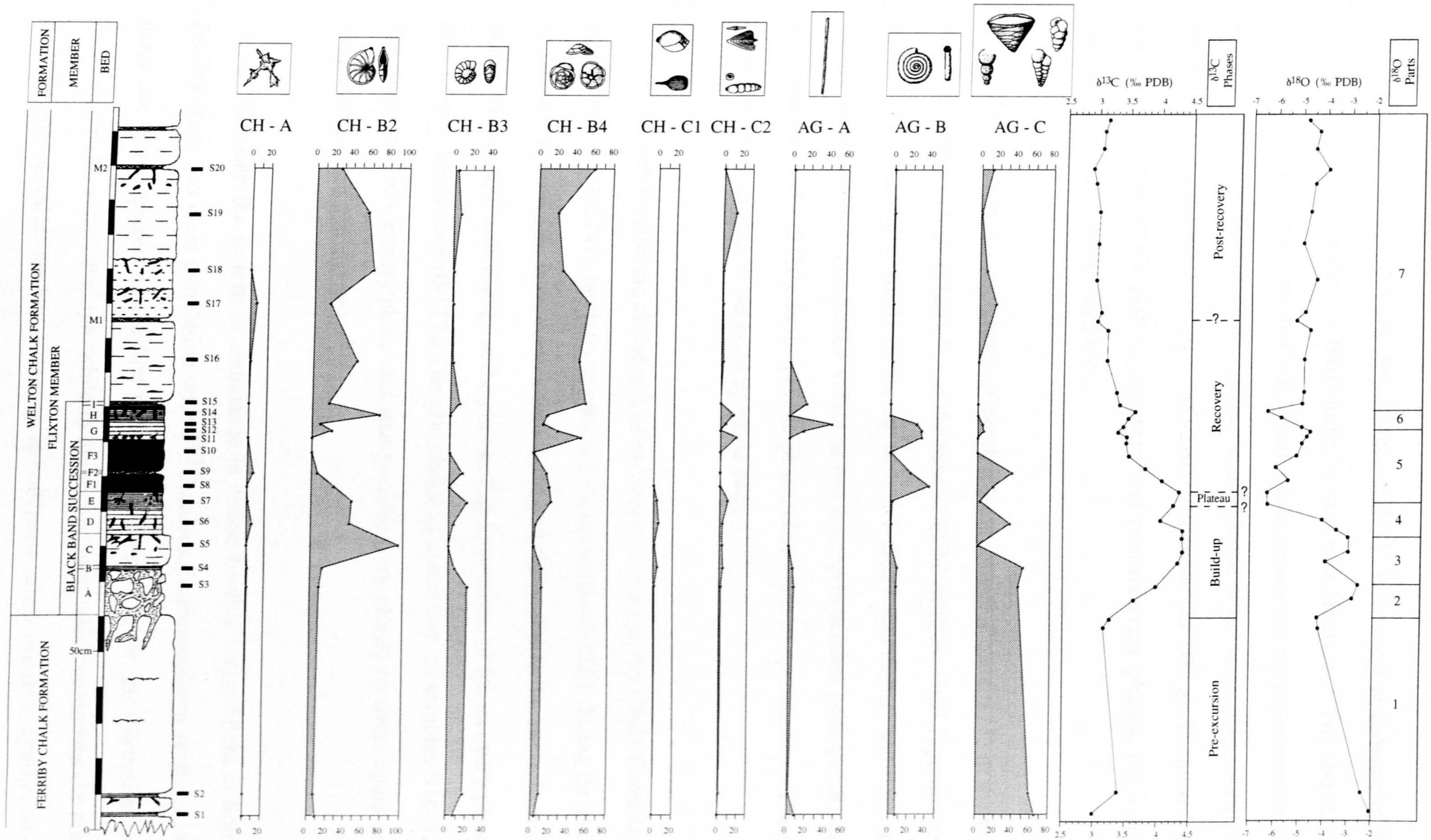


Figure 6.18. Correlation between geochemical changes and variation in percentage of important morphotype groups across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

6.4.2.1.3. Abundance

The correlation between the changes of $\delta^{13}C$ values and abundance of the coarse benthic foraminifera, at Eastbourne, is shown in Figure 6.7. The abundance can be divided into two parts. In the first part, which consists of the pre-excursion and build up phases of the isotope excursion, the abundance of the assemblage oscillates strongly, but on the whole is high (700-2701 specimens per 100 g). In the second part, which includes the plateau, recovery and post-recovery phases, the values oscillate less and are lower (216-953).

At Westbury the abundance of benthic foraminifera (Figure 6.11) in the pre-excursion phase is high (1123), but at the base of build up phase (bed 1) jumps to a peak (8774), then falls rapidly at the top of bed 1 (2627 specimens) and does not change significantly to bed 5. The values in bed 6 jump to another peak (5428), but fall rapidly in bed 7 (2180). In the plateau phase, abundance of specimens oscillates, but is always lower than in the build up phase (443-1717).

At South Ferriby the abundance of specimens in the Ferriby Chalk Formation is very high (2100-2247), but falls sharply in beds A and B (60-255), during the build up phase (Figure 6.15). It recovers a little in bed D (721), where the curve forms a trough, but through beds E to I, (in the plateau ? and lower part of the recovery phase) falls to very low values (0-117). The abundance of specimens in samples S16-S20 (the lower part of recovery phase and also post-recovery phase) recovers again and oscillates between 136 and 461.

Although the pattern of abundance in coarse benthic foraminifera at South Ferriby shows no clear correlation with $\delta^{13}C$ values, in the southern sections two parts can be recognised. In the first part, which consists of the pre-excursion and build-up phases, values are high, while in the second part, which comprises the post-build up phases, values are low. However, in both parts values oscillate significantly.

6.4.2.2. Coarse planktic foraminifera (250-500 μm)

6.4.2.2.1. Diversity and assemblage structure

The correlation between $\delta^{13}C$ values and assemblage structure of coarse planktic foraminifera at Eastbourne is shown in Figures 6.19 and 6.20. As is apparent the number of planktic foraminifera is much lower than that of benthic foraminifera. In the pre-excursion phase the assemblage is made of low diversity (6-8 species per sample, but 10 species in total) and no significant change occurs. Although the keeled planktic morphotypes are present, about 72-92‰ of the assemblage is made up of non-keeled morphotype (hedbergellids and whiteinellids). Two rotaliporids occur for the last time in the lower part of the first build-up phase (*Rotalipora deeckei* in the middle, and *Rotalipora greenhornensis* at the top, of bed 1). During this part the diversity does not change (6-9 species per sample and 10 species in total), but the percentage of keeled morphotypes reaches as much as 60% of the assemblage. Through the middle and upper parts of the first build-up phase (bed 2 to middle of bed 3) no last occurrences in the assemblage are recorded. The diversity recovers a little (5-10 species per sample and 10 species in total), but the percentage of keeled morphotypes through these parts is again low (about 13-23%). The last occurrence of the third rotaliporid (*Rotalipora cushmani*) occurs at the top of the trough interval (middle of bed 4). In this interval the total diversity does not change significantly from that of previous interval (9 species per sample and total), while the percentage of keeled morphotypes increases once again and reaches nearly to 56% of the assemblage. During the second build-up phase, 2 other keeled species (*Dicarinella imbricata* and *Praeglobotruncana stephani*) occur for the last time in bed 6, although 1 double-keeled planktic species (*Praeglobotruncana gibba*) and 1 non-keeled species (*Whiteinella baltica*) appear. The sample diversity varies significantly, but the total diversity is higher than that of previous phases (3-9 species per sample and 12 species in total). The percentage of keeled-morphotypes reaches a peak in bed 6 (about 91%), but then falls sharply to a very low values in the rest of the interval (about 0-2%).

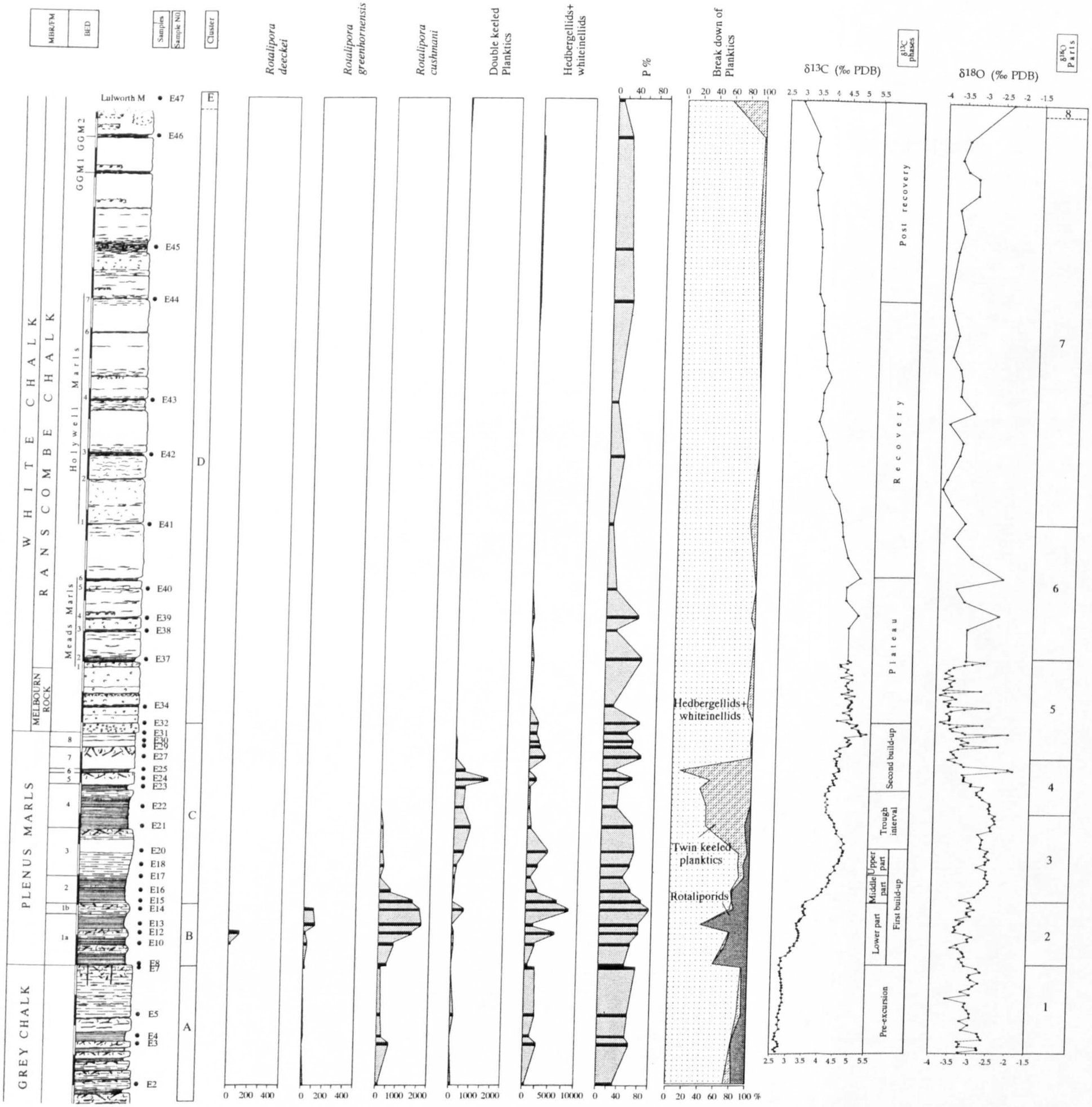


Figure 6.19. Correlation between geochemical changes and absolute abundance (per 100 g), P% and breakdown of coarse planktic foraminifera across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

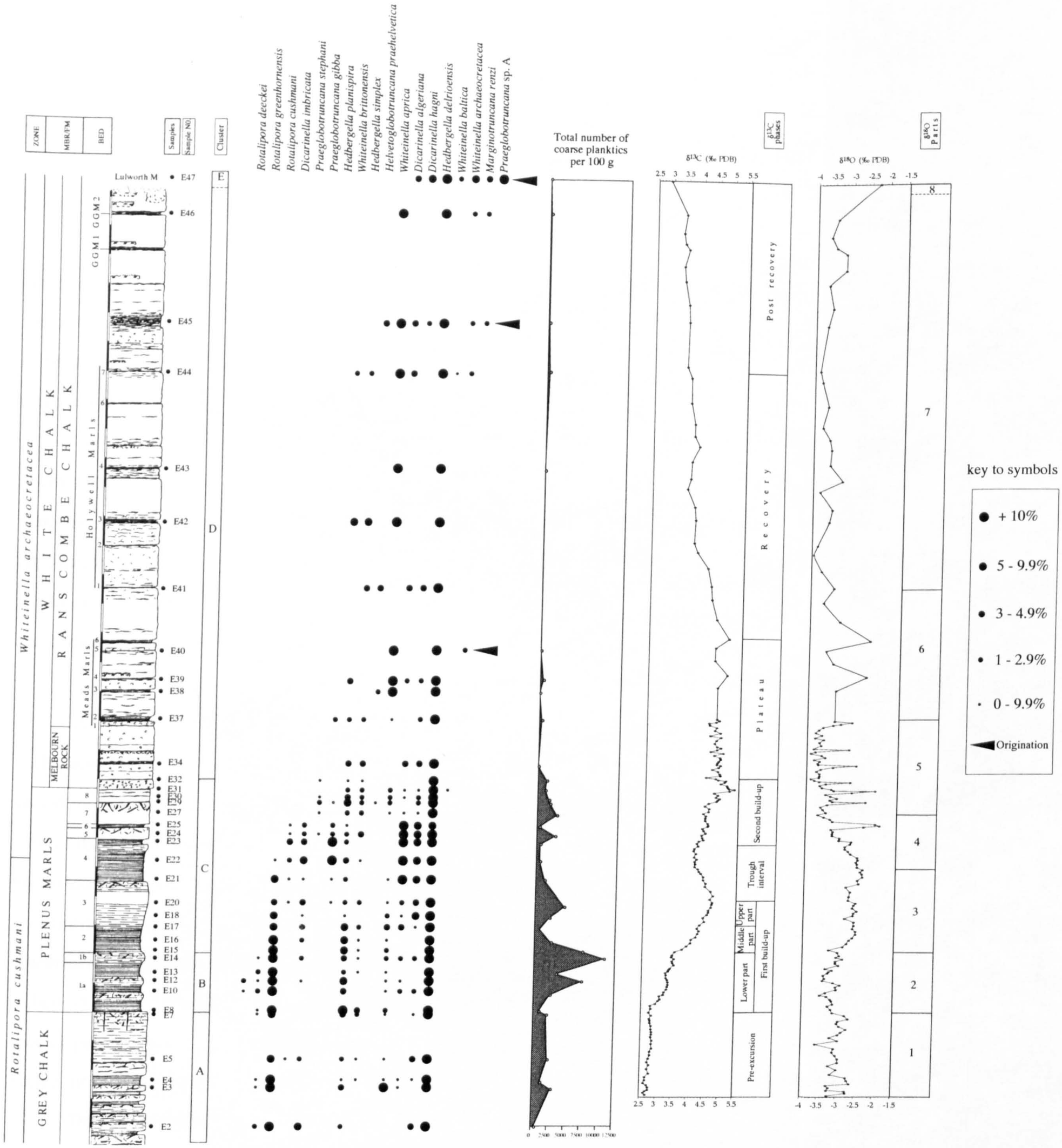


Figure 6.20. Correlation between geochemical changes and distribution of coarse planktic foraminifera across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. For key to symbols on graphic log see Figure 3.1.

During the plateau phase, 2 other species (*Praeglobotruncana gibba* and *Hedbergella planispira*) occur for the last time, while origination of 1 species (*Whiteinella archaeocretacea*) occurs. Compared to previous phases the diversity is lower (3-6 species per sample, but 10 species in total) and non-keeled morphotype is strongly dominant through the plateau phase (93-100%).

In the recovery phase of $\delta^{13}C$ curve (above Meads Marl 6 to probably Holywell Marl 7) 2 other non-keeled species (*Whiteinella brittonensis* and *Hedbergella simplex*) occur for the last time, but no origination is recorded. The diversity is similar to previous phase (2-7 species per sample, but 9 species in total) and non-keeled morphotype is still strongly dominant (about 91-96%).

In the post recovery phase 2 non-keeled species (*Helvetoglobotruncana praehelvetica* and *Whiteinella aprica*) have their last occurrences. Diversity is lower than that of previous phase (4-7 species per sample, but 9 species in total), while appearance of two new keeled species (*Marginotruncana renzi* and *Praeglobotruncana* sp. A) cause the percentage of keeled morphotypes at the top of the section to increase suddenly and reach 40% of the assemblage.

At Westbury the pre-excursion phase is represented only by one sample, which is characterised by low diversity (only 6 species are present). Both keeled and non-keeled morphotypes are present, but the percentage of keeled morphotypes is about 11% of the assemblage (Figures 6.21 and 6.22). During build up phase of the carbon excursion last occurrences of 3 rotaliporids (*Rotalipora deeckei* and *Rotalipora greenhornensis*, both in bed 1b and *Rotalipora cushmani* in bed 4), a dicarinellid (*Dicarinella imbricata* in bed 6) and a praeglobotruncanid (*Praeglobotruncana stephani* in bed 7) occur. During this phase the sample diversity varies significantly (4-10 species per sample and 14 species in total). In beds 4 and 6 the percentage of double-keeled morphotype increases (about 69 and 52% respectively) and forms two peaks.

During the plateau phase, 2 species have their last occurrences (*Hedbergella simplex* in Meads Marl 3 and *Dicarinella algeriana* in Meads Marl 4), and are replaced

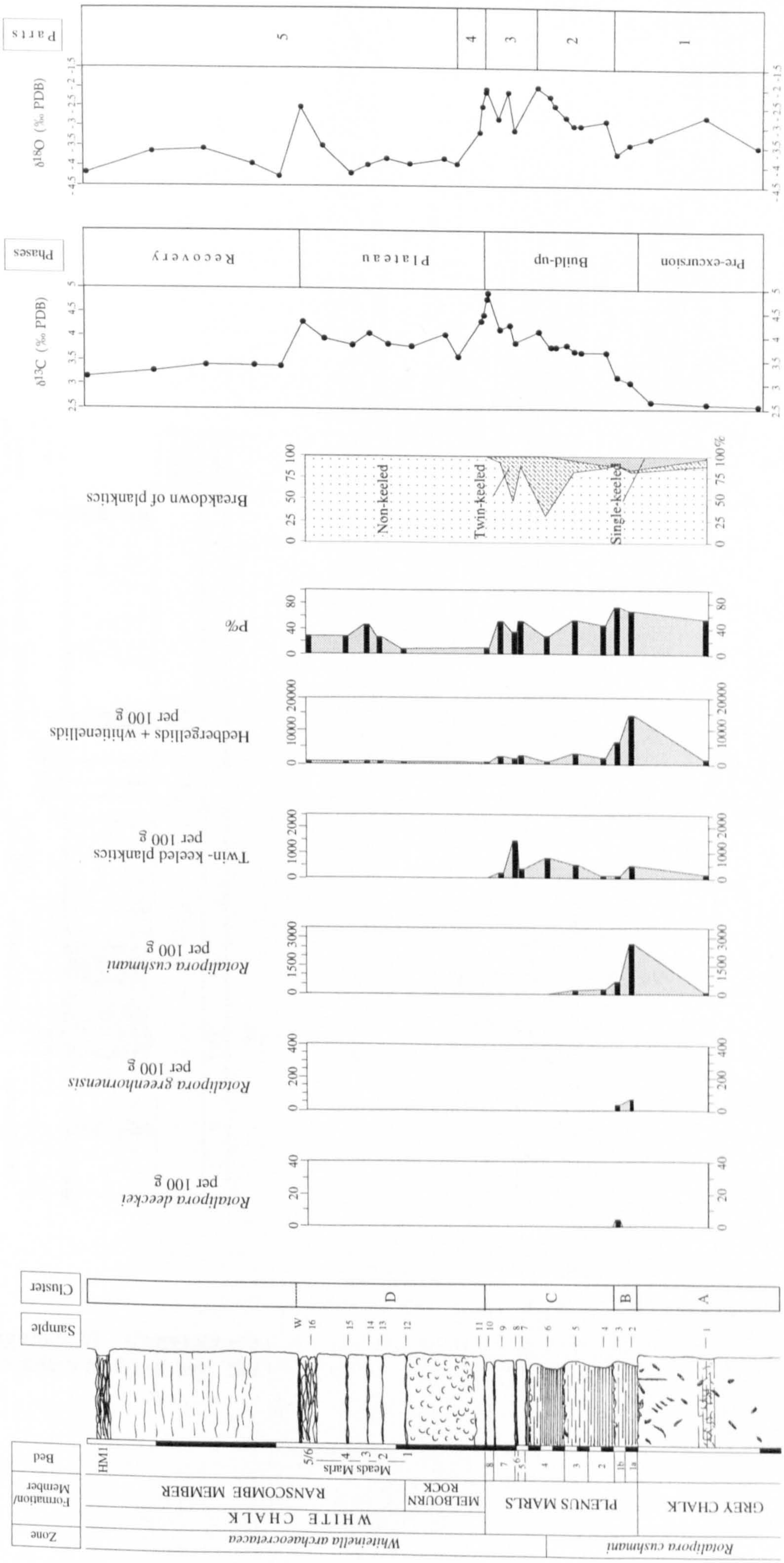


Figure 6.21. Correlation between geochemical changes and absolute abundance, P% and breakdown of planktic assemblage across the Cenomanian - Turonian boundary at Westbury. Scales in metres. See Figure 4.1 for key to symbols on graphic log.

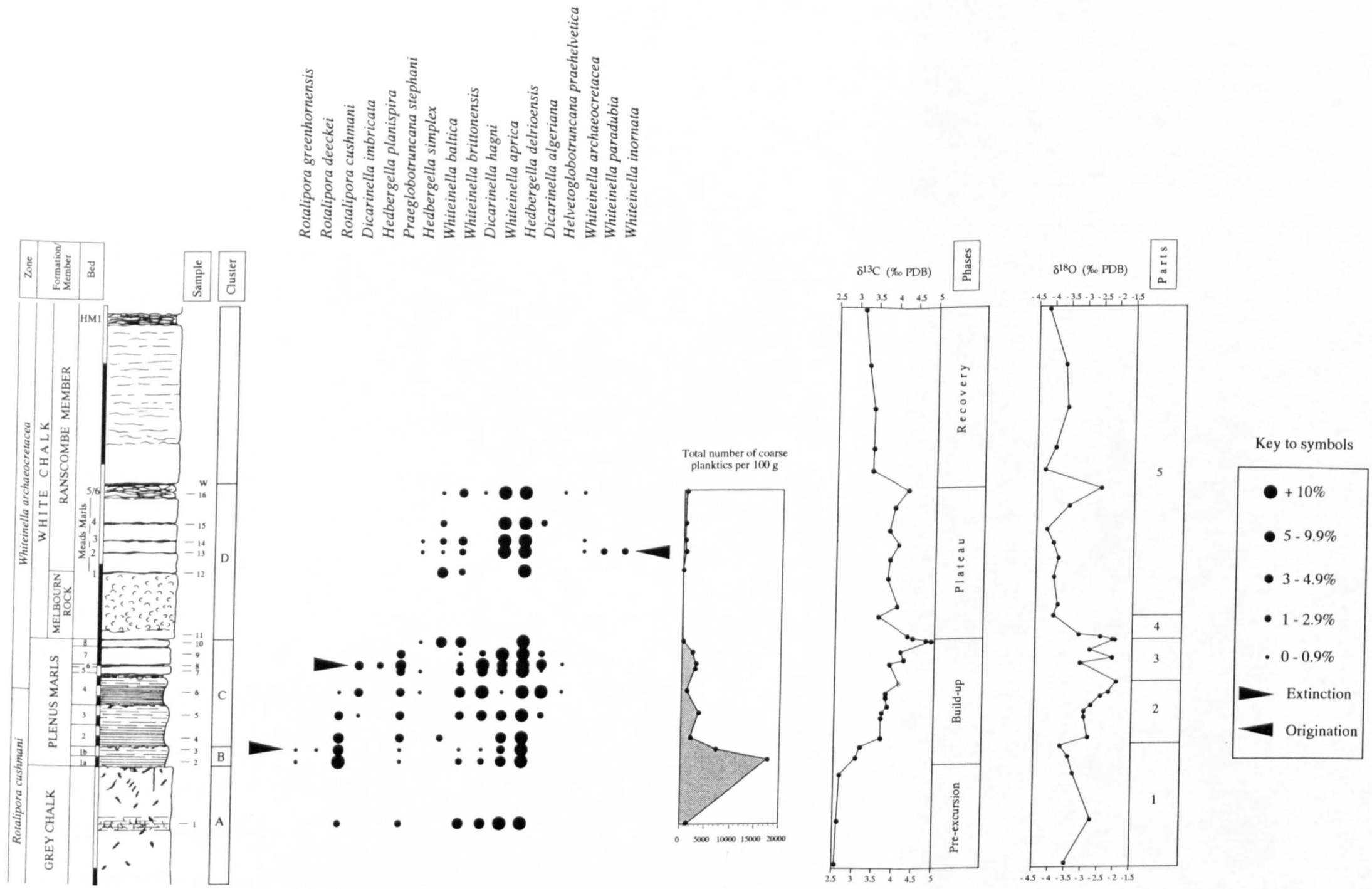


Figure 6.22. Correlation between geochemical changes and total number and distribution of coarse planktic foraminifera across the Cenomanian - Turonian boundary at Westbury. Scale in metres. For key to symbols on log see Figure 4.1.

by 3 new species (*Whiteinella archaeocretaceus*, *Whiteinella paradubia* and *Whiteinella inornata,* all in Meads Marl 2). In this phase the samples diversity varies significantly and the total diversity is lower than that of the second build-up phase (3-8 species per sample, but 11 species in total). Also, the assemblage consists almost completely of non-keeled morphotype (99.8-100%).

At South Ferriby in pre-excursion and early stage of build-up phase (Ferriby Chalk Formation and bed A) sample diversity varies significantly (1-7 species per sample and 8 species in total), but no last occurrences of the species occur. Both the keeled and non-keeled morphotypes are present, but the keeled morphotypes constitute about 0-36% of the assemblage (Figures 6.23 and 6.24). In bed B, $\delta^{13}C$ values continue to increase and this correlates with the last occurrence of *Rotalipora cushmani* and the appearance of *Helvetoglobotruncana praehelvetica.* Nine species are present in the unique sample and the percentage of keeled morphotypes is fairly high (about 35%). In beds C and D, where the $\delta^{13}C$ curve forms a peak and trough, respectively, no last occurrences are recorded and compared to other intervals the diversity is high (7-8 species per sample and 10 species in total), but the percentage of keeled morphotypes is fairly low (15.3-18.4%). In bed F1, where the second peak in the $\delta^{13}C$ curve occurs, no last occurrences are recorded, but *Praeglobotruncana gibba* appears. In this bed 8 taxon are Lazarus species and consequently the diversity is very low (3 species in unique sample), but the percentage of keeled morphotypes recovers a little (20%). Through beds F2 and F3, $\delta^{13}C$ values falls rapidly, which is accompanied with a small recovery in the diversity (5 species in bed F2) and also an increase in the percentage of keeled morphotypes (22.2%). The origination of new species begins at the top of bed G (*Marginotruncana renzi*) and bed H (*Whiteinella archaeocretacea*), during the recovery phase of the excursion, when both the diversity (5-8 species in samples, but 8 species in total) and percentage of keeled morphotypes (45-48%) is high. From bed I to top of the section, where $\delta^{13}C$ curve is in the recovery and post-recovery phase, 4 species have their last occurrences. The diversity

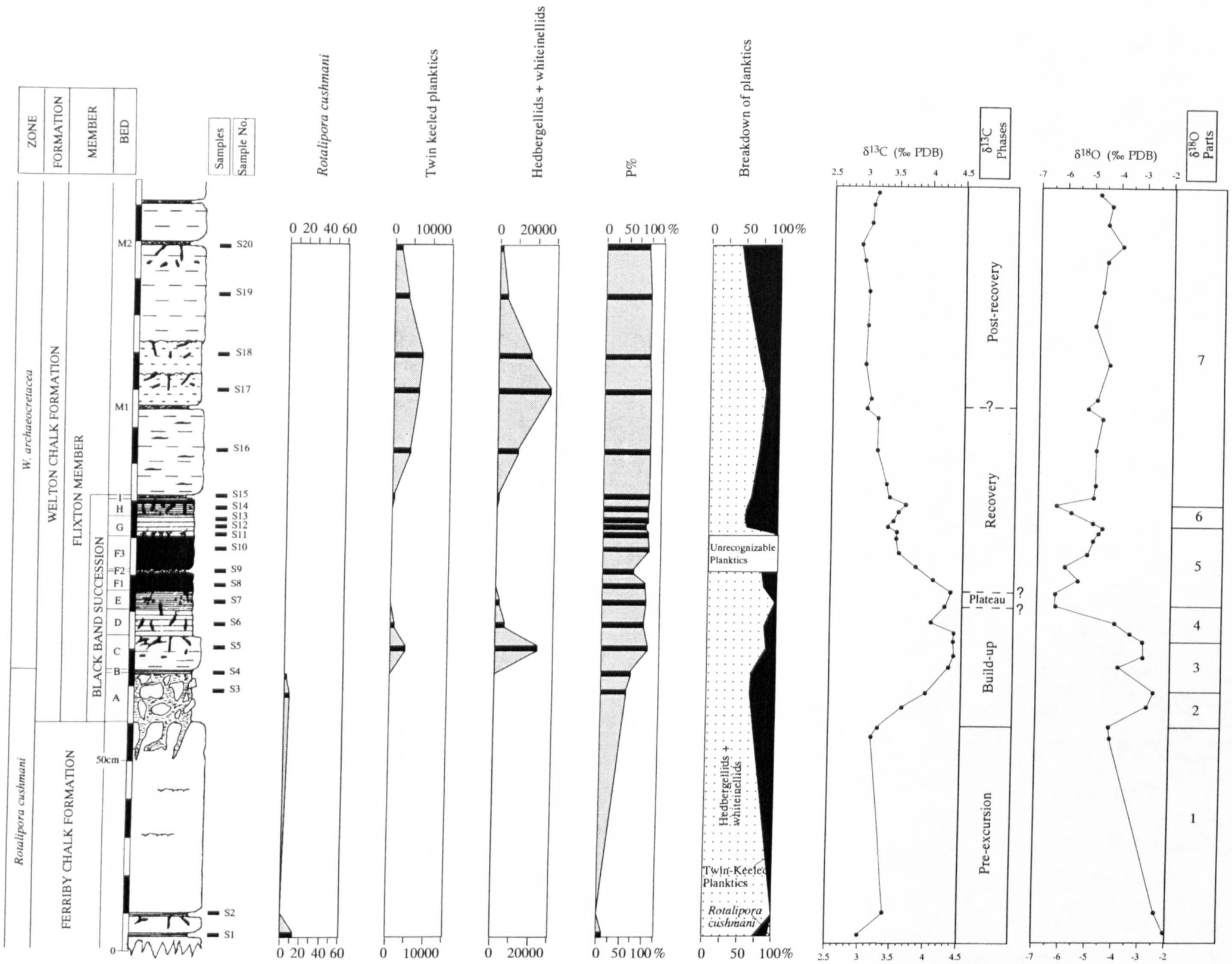


Figure 6.23. Correlation between geochemical changes and absolute abundance, P% and breakdown of coarse benthic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to symbols on graphic log.

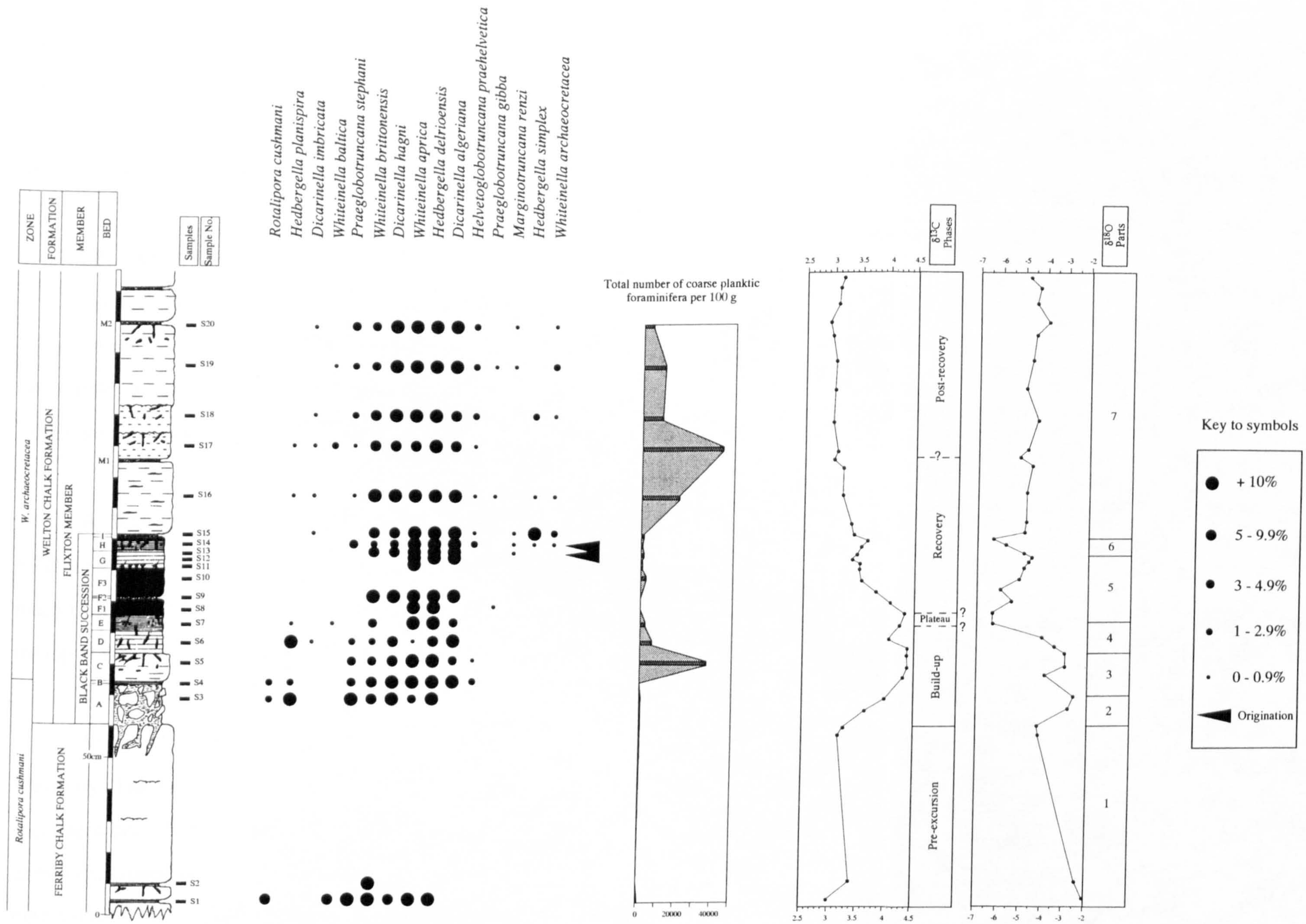


Figure 6.24. Correlation between geochemical changes and total number and distribution of coarse planktic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

is high (10-12 species per sample, but 14 species in total) and the percentage of keeled morphotypes on the whole is high as well (19.5-57.5%).

As is obvious, numbers of planktic species are lower than of benthics and changes correspondingly fewer. Nevertheless, extinction of rotaliporids broadly correlates with the build-up phase of the $\delta^{13}C$ excursion. Changes in the structure of the assemblage (keeled vs. non-keeled) are more frequent but also show some correlation with phases of the carbon excursion.

6.4.2.2.2. Abundance

As with benthics, at Eastbourne there are really two parts (Figure 6.20). Pre-excursion and build-up phases have abundant specimens with considerable variation (488-10846 specimens per 100 g) and a peak in bed 1. After the peak of the excursion values are much lower and the contrast is even more obvious (83-628).

At Westbury the pattern of abundance can be divided into two parts (Figure 6.22). In the pre-excursion to before the top of the excursion abundance is high with much fluctuation (1140-17436 specimens per 100 g) and a peak in bed 1, while from the top of the excursion abundance is low and the contrast is quite clear (77-591).

At South Ferriby the pattern of abundance differs from Eastbourne and Westbury. The pre-excursion phase correlates with very low abundance (26-223 specimens per 100 g), Figure 6.24. In beds A and B during build up phase of the carbon excursion, abundance is still very low (102-295). However, it jumps to a very high value (35922) in bed C, where there is a peak in the $\delta^{13}C$ excursion. Through beds D to I the abundance ranges between 60 and 6123, but from sample S16-S20, where the $\delta^{13}C$ curve is in the upper part of recovery and post-recovery phase the abundance is very high and ranges between 4751 to 43558.

The pattern of abundance, especially in southern sections, reveals that two parts can be recognised. In the first part, which correlates with pre-excursion and build up-phases (or before the top of the build-up phase in Westbury) values are high with much fluctuation, while in the second part, which correlates with the rest of the carbon excursion, values are low with less variation.

6.4.2.3. Ostracods

6.4.2.3.1. Diversity and assemblage structure

At Eastbourne, in the Grey Chalk, a diversified assemblage of ostracods occurs (13-22 species per sample, but 27 species in total), which is characterised by high percentage of podocopids (about 30-72%), Figures 6.25 - 6.28. During this interval only 1 species (*Cytherelloidea bonnemai*) occurs for the last time, although 3 other species (*Curfsina derooi*, *Imhotepia euglyphea* and *Cytherelloidea stricta*) occur only in one sample. During the first build-up phase (Beds 1-3), only 2 species have their last occurrences (*Oertliella alata* and *Neocythere kayei*), while 2 species appear (*Pterygocythere laticristata* and *Cytherelloidea hindei*) and 2 others (*Dolocytheridea* sp. A and *Phodeucythere cuneiformis*) occur only in one sample. The diversity in this part is lower than that of the previous phase (11-15 species per sample, but 20 species in total). From the base of bed 1 the percentage of podocopids declines rapidly from 60% and falls to about 30% in the middle of the bed, but increases again rapidly and forms a peak (about 79-91%) in beds 2 and 3. In the trough interval another species (*Pterygocythere laticristata*) has its last occurrence and the diversity decreases more (11-13 species per sample, but 17 species in total). During the second build-up phase 6 other species occur for the last time (*Oertliella donzei* and *Herrigocythere donzei* in bed 5, *Pontocyprella robusta* in the base of bed 8, *Bythoceratina umbonatoides* in the middle of bed 8, *Pterygocythere robusta* in the top of bed 8 and *Macrocypris siliqua* in the base of Melbourn Rock). Compared to the trough interval, the total diversity recovers, but sample diversity varies strongly (4-15 species per sample, but 21

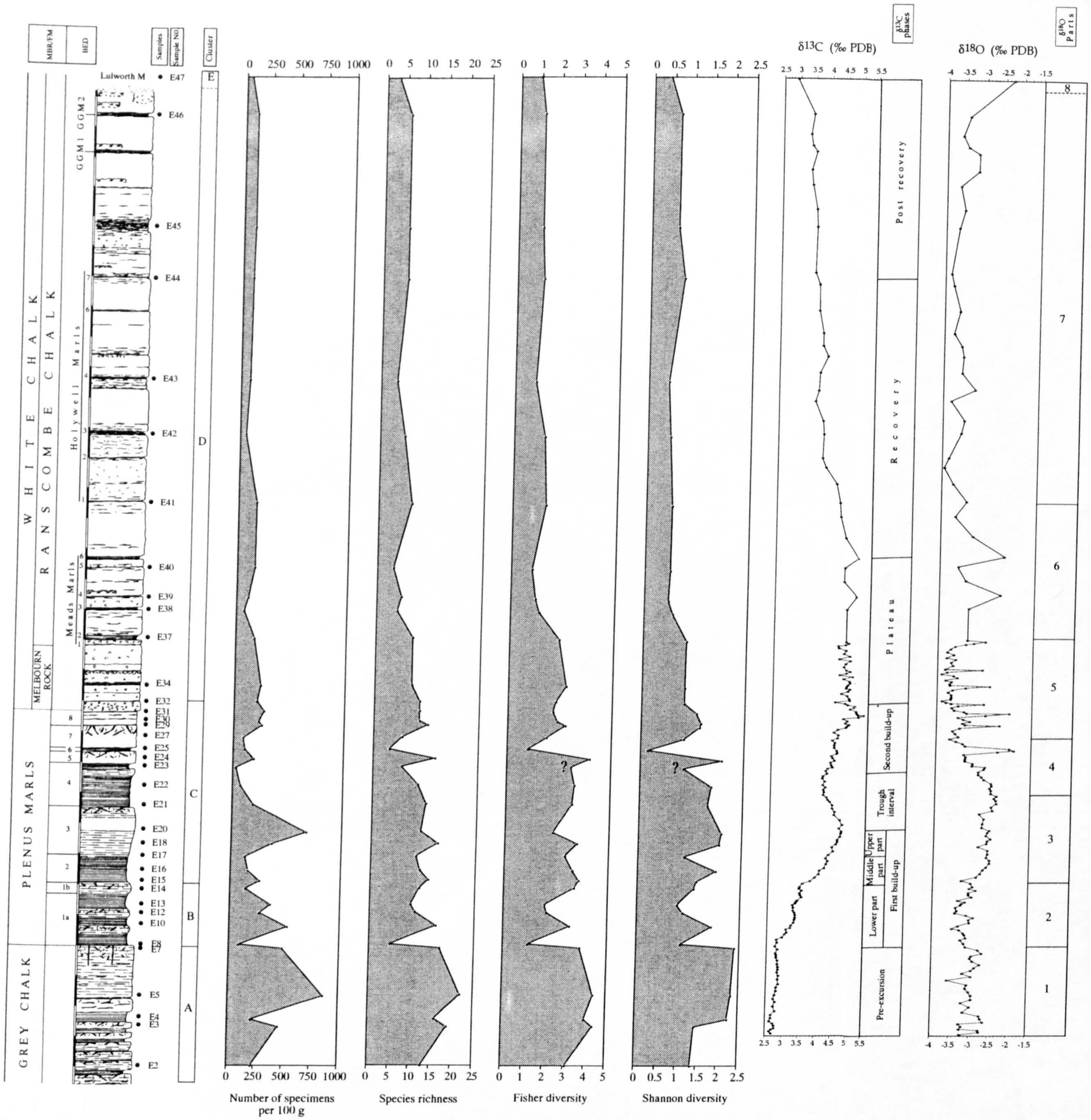


Figure 6.25. Correlation between geochemical changes and number of specimens and ostracod diversity curves across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Question marks indicate the low number of specimens, therefor uncertain diversities. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

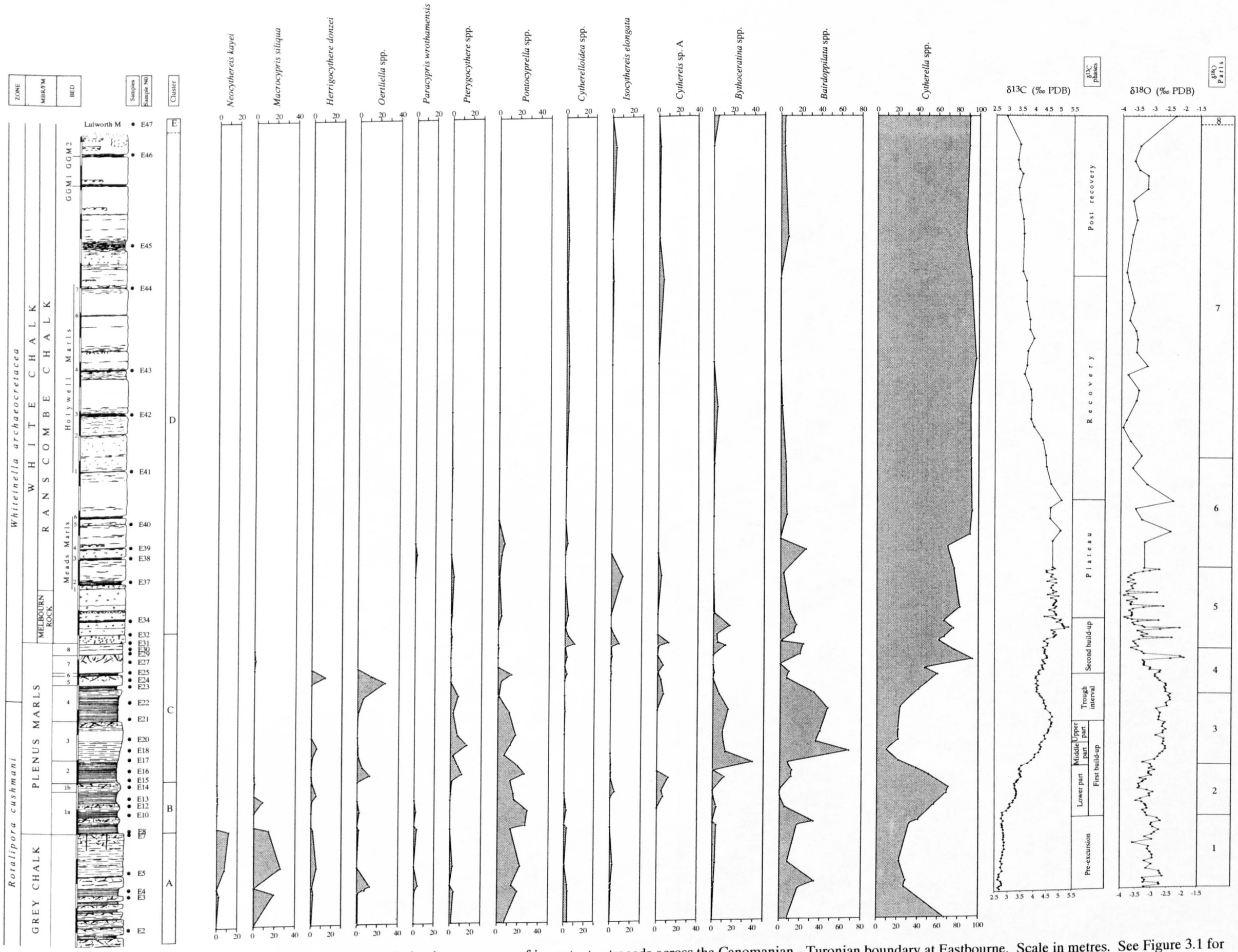


Figure 6.26. Correlation between geochemical changes and variation in percentage of important ostracods across the Cenomanian - Turonian boundary at Eastbourne. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

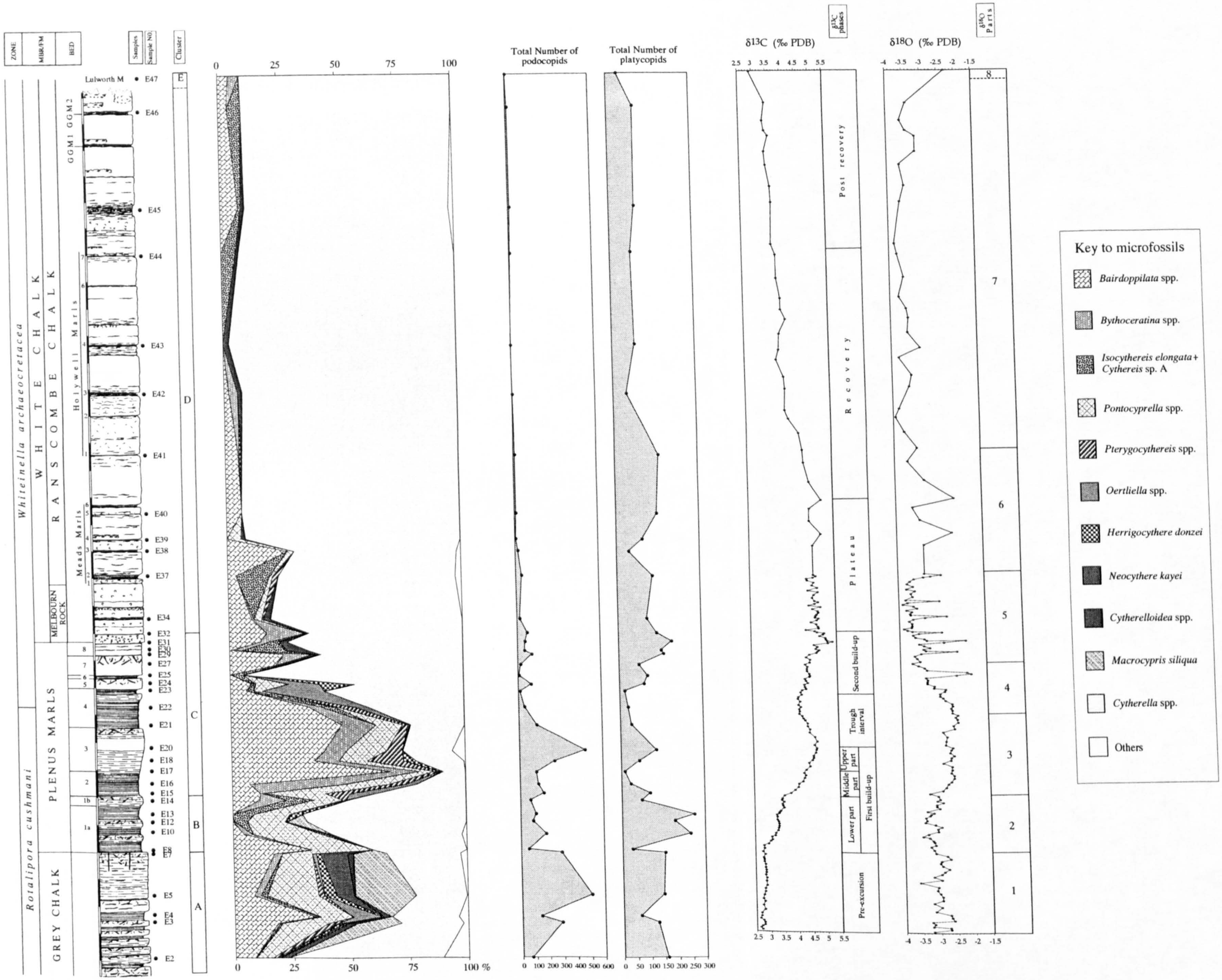


Figure 6.27. Correlation between geochemical changes and cumulative percent and abundance of platycopids and podocopids across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log and 3.15 for colour vision.

Figure 6.28. Correlation between geochemical changes and distribution of ostracods across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. For key to symbols on graphic log see Figure 3.1.

species in total). In this interval the percentage of the podocopids ranges between 6 and 51% and platycopids constitute the dominant group of the assemblage.

Through the plateau phase 5 other species have their last occurrences (*Cytherella chathamensis*, *Bythoceratina herrigi*, *Paracypris wrothamensis*, *Pontocyprella hindei* and *Pontocyprella harrisiana*), while one species, *Mosaeleberis* sp. A appears for the first time. Diversity decreases more (4-9 species per sample and 15 species in total) and the percentage of podocopids is low (about 6-34%).

In the recovery phase 2 other species (*Pterygocythere diminuta* and *Cytherelloidea kayei*) occur for the last time, but in the post recovery phase 6 species have their last occurrences (5 species alone in Gun Gardens Marl 2, which might be due to sampling). During these intervals the diversity falls more (3-7 species per sample, but 10 species in total) and the percentage of podocopids is very low (0-10.5%) and platycopids are the strongly dominant group.

At Westbury, the pre-excursion assemblage is diversified (17 species in the unique sample), in which podocopids constitute about 82% of the assemblage, and only one species (*Cytherelloidea bonnemai*) is restricted to this phase (Figures 6.29 - 6.31). In beds 1 and 2 the total diversity increases from that in the Grey Chalk (15-19 species per sample, but 21 species in total) and 5 more species appear (*Pontocyprella robusta*, *Pterygocythere laticristata*, *Bythoceratina umbonatoides*, *Cytherelloidea hindei* and *Bythoceratina umbonata*). In these beds podocopids are still dominant (59-77% in bed 1, and about 76% in bed 2). In beds 3 and 4, $\delta^{13}C$ values continue to increase and this correlates with high numbers of last occurrences: 3 species (*Neocythere kayei*, *Herrigocythere donzei* and *Pontocyprella robusta*) go in bed 3, although 1 species (*Habrocythere sp. A*) appears only in one sample restricted to bed 3. Two species (*Pterygocythere laticristata* and *Pterygocythere robusta*) occur in bed 4 for the last time, although 1 species (*Dolocytheridea* sp. A) appears only in one sample and is restricted to bed 4. The diversity in these beds does not change significantly compared to that of previous interval (13-20 species per sample and 21 species in

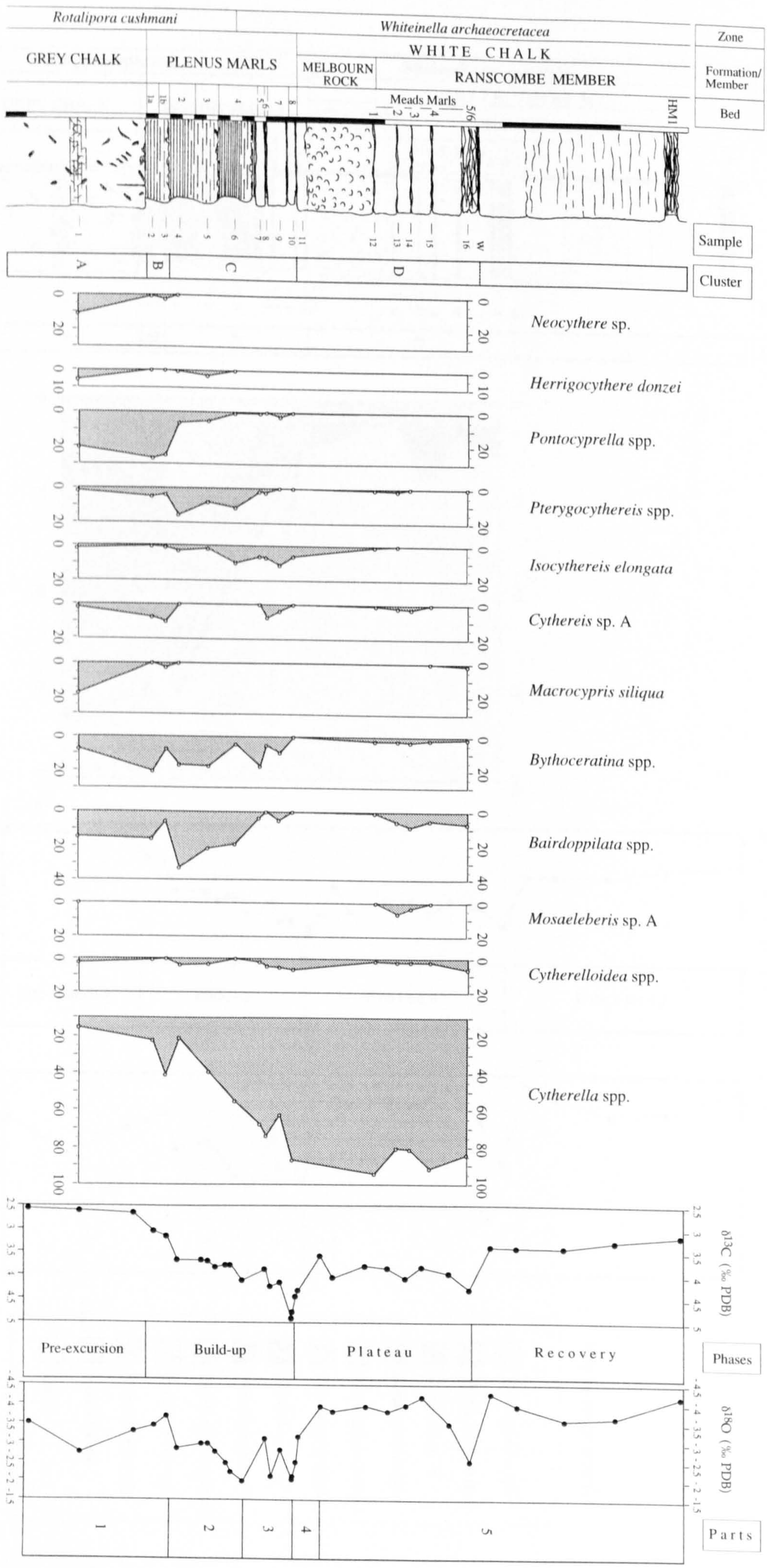


Figure 6. 29. Correlation between geochemical changes and variation in percentage of important ostracods across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log.

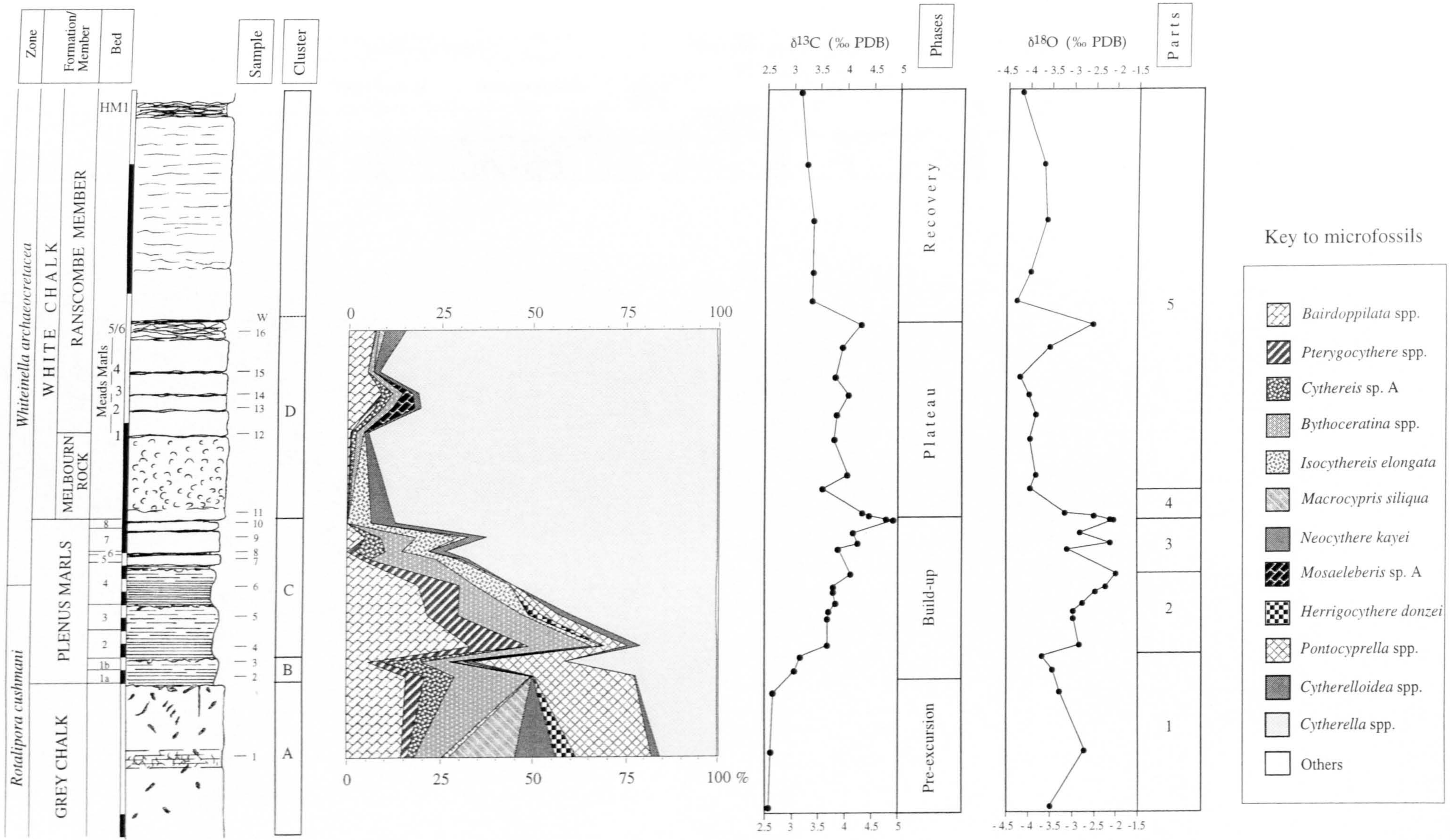


Figure 6. 30. Correlation between geochemical changes and cumulative percent of dominant ostracods across the Cenomanian - Turonian boundary at Westbury. Scale in metres. See Figure 4.1 for key to symbols on graphic log and 4.12 for colour vision.

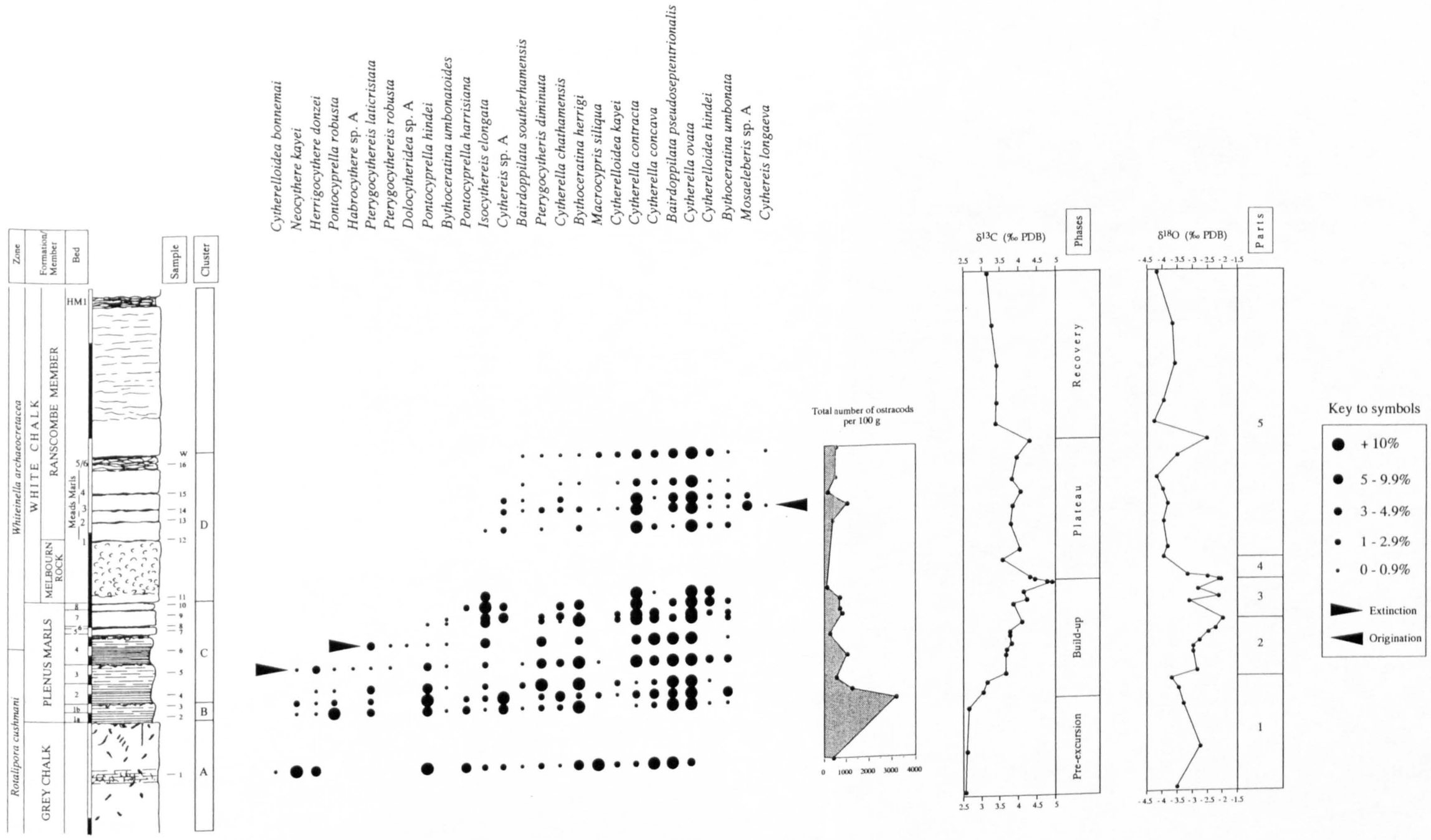


Figure 6.31. Correlation between geochemical changes and total number and distribution of ostracods across the Cenomanian - Turonian boundary at Westbury. Scale in metres. For key to sumbols on log see Figure 4.1.

total), but the dominance of podocopids in these beds decreases rapidly to 45% in bed 4. In the rest of the build up phase (beds 5-8), where $\delta^{13}C$ values are highest (3.8-4.9‰) only 3 species (*Pontocyprella hindei*, *Bythoceratina umbonatoides* and *Pontocyprella harrisiana*) have their last occurrences. The diversity falls to lowest values (5-12 species per sample, but 15 species in total) and podocopid percentage decreases steadily and falls to about 6.5% of the assemblage in bed 8.

Throughout the plateau phase 2 species (*Isocythereis elongata* and *Cythereis* sp. A) occur for the last time, while origination of 2 species (*Mosaeleberis* sp. A and *Cythereis longaeva*) occurs. During the plateau phase, diversity recovers (10-14 species per sample, but 16 species in total) and platycopids are strongly dominant. The percentage of podocopids ranges between approximately 4.5 and 18%.

At South Ferriby the number of ostracods is low (a total of 10 species occur throughout the section). In the pre-excursion phase 5 species occur (Figure 6.32). In bed A the last occurrence of *Cythereis* sp. A is recorded, which correlates with increasing $\delta^{13}C$ values . In bed C, where $\delta^{13}C$ values are at a peak, *Cornicythereis* sp. A, which is absent in southern sections, appears. Diversity in this bed is the same as in the pre-excursion phase (4 species). In bed D, the $\delta^{13}C$ curve forms a trough (4.0‰) and 2 new species (*Isocythereis elongata* and *Bythoceratina umbonata*), which are restricted only to one sample, appear. In this bed 5 species are Lazarus taxa, while 4 species are present (*Cytherella ovata*, *Cytherella contracta*, *Isocythereis elongata* and *Bytocerathina umbonata*). Through bed E to sample S18 no significant changes occur, while in sample S19, 3 species (*Bairdoppilata pseudoseptentrionalis*, *Bairdoppilata southerhamensis* and *Cytherelloidea kayei*) occur for the last time, while 5 species are present.

In general ostracods, also show a correlation between changes in $\delta^{13}C$ values and changes in diversity or structure of the assemblage. They seem to be slower to respond to changes in $\delta^{13}C$, although overall they start more diverse and dominated by podocopids and end less diverse and dominated by platycopids.

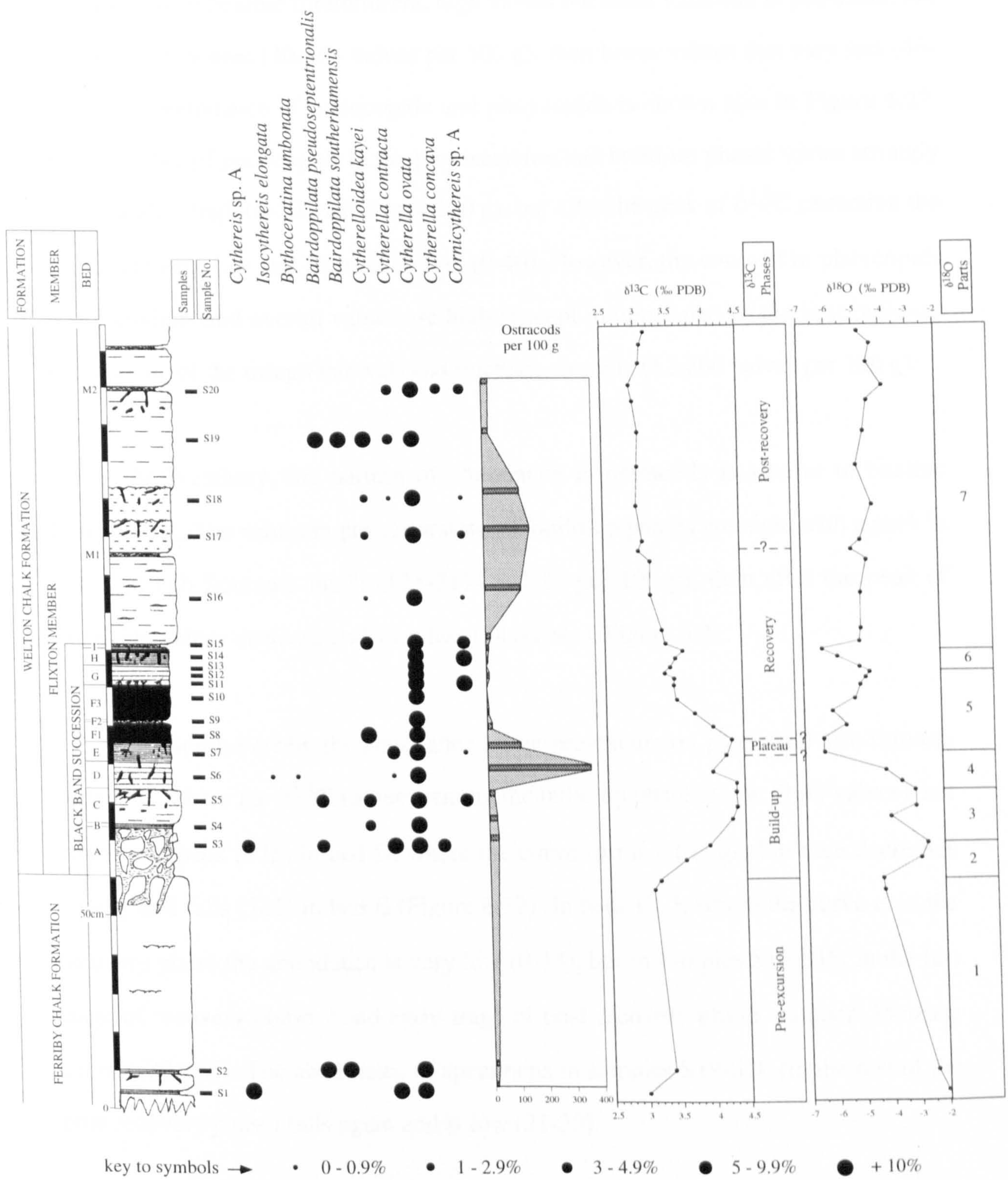


Figure 6.32. Correlation between geochemical changes and abundance and distribution of ostracods across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

6.4.2.3.2. Abundance

The correlation between $\delta^{13}C$ changes and the abundance of ostracods at Eastbourne is shown is Figure 6.25. As is apparent the pattern of abundance is broadly as with benthic foraminifera, high values but more variation in pre-excursion and build-up phases (30-864 valves per 100 g), then lower values that vary less (46-240). The abundance of podocopids and platycopids is shown also in Figure 6.27. Total number of podocopids in the pre-excursion and build-up phases varies strongly and overall is high (6-505 valves per 100 g), but after the peak of $\delta^{13}C$ excursion the values are very low and fluctuation less (0-40). However, the contrast in platycopids is not obvious and overall values are high (except in upper part of the first build-up phase to top of the trough interval) and fluctuate strongly (12-260 valves per 100 g).

At Westbury, the pattern of abundance in ostracods is similar to benthic foraminifera. The values in pre-excursion and build-up phases are high, with a peak in bed 1, which fluctuate much (125-3174 valves per 100 g), then after the peak of excursion values decrease and vary less (144-1041), Figure 6.31.

At South Ferriby the abundance in the pre-excursion phase and also through beds A-C, where the $\delta^{13}C$ values forming the build up phase is low (9-30 valves), but jumps to a peak (375) in bed D, where the curve forms a trough, but then decreases rapidly and falls (121) in bed E (Figure 6.32). In beds F1-I, where the curve is in the recovery phase the abundance is very low (0-18), but in samples S16-S18, in the last stage of recovery phase ? and early stage of post-recovery phase, numbers increase again (132-165). The abundance of specimens in samples S19-S20 (in the rest of the post-recovery phase) falls again and is low (21-25).

The similarities in abundance of benthic and planktic foraminifera and ostracods suggest taphonomic/preservation/processing control. However, consistent

differences between South Ferriby, Westbury and Eastbourne also indicate some original differences.

6.4.2.4. Fine benthic foraminifera (63-90 μm)

6.4.2.4.1. Diversity and assemblage structure

The correlation between changes of $\delta^{13}C$ values with diversity and assemblage structure of the fine benthic foraminifera at Eastbourne is shown in Figures 6.33 and 6.34. As is apparent the number of species which occur throughout the section is low (11 species in total). In the pre-excursion phase the population is not diversified (2-4 species in samples and 4 species in total), and the assemblage is dominated by *Praebulimina* sp. A (42.8-69.2%), which is absent in the coarse fraction, *Gyroidinoides* sp. A (30.7-38%) and *Osangularia* sp. A (0-18.7%), which is also absent in the coarse fraction. Lower part of the first build-up phase is the most diversified assemblage of all the section (4-7 species in samples, while 9 species in total), where 5 new species *Pleurostomella* sp. A, *Laevidentalina* sp., *Gavelinella* sp. *Lingulogavelinella globosa* and *Spiroplectammina praelonga* appear. In this part *Praebulimina* sp. A (39.2-57.1), *Gyroidinoides* sp. A (27-44%) are dominant species, although *Pleurostomella* sp. A (0-10.7%) and *Osangularia* sp. A (0-7.1%) are the other important elements of the assemblage. During the middle and upper parts of the first build-up phase only 1 last occurrence is recorded (*Pleurostomella* sp. A, in the middle of bed 3), while 1 species (*Frondicularia* sp.) appears only in one sample (bed 2). In this part the percentage of *Praebulimina* sp. A increases suddenly (44.4-67.8%) and with *Osangularia* sp. A (17.8-25%), *Gyroidinoides* sp. A (3.5-19.4%), *Laevidentalina* sp. (0-7.1%) and *Pleurostomella* sp. A (0-3.5%) constitutes the dominant species of the assemblage. Both the sample diversity and total diversity decrease (4-6 species per sample, while 6 species in total). In the unique sample of trough interval only 1 last occurrence is recorded (*Laevidentalina* sp., in the middle of bed 4). Diversity is low (4 species) and *Praebulimina* sp. A is still dominant species (86.5%), although *Gyroidinoides* sp. A (11.5%) and *Osangularia* sp. A (1.9%) are

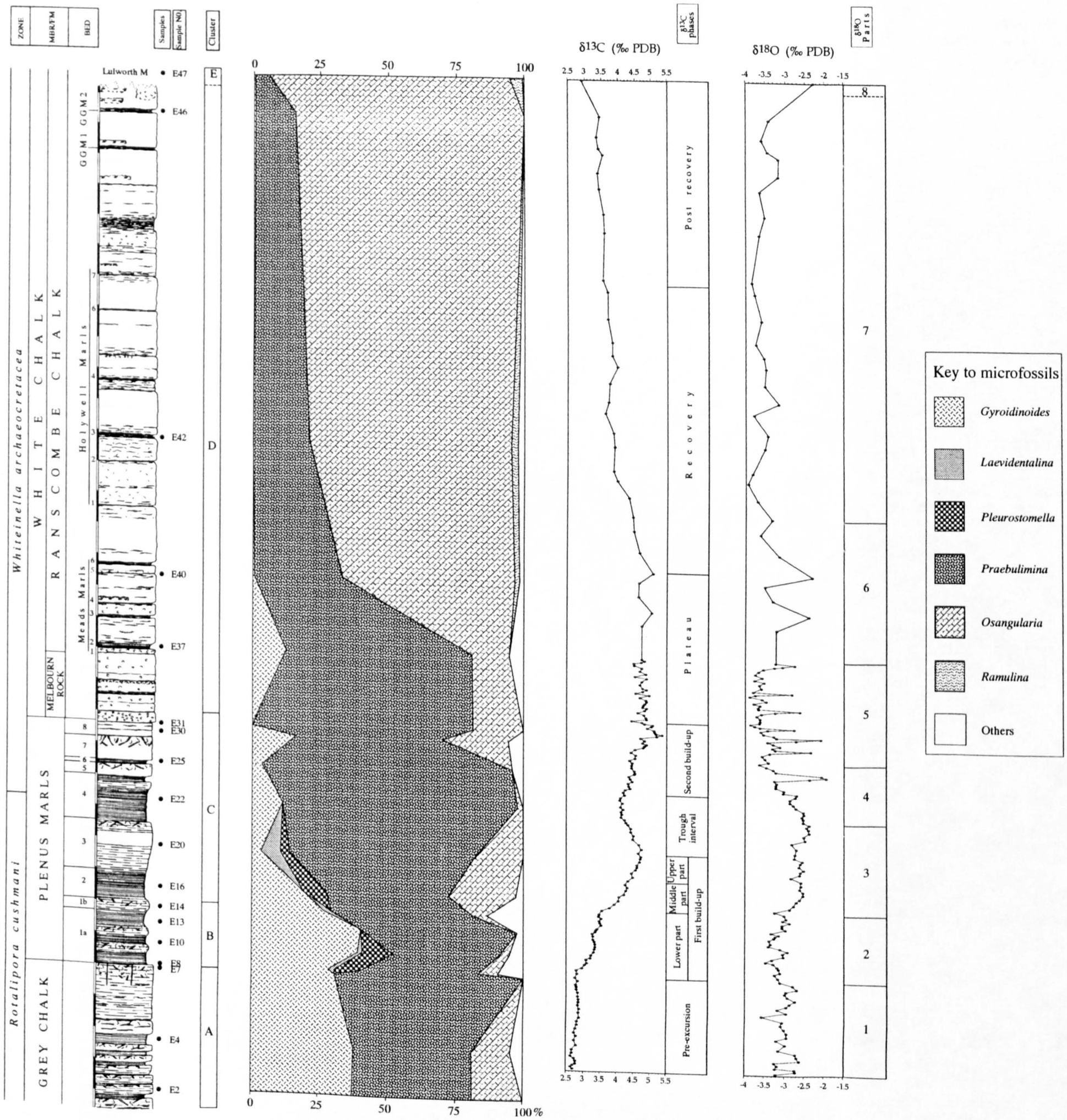


Figure 6.33. Correlation between geochemical changes and cumulative percent of dominant fine benthic foraminifera across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

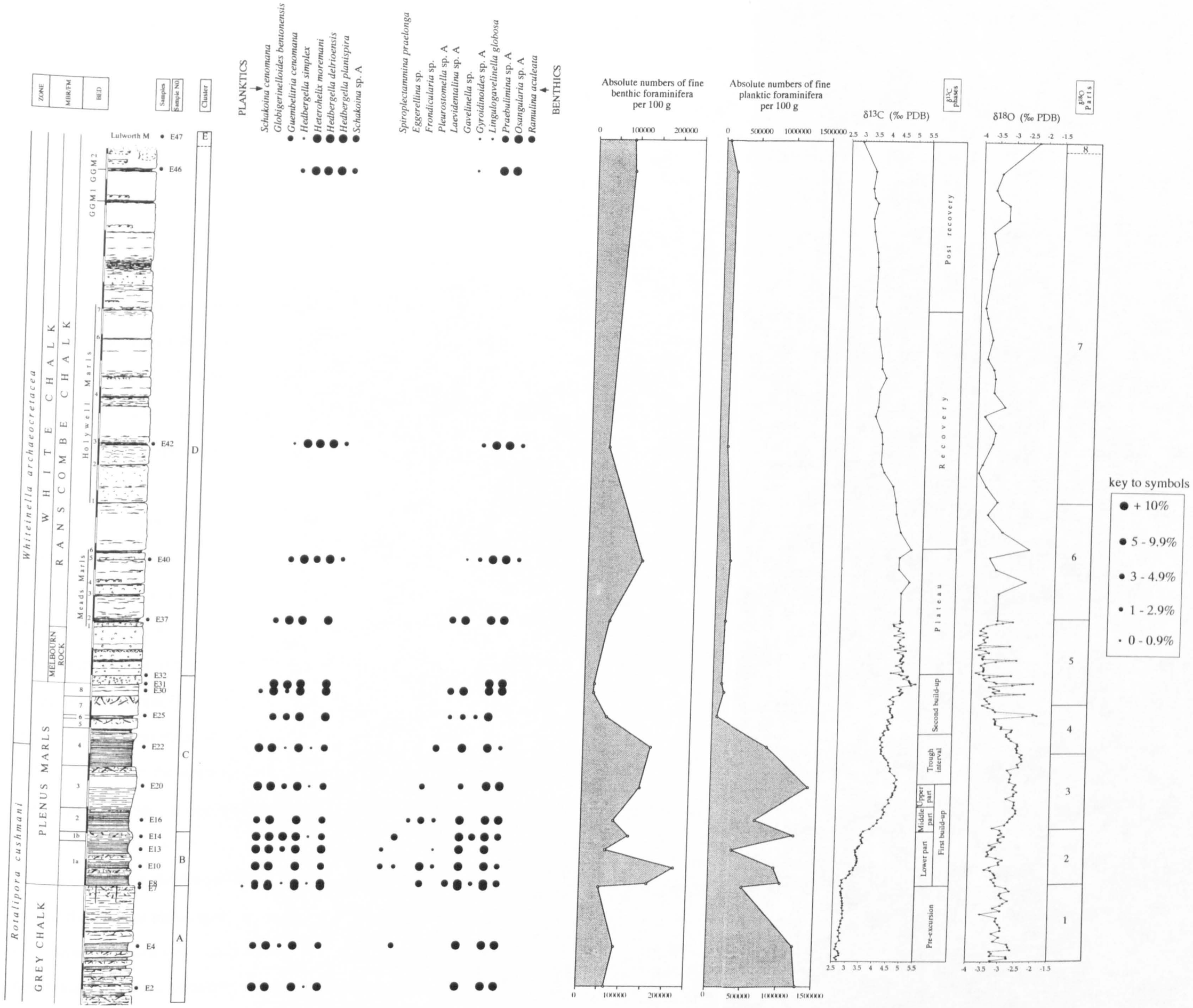


Figure 6.34. Correlation between geochemical changes and abundance and distribution of fine benthic and planktic foraminifera across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. For key to symbols on graphic log see Figure 3.1.

other constituents of the assemblage. The second build-up phase has no significant effect on the assemblage and *Praebulimina* sp. A still is dominant species of the assemblage (54-92.1%) and *Osangularia* sp. A (0-24.3) and *Gyroidinoides* sp. A (0-16.2%) are the other elements of the assemblage, but diversity recovers a little (2-4 species per sample and 5 species in total).

In the plateau phase *Gavelinella* sp. is replaced by *Ramulina aculeata.* and at the top *Praebulimina* sp. A (32.7-67.9%) is replaced rapidly by *Osangularia* sp. A (14.1-63.1%). In this phase, diversity recovers more (4-5 species per sample and 6 species in total). In the recovery and post recovery phases, the assemblage does not change significantly from that of the top of the plateau phase and *Osangularia* sp. A is strongly dominant (74.1-89.0%), while *Praebulimina* sp. A (5.2-21.1%) constitutes a minor percentage of the assemblage. Through these phases diversity does not change significantly (3-5 species per sample and 5 species in total).

At South Ferriby in the pre-excursion phase (sample S2) the diversity is only 3 species (*Gyroidinoides* sp. A, *Osangularia* sp. A and *Praebulimina* sp. A), Figures 6.35 and 6.36. The assemblage is dominated by *Osangularia* sp. A (81.2%), although *Gyroidinoides* sp. A (12.5%) and *Praebulimina* sp. A (6.2%) are the other elements of the assemblage. In the peak of $\delta^{13}C$ excursion (bed C) percentage of *Osangularia* sp. A decreases markedly (39.1%) and with *Praebulimina* sp. A (43.4%), and two new species, *Laevidentalina* sp. (8.6%) and *Ammobaculites rowei* (8.6%) constitute the other elements of the assemblage. In bed D, which is the trough in the $\delta^{13}C$ curve *Praebulimina* sp. A constitutes the dominant species (55.5%) and along with *Gyroidinoides* sp. A (33.3%), *Osangularia* sp. A (7.4%) and *Laevidentalina* sp. , (3.7%) constitutes the assemblage. However, in bedF1, where $\delta^{13}C$ values are at the end of the plateau phase or at the beginning of the recovery phase 2 species appear (*Ramulina aculeata* and *Labrospira* sp. A), both of which occur only in one sample. *Osangularia* sp. A is dominant element, (72%), although *Praebulimina* sp. A (13.9%) and *Ammobaculites rowei* (11.6%) are the other elements of the assemblage. In Beds

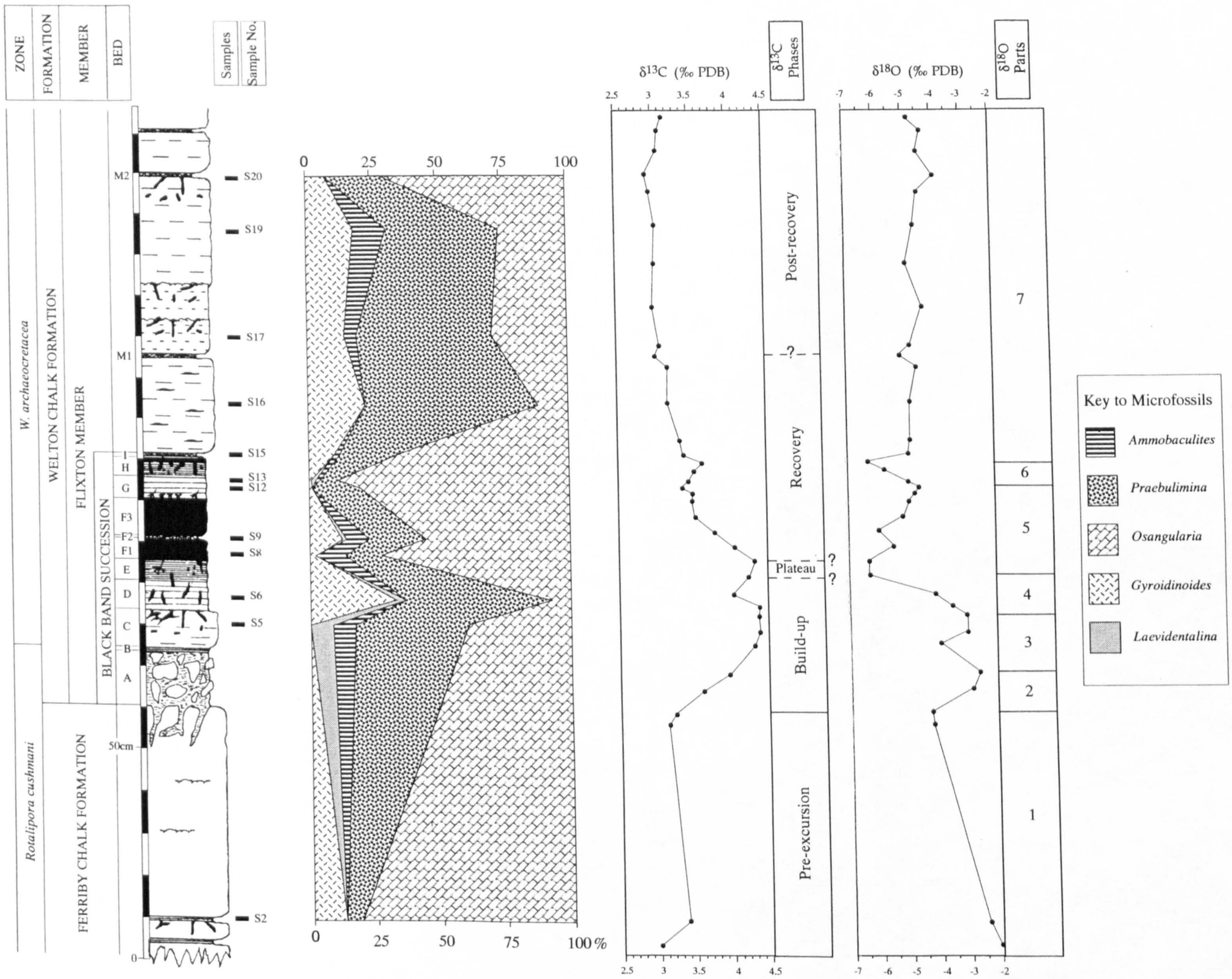


Figure 6.35. Correlation between geochemical changes and cumulative percent of dominant fine benthic foraminifera (based on just the five important species) across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. See Figure 5.1 for key to sumbols on graphic log.

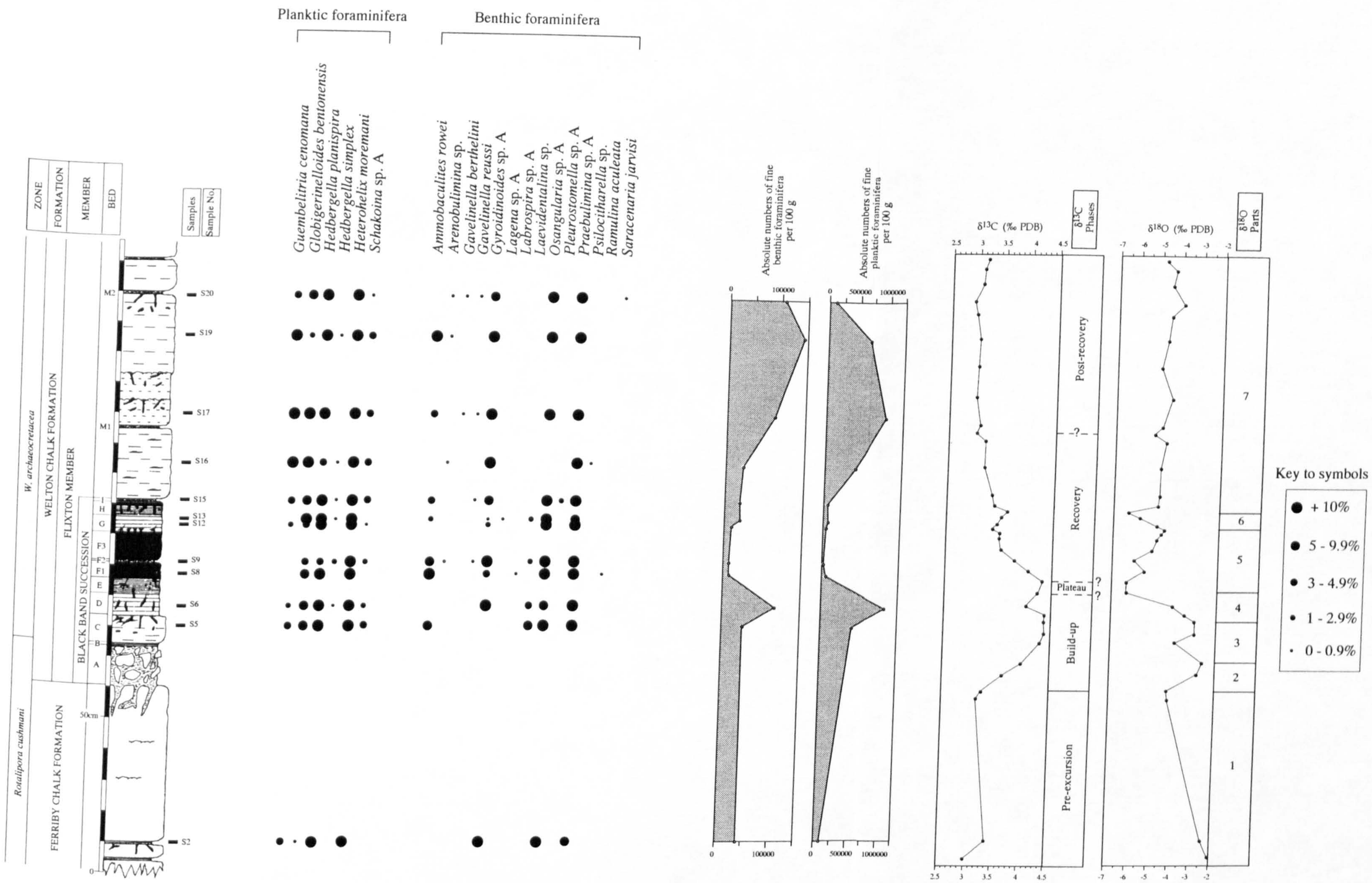


Figure 6.36. Correlation between geochemical changes with abundance and distribution of fine benthic and planktic foraminifera across the Cenomanian - Turonian boundary at South Ferriby. Scale in metres. For key to symbols on log see Figure 5.1.

F2 and F3, recovery phase of the excursion, no last occurrences are recorded, but *Gavelinella reussi* appears for the first time. $\delta^{13}C$ values increase from bed G to a peak in bed H (3.6‰), but drop again in bed I (3.3‰). During this interval *Laevidentalina* sp. is replaced by *Lagena* sp. A (in bed G). The structure of the assemblage does not change and *Osangularia* sp. A is still dominant species of the assemblage (64.8-88.5%), which along with *Praebulimina* sp. A (7-23%) and *Ammobaculites rowei* (0-2.1%) constitutes the elements of the assemblage. In sample S16, where $\delta^{13}C$ values form the last stage of the recovery phase *Psilocytharella* sp. appears and the structure of the assemblage changes significantly once again. In this sample *Praebulimina* sp. A (66.6%) becomes the dominant species and, along with *Gyroidinoides* sp. A (22.2%) and *Osangularia* sp. A (11.1%), constitutes the elements of the assemblage. In the Welton Chalk Formation above the marl 1, $\delta^{13}C$ values do not change significantly up to marl 2, but begin to rise again. This correlates with no last occurrence in the assemblage, but appearence of *Gavelinella berthelini.* The assemblage structure in samples S17-S19, the post-recovery phase in the $\delta^{13}C$ excursion, is as before and *Praebulimina* sp. A constitutes the dominant species of the assemblage (43.6-52.3%), but in sample S20, which correlates with the end of the post-recovery phase of $\delta^{13}C$ excursion 1 species (*Saracenaria jarvisi*) appears. In this sample the assemblage structure changes significantly and *Osangularia* sp. A (70.8%) constitutes dominant species of the population, although *Praebulimina* sp. A (21.8%) and *Gyroidinoides* sp. A (7.2%) are the other elements of the assemblage.

The results show that the population of fine benthic foraminifera is made essentially of 3 species, *Osangularia* sp. A, *Praebulimina* sp. A and *Gyroidinoides* sp. A., of which the 2 former are absent in the coarse fraction. Although at Eastbourne from the second part of the first build-up phase (bed 2) to the end of the plateau phase *Praebulimina* sp. A is the dominant species of the assemblage, at South Ferriby this relationship is less clear. Whereas in the first main peak *Praebulimina* sp. A is dominant species of the population, during the recovery and post-recovery Phase

(except at the top) *Praebulimina* sp. A is again dominant species of the assemblage. However, it seems that the abundance of *Osangularia* sp. A is controlled by other factors than that of $\delta^{13}C$ values, among which sea-level changes might be important.

6.4.2.4.2. Abundance

At Eastbourne the total number of fine benthic foraminifera fluctuates severely, but overall the abundance is high and ranges between 22459 and 217504 specimens per 100 g. The peak of abundance occurs in the lower part of first build-up phase (bed 1a), Figure 6.34.

At South Ferriby in the pre-excursion and the middle part of build-up phase the abundance is fairly high (S2-S5, 39928-40320 specimens per 100 g), but jumps to a higher value (S6, 100408) in the upper part of build-up phase. the plateau phase was not sampled. the lower and middle parts of recovery phase are characterised by low abundance (S8-S16, 9918-30360), but at the top and in the post-recovery phase the abundance recovers and shows high values (S16-S20, 32780-143298), Figure 6.36.

The total number of fine benthic foraminifera is independent of changes in the $\delta^{13}C$ values and none of the sections shows any correlation between abundance of fine benthic foraminifera and $\delta^{13}C$ values.

6.4.2.5. Fine planktic foraminifera

6.4.2.5.1. Diversity and assemblage structure

The diversity of fine planktic foraminifera at Eastbourne is not high and only 8 species occur throughout the section (Figure 6.34). Therefore changes in diversity are not significant. In the pre-excursion phase the number of species is low (5 species per sample, but 7 species in total) and the assemblage is dominated by *Guembelitria cenomana* (36.4-57.2%) *Heterohelix moremani* (24.4-28.9%), *Hedbergella planispira.* (7.4-26%) and *Globigerinelloides bentonensis* (5-10%). The appearance of *Schakoina*

cenomana at the top, although restricted to one sample, is the most important event. In the lower part of the first build-up phase the percentage of *Guembelitria cenomana* suddenly decreases (9.1-13.9%), while *Heterohelix moremani* (32.3-44.9%) shows higher percentages compared with the pre-excursion phase. In this phase only *Schakoina cenomana* is absent. In the middle and upper part of the first build-up phase, no last occurrences in the assemblage are recorded. Through the trough interval and second build-up phase, the assemblage structure does not change and *Heterohelix moremani* constitues a high proportion in the population (27.9-53.7%).

In the plateau phase of the $\delta^{13}C$ excursion *Schakoina* sp. A is replaced by *Globigerinelloides bentonensis.*

In the recovery phase only the absence of *Guembelitria cenomana* is significant, while *Heterohelix moremani* (48.4%) and *Hedbergella planispira* (32.1%) are dominant species of the assemblage.

In the post recovery phase of the $\delta^{13}C$ excursion *Guembelitria cenomana* re-appears, although the structure of assemblage is as before.

At South Ferriby only 6 species occur throughout the section, thus as with Eastbourne, changes in diversity are of low importance. In this section *Heterohelix moremani* is the most significant fine planktic species and constitutes a high proportion in the assemblage (53.8-71.3%) throughout the section . In the pre-excursion phase 4 species are present (*Heterohelix moremani, Guembelitria cenomana, Hedbergella planispira* and *Globigerinelloides bentonensis*), Figure 6.36. The assemblage structure of the fine planktic foraminifera recovers in beds C and D (beds A and B were not been sampled), where the build-up phase of $\delta^{13}C$ is forming, and 2 new species appear (*Schakoina* sp. A and *Hedbergella simplex*). Thereafter, the assemblage does not change significantly and no last or first occurrences are recorded up to top of the section.

As with the fine benthic foraminifera, last occurrence or appearance of the species of fine planktic foraminifera do not show any correlation with the $\delta^{13}C$ curve and changes in the $\delta^{13}C$ values have no effect on the structure of the assemblage.

6.4.2.5.2. Abundance

Abundance of both the total assemblage and the and main constituents of fine planktic foraminifera at Eastbourne are shown in Figure 6.37. As is obvious two parts can be recognised. In part 1, which includes the pre-excursion phase up to the top of the trough interval, the abundance is high (329579-1372550 specimens per 100 g), dominated by *Heterohelix moremani* (117909-683850), *Guembelitria cenomana* (194828-700740), *Hedbergella* spp. (71214-495000) and *Globigerinelloides bentonensis* (36760-276450), while in part 2, including the second build-up, plateau, recovery and post-recovery phases, the abundance is low (53692-200550) and assemblage is dominated by *Heterohelix moremani* (29328-106050) and *Hedbergella* spp. (15552-92400).

At South Ferriby in the pre-excursion phase the abundance of fine planktic foraminifera is low (S2, 80220 specimens per 100 g), but it jumps to a high values in the build-up phase (S5-S6, 503440-1011603, Figure 6.36). The plateau phase was not sampled. In the lower part of recovery phase the abundance is very low (S8-S15, 15312-71280), while throughout the rest of the $\delta^{13}C$ curve abundance recovers and values are again high (S16-S20, 105264-962483).

As with coarse planktic foraminifera, there in no systematic correlation between changes in the $\delta^{13}C$ curve and abundance of fine planktic foraminifera. Although at Eastbourne two major parts can be recognised, these parts are independent of $\delta^{13}C$ values.

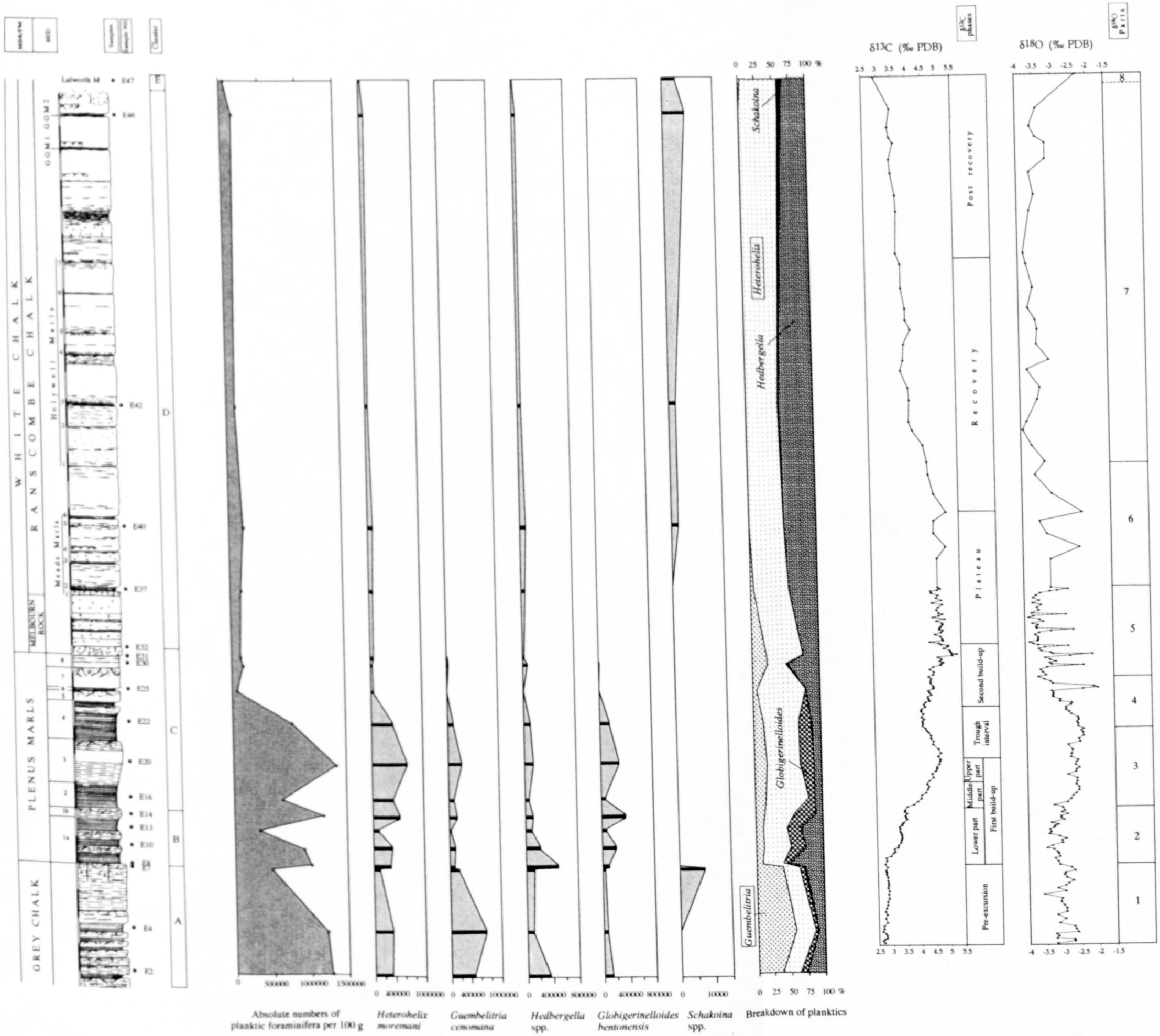


Figure 6.37. Correlation between geochemical changes and total number of specimens and breakdown of fine planktic foraminifera across the Cenomanian - Turonian boundary at Eastbourne (Beachy Head). Scale in metres. See Figure 3.1 for key to symbols on graphic log.

6.4.3. Influence of changes in $\delta^{18}O$

Unlike the situation with $\delta^{13}C$ values, $\delta^{18}O$ curves for three locations do not show a similar pattern so each locality will be considered separately. Based on $\delta^{18}O$ values each oxygen stable curve can be divided into different parts.

At Eastbourne samples from the Grey Chalk fluctuate slightly around an average of -2.9‰ (part 1), Figure 6.1. In bed 1 values are slightly more negative with an average of -3.1‰ (part 2). From the base of bed 2 the values gradually become less negative and after a minor oscillation form a peak (-2.3‰) in the middle of bed 4 (part 3). Then they decline rapidly to a minimum (-3.7‰) in bed 7 (part 4) and up to Meads Marl 2 they oscillate strongly between chalks and marls (part 5). Above this level to Holywell Marl 1 the values are low, but do not show a clear trend (part 6). From Holywell Marl 1 to Gun Gardens Marl 2 the values are very low and oscillate between -3.2‰ and -3.9‰ (part 7). However, in the Lulworth Marl there is a sudden jump to -2.3‰ in the $\delta^{18}O$ value (part 8).

At Westbury $\delta^{18}O$ values started at -3.5‰ rise to -2.7‰ in the *Chondrites* level and decline again to -3.6 ‰ in bed 1 (part 1), Figure 6.2. However, from the base of bed 2 values increase rapidly to a peak of -1.9‰ in the middle of bed 4, (part 2) then after strong oscillation they reach a second peak (-2.0‰) at the base of bed 8 (part 3). Then they become rapidly more negative and fall to -3.9‰ at the base of nodular chalk above the Plenus Marls (part 4), but do not change significantly up through the section and remain low (part 5), except in griotte marl 1 where there is a significantly less negative value (-2.5‰).

At South Ferriby $\delta^{18}O$ values in the Ferriby Chalk Formation started at -2.0‰ to -4.2‰ in the topmost Ferriby Chalk samples (part 1), Figure 6.3. In bed A values increase rapidly and form a peak (-2.5‰) in the middle of bed A (part 2). Then values fall to -3.8‰ in the base of bed C, but increase again and form the second peak (-2.9‰) at the top of the bed C (part 3). They then decrease sharply and fall to a trough

-6.3‰ in the middle of bed E (part 4), increase to another peak (-4.5‰) in bed G (part 5), drop sharply at a minimum (-6.3‰) in bed H (part 6), and thereafter oscillate about -4.6‰ (part 7).

6.4.3.1. Coarse benthic foraminifera

6.4.3.1.1. Diversity and assemblage structure

At Eastbourne part 1 of the $\delta^{18}O$ curve correlates with a highly diversified assemblage (34-39 species per sample, but 55 species in total) dominated by *Tritaxia* spp., *Gavelinella baltica* plus *Gavelinella cenomanica*, *Lenticulina* spp., *Dorothia gradata* plus *Plectina* spp, although 7 species (*Palmula baudouiniana*, *Arenobulimina pseudalbiana*, *Spiroplectammina praelonga*, *Tristix excavata*, *Arenobulimina bulleta*, *Labrospira* sp. A and *Nodosaria* sp. A) are restricted to this part and do not occur in the other phases (Figures 6.4 - 6.7). Part 2, correlates exactly with the first extinction step in the coarse benthic foraminiferal population, when 17 species are recorded for the last time, of which 2 species (*Frondicularia mucronata* and *Spiroloculina cretacea*) have a unique occurrence (Figures 6.4 - 6.7). However, during this part the assemblage is diversified (17-33 species per sample, but 46 species in total) and its structure remains nearly the same as in part 1, except that *Lingulogavelinella involuta* constitutes a major proportion of the assemblage. In part 3 only 2 last occurrences are recorded (*verneuilinoides* sp. A and *Frondicularia archiaciana*) and diversity is high (18-25 species per sample and 34 species in total), but assemblage structure changes significantly and *Textularia chapmani*, *Gaudryina austinana*, *Gavelinella berthelini*, *Gavelinella reussi*, *Lingulogavelinella globosa*, *Eggerellina* spp. and *Lenticulina* spp. constitute dominant taxa. However, the interval through part 4 to middle of part 5 (sample E32) correlates with the second extinction step, when 19 species occur for the last time. In this interval sample diversity is low (11-24 species), but total diversity is nearly as before (35 species). The structure of the assemblage in part 4 is dominated by *Gavelinella berthelini*, *Gavelinella reussi*, *Gaudryina austinana*, *Lingulogavelinella globosa*, *Textularia chapmani*, *Marssonella* spp., *Lenticulina* spp. and *Eggerellina*

spp., although in part 5 *Marssonella* spp. are dominant taxon of the assemblage at the expense of *Textularia chapmani* and *Eggerellina* spp. In part 6, 4 species (*Psilocytharella costulata* var. A, *Ramulina aculeata*, *Textularia* sp. A and *Reophax* sp. A) have their last occurrences. In this part diversity is low (8-12 species per sample and 15 species in total), but the assemblage structure does not change than previous part. Part 7 is characterised by 3 last occurrences (*Frondovaginulina inversa*, *Oolina globosa* and *Gaudryina austinana*) and origination of 4 species (*Tritaxia tricarinata* var. *jongmansi*, *Arenobulimina truncata*, *Lingulogavelinella aumalensis* and *Frondicularia verneuiliana*). Diversity is low (9-13 species per sample, but 15 species in total) and the assemblage is dominated only by a few species (*Marssonella* spp., *Gavelinella berthelini*, *Gavelinella reussi*, *Lingulogavelinella globosa* and *Tritaxia tricarinata*). In the unique sample of part 8 origination of 2 species occurs (*Arenobulimina preslii* and *Arenobulimina* sp. A), but diversity does not change significantly from that of previous part (13 species).

At Westbury part 1 correlates with a highly diversified assemblage (18-36 species in samples, but 49 species in total) dominated by *Tritaxia* spp., *Gavelinella baltica*, *Gavelinella cenomanica*, *Lenticulina* spp and *Lingulogavelinella involuta* (only in bed 1), although 19 species occur for the last time, of which 14 species have a unique occurrence (Figures 6.8 - 6.11). In part 2, 12 species have their last occurrences, among which 2 species (*Glomospira corona* and *Laevidentalina legumen*) are restricted to one sample. The diversity is high (22-29 species per sample, but 40 species in total) and assemblage structure is as in the previous part, except that percentages of *Marssonella* spp. and *Lingulogavelinella globosa* increase and *Reophax* sp. A constitutes a major constituent. Parts 3 and 4 are characterised by 12 other last occurrences, in which only 1 species (*Quadromorphina allomorphinoides*) occurs in one sample. In this parts diversity decreases (14-25 species per sample, but 29 species in total) and percentage of *Gavelinella berthelini*, *Gavelinella reussi* and *Marssonella* spp. (only at the top of the part 4) increase and with *Lingulogavelinella globosa*,

Lenticulina spp., *Gaudryina* spp., *Eggerellina* spp. and *Textularia chapmani* constitute dominant elements of the assemblage. In part 5, 7 species are replaced by 2 new ones (*Tritaxia tricarinata* var. *jongmansi* and *Lingulogavelinella aumalensis*) and 1 species (*Pseudonodosaria humilis*) occurs in a unique sample. In this part diversity is lower than that of previous parts (11-16 species per sample, but 21 species in total) and the structure of the assemblage is made essentially of *Gavelinella berthelini*, *Gavelinella reussi*, *Marssonella* spp., *Lingulogavelinella globosa*, *Lenticulina* spp., *Gaudryina* spp. and *Tritaxia tricarinata* (only at the top).

At South Ferriby part 1 of the $\delta^{18}O$ curve correlates with a moderately diversified assemblage (21-22 species per sample, but 27 species in total) dominated by *Tritaxia* spp., *Gavelinella baltica*, *Gavelinella cenomanica*, *Ammodiscus cretaceus*, *Hyperammina gaultina*, *Plectina* spp., *Dorothia gradata* and *Lenticulina* spp. (Figures 6.12 - 6.15). In this part only 1 species (*Arenobulimina pseudalbiana*) occurs for the last time and 4 species (*Planularia* sp. A, *Marssonella trochus* var. *oxycona*, *Arenobulimina bulleta* and *Tritaxia macfadyeni*) occur only in one sample. In part 2, 2 species (*Arenobulimina advena* and *Spiroplectammina praelonga*) occur for the last time, although one species (*Arenobulimina elongata*) occurs only in this part. The diversity increases (23 species), while the assemblage structure is as part 1. In part 3, 4 other last occurrences are recorded (*Plectina mariae*, *Dorothia gradata*, *Eggerellina brevis* and *Gavelinella baltica*), although 1 species (*Pseudonodosaria humilis*) occurs only in one sample. Compared to previous parts diversity is lower (12-19 species per sample, but 25 species in total) and structure of the assemblage in the lower portion (bed B) is as parts 1 and 2, while in the upper portion (bed C) is quite different and about 95% of the assemblage is made of *Lenticulina* spp. In part 4, 9 species have their last occurrences and 2 other species (*Saracenaria bronni* and *Gyroidinoides* sp. A) are restricted ones. Diversity does not change significantly from that of part 3 (14-18 species per sample, but 22 species in total) and structure of the assemblage in the lower portion (bed D) is made essentially of *Lenticulina* spp., *Textularia chapmani* and

Lingulogavelinella globosa, while in the upper portion (bed E) it is made of *Lenticulina* spp., *Lingulogavelinella globosa*, *Gavelinella berthelini* and *Gavelinella reussi.* In part 5, 5 other species occur for the last time and 1 species (*Glomospira corona*) occurs in a unique sample. Diversity is low (5-11 species per sample, but 18 species in total) and assemblage structure changes in different beds. In the lower part of black shale (bed F1) assemblage is dominated by *Lenticulina* spp., *Gavelinella berthelini*, *Gavelinella reussi*, *Ammodiscus cretaceus*, *Hyperammina gaultina* and *Eggerellina* spp. in bed F2, *Gavelinella baltica*, *Gavelinella cenomanica Ammodiscus cretaceus*, *Hyperammina gaultina* and *Tritaxia* spp. are dominant. The upper portion of this part (bed G) is dominated by *Gavelinella berthelini*, *Gavelinella reussi*, *Ammodiscus cretaceus* and *Hyperammina gaulthina.* In part 6, only 2 species occur for the last time (*Eggerellina mariae* and *Gavelinella* sp.), while one species is restricted (*Frondicularia lanceola*). Diversity is very low (5-7 species per sample and 10 species in total) and assemblage structure is made of *Gavelinella berthelini*, *Gavelinella reussi*, *Ammodiscus cretaceus*, *Hyperammina gaulthina* and *Lenticulina* spp. Part 7 is characterised by 9 last occurrences, 1 restricted species (*Astacolus* sp. A), appearance of 2 species (*Pseudospiroplectinata praelonga* and *Valvulineria lenticula*) and origination of 2 new species (*Lingulogavelinella aumalensis* and *Arenobulimina truncata*). Diversity recovers (5-11 species per sample, but 19 species in total) and throughout the part *Gavelinella berthelini*, *Gavelinella reussi* and *Lenticulina* spp are dominant species, although *Gaudryina* spp. (in sample S17) and *Lingulogavelinella globosa* (in sample S19) are the other elements.

Although at Westbury and South Ferriby there is not a clear relationship between changes in $\delta^{18}O$ values and diversity of benthic foraminifera the two major extinction steps at Eastbourne correlate with more negative $\delta^{18}O$ values and in times, when $\delta^{18}O$ values are less negative, the number of last occurrences is very low. This suggests that extinction of benthic foraminifera was to some extend related to changes in $\delta^{18}O$ values.

6.4.3.1.2. Morphotype groups

The correlation between $\delta^{18}O$ values and changes in the coarse benthic morphotype groups at Eastbourne is shown in Figure 6.16. Morphotype AG-C is dominant in part 1 (33.8-61.1%), although CH-B_3 (16.2-29.2%) and CH-B_2 (12.2-19.0%) are the other elements of the assemblage and CH-C_2 (1.7-11.1%) and CH-B_4 (0.3-9.0%) constitute only minor percentage of the assemblage. In part 2 AG-C morphotype is still the major constituent of the assemblage (10.8-58.1%), although the percentage of CH-B_1 increases suddenly (3.0-39.0%) and along with CH-B_3 (0-18.7%), CH-B_2 (0.2-16.9%) and CH-B_4 (2.6-14.4%) constitutes the morphotype groups of the assemblage. However, in parts 3 and 4 AG-C (37.6-76.9%) and CH-B_3 (3.9-27.4%) are the dominant morphotypes, although from the middle of part 4 the percentage of CH-B4 morphotype increases rapidly (18.9-30.5%). In parts 5-8 AG-C (22.6-63.3%) and CH-B_4 (7.2-69.4%) constitute dominant morphotypes, although CH-B_3 (0-30.8%) and CH-B_2 (0.2-10.2%) are the other important elements of the assemblage.

At Westbury AG-C (13.6-49.9%), CH-B_3 (12.0-20.6%), CH-B_2 (6.5-16.1%) and CH-C_2 (0.2-9.2%) are important morphotypes of the assemblage, although at the top CH-B_1 constitutes the most dominant morphotype group of the assemblage (0.7-43.3%), Figure 6.17. In parts 2-4, AG-C (14.8-54.7%), CH-B_3 (13.8-35.4%) and CH-B_2 (6.6-16%) are dominant morphotypes, although the percentage of CH-B_4 morphotype increases rapidly up through the parts (13.6-54.9%). Part 5 is characterised by dominance of CH-B_4 (19.3-56.6%), AG-C (20.1-48.7%) and CH-B_3 (7.2-28.3%) morphotype groups, although CH-B_2 (0-9.5%) and CH-C_1 (0.9-8.2%) are the other morphotypes of the assemblage.

The correlation between $\delta^{18}O$ values and changes in the morphotype groups at South Ferriby is shown in Figure 6.18. In part 1 up to the lower portion of part 3, morphotype AG-C is dominant (45.3-64.7%), although CH-B_3 (5.6-20.0%), CH-B_4

(4.4-9.8%), AG-B (6.4-7.6%) and AG-A (1.6-7.3%) are the other morphotype groups present. In the upper portion of part 3 the percentage of morphotype CH-B_2 increases suddenly (95.0%) such that constitutes strongly dominant morphotype of the assemblage. In parts 4-6, morphotype groups CH-B_2 (0-73.3%), CH-B_4 (0-50%), AG-B2 (0-41.6%), AG-C (0-37.9%) and CH-B_3 (0-19.3%) are dominant, although in part 6 AG-A constitutes a major morphotype of the assemblage (0-45.4%). In part 7 morphotypes CH-B_2 (17.6-63.2%) and CH-B_4 (20.8-59.2%) are dominant, while morphotypes AG-C (0-17.6%), CH-C_2 (0-14.0%) and CH-B_3 (0.2-9%) are present.

Results show that there is no clear relationship between changes in $\delta^{18}O$ values and structure of morphotype groups and it seems that morphotypes are more influenced by $\delta^{13}C$ values than by $\delta^{18}O$ values.

6.4.3.1.3. Abundance

The correlation between the changes of $\delta^{18}O$ values and abundance of the coarse benthic foraminifera, at Eastbourne, is shown in Figure 6.7. The abundance can be divided into two parts. In the first part, which consists of parts 1 to the middle of part 5 of the $\delta^{18}O$ curve, abundance of the assemblage oscillates strongly, but on the whole is high (700-2701 specimens per 100 g). In the second part, which includes the remaining parts of the $\delta^{18}O$ curve, values oscillate less and are lower (216-953).

At Westbury the abundance of benthic foraminifera in part 1 fluctuates strongly (1123-8774 species per 100 g), Figure 6.11. Then values do not change significantly up to middle of part 3, where abundance jumps to a peak (5428), but falls rapidly at the top (2180). In parts 4 and 5, abundance oscillates, but is always lower than in previous parts (443-1727).

At South Ferriby the abundance of specimens in part 1 is the highest of all the section (2100-2247 per 100 g), but falls sharply in parts 2 and 3 (60-311), Figure

6.15. It recovers a little in the base of part 4 (721), but from the top of part 4 to base of part 7 falls to very low values (0-117). The abundance of specimens during the rest of part 7 recovers again and oscillates between 136 and 461.

In the southern sections (Eastbourne and Westbury), two distinctive parts in the abundance of coarse benthic foraminifera can be recognised. First part is characterised by high abundance and much fluctuation, while in the second part abundance is low with less fluctuation. Neither of these parts can be recognised at South Ferriby, which does not show a correlation between abundance and changes in $\delta^{18}O$ values.

6.4.3.2. Coarse planktic foraminifera

6.4.3.2.1. Diversity and assemblage structure

At Eastbourne part 1 of the $\delta^{18}O$ curve correlates with low diversity (6-8 species, but 10 species in total) and no last occurrences are recorded. Although the keeled planktic morphotypes are present about 75% of the assemblage is made up of non-keeled morphotype (Figures 6.19 and 6.20). The first rotaliporid (*Rotalipora deeckei*) occurs for the last time in the middle of part 2, and higher up the second rotaliporid (*Rotalipora greenhornensis*) last occurs at the top. In this part diversity does not change (6-9 species per sample and 10 species in total), but the proportion of keeled morphotypes reaches as much as 60% of the assemblage. In part 3 no last occurrences are recorded, but diversity increases slightly (5-10 per sample, but 10 species in total). Percentage of keeled morphotypes in the lower and middle of the part (beds 2 and 3) is fairly low (13.2-22.9%) , but at the top (bed 4) is very high (56.7%). In part 4, the last rotaliporid (*Rotalipora cushmani*) and 2 other keeled species (*Dicarinella imbricata* and *Praeglobotruncana stephani*) occur for the last time, while a double-keeled species (*Praeglobotruncana gibba*) appears. Compared to the previous part, diversity does not change significantly (7-9 species per sample and 10 species in total), but the percentage of keeled-morphotypes is very high and reaches to

a peak at the top (90.9% in bed 6). In part 5 the last occurrences of 2 species are recorded (*Praeglobotruncana gibba* and *Hedbergella planispira*), while 1 species appears (*Whiteinella baltica*). Compared to part 4, sample diversity is lower, but total diversity does not change (4-8 species per sample, but 10 species in total). Throughout this part the percentage of keeled morphotypes is very low (0-7.2 %) and non-keeled morphotype is quit dominant. Part 6 is characterises by no last occurrences, but appearance of 1 non-keeled morphotype (*Whiteinella archaeocretacea*). In this part diversity is low (3-5 species per sample and 8 species in total) and percentage of keeled morphotypes falls to very low values (0-9.0%). In part 7, 4 species (*Whiteinella brittonensis*, *Hedbergella simplex*, *Helvetoglobotruncana praehelvetica* and *Whiteinella aprica*) have their last occurrences, while origination of 1 new species (*Marginotruncana renzi*) is recorded. In this part diversity increases a little (2-7 species per sample, but 10 species in total) and the assemblage structure, as in the previous part, is made of non-keeled morphotype (93.4-100%). In the unique sample of part 8, origination of 1 new species (*Praeglobotruncana* sp. A) is recorded. Diversity is low (7 species), but percentage of keeled morphotypes increases significantly (44.0%).

At Westbury during part 1 of the $\delta^{18}O$ curve two rotaliporids (*Rotalipora deeckei* and *Rotalipora greenhornensis*) occur for the last time. Diversity is low (6-8 species per sample, but 8 species in total). Both keeled and non-keeled morphotypes are present, but the percentage of keeled morphotypes is fairly low (10.1-18.0%), Figures 6.21 and 6.22. In part 2 the third rotaliporid (*Rotalipora cushmani*) occurs for the last time, while 5 species (*Helvetoglobotruncana praehelvetica*, *Dicarinella imbricata*, *Dicarinella algeriana*, *Hedbergella simplex* and *Whiteinella baltica*) appear. Diversity increases a little (5-10 species per sample, but 11 species in total) and percentage of keeled morphotypes reaches to a peak at the top (69.1% in bed 4). During parts 3 and 4 the last occurrences of 2 other species (*Dicarinella imbricata* and *Praeglobotruncana stephani*) are recorded, while 1 species (*Hedbergella planispira*) occurs in a unique sample. Diversity does not change significantly (4-9 species per

sample and 11 species in total), but the assemblage structure essentially is made of non-keeled morphotype, except in the middle of the part (bed 6), where keeled morphotypes constitute about 51% of the assemblage. In part 5, 1 species (*Hedbergella simplex*) is replaced by 2 new ones (*Whiteinella paradubia* and *Whiteinella inornata*). Diversity decreases a little (3-8 species per sample and 11 species in total) and the non-keeled morphotype is strongly dominant species (99.8-100%).

At South Ferriby part 1 of the $\delta^{18}O$ curve is characterised by no significant changes in the planktic population. Diversity is low (1-7 species per sample and 7 species in total). Both the keeled and non-keeled morphotypes are present, but the percentage of keeled morphotypes varies significantly in samples (0-26.6%), Figures 6.23 and 6.24. In the unique sample of part 2, the total diversity is as part 1 (7 species), but percentage of keeled morphotypes increases and reaches to 37.6% of the assemblage. In part 3 last occurrence of a rotaliporid (*Rotalipora cushmani*, in bed B) and appearence of 2 new species (*Dicarinella algeriana* and *Helvetoglobotruncana praehelvetivca*) are recorded. In this part diversity increases (7-9 species per sample, but 9 species in total), but percentage of keeled morphotypes varies significantly (15.3-36%). In part 4 no last occurrence is recorded, while a keeled species (*Dicarinella imbricata*) appears. In this part diversity does not change significantly (6-8 species per sample, but 9 species in total) and the keeled morphotypes constitute between 3.6 to 18.4% of the assemblage. In part 5 no last occurrences is recorded, but 1 keeled species appears (*Praeglobotruncana gibba*). Diversity is low (3-5 species per sample, but 6 species in total) and structure of the assemblage is largely made of non-keeled morphotype (54.9-100%). Part 6 is characterised by no last occurrences, re-appearance of one species (*Hedbergella simplex*) and origination of 2 new species (*Marginotruncana renzi* and *Whiteinella archaeocretacea*). In this part both the diversity (6-10 species per sample, but 10 species in total) and percentage of keeled morphotypes (46.2-48.1%) increases. In part 7 only the last occurrence of 2 species

(*Hedbergella planispira* and *Hedbergella simplex*) seems to be important, while no origination occurs. Compared to other parts, diversity is high (10-12 species per sample, but 14 species in total) and percentage of keeled morphotypes ranges between 19.5 to 57.5%.

Although, benthic foraminifera (at least at Eastbourne) show a clear relationship between changes in $\delta^{18}O$ values and diversity (number of last occurrences), this relationship seems less clear in planktic foraminifera, which suggests that changes in $\delta^{18}O$ values did not significantly effect diversity of planktic foraminifera.

6.4.3.2.2. Abundance

At Eastbourne, as with benthics, there are really just two parts. From part 1 to middle of part 5 of the $\delta^{18}O$ curve abundance is high with considerable variation (488-10846 specimens per 100 g) and a peak in bed 1. Then values are much lower and the contrast is even more obvious (83-628) than with abundance of benthic foraminifera, Figure 6.20.

At Westbury the pattern of abundance can be divided into two parts. In parts 1 to 3 of the $\delta^{18}O$ curve abundance is high with much fluctuation (1140-17436 specimens per 100 g) and a peak at the top of part 1. Thereafter abundance is low and the contrast is quite clear (77-591), Figure 6.22.

At South Ferriby parts 1 and 2 correlates with very low abundance (26-295 specimens per 100 g), but abundance jumps to a peak at the top of part 3 (35922). In part 4 values decrease again (2150-6123). However, through parts 5-6 to the base of part 7, values are very low (60-2424), but then increase again to very high values (4751-43558), Figure 6.24.

As mentioned earlier, the pattern of abundance, especially in southern sections, reveals that two parts can be recognised. In the first part values are high with much fluctuation, while in the second part values are low with less variation. However, these parts do not correlate with changes in $\delta^{18}O$ values

6.4.3.3. Ostracods

6.4.3.3.1. Diversity and assemblage structure

The correlation between the changes in $\delta^{18}O$ values and diversity and assemblage structure of ostracods are shown in Figures 6.25 - 6.28. Part 1 of the $\delta^{18}O$ curve correlates with a diversified assemblage occurs (13-22 species per sample, but 27 species in total), which is characterised by high percentage of podocopids (29.4-77.4%). During this part only 1 species (*Cytherelloidea bonnemai*) occurs for the last time, although 3 others (*Curfsina derooi*, *Imhotepia euglyphea* and *Cytherelloidea stricta*) are restricted to this interval. In part 2, 2 other species (*Oertliella alata* and *Neocythere kayei*) occur for the last time, while 1 species (*Pterygocythere laticristata*) appears. In this part both sample diversity and total diversity fall (5-16 species per sample, and 21 species in total). Although the percentage of podocopids at the base of this part is high (42.3-60%), it falls to low values in the middle (29.7-31.2%) and increases again at the top (49.6%). In part 3 no last occurrences are recorded, although 2 species (*Dolocytheridea* sp. A and *Phodeucythere cuneiformis*) occur only in one sample and 1 species (*Cytherelloidea hindei*) appears. Compared to the previous part sample diversity decreases, but total diversity does not change (11-16 species per sample, but 21 species in total) and podocopids constitute the strongly dominant group of the assemblage (61.8-90.5%). Part 4 is characterised by last occurrences of 3 species (*Pterygocythere laticristata*, *Oertliella donzei* and *Herrigocythere donzei*). In this part both the diversity (4-15 species per sample, but 16 species in total) and percentage of podocopids decreases (5.6-59.4%). In part 5, 6 species have their last occurrences, while origination of 1 new species (*Mosaeleberis* sp. A) is recorded. Compared to the previous part, sample diversity decreases, while

total diversity increases (9-13 species per sample, but 19 species in total) and percentage of podocopids does not recover (14.6-38.1%). In part 6 last occurrences of species continue and 4 other species (*Paracypris wrothamensis*, *Pontocyprella hindei*, *Pontocyprella harrisiana* and *Pterygocythere diminuta*) occur for the last time. Diversity falls to low values (4-8 species per sample, but 11 species in total) and assemblage structure is strongly dominated platycopids (69.9-94%). In part 7, 7 other species have their last occurrences (5 species occur for the last time in Gun Gardens Marl 2 alone, which might be due to sampling). In this part diversity is low (4-7 species per sample, but 11 species in total) and as the previous part platycopids are the strongly dominant group (89.6-100%). In the unique sample of part 8 only 3 species are present (*Bythoceratina umbonata*, *Bairdoppilata pseudoseptentrionalis* and *Cytherella ovata*) and platycopids are strongly dominant (91.0%).

At Westbury part 1 of the $\delta^{18}O$ curve correlates with a diversified assemblage (17-19 species per sample, but 22 species in total), in which only 1 platycopid (*Cytherelloidea bonnemai*) occurs in just one sample and the assemblage is strongly dominated by podocopids (58.7-82.2%), Figures 6.29 and 6.31. In part 2, 5 species (*Neocythere kayei*, *Herrigocythere donzei*, *Pontocyprella robusta*, *Pterygocythere laticristata* and *Pterygocythere robusta*) are recorded for the last time, while 2 species (*Habrocythere* sp. A and *Dolocytheridea* sp. A) occur only in one sample. During this part diversity is high (13-20 species per sample and 22 species in total), but percentage of podocopids decreases rapidly (45.0-75.5%). Parts 3 and 4 are characterised by last occurrences of 3 species (*Pontocyprella hindei*, *Bythoceratina umbonatoides* and *Pontocyprella harrisiana*). Diversity falls (5-12 species per sample, but 15 species in total) and percentage of podocopids continues to decrease rapidly (6.4-32.1%). In part 5, 2 other species occur for the last time (*Isocythereis elongata* and *Cythereis* sp. A), while origination of 2 new species is recorded (*Mosaeleberis* sp. A and *Isocythereis longaeva*). Diversity increases (10-14 per sample, but 16 species in total) and platycopids are strongly dominant in the assemblage (82.1-95.6%).

At South Ferriby a total of 10 species is present. In part 1 of the $\delta^{18}O$ curve correlates with a low diversity assemblage (3 species per sample, but 5 species in total), no last occurrences are recorded, Figure 6.32. In the unique sample of part 2, one species is recorded for the last time (*Cythereis* sp. A), while 1 species is a Lazarus taxon (*Bairdoppilata southerhamensis*) and 1 species appears for the first time (*Cytherella concava*). Compared to part 1 diversity does not change (5 species). In part 3 no last occurrences are recorded, but 1 new species appears (*Cornicythereis* sp. A) and two species are Lazarus taxa (*Cytherella contracta* and *Cytherella concava*). Diversity is lower than in the previous part (2-4 species per sample and 4 species in total). Part 4 is characterised by no last occurrences, but appearance of 2 species (*Isocythereis elongata* and *Bythoceratina umbonata*), both of which are restricted to one sample. In this part diversity recovers a little (3-4 species per sample, but 5 species in total). In part 5 no last or first occurrences are recorded and diversity is low (1-2 species per samples, but 3 species in total). Part 6 is characterised by no last occurrences and diversity is very low (1-2 species per sample and 2 species in total). However, in part 7, 3 species are recorded for the last time (*Bairdoppilata pseudoseptentrionalis*, *Bairdoppilata southerhamensis* and *Cytherelloidea kayei*), nevertheless diversity is high (3-5 species per sample and 7 species in total).

As the results show, at Eastbourne the structure of the assemblage (platycopids vs. podocopids) is strongly correlated with $\delta^{18}O$ values. In intervals with more negative values (warmer intervals) platycopids are dominant, while in intervals with less negative values (temperate or colder intervals) podocopids constitute the dominant group in the assemblage. However, at Westbury and South Ferriby the relationship between $\delta^{18}O$ values and dominance of podocopids or platycopids is less clear.

6.4.3.3.2. Abundance

The correlation between $\delta^{18}O$ changes and the abundance of ostracods at Eastbourne is shown is Figure 6.28. The pattern of abundance is broadly as with benthic foraminifera, high values but more variation in Part 1 to middle of part 5 of the $\delta^{18}O$ curve (30-864 valves per 100 g), then lower values that vary less (46-240).

The abundance of podocopids and platycopids is shown also in Figure 6.27. Total number of podocopids in part 1 to middle of part 5 of the $\delta^{18}O$ curve varies strongly and overall is high (6-505 valves per 100 g), with two peaks in parts 1 and 3. Thereafter values are very low and fluctuate less (0-40). However, in platycopids the contrast is not obvious and on the whole values remain high and fluctuate strongly (12-260 valves per 100 g), except in part 3 to middle of part 4 where values are low (12-127).

At Westbury, the pattern of abundance in ostracods is similar to that of benthic foraminifera. The values in parts 1-3 of the $\delta^{18}O$ curve are high, with a peak at the top of part 1 and they fluctuate considerably (244-3174 valves per 100 g), then values decrease and vary less (125-1041), Figure 6.31.

At South Ferriby the abundance of ostracods in parts 1-3 of the $\delta^{18}O$ curve is low (9.3-30 valves per 100g), but jumps to a peak (375) in the middle of part 4, then falls rapidly (121) at the top of part 4. Through part 5 to the base of part 7 abundance is very low (0-18), but in the middle of part 7 numbers increase again (132-165). The abundance of specimens in the rest of part 7 falls again (21-25), Figure 6.32.

As mentioned earlier, there are similarities in the pattern of abundance of benthic and planktic foraminifera and of ostracods which suggest taphonomic/ preservation/processing control. However, consistent differences between South Ferriby, Westbury and Eastbourne also indicate some original differences.

6.4.3.4. Fine benthic foraminifera (63-90 μm)

6.4.3.4.1. Diversity and assemblage structure

The correlation between changes of $\delta^{18}O$ values with diversity and assemblage structure of the fine benthic foraminifera at Eastbourne is shown in Figures 6.33 and 6.34. As is apparent only 11 species occur in total. In part 1 of the $\delta^{18}O$ curve the population is not diversified (2-4 species per sample and 4 species in total), and the assemblage is dominated by *Praebulimina* sp. A (42.8-69.2%), *Gyroidinoides* sp. A (30.7-38%) and *Osangularia* sp. A (0-18.7%). Part 2 is the most diversified assemblage of all the section (4-7 species per sample, and 9 species in total), where 5 new species *Pleurostomella* sp. A, *Laevidentalina* sp., *Lingulogavelinella globosa*, *Gavelinella* sp. and *Spiroplectammina praelonga* appear. In this part *Praebulimina* sp. A (39.2-57.1), *Gyroidinoides* sp. A (27-44%) are dominant species, although *Pleurostomella* sp. A (0-10.7%) and *Osangularia* sp. A (0-7.1%) are the other important elements of the assemblage. In part 3 only 1 last occurrence is recorded (*Pleurostomella* sp. A), while 1 species (*Frondicularia* sp.) appears only in one sample. In this part the percentage of *Praebulimina* sp. A increases suddenly (44.4-67.8%) and with *Osangularia* sp. A (17.8-25%), *Gyroidinoides* sp. A (3.5-19.4%), *Pleurostomella* sp. A (3.5-8.3%) and *Laevidentalina* sp. (0-7.1%) constitutes the dominant species of the assemblage, also both the sample and total diversity decrease (4-6 species per sample, and 6 species in total). In part 4 only 1 last occurrence is recorded (*Laevidentalina* sp.). *Praebulimina* sp. A is strongly dominant (86.5-92.1%), although *Gyroidinoides* sp. A (3.9-11.5%) is the other species of the assemblage and compared to previous part, diversity does not change significantly (4 species per sample and 6 species in total). In part 5, one species occurs for the last time (*Gavelinella* sp.) and *Praebulimina* sp. A (54-81.3%), *Osangularia* sp. A (14.1-24.3%) and *Gyroidinoides* sp. A (0-16.2%) are important elements of the assemblage. In this part diversity is low (2-4 species per sample and 4 species in total). In the unique sample of part 6 no last occurrence is recorded, while *Ramulina aculeata* appears for the first time. In this part, the assemblage structure changes significantly

and *Osangularia* sp. A constitutes the dominant species of the assemblage (63.1%), while *Praebulimina* sp. A (32.7%) and *Ramulina aculeata* (1.6%) are the other species in the assemblage. Diversity in this part recovers a little than that of the previous part (5 species). Part 7 is characterised by no last or first occurrences and structure and diversity of the assemblage is as before (3-4 species per sample, but 5 species in total). However, in the unique sample of part 8 the percentage of *Osangularia* sp. A increases more (89%), but diversity remains as part 7 (5 species).

At South Ferriby in part 1 of the $\delta^{18}O$ values the diversity is only 3 species (*Gyroidinoides* sp. A, *Osangularia* sp. A and *Praebulimina* sp. A). The assemblage is dominated by *Osangularia* sp. A (81.2%), although *Gyroidinoides* sp. A (12.5%) and *Praebulimina* sp. A (6.2%) are the other elements of the assemblage (Figures 6.35 and 6.36). In part 2 no sample was taken, but in part 3 percentage of *Osangularia* sp. A decreases significantly (39.1%) and with *Praebulimina* sp. A (43.4%), and 2 new species, *Laevidentalina* sp. (8.6%) and *Ammobaculites rowei* (8.6%) constitute the other elements of the assemblage. In the unique sample of part 4 no last occurrence is recorded and compared to previous part, the percentage of *Praebulimina* sp. A (55.5%) and *Laevidentalina* sp. (3.7%) does not change significantly, but the percentage of *Gyroidinoides* sp. A increases (33.3%) and *Osangularia* sp. A indicates lower percentage. In this part diversity does not change (4 species). Part 5 is characterised by no last occurrences, but the appearance of 4 species (*Arenobulimina* sp., *Gavelinella reussi*, *Ramulina aculeata* and *Labrospira* sp. A), although the two later occur only in one sample). In this part the assemblage structure changes significantly once again and *Osangularia* sp. A constitutes dominant species of the assemblage (55.3-79.7%), while *Praebulimina* sp. A (18.8-21.3%), *Gyroidinoides* sp. A (1.4-12.6%), *Ammobaculites rowei* (0-11.6%) and *Laevidentalina* sp. (0-1.9%) are the other elements of the assemblage. Diversity also changes significantly from that of the previous part (3-7 species per sample, but 9 species in total). In the unique sample of part 6 the last occurrence of 1 species is recorded (*Laevidentalina* sp.), while

1 species appears (*Lagena* sp. A, only in one sample). In this part *Osangularia* sp. A is strongly dominant species (88.5%) and *Praebulimina* sp. A is other species of the assemblage (7%), while other species are low important. Compared to the previous part diversity decreases (6 species). In part 7 no last occurrences is recorded, but 4 species appear (*Pleurostomella* sp. A, *Psilocytharella* sp., *Saracenaria jarvisi* and *Gavelinella berthelini*, although the three former occur only in one sample). At the base of this part, *Osangularia* sp. A is dominant (64.8%), but in the middle, *Praebulimina* sp. A becomes dominant species (43.6-66.6%). However, at the top *Osangularia* sp. A constitutes again dominant species of the assemblage (70.8%). In this part diversity is high (4-7 species per sample, but 10 species in total).

Both at Eastbourne and South Ferriby diversity of fine benthic foraminifera is low and *Osangularia* sp. A, *Praebulimina* sp. A and *Gyroidinoides* sp. A are major constituents of the assemblage. However, it seems that there is not any clear relationship between the pattern of distribution of taxa and $\delta^{18}O$ values.

6.4.3.4.2. Abundance

As mentioned earlier, at Eastbourne the abundance of fine benthic foraminifera fluctuates severely throughout the section and overall is high (22459-217504 specimens per 100 g). The peak of abundance occurs in part 2 of the $\delta^{18}O$ curve (Figure 6.34).

At South Ferriby in part 1 of the $\delta^{18}O$ curve the abundance is high (40320 specimens per 100 g). Part 2 was not sampled, but in part 3 the abundance is similar to part 1 (39928). In part 4 abundance jumps to a high value (100408), but in parts 5, 6 and base of part 7 values fall and range between 9918 and 30360. The total number of fine benthic foraminifera in the rest of part 7 recovers again and oscillates from 32780 to 143298 (Figure 6.36).

Correlation between changes in $\delta^{18}O$ values and abundance of the fine benthic foraminifera reveals that there is no clear relationship between these two factors. Changes in the abundance are independent of $\delta^{18}O$ values.

6.4.3.5. Fine planktic foraminifera

6.4.3.5.1. Diversity and assemblage structure

At Eastbourne only 8 fine planktic foraminifera occur throughout the section (Figure 6.34), therefore changes in the diversity are of low importance. In part 1 of the $\delta^{18}O$ curve the number of species is low (5 species per sample, but 7 species in total) and the assemblage is dominated by *Guembelitria cenomana* (36.4-57.2%), *Heterohelix moremani* (24.4-28.9%), *Hedbergella planispira.* (7.4-26%) and *Globigerinelloides bentonensis* (5-10%). The appearance of *Schakoina cenomana* at the top, although restricted to one sample, is the most important event. In part 2 of the $\delta^{18}O$ curve diversity is about the same as previous part (4-6 species per sample and 7 species in total), but percentage of *Guembelitria cenomana* suddenly decreases (9.1-13.9%) and that of *Heterohelix moremani* increases (32.3-44.9%). In this part only *Schakoina cenomana* is absent. Parts 3 and 4 are characterised by low diversity (4-6 species per sample, but 6 species in total), a high proportion of *Heterohelix moremani* (49.8-73.2%) and no last occurrences in the assemblage. In part 5, diversity decreases (4-5 species per sample, but 5 species in total) and one species occurs for the last time (*Globigerinelloides bentonensis*). The unique sample of part 6 is characterised by low diversity (5 species), dominance of *Heterohelix moremani* (52.8%) and appearance of a new species (*Schakoina* sp. A). In this part *Guembelitria cenomana* is a Lazarus taxon. Part 7 is characterised by low diversity (5 species in both sample and total diversities) and no last occurrences. In the unique sample of part 8 diversity recovers a little (6 species) and *Guembelitria cenomana* re-appears (3.3%), while *Heterohelix moremani* is still dominant species in the assemblage (54.6%).

At South Ferriby only 6 fine planktic foraminifera occur throughout the section, among which *Heterohelix moremani* constitues the dominant species in the assemblage (53.8-71.3%). In part 1 of the $\delta^{18}O$ curve 4 species are present (*Heterohelix moremani*, *Hedbergella planispira*, *Guembelitria cenomana* and *Globigerinelloides bentonensis*), Figure 6.36. The structure of the fine planktic foraminiferal assemblage in part 3 is as part 1 (part 2 was not sampled), except the appearence of a new species (*Schakoina* sp. A) and no last occurences are recorded. However, part 4 is more diversified and another new species (*Hedbergella simplex*) appears. Thereafter no last or first occurrences are recorded up to top of the section.

As the results show, neither at Eastbourne nor at South Ferriby is there a significant correlation between $\delta^{18}O$ and diversity, or between $\delta^{18}O$ and the structure of the fine planktic assemblage.

6.4.3.5.2. Abundance

At Eastbourne in part 1 of the $\delta^{18}O$ curve the fine planktic foraminifera are abundant (488908-1278655 specimens per 100 g), and the assemblage is dominated by *Guembelitria cenomana* (194828-700740 specimens per 100 g), *Heterohelix moremani* (119470-354492) and *Hedbergella* spp. (107172-349860, Figure 6.37). In part 2 of the $\delta^{18}O$ curve the abundance of assemblage is high (329579-1192244), but the total number of *Guembelitria cenomana* decreases suddenly (39776-166430) and instead *Heterohelix moremani* increases in numbers (117909-535602). In parts 3 and 4 of the $\delta^{18}O$ the number of specimens is a very high (640926-1372550), but at the top of part 4 it suddenly falls to very low value (74304). This causes the abundance of species to fluctuate significantly (*Heterohelix moremani* 54432-683850, *Globigerinelloides bentonensis* 0-276450, *Guembelitria cenomana* 4320-266750, *Hedbergella* spp. 15552-145500). In part 5 the total numbers are low (130424-156606) compared to part 3 and middle of part 4, and the main constituents of the assemblage are: *Hedbergella* spp. (30688-72233), *Heterohelix moremani* (43704-

81925), *Guembelitria cenomana* (7250-36420) and *Globigerinelloides bentonensis* (0-4249). The unique sample of part 6 is characterised by low abundance (200550), and *Heterohelix moremani* (106050), *Hedbergella* spp. (92400) and *Schakoina* sp. A (2100) are main constituents of the assemblage. In part 7 the abundance is low (116314-159510) and does not significantly recover compared with part 6. In part 7 *Heterohelix moremani* (56364-93252) and *Hedbergella* spp. (57901-59714) are important elements of the assemblage, while *Schakoina* sp. (2049-6544) is of low importance. In part 8 the abundance falls to a very low value and is only 53692 specimens per 100 g (*Guembelitria cenomana* 1804, *Heterohelix moremani* 29328, *Hedbergella* spp. 18499 and *Schakoina* sp. A 4060).

At South Ferriby in part 1 of the $\delta^{18}O$ curve abundance is low (80220 specimens per 100 g) and only 4 species are present (*Heterohelix moremani* 48300, *Hedbergella planispira* 28140, *Guembelitria cenomana* 2520 and *Globigerinelloides bentonensis* 1260 specimens). In part 3 (part 2 was not sampled) abundance increases significantly (503440, *Heterohelix moremani* 331576, *Hedbergella planispira* 83328, *Globigerinelloides bentonensis* 39928 and *Guembelitria cenomana* 22568). The peak of abundance occurs in part 4 (1011603), when the total numbers of *Heterohelix moremani* (552244), *Globigerinelloides bentonensis* (111166) and *Hedbergella planispira* (311982) increases, but the abundance of *Guembelitria cenomana* (10758) decreases. In parts 5, 6 and the base of part 7, the assemblage is characterised by a low abundance (15312-71280), but thereafter abundance recovers and ranges from 105264 to 962483. During parts 5 to 7, the total numbers of *Heterohelix moremani* (8874-564566), *Guembelitria cenomana* (0-136040), *Globigerinelloides bentonensis* (1044-125837) and *Hedbergella planispira* (1131-98629) fluctuate significantly.

As the results show, neither at Eastbourne nor at South Ferriby is there a significant correlation between $\delta^{18}O$ and the abundance of the fine planktic assemblage. Total numbers of specimens are independent of changes in $\delta^{18}O$ values.

6.4.4. Influence of biotic interaction

6.4.4.1. Benthic foraminifera

As discussed earlier, biotic interactions, among the benthic foraminifera are apparent between different genera or even between different species of the same genus. This competition tends to favour small taxa, while larger species do not survive. There are some examples of this biotic interaction, which has been mentioned in detail in section 6.2.4. Apart from large species, which succumb promptly at the beginning of the stressed condition (i.e. *Plectina* spp., *Dorothia gradata*, *Laevidentalina distincta*, *Gavelinella baltica*, *Gavelinella cenomanica*, *Nodosaria* spp., *Spiroplectammina praelonga* in the Grey Chalk or early beds of the Plenus Marls), among tritaxiids, nodosariids and gavelinellids large species of a particular genus are replaced by smaller ones (i.e. *Lingulogavelinella involuta* by *Lingulogavelinella globosa*, *Tritaxia macfadyeni* and *Tritaxia pyramidata* by *Tritaxia tricarinata*) and even size-reduction (dwarfism) in some species happens (i.e. reduction in the size of *Tritaxia tricarinata* and *Eggerellina mariae* after or through the event).

6.4.4.2. Planktic foraminifera

The effect of biotic interactions among planktic foraminifera is less clear. However, it seems that the main competition was between single-keeled and double-keeled morphotypes, when after the extinction of *Rotalipora cushmani*, a proliferation in the double-keeled planktics (dicarinellids and praeglobotruncanids) happened.

6.4.4.3. Ostracods

The effect of biotic interactions among in ostracods are apparent between two major groups, podocopids and platycopids. The effect of this competition is clear at Eastbourne, where there is a fluctuation in dominance between these two groups. In less negative $\delta^{18}O$ values podocopids were dominant, while platycopids constituted dominant group in more negative $\delta^{18}O$ values.

Although the influence of biotic interactions is apparent among both benthic and planktic foraminifera and ostracods, its effect on the Cenomanian-Turonian boundary mass extinction seems to be relatively insignificant. However, size reduction in some species and the replacement of large species by small species might be relevant to the productivity vs. famine models of the cause of the Cenomanian-Turonian boundary mass extinction.

6.4.5. Combined effects

6.4.5.1. Benthic foraminifera

Of the four factors which might have influenced the Cenomanian-Turonian mass extinction, the influence of substrate and of biotic interaction were relatively unimportant. The facies changes affected only low percentages of benthic foraminifera (i.e. 4.5% at Eastbourne). Competition between different taxa (biotic interaction), which resulted in small taxa to surviving, while larger ones succumbed, also affected a small number of taxa. However, the combined effects of $\delta^{13}C$ and $\delta^{18}O$ values on the benthic assemblage were very significant. At Eastbourne in the pre excursion phase, which coincides with low $\delta^{13}C$ excursion (2.7‰ on average) and less negative $\delta^{18}O$ values (-2.9‰ on average) a total of 55 species was recorded. In bed 1 the first major extinction step occurred. In this bed, characterised by increasing $\delta^{13}C$ values (3.2‰ on average) and decreasing $\delta^{18}O$ values (-3.1‰ on average), about 24% of species were recorded for the last time. The interval between the base of bed 2 to base of bed 4 is characterised by increasing in both $\delta^{13}C$ (4.3‰ on average) and $\delta^{18}O$ (-2.6‰ on average) values, although at the top $\delta^{13}C$ values decreased. In this interval only 2 species had their last occurrences (*Verneuilinoides* sp. A and *Frondicularia archiaciana*). The second major extinction step, from the middle of bed 4 to base of the Melbourn Rock, is characterised by increasing $\delta^{13}C$ value (4.4‰ on average) and decreasing $\delta^{18}O$ values (-3.0‰ on average), in which about 32% of species occurred for the last time. The post build-up phases (plateau, recovery and post-recovery phases), during which $\delta^{13}C$ were static or returning to low values, coincides with

decreasing $\delta^{18}O$ values (about -3.5‰ on average, although at the top $\delta^{18}O$ value increased to -2.3‰). This interval was characterised by low numbers of last occurrences (8 species), and origination of 6 new species (*Tritaxia tricarinata* var. *jongmansi*, *Lingulogavelinella aumalensis*, *Arenobulimina* truncata, *Frondicularia verneuiliana*, *Arenobulimina preslii* and *Arenobulimina* sp. A).

At Westbury in the unique sample of the Grey Chalk a total of 36 species was recorded. This coincided with low $\delta^{13}C$ value (2.6‰) and less negative $\delta^{18}O$ value (-2.7‰). In the build-up phase (4.1‰ on average), which is accompanied by increasing $\delta^{18}O$ values (-2.6‰ on average) 26 species had their last occurrences and 7 species occurred only in one sample. In post build-up phase (3.6‰ on average), which coincides with decreasing $\delta^{18}O$ values (-3.7‰ on average), number of last occurrences decreased (7 species had their last occurrences and one species occurred only in one sample), but only origination of 2 new species was recorded (*Tritaxia tricarinata* var. *jongmansi* and *Lingulogavelinella aumalensis*).

At South Ferriby, the pre-excursion phase (samples S1-S2, 3.1‰ on average) is accompanied by less negative $\delta^{18}O$ values (-2.2‰ on average) and a total of 27 species occurred. The build-up phase (4.1‰ on average) coincides with decreasing $\delta^{18}O$ values (-3.2‰ on average), during which 15 species occurred for the last time and 4 species had a unique occurences. In post build-up phases (2.9‰ on average), where $\delta^{18}O$ values decrease significantly (-4.9‰ on average) 20 species had their last occurrences, while 3 species occured in a unique sample. In this interval origination of 2 species (*Lingulogavelinella aumalensis*, *Arenobulimina truncata*) and appearance of 1 species (*Pseudospiroplectinata plana*) was recorded.

In all three sections the combined effect of rising $\delta^{13}C$ and falling $\delta^{18}O$ values on the benthic foraminifera was obvious. The pre excursion phase was characterised by less negative $\delta^{18}O$ values and highly diversified assemblage. At Eastbourne during

the first part of the build-up phase extinctions only occur where $\delta^{18}O$ is falling (bed 1) whereas $\delta^{13}C$ values continue to rise up into bed 3, but are not accompanied by any more last occurrences. At Westbury and South Ferriby major last occurrences were recorded during the build-up phase of carbon excursion and although at the former $\delta^{18}O$ values increase, but at the later $\delta^{18}O$ values decrease. In all three sections in the post build-up phases both $\delta^{13}C$ and $\delta^{18}O$ values decrease and it might have been the main reason for low recovery in diversity of the benthic foraminiferal assemblage.

6.4.5.2. Planktic foraminifera

Although substrate has no direct influence on the planktic assemblage at Eastbourne p% (planktic foraminifera as a percentage of the total foraminifera in the >250 μm) was consistently higher in chalks than marls in the five major marl-chalk rhythms in the Plenus Marls. Possible biotic interactions might have occurred between single-keeled and double-keeled morphotypes. At both Eastbourne and Westbury after the extinction of *Rotalipora cushmani* there was a proliferation in the double-keeled morphotype. However, the combined influence of $\delta^{13}C$ and $\delta^{18}O$ values on the planktic assemblage was also significant. At Eastbourne in the Grey Chalk, characterised by normal conditions in the environment (low $\delta^{13}C$ values and less negative $\delta^{18}O$ values), no significant changes in the assemblage occurred. In bed 1, when stress conditions began (increasing $\delta^{13}C$ values and decreasing $\delta^{18}O$ values) about 12% of species had their last occurrences. The percentage of last occurrences in bed 3 and base of bed 4, where, both $\delta^{13}C$ and $\delta^{18}O$ values increase was nil (although, at the top $\delta^{13}C$ values decrease). However, the major extinction step in the planktic assemblage began from the middle of bed 4 to base of Melbourne Rock, which coincides with increasing $\delta^{13}C$ value and decreasing $\delta^{18}O$ values. In this interval about 23.5% of species had their last occurrences. In the post build-up phases, which coincides with decreasing $\delta^{18}O$ values 5 species had their last occurrences, but origination of 3 species was recorded (*Whiteinella archaeocretacea*, *Marginotruncana renzi* and *Praeglobotruncana* sp. A)

At Westbury a total of 17 species occurred throughout the section. In the unique sample of the Grey Chalk, where $\delta^{13}C$ value is low and $\delta^{18}O$ value is less negative, only 6 species occurred. In the build-up phase, where $\delta^{18}O$ values are increasing 4 species occurred for the last time (*Rotalipora greenhornensis*, *Rotalipora cushmani*, *Dicarinella imbricata* and *Praeglobotruncana stephani*) and 2 species occurred only in one sample (*Rotalipora deeckei* and *Hedbergella planispira*). However, in the post build-up phase, which coincides with decreasing $\delta^{18}O$ values 2 species had their last occurrences (*Hedbergella simplex* and *Dicarinella algeriana*), while 2 species occurred only in one sample (*Whiteinella paradubia* and *Whiteinella inornata*) and origination of 1 species (*Whiteinella archaeocretacea*) recorded.

At South Ferriby the appearance of species is more important than disappearance. Therefore, it was difficult to interpret the effect of combined factors on the planktic assemblage.

Although, at Eastbourne the two major extinction steps coincided with increasing $\delta^{13}C$ values and decreasing $\delta^{18}O$ values, at Westbury the successive last occurrences in the build-up phase coincided with increasing $\delta^{18}O$ values.

6.4.5.3. Ostracods

As with benthic foraminifera, the effects of substrate and biotic interaction on the ostracods assemblage were not important. At Eastbourne only 3% of the assemblage was affected by changes in substrate. Although the effect of biotic interactions (podocopids vs. platycopids) are clear, this was not a major cause of ostracod turn-over at the Cenomanian-Turonian boundary. However, the combined of $\delta^{13}C$ values and $\delta^{18}O$ values on the ostracod assemblage was very significant. At Eastbourne in the Grey Chalk, characterised by normal condition in the environment (low $\delta^{13}C$ values and less negative $\delta^{18}O$ values) ostracods were diverse and a total of 27 species was present. In this part of the section podocopids constituted a high proportion of the assemblage (29.4-77.4%). Bed 1, characterised by increasing $\delta^{13}C$

values and decreasing $\delta^{18}O$ values coincided with last occurrences of about 7.5% of assemblage and high proportion of platycopids (40.0-70.3%). In the interval between bed 2 and the base of bed 4, no last occurrences are recorded, but 3 species (*Cytherelloidea hindei, Dolocytheridea* sp. A and *Phodeucythere cuneiformis*) occurred for the first time, although the two laters occured only in a unique sample . During this interval podocopids were strongly dominant (61.8-90.5%). The second major extinction step began from the middle of bed 4 to the base of Melbourne Rock. This interval is characterised by increasing $\delta^{13}C$ values and decreasing $\delta^{18}O$ values, during which about 33% of ostracods had their last occurrences and high proportion of platycopids occur (40.6-94.4%). The interval between the middle of the Melbourne Rock and Gun Gardens Marl 2 coincides with the post build-up phases, in which $\delta^{13}C$ values stop increasing or start to decrease, and $\delta^{18}O$ values decrease. In this interval the number of last occurrences decreased (13 species, of which 5 species occurred for the last time in Gun Gardens Marl 2, which might be due to sampling), but origination of only 1 species occurred (*Mosaeleberis* sp. A) and platycopids were strongly dominant (69.9-100%).

At Westbury in the normal conditions of the Grey Chalk (low $\delta^{13}C$ value and less negative $\delta^{18}O$ value) 17 species occurred. During the build-up phase, accompanied by increasing $\delta^{18}O$ values, 8 species had their last occurrences, while 2 species occurred only in one sample. In the post build-up phase, which coincides with decreasing $\delta^{18}O$ values the number of last occurrences decreased and 2 species (*Isocythereis elongata* and *Cythereis* sp. A) replaced by 2 other species (*Mosaeleberis* sp. A and *Cythereis longaeva*).

At South Ferriby a total of 10 species occurs throughout the section and due to low diversity, the incomplete and very condensed nature of the section interpretation is difficult.

As with benthic and planktic foraminifera, the combined effect of $\delta^{13}C$ and $\delta^{18}O$ value on the ostracod assemblage is apparent. At Eastbourne both the major extinction steps, in bed 1 and the interval between the middle of bed 4 to the base of the Melbourne Rock coincide with increasing $\delta^{13}C$ values and decreasing $\delta^{18}O$ values. However, it seems that the structure of ostracods (podocopids vs. platycopids) was mainly controlled by $\delta^{18}O$ values. At Westbury last occurrences in the build-up phase coincided with increasing $\delta^{18}O$ values.

6.5. Summary of most important changes in fauna

6.5.1. Reduction in diversity

All three sections show a severe decline in the diversity of both benthic and planktic foraminifera and ostracods through the Cenomanian-Turonian boundary. At Eastbourne two main extinction phases was recorded, while at Westbury and South Ferriby there was a continuous decline in diversity. The distribution pattern of different assemblages shows that much of the decline in diversity was due to genuine extinction and not to a pseudoextinction (Lazarus taxa). Examples of Lazarus taxa are more clear at Eastbourne, where e.g. *Arenobulimina* spp. disappear at the beginning of stressed-condition, but re-appear with three new species after the event.

6.5.2. Reduction in the abundance of microfossils

There was a severe reduction in the abundance of different assemblages through the Cenomanian-Turonian boundary as well. At Eastbourne and Westbury the most significant reduction was recorded after the main decline in diversity, while at South Ferriby the main reduction occurred in the upper part of the Black Band succession (beds F1-I).

6.5.3. Reduction in size of surviving species and/or replacement of large species by smaller ones.

The studied sections show that there was a tendency towards having smaller test. Apart from a number of large species, which succumbed promptly at the beginning of the stressed-condition (*Plectina* spp., *Dorothia gradata*, *Nodosaria* spp., *Laevidentalina distincta*, *Gavelinella baltica*, *Gavelinella cenomanica*, *Spiroplectammina praelonga* in the Grey Chalk or early beds of the Plenus Marls), replacement of large species by smaller ones was also apparent e.g., *Lingulogavelinella involuta* was replaced by *Lingulogavelinella globosa*, two large gavelinellids, *Gavelinella cenomanica* and *Gavelinella baltica* were replaced by *Gavelinella berthelini* and *Gavelinella reussi*, and two large tritaxiids, *Tritaxia macfadyeni* and *Tritaxia pyramidata* were replaced by *Tritaxia tricarinata* . Size reduction among the survivors is clear in some species. Specimens of *Tritaxia tricarinata* in bed 1 and above are smaller than those in the Grey Chalk Formation. Size of the test in *Eggerellina mariae* became shorter promptly after the extinction of *Eggerellina brevis*.

6.6. Possible causes of important influences

As the results show there was a decline in both the diversity and abundance of different microfossils assemblages. At Eastbourne and Westbury most extinctions occurred through the Plenus Marls, but abundance of all the assemblages declined severely after bed 8.

The absolute number of benthic foraminiferal survivors at Eastbourne is shown in Figure 6.38. As is apparent, individual survivors have distinctive patterns. If the decline in abundance of all microfossils were due to taphonomic/preservational causes or processing, then one would expect absolute numbers of all surviving species to decline. In fact some increase in absolute abundance when overall abundance declines (e.g. *Marssonella* spp.), which is very difficult, if not impossible, to explain as an artefact of preservation or processing.

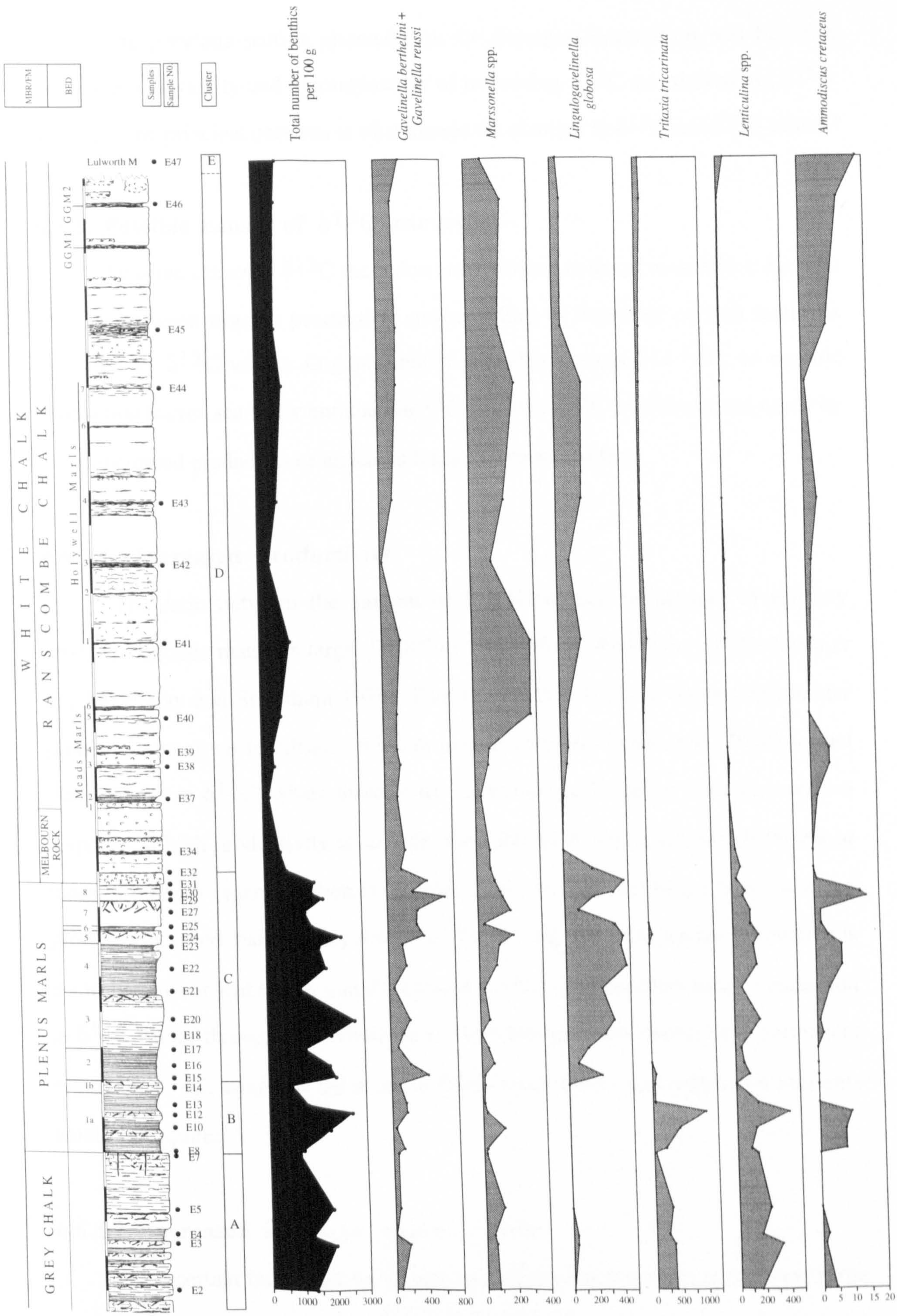


Figure 6.38. Absolute number of coarse benthic foraminiferal survivors across the Cenomanian - Turonian boundary at Eastbourne. Scale in metres. See Figure 3.1 for key to symbols on graphic log.

The previous section showed that the strongest correlation was between reduction in diversity and a combination of increasing $\delta^{13}C$ and decreasing $\delta^{18}O$ values, so the principal question is what caused the changes in $\delta^{13}C$ and $\delta^{18}O$ values?

6.6.1. Possible causes of $\delta^{13}C$ excursion

Possible causes of $\delta^{13}C$ excursion are discussed in detail in section 6.2.2. The balance between organic production and recycling or burial of organic matter is recorded by $\delta^{13}C$ values. Organic matter is highly enriched in ^{12}C, so organic production leaves sea water enriched in ^{13}C. Positive $\delta^{13}C$ excursions can occur by either increased production or increased burial of organic carbon.

6.6.1.1. Increased productivity

The ratio between the amount of fossilised and the amount of primary produced organic matter is large, 1:1000 to 1:10 000 (cf. Pytkowicz, 1973: Bolin *et al.*, 1979: Hay and Southham 1979). That is, less than 0.1% of the organic matter produced annually is fossilised; 99.9% or more is recycled. Jarvis *et al.* (1988) argued that changes in $\delta^{13}C$ values through the Cenomanian-Turonian boundary were a response to high productivity in surface water due to strong upwelling. If 99.9% or more of modern organic carbon is recycled, it is very difficult to see how increased productivity could maintain any shift in $\delta^{13}C$ for long. Besides, organic production is controlled by nutrient supply and if increased production caused the positive excursion in $\delta^{13}C$ values through the Cenomanian-Turonian boundary event, for a permanent removal of ^{12}C, which lasted about 250 000 years even more additional nutrients would be required.

6.6.1.2. Increased burial of organic carbon

One certain fact about the Cenomanian-Turonian boundary is that very large quantities of organic carbon were buried (Herbin *et al.*, 1986). Therefore, it can be postulated that the positive $\delta^{13}C$ excursion was due to increased burial of organic

carbon and consequently due to permanent removal of ^{12}C from the oceanic reservoir, which need not necessarily be accompanied by high productivity in surface waters.

So increased burial of organic carbon seems the more likely cause for the positive $\delta^{13}C$ excursion, without increasing the productivity.

6.6.2. Possible causes of changing $\delta^{18}O$ values

Possible causes of changing $\delta^{18}O$ values are discussed in detail in section 6.2.3. The main reasons for changes in $\delta^{18}O$ values are: (1) a primary temperature change in the water of the photic zone where the coccoliths were secreting calcite; (2) changes in salinity of surface water or (3) post-depositional diagenesis such as precipitation of carbonate cement.

6.6.2.1. Diagenetic effects

Oxygen isotope ratios are more readily altered than $\delta^{13}C$ values during diagenesis, partly because oxygen isotopes show large temperature-related fractionation. Also, additional cement during burial diagenesis and recrystallisiation may cause precipitation of new isotopically light carbonate cements. Therefore, one possibility for $\delta^{18}O$ changes might this diagenetic effect. However, if the principal cause of changes in $\delta^{18}O$ values was diagenetic why should there be any correlation at all between changes in microfauna and changes in $\delta^{18}O$ values? At Eastbourne there is a good correlation between $\delta^{18}O$ values and composition of the ostracod fauna (platycopids vs. podocopids). This suggests that at least some of the changes in the $\delta^{18}O$ values are due to primary causes (temperature and/or salinity) and not due to diagenetic effects.

6.6.2.2. Changes in salinity of surface water

If salinity changes were the cause a possible model would be "dilution cycles" where increased terrestrial runoff increases input of terrestrial clay content to produce

marl beds and also reduce salinity of surface water (Arthur *et al.*, 1986; Bottjer *et al.*, 1986). If this had occurred, there should be a good correlation between substrate (i.e. lithology) and faunal changes. However, as the results show, there is no such correlation and microfaunal assemblages do not show any significant differences in marls compared with chalks.

6.6.2.3. Changes in temperature of surface sea water

Jefferies (1962, 1963a) suggested that the main cause for changes in micro- and macrofauna through the Plenus Marls of the Anglo-Paris Basin was temperature. He suggested that a calcite pulse fauna, including the belemnite *Actinocamax plenus* (Blainville) and the bivalves *Oxytoma seminudum* (Dames) and *Lyropecten (Aequipecten) arlesiensis* (Woods), which are characteristic of beds 4-6, represented an influx of colder, boreal waters. However, one possible influence of changes in $\delta^{18}O$ values on the micro- and macrofaunal assemblages would be via the solubility of O_2. At present podocopid % is strongly influenced by O_2 levels (Whatley, 1991). High podocopid % correlates with high O_2 levels. The fact that podocopid % correlates with $\delta^{18}O$ values at least early on in the Cenomanian-Turonian boundary event suggests the primary influence on $\delta^{18}O$ was temperature and the effect on benthos was via dissolved oxygen levels.

6.7. Proposed models for the Cenomanian-Turonian boundary event

The changes in the micro- and macrofaunal assemblages through the Cenomanian-Turonian boundary have been investigated by different workers and each tried to explain the changes by different models. Among the proposed models two seem to be more compatible with the results obtained here: the productivity model of Jarvis *et al.* (1988) and the famine model of Paul and Mitchell (1994).

6.7.1. Productivity model

This model was proposed by Jarvis *et al.* (1988). They documented the Dover section and concluded that there was a correlation between $\delta^{13}C$ values and faunal changes, particularly the extinctions. According to them increased productivity (triggered by high sea level) led to increased organic rain which lowered O_2 levels and expanded the oxygen minimum zone. This in turn led to burial of organic carbon, the $\delta^{13}C$ excursion and the successive extinction of planktic foraminifera, which were assumed to have been depth stratified (Hart, 1980). Therefore, they regarded the Cenomanian-Turonian boundary event as an oceanic anoxic event.

6.7.2. Famine model

An alternative argument to explain the Cenomanian-Turonian boundary event was suggested by Paul and Mitchell (1994), which is called the famine model. They documented two sections at Dover (England) and Menoyo (Spain) and showed that Cenomanian-Turonian boundary was accompanied by reduced coccolith productivity for about 250 000 years. They concluded that high burial of organic carbon deposited in the Cenomanian-Turonian boundary sequestered nutrients and resulted in the decline in oceanic productivity in shallow seas such as the Anglo-Paris Basin. This in turn caused the extinctions, the selective removal of large taxa, and the reduced abundance.

Although there are some evidence from my results to support each of the models, there are also some questions that cannot be explained by them.

6.8. Evidence in favour and/or compatible with the productivity model (expanded OMZ)

6.8.1. increased burial of organic carbon

The large quantity of deposited organic carbon in the Cenomanian-Turonian boundary can be easily explained by the productivity model. A major change in oceanic circulation during the latest Cenomanian (possibly associated with a major transgressive pulse) caused widespread upwelling of nutrient-rich deep-water towards

the ocean surface (cf. Summerhayes, 1987) causing a massive productivity event. High surface productivity led to the development of an intensified and expanded oxygen minimum zone in the underlying water column, because oxygen is utilised during the breakdown of organic matter as it rains downwards from the surface water, and consequently widespread deposition of organic-rich mud in deeper-water areas. However, Demaison and Moore (1980) showed there is not any systematic correlation between primary production and the organic carbon content of bottom sediments in the oceans. Furthermore, Calvert *et al.*, (1992) demonstrated that there is no link between amounts of buried organic carbon and anoxia in present oceans.

6.8.2. Progressive extinction of deep, intermediate and shallow dwelling planktic foraminifera

Modern planktic foraminifera are stratified in the water column (Bé, 1977), defined as shallow-water (adult tests <50 m), intermediate-water (mature tests 50-100 m), and deep-water (adult test >100 m) types. Each one of these three faunas has a distinctive morphology, ranging from non-keeled shallow-water fauna to heavily calcified keeled species, which live in the deeper water areas. It has been suggested (Hart and Bailey, 1979: Hart, 1980, 1985: Hart and Ball, 1986) that comparable Cretaceous morphotypes exhibited the same relative depth relationship. Non-keeled genera (*Hedbergella, Whiteinella*) inhabited shallow-water, incipiently keeled forms (*Praeglobotruncana, Dicarinella, Helvetoglobotruncana*) lived in intermediate-water and large, keeled taxa (*Rotalipora, Marginotruncana*) were restricted to deep-water areas. Among the rotaliporids, *Rotalipora deeckei* was larger, more heavily calcified, and had a thicker test, than *Rotalipora greenhornensis,* and *Rotalipora cushmani,* thus occupying deeper depth. Similarly *Rotalipora greenhornensis* was larger and heavier than *Rotalipora cushmani.* It has been suggested (Hart, 1980) that planktic foraminifera progressively migrate downwards to their preferred water depth during ontogeny with gametogenesis occurring only at the bottom of their depth range. At Eastbourne, the last appearances were recorded is follows: *Rotalipora deeckei* in the

middle of bed 1, *Rotalipora greenhornensis* at the top of bed 1 and *Rotalipora cushmani* in the middle of bed 4. At Westbury, unlike the situation at Eastbourne, the two largest and deepest species of rotaliporids (*Rotalipora deeckei* and *Rotalipora greenhornensis*) go out together at the top of bed 1, although the last occurrence of *Rotalipora cushmani* was recorded in bed 4. At South Ferriby, *Rotalipora cushmani* occurs only at Ferriby Chalk Formation and beds A and B of Black Band succession and the two other rotaliporids (*Rotalipora deeckei* and *Rotalipora greenhornensis*) were absent. In the studied section, the successive extinction of rotaliporids (*Rotalipora deeckei, Rotalipora greenhornensis, Rotalipora cushmani*), which based on their size and thickness were depth stratified, is compatible with expansion and migrating upwards of oxygen minimum zone within the water column, arresting the gametogenesis of the species and consequently causing their extinction.

However, Corfield *et al.* (1990) are doubtful about depth stratification of planktic foraminifera and state that extinction of benthic and planktonic foraminifera and macrofossil taxa cannot clearly be related to the expansion of the Cenomanian-Turonian oxygen-minimum zone. Paul and Mitchell (1994) documented the Dover section and argued that the water was deep enough for fully grown specimens of *Rotalipora greenhornensis* and *Rotalipora cushmani*, the deepest-dwelling planktonic foraminifera, to be preserved even in the first rhythm, when the water was shallowest, with sea level 150 m lower than it was before the event (Haq *et al.*, 1988). Furthermore if the expansion of the oxygen minimum zone is considered to be a response to *eustatic* rise there should still have been the same column of water above for the *Rotalipora deeckei* and *Rotalipora greenhornensis* to complete their life cycles.

6.8.3. Selection among planktic foraminifera for small size.

As discussed above, modern planktic foraminifera are depth stratified and all juveniles live in surface waters shallower than 50 m. They progressively migrate downwards to their preferred water depth during ontogeny with gametogenesis occurring only at the bottom of their depth range. Therefore, expansion and migration

of oxygen minimum zone upward would arrest gametogenesis of the species successively. An alternative for species would be reproduction before sinking into the oxygen minimum zone and suffocating. The best example for this alternative is *Rotalipora cushmani.* At Eastbourne the size of *Rotalipora cushmani* in the Grey Chalk and bed 1 differs from its size in beds 2-4 of the Plenus Marls. The specimens in the former beds were larger, but size was reduced in the later beds, which suggests they reproduced at a smaller size before suffocating by an expanded oxygen minimum zone.

6.8.4. Sudden dominance of triserial morphotypes in the fine planktic foraminiferal assemblage

Among the shallow water planktics species, guembelitriids are inferred to have lived closest to the ocean surface (Keller *et al.*, 1993), hedbergellids and *Globigerinelloides* occupy deeper water, while heterohelicids are inferred to occupy water depth between those species (Stott and Kennett, 1990; Barrera and Keller, 1990). Keller *et al.* (1993) have shown that the *Guembelitria/Heterohelix*, ratio is related to palaeobathymetry, high proportion of *Guembelitria* indicates shallow water. At Eastbourne in the Grey Chalk triserial morphotypes (guembelitriids) were strongly dominant, while from the base of bed 1, biserial morphotypes (heterohelicids) suddenly became dominant. However, with the model of Keller *et al.* (1993), it is difficult to interpret the high *Guembelitria/Heterohelix* ratio in cluster A (Grey Chalk), where a high sea level was apparent. In the overlying clusters this ratio was promptly reversed, which can be interpreted as due to high productivity in the surface water, when more opportunistic species, i.e. *Heterohelix,* took advantage of a sudden increase of the food and consequently became dominant. However, Eicher and Worstell (1970) found that species of *Heterohelix* and *Hedbergella* in the Cenomanian and Turonian strata from the western interior of the United States were the first planktics to appear in a marine transgression and the last to disappear in the regression.

6.8.5. Surviving of infaunal, semi-infaunal benthic morphotypes

The availability of free oxygen generally decreases down a sediment profile until the redox boundary is reached, where free oxygen is absent (Ekdale, 1985). Infaunal, semi-infaunal dwelling groups will therefore be pre-adapted to low oxygen levels (Byers, 1977). Corliss and Chen, (1988) suggested that changing from epifaunal to infaunal dominance is a reflection of high organic-carbon flux. During periods of high organic flux infaunal groups will increase because they are the only foraminifera that can survive in the periods with a high amount of food and also low oxygen (Byers, 1977; Jarvis *et al.*, 1988; Koutsoukos *et al.*, 1990; Leary and Peryt, 1991; Jorissen *et al.*, 1992). At Eastbourne in the Grey Chalk and bed 1 epifaunal morphotypes were abundant, while from the top of bed 1 upwards infaunal, semi-infaunal morphotypes became abundant and dominate the assemblage. At both Eastbourne and Westbury the dominant surviving benthic taxa were two epifaunal-shallow infaunal gavelinellids (*Gavelinella berthelini* and *Gavelinella reussi*), one infaunal gavelinellid (*Lingulogavelinella globosa*), one infaunal tritaxiid (*Tritaxia tricarinata*) and one infaunal eggerellid (*Marssonella trochus* var. *turris*).

Data from abundance of nannofossils at Dover (Lamolda *et al.*, 1994), SE England, and at Menoyo, N. Spain (Paul *et al.* 1994) suggest a lower productivity during late Cenomanian times. Apart from these, epifaunal species which became extinct (*Gavelinella baltica, Gavelinella cenomanica* and *Lingulogavelinella involuta*) in the early beds of the Plenus Marls were large species.

6.9. Problems with productivity model

6.9.1. Reduction in abundance of both planktic and benthic foraminifera

The productivity model postulates that oxygen deficiency began in bottom water and, then with expansion and migration of oxygen minimum zone upward, the water column was affected gradually, that is benthics should have been the first and planktics the next group to suffer from the low oxygen stressed-condition imposed on

the environment. However, at both Eastbourne and Westbury the major decline in abundance of benthic and planktic foraminifera and ostracods occurred together after bed 8 of the Plenus Marls, which is in marked contrast with expansion of oxygen minimum zone in the water column, affecting the benthics first and planktics later.

6.9.2. Selective extinction of large benthic foraminifera and replacement with smaller forms

Although, expansion of the oxygen minimum zone accounts for extinction of largest and deepest planktic foraminifera (*Rotalipora* spp.) and replacement of them by smaller forms (dicarinellids and praeglobotruncanids), it seems difficult to explain extinction of large benthic foraminifera. If oxygen deficiency in the environment was the main cause of stressed condition for benthics, why did they not behave as Lazarus taxa and abandon the environment? (like *Arenobulimina*, which left the environment at the beginning of the event). Migration of species to shallow water, which was well oxygenated due to high photosynthesis of phytoplankton was an alternative for them.

6.9.3. Increased platycopid %

At Eastbourne two intervals of low abundance of platycopids (Grey Chalk and bed 2 to middle of bed 4) correlate with less negative $\delta^{18}O$ values, while high abundance correlates with more negative $\delta^{18}O$ values (bed 1 and middle of bed 4 to Gun Gardens Marl 2). This suggests that dominance of platycopids was mainly controlled by $\delta^{18}O$ values. Platycopid ostracods are naturally adapted to low oxygen environments and their dominance suggests lowered oxygenation levels in bottom water. They benefit the filter feeding system and due to high rate of respiration are relatively immune to oxygen deficiency (Whatley, 1991). The variation in the platycopid percentage mirrors the changes in the $\delta^{18}O$ signature, with high platycopid percentage at times of climatic warming. Since warm water holds less dissolved oxygen than cold water this implies that temperature may have been important in controlling oxygenation. At times when the temperature rose, the quantities of oxygen

in deep waters were reduced. This suggests that there was not any correlation between abundance of platycopids and increasing $\delta^{13}C$ values, which in productivity model has been regarded as the main factor to induce oxygen depletion in the environment. However, at Westbury the situation is in marked contrast with Eastbourne and dominance of platycopids correlates with $\delta^{13}C$ values, so that from bed 2 to top of bed 8 the percentage of platycopids declined steadily. Therefore at Westbury increased platycopids % is compatible with the productivity model.

6.10. Evidence in favour of and/or compatible with the famine model

6.10.1. Progressive extinction of large benthic foraminifera and replacement with smaller forms.

Flessa *et al.* (1986) postulated that lower population densities, lower birth rates, and greater nutritional requirement of larger organisms were the most likely proximal reasons for the greater susceptibility of larger organisms to extinction. These results show that in many cases the extinction of the species was strongly correlated with the size of the test and larger species were those which succumbed first, e.g. in the benthic foraminifera *Spiroplectammina praelonga, Nodosaria* sp. A, *Plectina* spp., *Laevidentalina distincta, Lingulogavelinella involuta, Laevidentalina pseudochrysalis, Gavelinella baltica, Gavelinella cenomanica, Dorothia gradata, Tritaxia macfadyeni* and *Tritaxia pyramidata* were those which succumbed first. Even within a given genus those species with a larger test succumbed first. Among tritaxiids, two larger species, *Tritaxia macfadyeni* and *Tritaxia pyramidata* succumbed, while *Tritaxia tricarinata,* which is characterised by a smaller test survived. Whitin the nodosariids this trend is clear in the *Laevidentalina* spp., where *Laevidentalina distincta* was the first to succumb, followed by the extinction of *Laevidentalina pseudochrysalis* (Westbury), *Laevidentalina strangulata, Laevidentalina soluta* and eventually *Laevidentalina gracilis.* In the gavelinellids, *Gavelinella cenomanica* and *Gavelinella baltica* were replaced by two smaller forms, *Gavelinella reussi* and *Gavelinella berthelini, Lingulogavelinella involuta* was replaced promptly by a smaller form,

Lingulogavelinella globosa in bed 2. The Turonian species of this group *Lingulogavelinella aumalensis,* which appears in the uppermost part of the sections, is even more smaller.

6.10.2. Progressive extinction of large, medium and small planktic foraminifera

The stepwise extinction of planktic foraminifera (successive extinction of rotaliporids and praeglobotruncanids) in the studied sections can also be explained by famine model. During the famine period (low productivity) the largest planktic foraminifera (*Rotalipora* spp.) would be affected first, while hedbergellids - whiteinellids, with small tests were the last victims of the harsh condition (Paul and Mitchell, 1994). So sudden removal of larger genus of both benthic and planktic foraminifera is compatible with famine model.

6.10.3. Reduction in size of surviving benthic foraminifera

Of particular significance in the studied section was size reduction among some of the survivors. The reduction in size of the test could have been an adaptation for reproduction before starvation. Two prominent examples are *Tritaxia tricarinata* and *Eggerellina mariae*. In the former size of the test from bed 1 upward was smaller than pre-event (Grey Chalk) and in the latter, size of the test promptly became smaller after the extinction of *Eggerellina brevis*. Therefore, it is possible that extinction of large benthic foraminifera was due to their higher food requirements, which was not accessible, so they were victims of harsh environment, succumbed promptly or were replaced with smaller forms.

6.10.4. Reduction in abundance

Food supply is of crucial importance in population growth and when food supply is exhausted populations crash (Tenore, 1977; Tenore and Hanson, 1980; Alongi and Tenore, 1985). At both Eastbourne and Westbury the abundance of benthic

and planktic foraminifera and ostracods decreased significantly after bed 8. This suggests that a food-shortage affected the environment, because lower productivity will support lower biomass.

6.11. Problems with the famine model

6.11.1. Increased burial of organic carbon

In the famine model, increased burial of organic carbon is taken as the starting point, but its ultimate cause is unknown at present. It is inferred that this reduced availability of nutrients to the surface waters. Enhanced preservation of organic matter in a stagnant system (exceptionally warm, equable climate) might have been the main cause for the increased burial of organic matter.

It has been shown that there was a reduction in the diversity of both benthic and planktic foraminifera and ostracods through the Cenomanian-Turonian boundary. The coincidence of main extinction events with rising $\delta^{13}C$ values and falling $\delta^{18}O$ values suggest a compromise. The main effect was burial of organic carbon which led to increasing $\delta^{13}C$ excursion and consequently imposing period of famine (Paul and Mitchell, 1994). This was the main stress on organisms, but rising sea water temperature which reduced oxygen levels, caused the rise in platycopid % and led to more negative $\delta^{18}O$ values was the other factor.

In all three sections high diversity in the different assemblages correlated with low $\delta^{13}C$ values and less negative $\delta^{18}O$ values in pre-excursion phase. At Eastbourne, the most complete and expanded section in the pre-excursion phase, benthic and planktic foraminifera and ostracods were diversified and abundant, and podocopids were strongly dominant. The first major extinction step in bed 1 coincided with increasing $\delta^{13}C$ values and decreasing $\delta^{18}O$ values. The combined effect of $\delta^{13}C$ and $\delta^{18}O$ imposed both low availability of food and oxygen deficiency to the environment, during which large species succumbed promptly (except *Rotalipora*

cushmani), while small species survived. In the ostracod assemblage, podocopids lost their dominance and platycopids replaced them. The interval between bed 2 to the base of bed 4 is characterised by no significant change in microfossils assemblages (only 2 benthic foraminifera species had their last occurrences). This interval correlates with increasing both $\delta^{13}C$ and $\delta^{18}O$ values (although at the top $\delta^{13}C$ values decrease). It can be concluded that increasing $\delta^{13}C$ values by themselves were not crucial in diversity reduction, but the reduction in extinctions might have been partly due to greater availability of oxygen, which is supported by the dominance of podocopids in the ostracod assemblage. The second major extinction phase, which lasted from the middle of bed 4 to the base of the Melbourn Rock, coincided again with increasing $\delta^{13}C$ values and decreasing $\delta^{18}O$ values. This combination again imposed stress on the environment and consequently caused a major reduction in the diversity of microfossil assemblages. In this interval, platycopids became dominant in the ostracod assemblage. Through the interval between middle of the Melbourn Rock to Gun Gardens Marl 2, although $\delta^{13}C$ values stop increasing and begin to return to lower values, recovery in the benthic assemblages was very slow and the number of new species or reappearance of Lazarus species was very low. This could have been due to more negative $\delta^{18}O$ values and consequently to low oxygen condition in the environment, which is suggested by the high dominance of platycopids. Nevertheless recovery in the planktic foraminifera was satisfactory, which might have been due to independence of planktic foraminifera to low oxygen condition imposed on the sea floor. However, in the Lulworth Marl, where $\delta^{18}O$ value jumps to a high value, platycopids are still dominant and recovery in the benthic assemblages was still poor. This could have been due to high sea-level and consequently lack of food on sea floor during the deposition of Lulworth Marl. At both Westbury and South Ferriby the main reduction in diversity was concentrated through the Plenus Marls and Black Band succession, respectively. Although at Westbury decline in diversity coincided with both increasing $\delta^{13}C$ and $\delta^{18}O$ values, at South Ferriby decline in diversity through the Black Band succession coincided with decreasing in $\delta^{18}O$ values. Diversity

declines in two steps at Eastbourne, which correlate with the combination of increasing $\delta^{13}C$ and falling $\delta^{18}O$. Abundance does not decline significantly until the peak of the $\delta^{13}C$ excursion. This suggests that changes in productivity and oxygen levels caused the initial extinction, but a prolonged period of famine following the extinction caused the decline in absolute abundance (and possibly also the small size in some species). With the recovery period, new taxa appeared and abundance increased apparently.

Therefore, the combination of less food and oxygen in the environment might have been the main cause for extinction of different assemblages through the Cenomanian-Turonian boundary.

CHAPTER 7

CHAPTER 7

SUMMARY OF CONCLUSIONS

Based on micropaleontological, sedimentological and geochemical analysis of three studied sections some results have been obtained as follow.

1. The Cenomanian-Turonian boundary event, which lasted approximately for 250 000 ys. (Paul and Mitchell, 1994) is characterised by a positive $\delta^{13}C$ excursion and extinction of many benthic and planktic foraminifera and ostracods, temporarily disappearance of some species from the environment and a severe decline in the abundance of all microfaunal assemblages. At Eastbourne, the most complete and expanded section, the number of benthic species above the Plenus Marls is about a quarter of initial number in the Grey Chalk.

2. The late Cenomanian event indicates a selective extinction pattern, affecting large species among benthic foraminifera, large and deep-water dwellers among planktic foraminifera and podocopid species among the ostracods. Large species (high volume to surface ratio) succumb first among both benthic and planktic foraminifera.

3. Based on percentage data of coarse benthic foraminifera (>250 μm) five clusters at Eastbourne (labelled A_E-E_E) and four clusters at Westbury (labelled A_W-D_W) can be distinguish. Each cluster is characterised by a certain faunal assemblage confined to a limited stratigraphic interval. Clusters are not repeated up section.

4. Values for three types of diversity (simple, Fisher and Shannon) in both foraminiferal and ostracod communities allow recognition of three different intervals in the southern sections. The first interval coincides with cluster A and is characterised by very high values in diversities, in which total numbers of opportunistic species

(*Lingulogavelinella globosa*, *Marssonella* spp., *Gavelinella berthelini* plus *Gavelinella reussi* and *Ammodiscus cretaceous*) are low. The second interval includes clusters B and C, during which diversities decline in both microfaunal assemblages. The total number of opportunistic species increases gradually up through the clusters, reaching a peak in the upper parts of the Plenus Marls and immediately overlying chalk; this reflects a progressively more stressed environment. The third interval comprises clusters D and E (Eastbourne), which are characterised by very low values in all three diversities. In these clusters, the benthic foraminiferal population is characterised by high dominance of opportunistic species, while amongst the ostracods, *Cytherella ovata* is strongly dominant (more than 90%).

5. Neither benthic nor planktic foraminifera show a systematic relationship with lithology, however, P% (planktic foraminifera as a percentage of the total foraminifera in the >250 μm fraction) shows a consistent relationship with the five major marl-chalk rhythms in the Plenus Marls recognised by Jefferies (1962). In general the number of planktic foraminifera increases in the chalks. These rhythms probably represent the 20 000 yr. Milankovitch precession cycle.

6. At Eastbourne two major extinction events are recognisable: the bed 1 interval: and the bed 4 to lowermost Melbourn Rock interval. Between these two levels the extinction shows a graded pattern and a gradual decline in diversity occurs. If we consider only the more common species with consistent occurrences, the extinctions occur at the top of bed 1 (extinction 1) and the lowermost part of the Melbourn Rock (extinction 2).

7. The studied interval comprises two mass extinctions and a survival interval in the Harries model. The recovery interval is beyond the studied parts of the sections.

8. The platycopid signal suggests low oxygenation at the times of reduction in benthic foraminiferal diversity (bed 1, and middle of bed 4 to base of Melbourn Rock). These extinction periods are associated with warm water intervals (decrease in $\delta^{18}O$) and not necessarily due to deposition of high amount of organic matter (high $\delta^{13}C$ values).

9. The correspondence between $\delta^{13}C$ values and the extinction of microfauna suggests either a low oxygen condition (Jarvis *et al*, 1984) or a food crisis in the environment (Paul and Mitchell, 1984). However, the response of biota to these two different factors is identical.

10. At Eastbourne, extinction of *Rotalipora cushmani* occurs a little higher than previous records in the Anglo - Paris Basin. At Dover this species becomes extinct at the top of bed 3, while at Eastbourne has its last occurrence in the middle of bed 4.

11. At Westbury two rotaliporids (*Rotalipora greenhornensis* and *Rotalipora deeckei*) go out together. This difference may reflect either the more highly condensed section at Westbury or missing strata.

12. Important extinctions of planktic foraminifera occur in the lower part of the Plenus Marls. The species *Rotalipora deeckei*, *Rotalipora greenhornensis* and *Rotalipora cushmani* become extinct in the middle of bed 1a, top of bed 1b and middle of bed 4, respectively. These successive extinctions correlate with the build-up phases of the carbon excursion, which shows sequestering of nutrient and consequently less availability of food in the environment (famine model). This resulted in extinction of the largest planktic foraminifera first. The alternative explanation is that expansion of the oxygen minimum zone in the water column (productivity model) arrested gametogenesis of the deepest dwelling planktic foraminifera first.

13. The assemblage of fine (63-90 μm) benthic foraminifera has a low diversity, and is mainly composed of *Praebulimina*, *Gyroidinoides* and *Osangularia*. The fine benthic assemblage shows a different pattern from the coarse benthic assemblage. At Eastbourne the assemblage is more influenced by sea level changes than the other factors (i.e. $\delta^{13}C$ and $\delta^{18}O$ values). The percentage of deep-water dwelling *Osangularia,* (Sliter, 1972), falls across the two erosion surfaces (sub Plenus erosion surface and sub-bed 2 erosion surface of Jefferies, 1962), but then increases in clusters D and E, when there was a high sea level stand. The distribution pattern of dominant fine benthic species at South Ferriby shows quite a difference from the Eastbourne section. At South Ferriby, under the stressed environment (high $\delta^{13}C$ values), *Osangularia* forms the dominant taxon and at the time of decline in stress and high sea level stand *Praebulimina* is the most significant species of the assemblage. This different distribution pattern in the fine fraction assemblage is difficult to interpret.

14. At southern sections, during the plateau phase of $\delta^{13}C$ excursion no new benthic foraminifera appear, but origination of a podocopid ostracod (*Mosaeleberis* sp. A) in the early stage of this phase does occur. At Westbury this species is accompanied by another podocopid, *Cythereis longaeva.* Appearance of ostracods earlier than benthic foraminifera may reflect the ability of ostracods to survive abrupt environmental changes. It thus further reflects their environmental tolerance and also shows that benthic foraminifera are more sensitive than ostracods to stress since they reappear more slowly than ostracods.

15. Foraminifera adopt a variety of behavioural strategies to obtain their food (Lipps, 1983: Jones and Charnock, 1985). One possibility for survival of the CH-B4 (*Lingulogavelinella berthelini* and *Lingulogavelinella reussi*), AG-C (*Marssonella* spp.) and CH-B3 (*Lingulogavelinella globosa*) morphotype groups at the Cenomanian-Turonian boundary might be due to the mechanisms they use for survival

during low availability of food. The survival strategy of this group during periods of famine might have been a rapid turnover of ATP, which allows these foraminifera to take advantage of sudden nutrient inputs; this state of readiness, however, is maintained at the cost of the protoplasm, which benthic foraminifera are apparently capable of metabolising in times of starvation. However, it is not clear why all the benthic foraminifera cannot take advantage of such a strategy to survive in the famine periods?

16. Sudden extinction of the epifaunal group (*Gavelinella baltica*, *Gavelinella cenomanica* and *Lingulogavelinella involuta*) in the early beds of the Plenus Marls, in southern sections, most likely reflects the selective extinction pattern, which resulted in the larger benthic foraminifera succumbing first, due to more their larger food requirement than the smaller species.

17. The recovery in the benthic foraminiferal and ostracod assemblage is less satisfactory than with planktic foraminifera. The reason for this could be due to warm sea water (low $\delta^{18}O$ values through cluster D) and consequently low oxygenation in the environment or low migration rate of micro-benthos after a long period of stress or perhaps due to deepening of the water and consequently low availability of food at the sea floor.

18. The marl succession above the Ferriby Chalk Formation has been divided into eleven beds (lettered A, B, C, D, E, F1, F2, F3, G, H, I). These beds can be correlated with southern sections.

19. Re-appearance of some late benthic foraminifera in bed F2 at South Ferriby could be explained by a sudden fall in sea level, causing shallowing of the basin to the shore and consequently, more productivity at the sea floor which resulted in the reappearance of some late Cenomanian benthic fauna.

20. At South Ferriby, the low proportion of keeled planktic foraminifera in beds E to G, compared with the succession below and above could be due to expansion of the oxygen minimum zone in the water column, which resulted in arresting the gametogenesis of the deep dwelling fauna (productivity model) or due to low availability of food (famine model) and consequently succumbing these large species.

21. *Schakoina* has been interpreted as representing a questionable shallow-water form by Hart (1980) and deep-water form by Douglas and Savin (1978). The appearance of this species at the top of cluster A, where a deepening of the basin is apparent, and its re-appearance in Meads Marl 5 (cluster D, Eastbourne), where a deep-water genus (*Osangularia*) becomes strongly dominant, suggests it was a deep-water form.

22. Although the environmental effects of the Cenomanian-Turonian boundary "event" can be inferred from benthic and planktic microfauna, the ultimate cause remains elusive. Late Cenomanian benthic and planktic foraminifera, as well as ostracod assemblages indicate stressed conditions leading to species extinctions through the boundary. These stressed conditions may be explained by the combination effects of less availability of food and oxygen in the environment, which resulted in the extinction of different microfaunal assemblages through the Cenomanian-Turonian boundary. However, the effect of extraterrestrial impacts as a major cause for the Late Cenomanian event cannot be completely ruled out.

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Plates

PLATE 1

Late Cenomanian - early Turonian strata at Eastbourne (Beachy Head)

Plate 1A. Late Cenomanian - early Turonian strata exposed in south east England, Eastbourne (Beachy Head). The Grey Chalk Formation, Plenus Marls and post Plenus Marls strata (Melbourn Rock and Ranscombe Chalk Member) are clearly visible. The Plenus Marls comprise 8 beds, each characterised by a distinctive microfaunal assemblage and lithology. Bag for scale.

G: Grey Chalk Formation

P: Plenus Marls

R: Ranscombe Chalk Member

Plate 1B. Typical Meads Marls seams within the Ranscombe Chalk Member (post Plenus Marls strata) in south east England, Eastbourne (Beachy Head). Meads Marls comprise 6 marly seams and occur in the latest Cenomanian - early Turonian strata. Arrows indicate Meads Marls 3 and 4. Hammer for scale.

PLATE 1

A

B

PLATE 2

Close up view of late Cenomanian - early Turonian strata exposed at Eastbourne, Beachy Head

Late Cenomanian - early Turonian strata at Eastbourne (Beachy Head).
Beds 1-3 of the Plenus Marls are clearly visible, although it is difficult to indicate beds 4 to 8 separately. Hammer for scale.
G: Grey Chalk platform
Numbers: Beds 1-8 of the Plenus Marls
M: Melbourn Rock Beds

PLATE 2

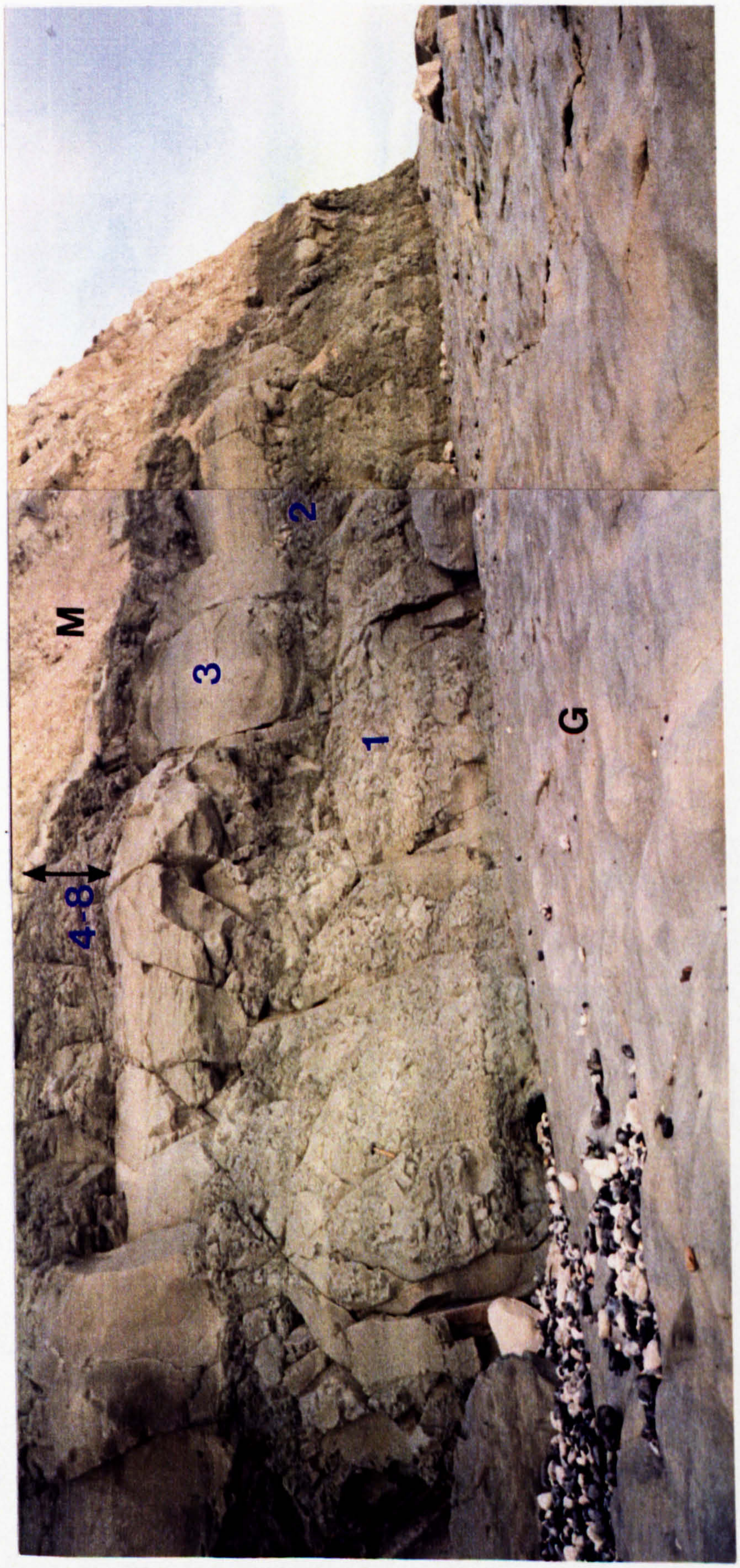


PLATE 3

Late Cenomanian - early Turonian strata at Westbury (Wiltshire)

Plate 3A. Late Cenomanian - early Turonian strata exposed at Westbury, Wiltshire. The thickness of the Plenus Marls Formation in this section is less than at Eastbourne. The exposure of Grey Chalk is less prominent, but the Plenus Marls and post Plenus strata (Melbourn Rock and Ranscombe Chalk Member) are clearly visible.

G: Grey Chalk

P: Plenus marls

R: Ranscombe Chalk Member

Plate 3B. *Chondites* burrow systems developed in the Grey Chalk (pre Plenus Marls strata) exposed at Westbury, Wiltshire. These traces are filled with poorly contrasting chalk. Arrows indicate some prominent *Chondrites* burrows. Hammer for scale.

PLATE 3

A

B

PLATE 4

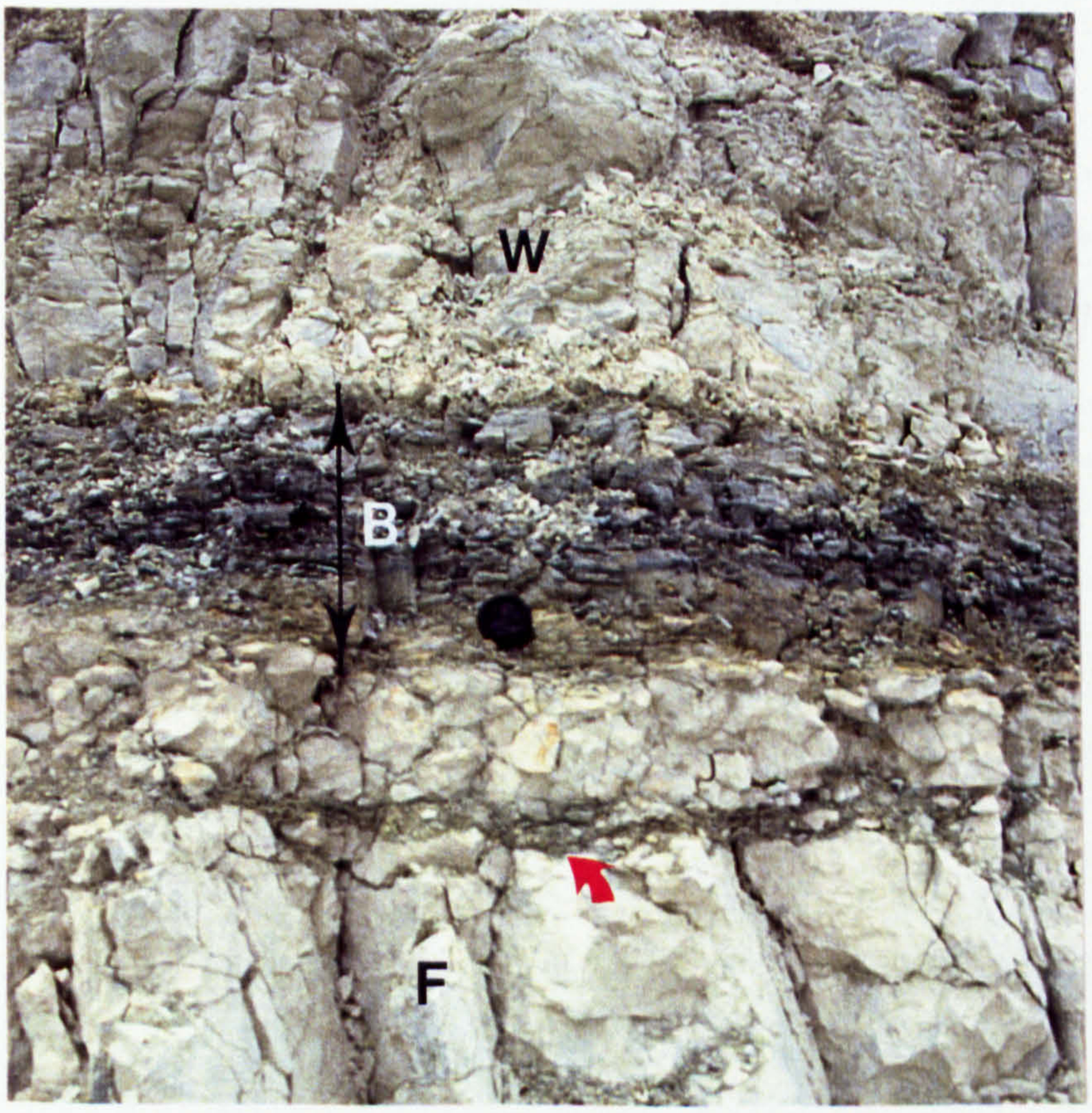
Late Cenomanian - early Turonian strata at South Ferriby (Lincolnshire)

Plate 4A. Exposure of the Black Band succession at South Ferriby, Lincolnshire. The Ferriby Chalk Formation is below, and the Welton Chalk Formation above, the Black Band. The section is very condensed and incomplete.
F: Ferriby Chalk Formation
B: Black Band
W: Welton Chalk Formation

Plate 4B. Close up view of the Black Band succession at South Ferriby, Lincolnshire. The Black Band comprises 11 beds, which are located between the Ferriby Chalk Formation below and the Welton Chalk Formation above. Arrow indicates marly bed in the Ferriby Chalk Formation from which sample S_2 was taken. Lens cover for scale.
F: Ferriby Chalk Formation
B: Black Band
W: Welton Chalk Formation

PLATE 4

A



B

PLATE 5

Benthic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

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***Arenobulimina bulleta* Barnard and Banner**

Figure 1. Ferriby Chalk Formation (sample S2), South Ferriby. x84.

***Arenobulimina pseudalbiana* Barnard and Banner**

Figure 2. Ferriby Chalk Formation (sample S2), South Ferriby. x122.

***Arenobulimina elongata* Barnard and Banner**

Figure 3. Black Band succession (sample S3), Welton Chalk Formation, South Ferriby. x115.

***Arenobulimina advena* (Cushman)**

Figure 4. Ferriby Chalk Formation (sample S1), South Ferriby. x82.

***Spiroloculina cretacea* Reuss**

Figure 5. Plenus Marls Formation (sample E10), Eastbourne. x84.

***Palmula baudouiniana* (d'Orbigny)**

Figure 6. Grey Chalk Formation, (sample E2), Eastbourne. x68.

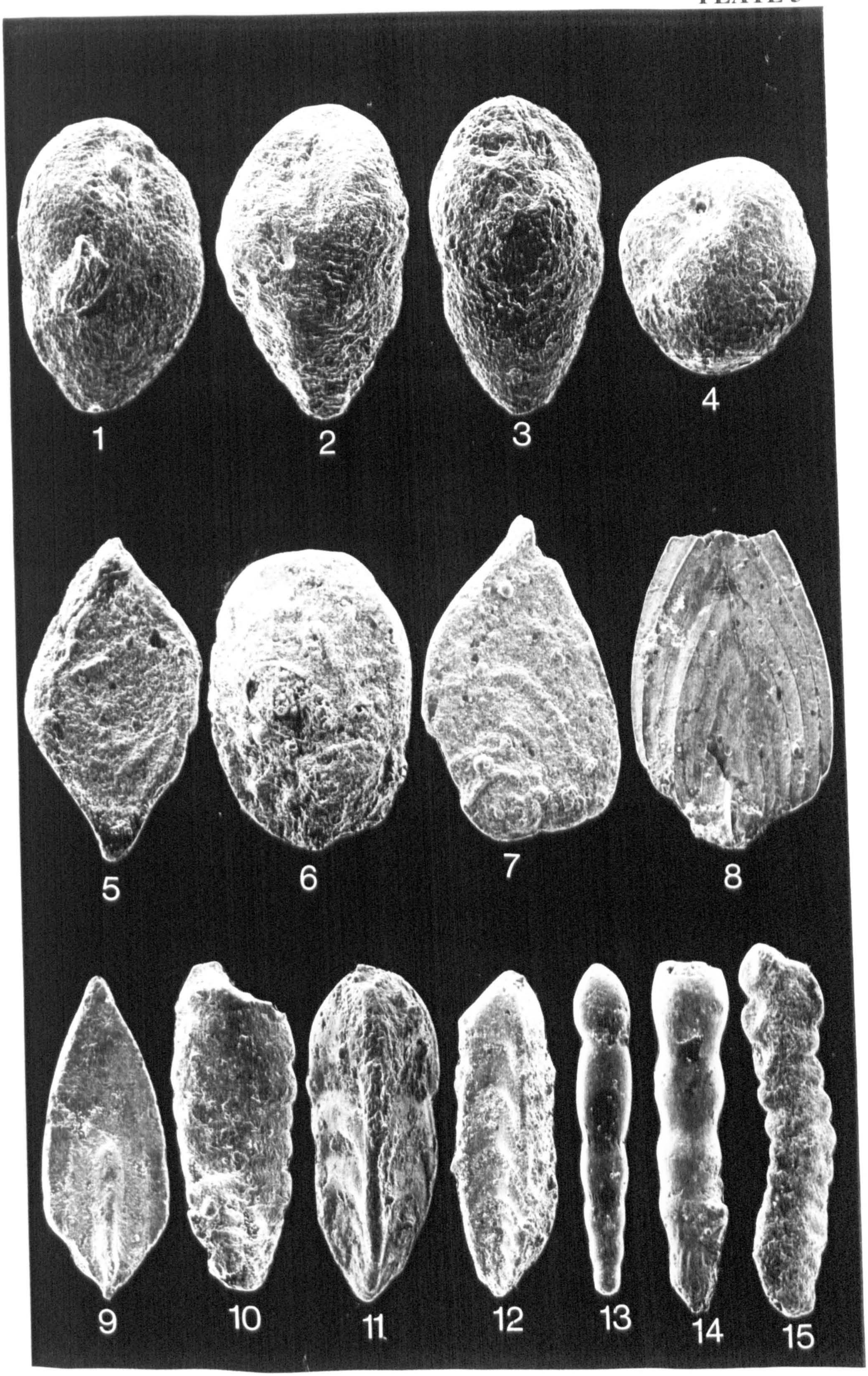
***Palmula* sp. A**

Figure 7. Grey Chalk Formation (sample E5), Eastbourne. x47.

***Frondicularia cordai* (Reuss)**

Figure 8. Grey Chalk Formation Formation (sample E3), Eastbourne. x34.

PLATE 5



(Plate 5 continued)

Frondicularia mucronata **(Reuss)**

Figure 9. Plenus Marls Formation (sample E12), Eastbourne. x57.

Spiroplectammina praelonga **(Reuss)**

Figure 10. Grey Chalk Formation (sample E5), Eastbourne. x73.

Tristix excavata **(Reuss)**

Figure 11. Grey Chalk Formation (sample E4), Eastbourne. x72.

Tristix maertensi **(Reuss)**

Figure 12. Grey Chalk Formation (sample W1), Westbury. x64.

Nodosaria **sp. A**

Figure 13. Grey Chalk Formation (sample W1), Westbury. x44.

Nodosaria **sp. B**

Figure 14. Grey Chalk Formation (sample E5), Eastbourne. x48.

Pseudospiroplectinata plana **(Gorbenko)**

Figure 15. Plenus Marls Formation (sample E10), Eastbourne. x64.

PLATE 6

Benthic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

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Plectina mariae **(Franke)**

Figure 1. Grey Chalk Formation (sample E4), Eastbourne. x78.

Plectina cenomana **Carter and Hart**

Figure 2. Grey Chalk Formation (sample E2), Eastbourne. x83.

Tritaxia macfadyeni **(Cushman)**

Figure 3. Plenus Marls Formation (sample E8), Eastbourne. x35.

Ataxophragmium depressum **(Perner)**

Figure 4. Grey Chalk Formation (sample E7), Eastbourne. x94.

Gavelinella cenomanica **(Brotzen)**

Figures 5-6. Plenus Marls Formation (sample E8), Eastbourne. Both figures, x106.

Gavelinella baltica **Brotzen**

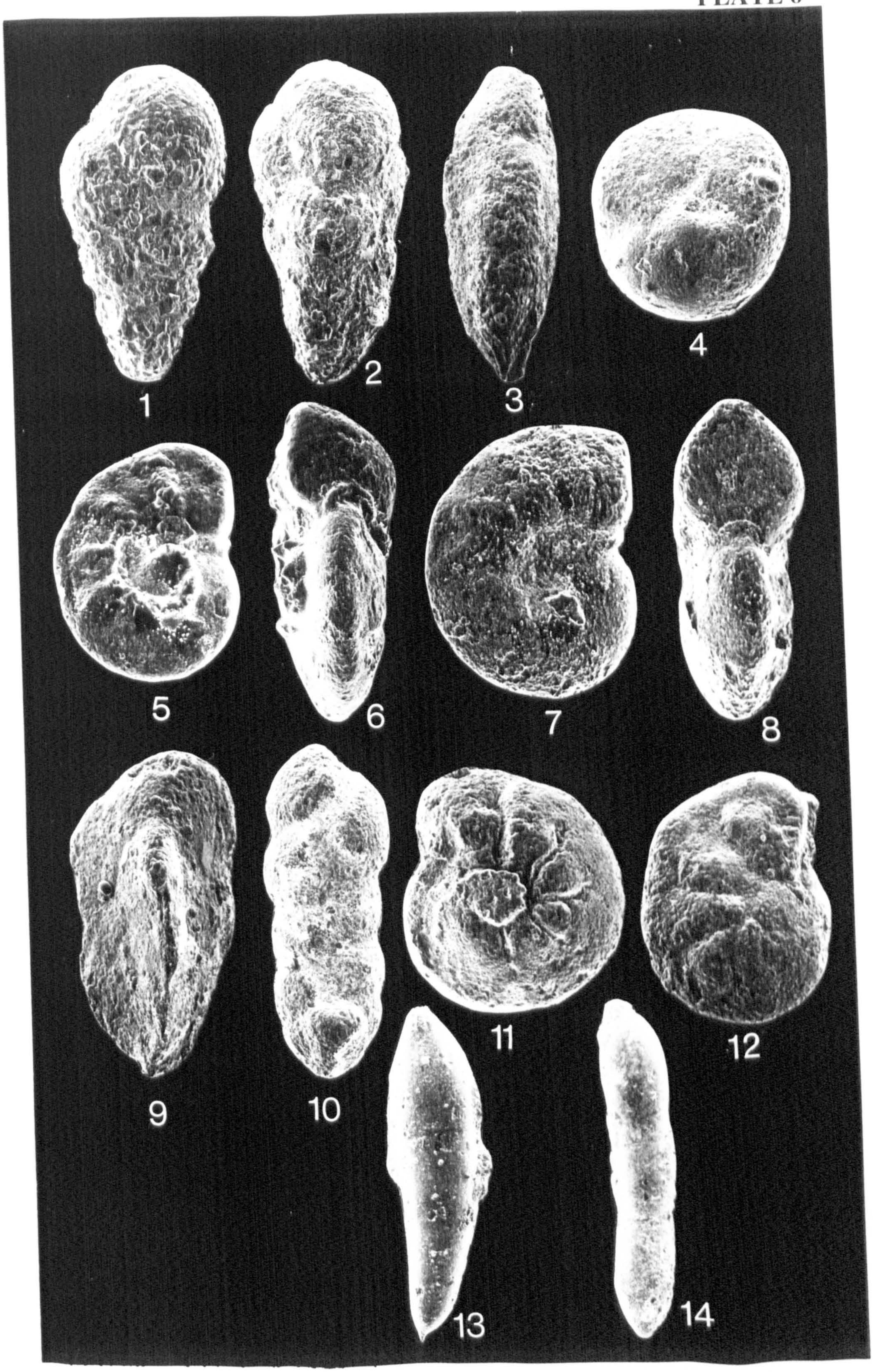
Figures 7-8. Plenus Marls Formation, (sample E12), Eastbourne. Figure 7, x96; figure 8, x107.

Tritaxia pyramidata **(Reuss)**

Figure 9. Grey Chalk Formation (sample E7), Eastbourne. x89.

Dorothia gradata **(Berthelin)**

Figure 10. Grey Chalk Formation (sample E12), Eastbourne. x60.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(Plate 6 continued)

Lingulogavelinella involuta **Owen**

Figures 11-12. Plenus Marls Formation (sample E13), Eastbourne. Figure 11, x98; figure 12, x87.

Laevidentalina pseudochrysalis **(Reuss)**

Figure 13. Grey Chalk Formation (sample W1), Westbury. x56.

Laevidentalina distincta **(Reuss)**

Figure 14. Grey Chalk Formation (sample W1), Westbury. x41.

PLATE 7

Benthic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

---

***Frondicularia archiaciana* d'Orbigny**

Figure 1. Black Band succession, Welton Chalk Formation (sample S8), South Ferriby. x42.

***Dentalina* sp. A**

Figures 2. Plenus Marls Formation (sample E26), Eastbourne. x58.

***Planularia biochei* Berthelin**

Figure 3. Black Band succession (sample S6), Welton Chalk Formation, South Ferriby. x83.

***Planularia* sp. A**

Figure 4. Plenus Marls Formation (sample W6), westbury. x89.

***Quinqueloculina antiqua* Franke**

Figure 5. Plenus Marls Formation (sample E27), Eastbourne. x104.

***Laevidentalina legumen* (Reuss)**

Figure 6. Plenus Marls Formation Formation (sample W5), Westbury. x66.

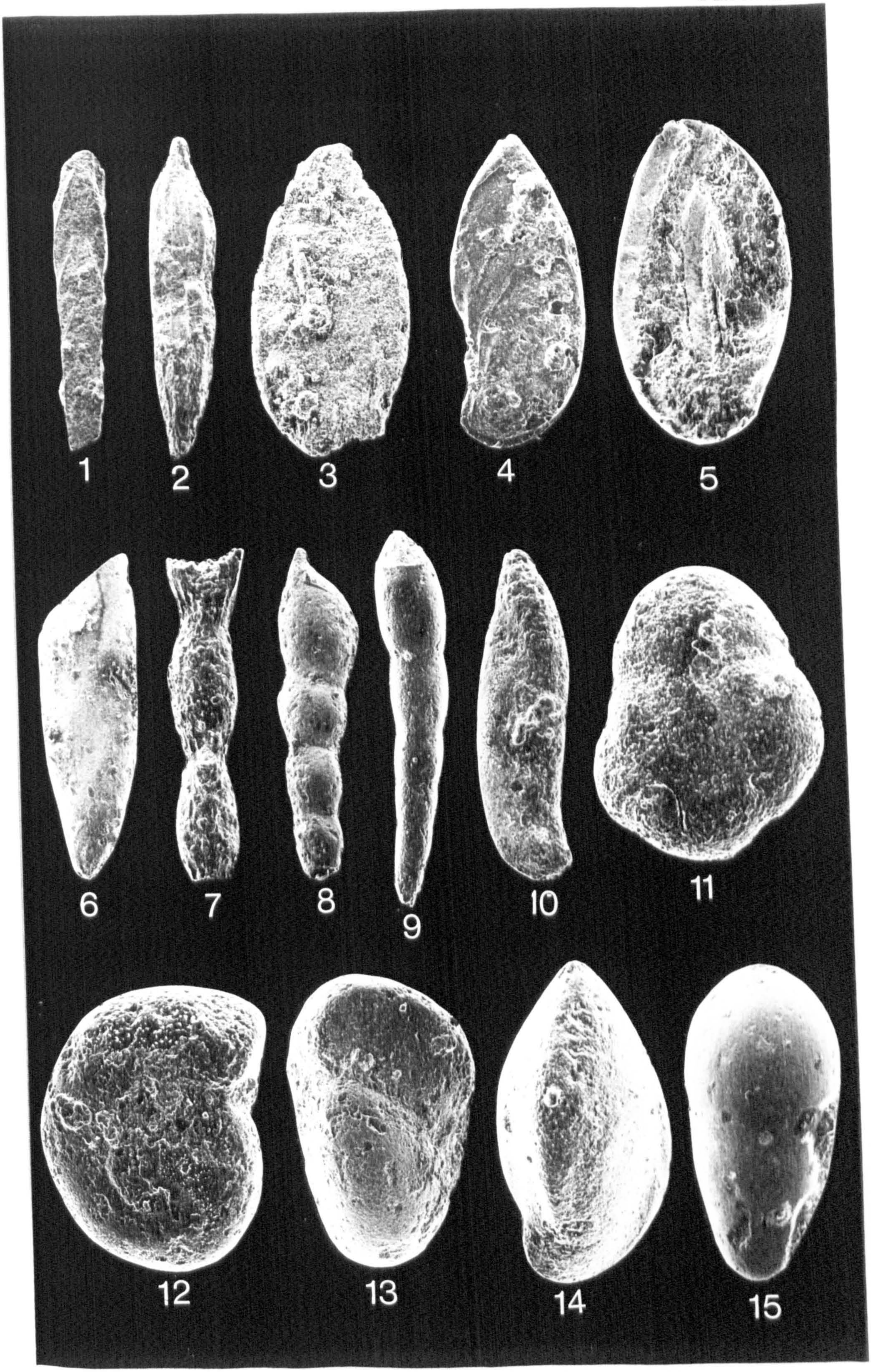
***Laevidentalina strangulata* (Reuss)**

Figures 7. Plenus Marls Formation (sample E23), Eastbourne. x53.

***Laevidentalina soluta* (Reuss)**

Figure 8. Grey Chalk Formation (sample E7), Eastbourne. x60.

PLATE 7



(Plate 7 continued)

***Laevidentalina gracilis* d'Orbigny**

Figure 9. Plenus Marls Formation (sample E22), Eastbourne. x66.

***Astacolus* sp. A**

Figures 10. Plenus Marls Formation, (sample E17), Eastbourne. x57.

***Quadromorphina allomorphinoides* (Reuss)**

Figure 11. Black Band succession (sample S6), Welton Chalk Formation. South Ferriby. x106.

***Gyroidinoides* sp. A**

Figures 12-13. Grey Chalk Formation (sample E4), Eastbourne. Both Figures, x125.

***Saracenaria jarvisi* (Brotzen)**

Figure 14. Plenus Marls Formation (sample E23), Eastbourne. x113.

***Pseudonodosaria humilis* (Roemer)**

Figure 15. Ranscombe Chalk Member (sample W13), Westbury. x52.

PLATE 8

Benthic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

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***Reophax* sp. A**

Figure 1. Plenus Marls Formation (sample E16), Eastbourne. x44.

***Frondovaginulina inversa* (Reuss)**

Figure 2. Welton Chalk Formation (sample S19), South Ferriby. x35.

***Frondicularia gaultina* Reuss**

Figures 3. Plenus Marls Formation (sample E10), Eastbourne. x43.

***Marginulina* sp. A**

Figure 4. Grey Chalk Formation (sample E4), Eastbourne. x65.

***Frondicularia lanceola* Reuss**

Figure 5. Black Band succession (sample S14), Welton Chalk Formation, South Ferriby. x48.

***Textularia chapmani* (Lalicker)**

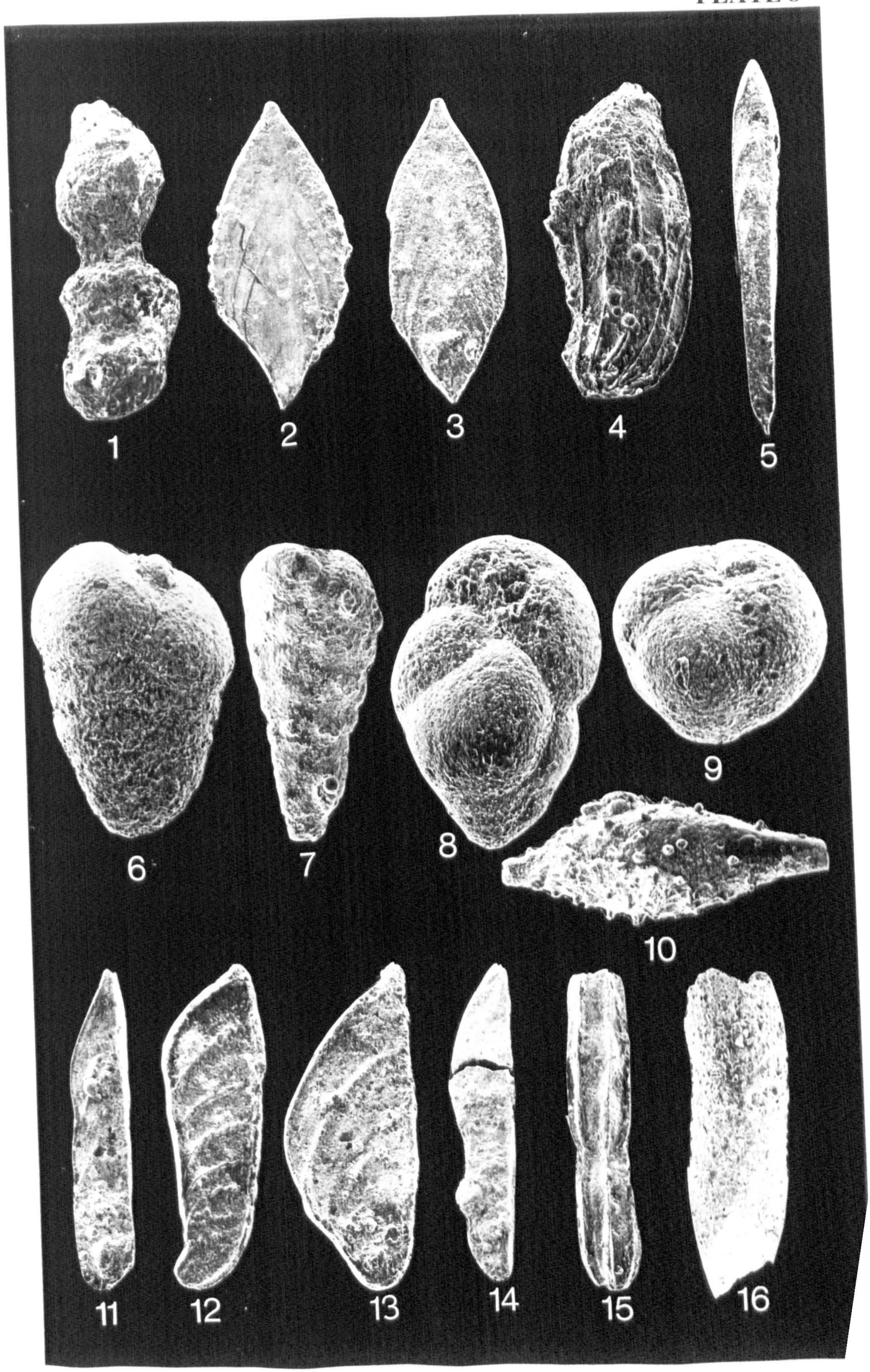
Figures 6. Plenus Marls Formation, (sample E17), Eastbourne. x104.

***Textularia* sp. A**

Figure 7. Plenus Marls Formation (sample E7), Eastbourne. x79.

***Eggerellina mariae* Ten Dam**

Figure 8. Plenus Marls Formation (sample E25), Eastbourne. x114.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(Plate 8 continued)

Eggerellina brevis (Marie)

Figure 9. Plenus Marls Formation (sample E25), Eastbourne. x117.

Ramulina aculeata Wright

Figure 10. Plenus Marls Formation (sample E8), Eastbourne. x78.

Psilocytharella costulata (Roemer) var. A

Figure 11. Plenus Marls Formation (sample W2), Westbury. x57.

Psilocytharella costulata (Roemer) var. B

Figure 12. Plenus Marls Formation (sample W4), Westbury. x43.

Psilocytharella costulata (Roemer) var. C

Figure 13. Plenus Marls Formation (sample W4), Westbury. x66.

Psilocytharella costulata (Roemer) var. D

Figure 14. Plenus Marls Formation (sample W2), Westbury. x33.

Pyramidulina obscura (Reuss)

Figure 15. Plenus Marls Formation (sample E18), Eastbourne. x72.

Bathysiphon sp. A

Figure 16. Grey Chalk Formation (sample E5), Eastbourne. x66.

PLATE 9

Benthic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

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Oolina globosa **Montagu**

Figure 1. Plenus Marls Formation (sample E24), Eastbourne. x127.

Gaudryina austinana **Cushman**

Figure 2. Plenus Marls Formation (sample E17), Eastbourne. x102.

Gaudryina stephensoni **Cushman**

Figure 3. Black Band succession (sample S5), Welton Chalk Formation, South Ferriby. x87.

Tritaxia tricarinata **var.** *jongmansi* **(Schijfsma)**

Figure 4. Ranscombe Chalk Member (sample W14), Westbury. x66.

Frondicularia verneuiliana **d'Orbigny**

Figures 5. Ranscombe Chalk Member (sample E46), Eastbourne. x25.

Arenobulimina pressli **(Reuss)**

Figures 6. Ranscombe Chalk Member, (sample E47), Eastbourne. x101.

Arenobulimina truncata **(Reuss)**

Figure 7. Ranscombe Chalk Member (sample E45), Eastbourne. x134.

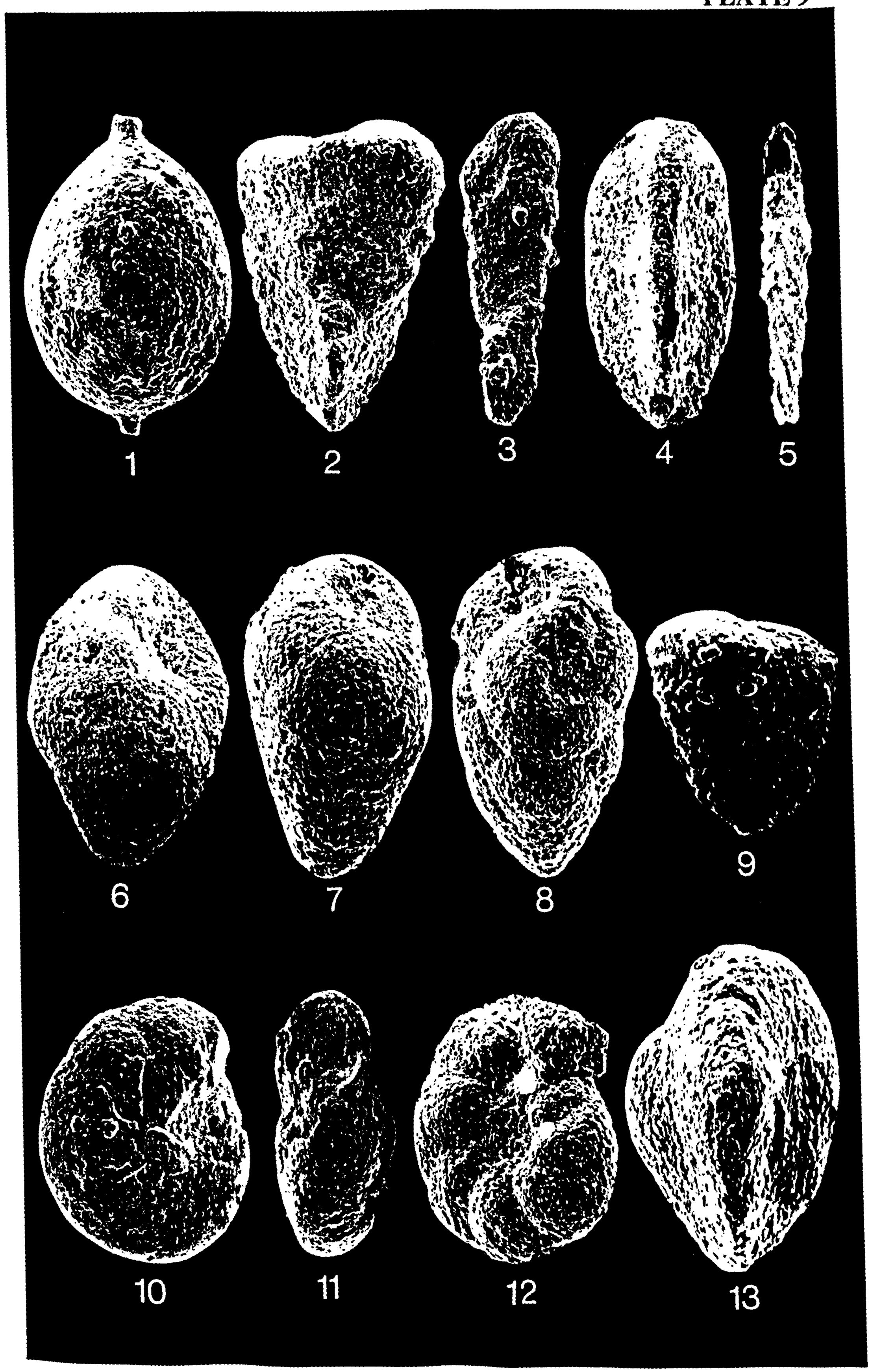
Arenobulimina **sp. A**

Figure 8. Ranscombe Chalk Member (sample E47), Eastbourne. x95.

Textularia **sp. B**

Figure 9. Plenus Marls Formation (sample E25), Eastbourne. x117.

PLATE 9



(Plate 9 continued)

Valvulineria lenticula (Reuss)

Figures 10-11. Welton Chalk Formation (sample S18), South Ferriby. Both figures x61.

Ligulogavelinella aumalensis (Sigal)

Figure 12. Ranscombe Chalk Member (sample W13), Westbury. x114.

Tritaxia tricarinata (Reuss)

Figure 13. Plenus Marls Formation (sample E12), Eastbourne. x96.

PLATE 10

Benthic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

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***Marssonella trochus* var. *turris* (d'Orbigny)**

Figure 1. Ranscombe Chalk Member (sample E39), Eastbourne. x112.

***Marssonella trochus* var. *oxycona* (Reuss)**

Figure 2. Ranscombe Chalk Member (sample E40), Eastbourne. x104.

***Gavelinella reussi* (Khan)**

Figure 3. Plenus Marls Formation (sample E25), Eastbourne. x107.

***Gavelinella berthelini* (Keller)**

Figures 4-5. Ranscombe Chalk Member (sample E39), Eastbourne. Figure 4, x96; figure 5, x124.

***Lingulogavelinella globosa* (Brotzen)**

Figures 6. Plenus Marls Formation (sample E25), Eastbourne. x87.

***Lenticulina* spp.**

Figures 7-10. Lower Chalk, (samples E2-E7), Eastbourne. Figure7, x89; figure 8, x80; figure 9, x53; figure 10, x70.

***Ammodiscus cretaceus* (Reuss)**

Figure 11. Black Band succession (sample S3), Welton Chalk Formation, South Ferriby. x53.

PLATE 10

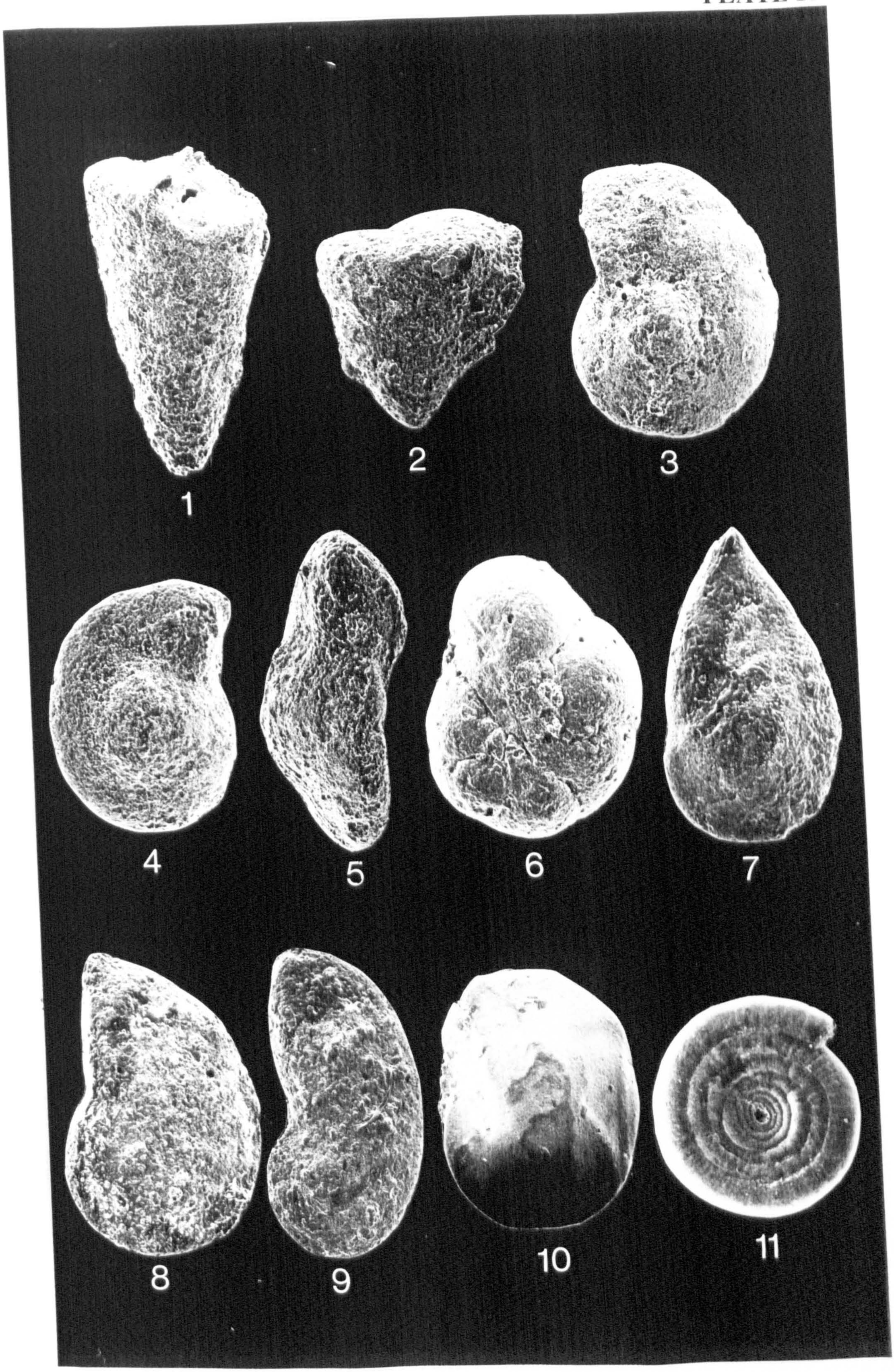

PLATE 11

Planktic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

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***Rotalipora deeckei* (Franke)**

Figures 1-3. Plenus Marls Formation (sample E10), Eastbourne. Figure 1, x97; figure 2, x97; figure 3, x92.

***Rotalipora greenhornensis* (Morrow)**

Figures 4-6. Plenus Marls Formation (sample E10), Eastbourne. Figure 4, x102; figure 5, x127; figure 6, x105.

***Rotalipora cushmani* (Morrow)**

Figures 7-9. Plenus Marls Formation (sample E8), Eastbourne. Figure 7, x95; figure 8, x125; figure 9, x95.

***Praeglobotruncana stephani* (Gandolfi)**

Figure 10. Welton Chalk Formation (sample S18), South Ferriby. x90.

***Hedbergella planispira* (Tappan)**

Figure 11. Black Band succession (sample S6), Welton Chalk Formation, South Ferriby. x112.

***Hedbergella simplex* (Morrow)**

Figure 12. Ranscombe Chalk Member, (sample E42), Eastbourne. x110.

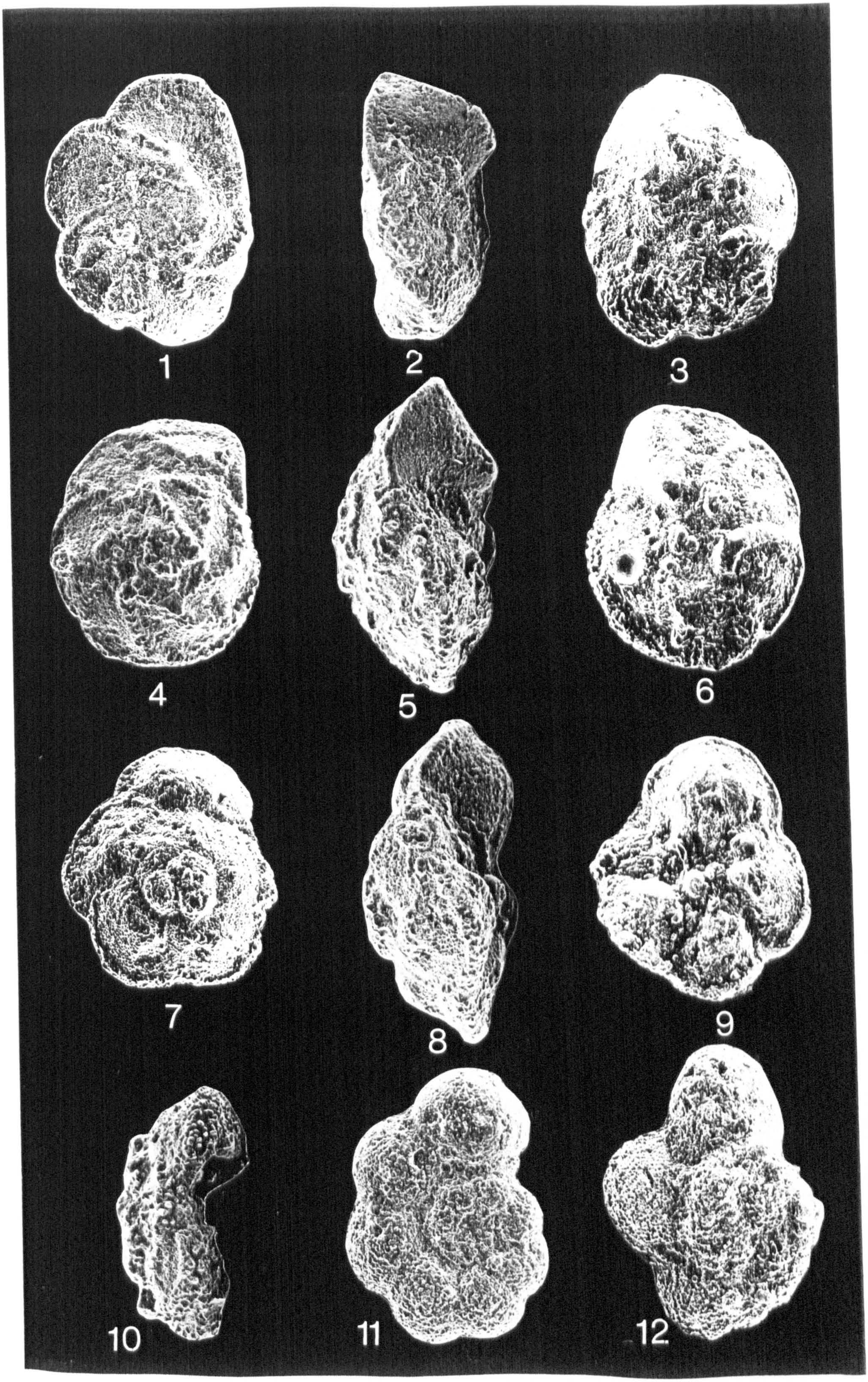
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PLATE 12

Planktic foraminifera recovered from the coarse fraction (>250 μm) from the Cenomanian - Turonian boundary

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***Whiteinella brittonensis* (Loeblich and Tappan)**

Figure 1. Plenus Marls Formation (sample E13), Eastbourne. x107.

***Hedbergella delrioensis* (Carsey)**

Figure 2. Plenus Marls Formation (sample E10), Eastbourne. x134.

***Whiteinella archaeocretacea* (Pessagno)**

Figure 3. Welton Chalk Formation (sample S17), South Ferriby. x97.

***Whiteinella aprica* Loeblich and Tappan**

Figure 4. Welton Chalk Formation (sample S18), South Ferriby. x70.

***Dicarinella hagni* (Scheibnerova)**

Figure 5. Welton Chalk Formation (sample S17), South Ferriby. x86.

***Dicarinella algeriana* (Caron)**

Figure 6. Welton Chalk Formation (sample S17), South Ferriby. x97.

***Marginotruncana renzi* (Gandolfi)**

Figures 7-9. Ranscombe Chalk Member (sample E47), Eastbourne. Figure 7, x104; figure 8, x148; figure 9, x104.

***Praeglobotruncana* sp. A**

Figures 10-12. Ranscombe Chalk Member (sample E47), Eastbourne. Figure 10, x105; figure 11, x113; figure 12, x117.

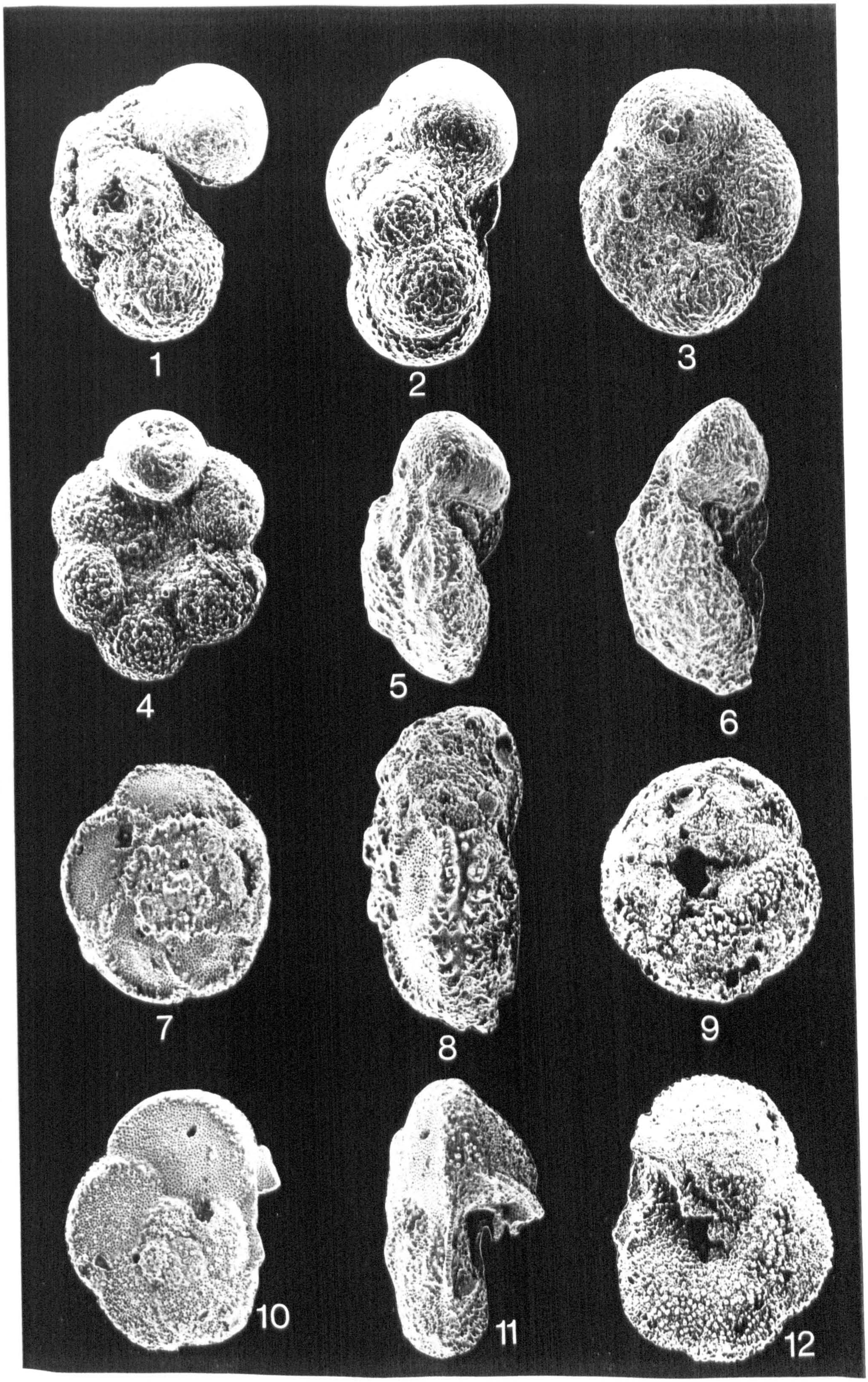
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PLATE 13

Ostracods recovered from the Cenomanian - Turonian Boundary

Cytherelloidea bonnemai **Weaver**

Figure 1. Right valve. Grey Chalk Formation (sample E5), Eastbourne. x82.

Cytherelloidea stricta **(Jones and Hinde)**

Figure 2. Left valve. Grey Chalk Formation (sample E5), Eastbourne. x79.

Curfsina derooi **Weaver**

Figure 3. Left valve. Grey Chalk Formation (sample E2), Eastbourne. x57.

Imhotepia euglyphea **Weaver**

Figure 4. Left valve. Grey Chalk Formation (sample E3), Eastbourne. x85

Neocythere kayei **Weaver**

Figure 5. Right valve. Grey Chalk Formation (sample W1), Westbury. x104.

Bythoceratina umbonatoides **(Kaye)**

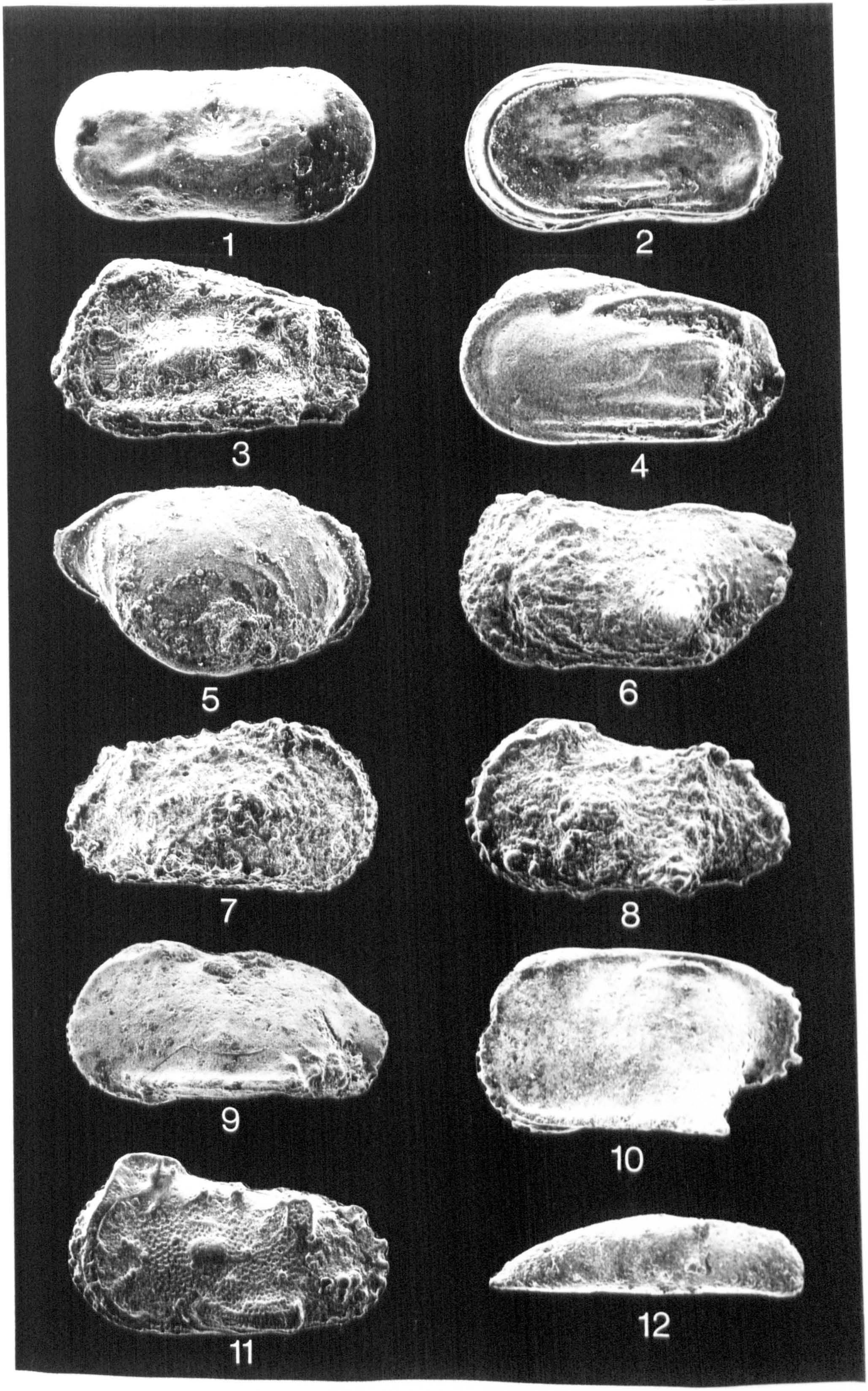
Figure 6. Left valve. Grey Chalk Formation (sample W2), Westbury x89.

Oertliella donzei **Weaver**

Figure 7. Right valve. Plenus Marls Formation (sample E22), Eastbourne. x87.

Oertliella alata **Weaver**

Figure 8. Left valve. Plenus Marls Formation (sample E10), Eastbourne. x88.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(Plate 13 continued)

Pterygocythereis laticristata (Bosquet)

Figure 9. Left valve. Plenus Marls Formation (sample W2), Westbury. x52.

Pterygocythereis robusta Weaver

Figure 10. Left valve. Plenus Marls Formation (sample E31), Eastbourne. x65.

Herrigocythere donzei (Weaver)

Figure 11. Left valve. Plenus Marls Formation (sample E12), Eastbourne. x91.

Macrocypris siliqua (Jones)

Figure 12. Right valve. Plenus Marls Formation (sample E14), Eastbourne. x39.

PLATE 14

Ostracods recovered from the Cenomanian - Turonian Boundary

Pontocyprella robusta Weaver

Figures 1-2. Figure 1, left valve; figure 2, right valve. Plenus Marls Formation (sample W2), Westbury. Figure 1, x75; figure 2, x71.

Dolocytheridea sp. A

Figure 3. Right valve. Plenus Marls Formation (sample W4), Westbury. x76.

Pontocyprella hindei Weaver

Figure 4. Right valve. Grey Chalk Formation (sample W1), Westbury. x75.

Pontocyprella harissiana (Jones)

Figures 5-6. Both figures show left valves. Grey Chalk Formation (sample W1), Westbury. Figure 5, x64; figure 6, x82.

Paracypris wrothamensis Kaye

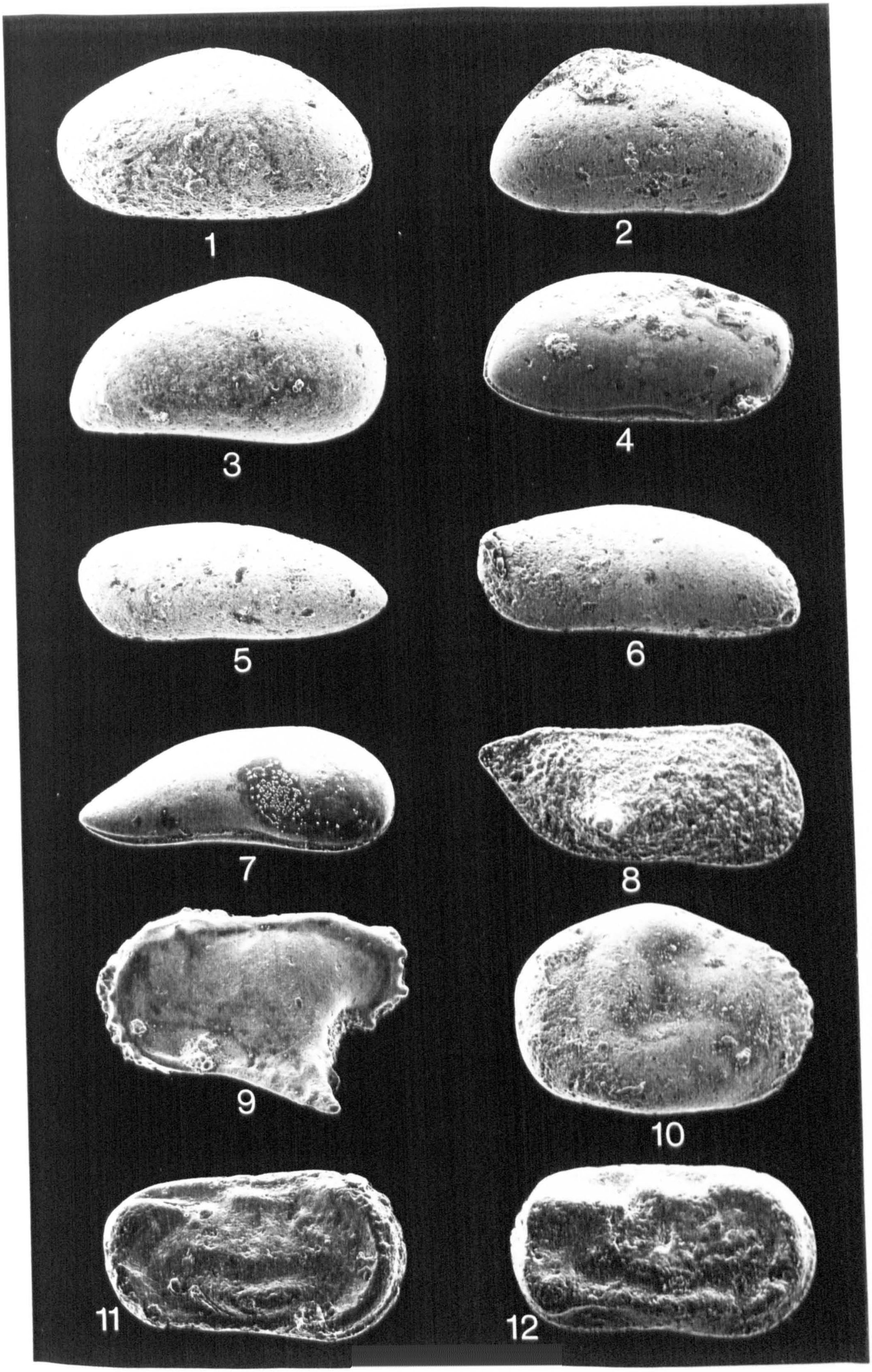
Figure 7. Right valve. Grey Chalk Formation (sample E5), Eastbourne. x69.

Bythoceratina herrigi Weaver

Figure 8. Right valve. Plenus Marls Formation (sample W2), Westbury. x75.

Pterygocythereis diminuta Weaver

Figure 9. Left valve. Grey Chalk Formation (sample E5), Eastbourne. x74.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(Plate 14 continued)

Cytherella chathamensis **Weaver**

Figure 10. Right valve. Grey Chalk Formation (sample W1), Westbury. x84.

Cytherelloidea kayei **Weaver**

Figure 11. Right valve. Welton Chalk Formation (sample S17), South Ferriby. x97.

Cytherelloidea hindei **Kaye**

Figure 12. Right valve. Ranscombe Chalk Member (sample W16), Westbury. x68.

PLATE 15

Ostracods recovered from the Cenomanian - Turonian Boundary

Bairdoppilata pseudoseptentrionalis Mertens

Figure 1. Left valve. Plenus Marls Formation (sample W8), Westbury. x67.

Bairdoppilata southerhamensis Weaver

Figure 2. Left valve. Grey Chalk Formation (sample E7), Eastbourne. x67.

Isocythereis elongata Weaver

Figure 3. Left valve. Plenus Marls Formation (sample W8), Westbury. x57.

Cythereis sp. A

Figure 4. Left valve. Plenus Marls Formation (sample E10), Eastbourne. x61.

Cytherella concava Weaver

Figure 5. Right valve. Plenus Marls Formation (sample E20), Eastbourne. x80.

Cytherella contracta van Veen

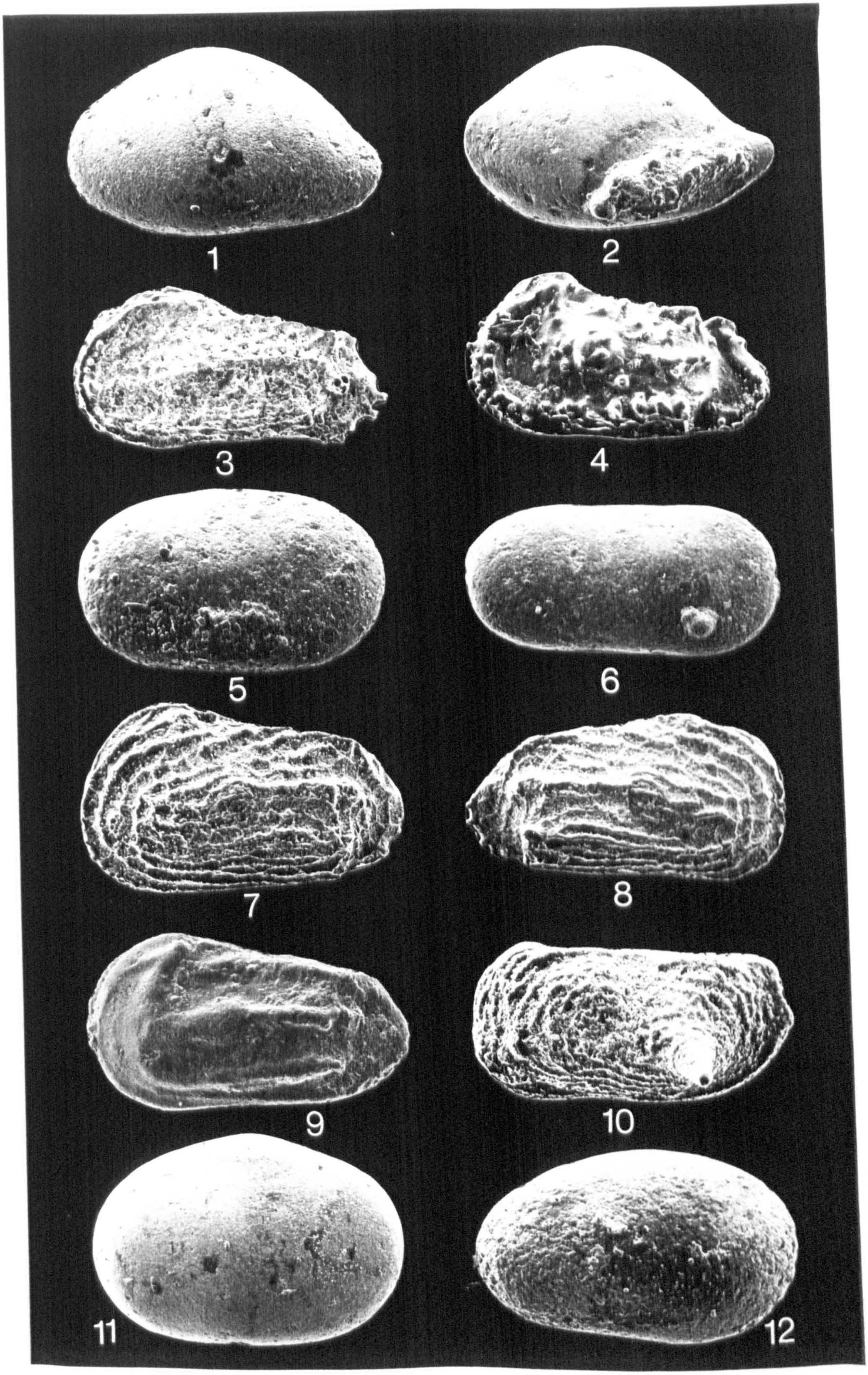
Figure 6. Right valve. Plenus Marls Formation (sample E15), Eastbourne x78.

Mosaeleberis sp. A

Figures 7-8. Figure 7, left valve; figure 8, right valve. Ranscombe Chalk Member (sample E37), Eastbourne. Figure 7, x78; figure 8, x75.

Cornicythereis sp. A

Figure 9. Left valve. Welton Chalk Formation (sample S17), South Ferriby. x85.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(Plate 15 continued)

Bythoceratina umbonata **(Williamson)**

Figure 10. Left valve. Grey Chalk Formation (sample E5), Eastbourne. x98.

Cytherella ovata **Roemer**

Figures 11-12. Figure 11, female right valve; figure 12, male right valve. Plenus Marls Formation (sample E12), Eastbourne. Figure 11, x61; figure 12, x76.

PLATE 16

Foraminifera recovered from the fine fraction (63-90 μm) from the Cenomanian - Turonian boundary

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Benthic foraminifera

***Praebulimina* sp. A**

Figure 1. Welton Chalk Formation (sample S17), South Ferriby. x244.

***Osangularia* sp. A**

Figure 2. Black Band succession (sample S13), Welton Chalk Formation, South Ferriby. x418.

***Pleurostomella* sp. A**

Figure 3. Grey Chalk Formation (sample E7), Eastbourne. x189.

***Laevidentalina* sp.**

Figure 4. Plenus Marls Formation (sample E20), Eastbourne. x191.

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Planktic foraminifera

***Heterohelix moremani* (Cushman)**

Figure 5. Grey Chalk Formation (sample E7), Eastbourne. x216.

***Guembelitria cenomana* (Cushman)**

Figure 6. Grey Chalk Formation (sample E7), Eastbourne. x401.

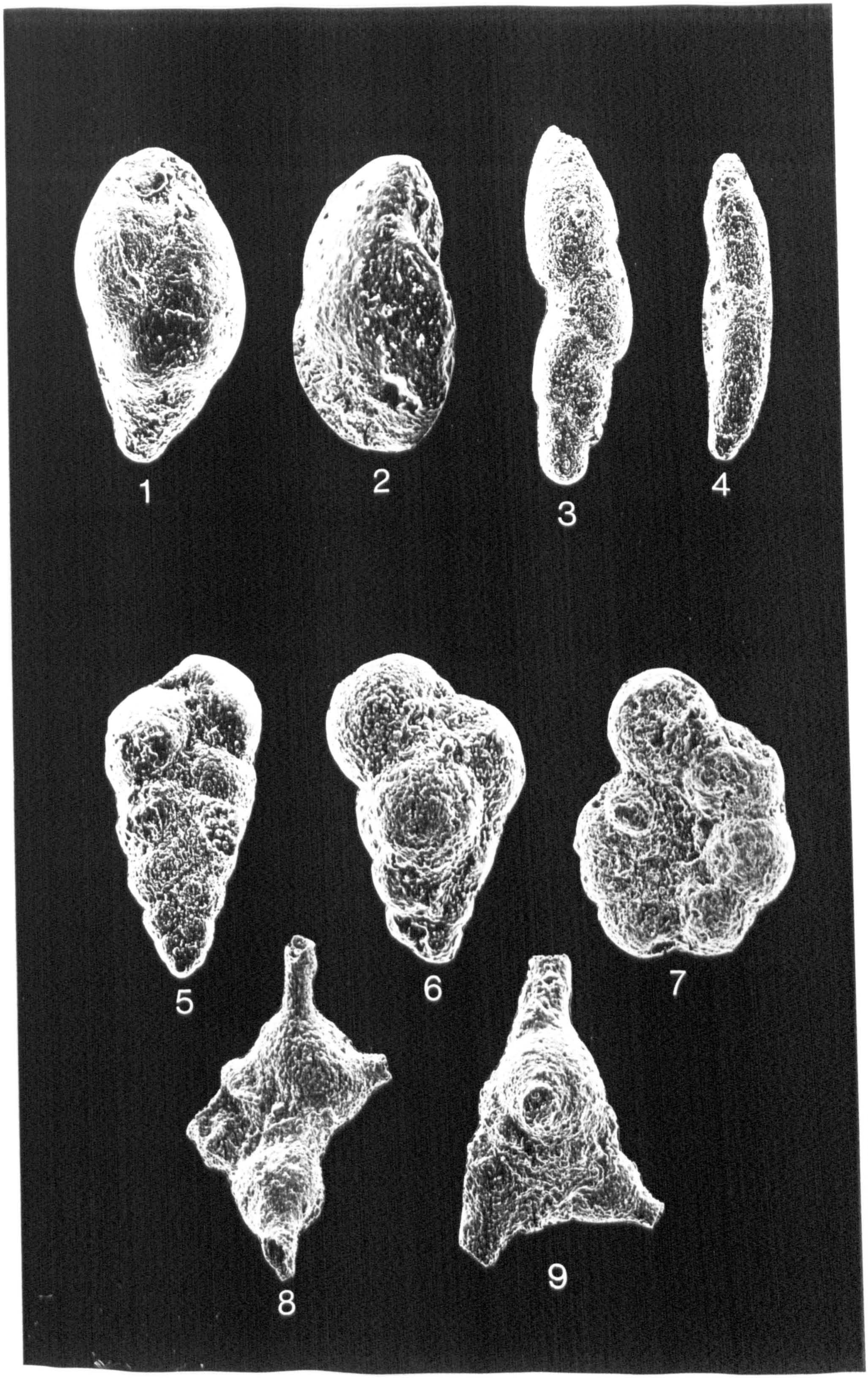
***Globigerinelloides bentonensis* (Morrow)**

Figure 7. Welton Chalk Formation (sample S17), South Ferriby. x253.

***Schakoina* sp. A**

Figurs 8-9. Welton Chalk Formation (sample S17), South Ferriby. Figure 8, x211; figure 9, x207.

PLATE 16



Appendices

A: FULL NAMES OF BENTHIC FORAMINIFERA REFERRED TO IN THE TEXT.

After the specific names, the first number is the Plate number and the second is the Figure number for those species illustrated in this thesis.

Ammobaculites rowei -
Ammodiscus cretaceus (Reuss) 10 (11)
Arenobulimina advena (Cushman) 5 (4)
Arenobulimina bulleta Barnard and Banner 5 (1)
Arenobulimina elongata Barnard and Banner 5 (3)
Arenobulimina preslii (Reuss) 9 (6)
Arenobulimina pseudalbiana Barnard and Banner 5 (2)
Arenobulimina sp. A 9 (8)
Arenobulimina sp. indet. -
Arenobulimina truncata (Reuss) 9 (7)
Astacolus sp. A 7 (10)
Ataxophragminum depressum (Perner) 6 (4)
Bathysiphon sp. A 8 (16)
Bullopora laevis (Sollas) -
Dentalina sp. A 16 (4)
Dorothia gradata (Berthelin) 6 (10)
Eggerellina brevis (Marie) 8 (9)
Eggerellina mariae Ten Dam 8 (8)
Eggerellina sp. indet. -
Frondicularia archiaciana d'Orbigny 7 (1)
Frondicularia cordai (Reuss) 5 (8)
Frondicularia gaulthina Reuss 8 (13)
Frondicularia lanceola Reuss 8 (5)
Frondicularia mucronata (Reuss) 5 (9)
Frondicularia sp. indet. -
Frondicularia verneuiliana d'Orbigny 9 (5)
Frondovaginulina inversa (Reuss) 8 (2)
Gaudryina austinana Cushman 9 (2)
Gaudryina stephensoni Cushman 9 (3)
Gavelinella baltica Brotzen 6 (7-8)
Gavelinella berthelini (Keller) 10 (4-5)
Gavelinella cenomanica (Brotzen) 6 (5-6)
Gavelinella reussi (Khan) 10 (3)
Gavelinella sp. indet. -
Globulina prisca (Reuss) -
Glomospira corona Cushman and Jarvis -
Gyroidinoides sp. A 7 (12-13)
Hyperammina gaultina Ten Dam -
Labrospira sp. A -
Laevidentalina distincta (Reuss) 6 (14)
Laevidentalina gracilis (d'Orbigny) 7 (9)
Laevidentalina legumen (Reuss) 7 (6)
Laevidentalina pseudochrysalis (Reuss) 6 (13)
Laevidentalina soluta (Reuss) 7 (8)
Laevidentalina sp. indet. 16 (4)
Laevidentalina strangulata (Reuss) 7 (7)
Lagena sp. A -
Lenticulina spp. 10 (7-10)
Lingulogavelinella aumalensis (Sigal) 9 (12)
Lingulogavelinella globosa (Brotzen) 10 (6)
Lingulogavelinella involuta Owen 6 (11-12)
Marginulina sp. A -

Marssonella trochus var. *oxycona* (Reuss) 10 (2)
Marssonella trochus var. *turris* (D'Orbigny) 10 (1)
Nodosaria sp. A 5 (13)
Nodosaria sp. B 5 (14)
Oolina globosa Montagu 9 (1)
Osangularia sp. A 16 (2)
Palmula baudouiniana (d'Orbigny) 5 (6)
Palmula sp. A 5 (7)
Planularia biochei Berthelin 7 (3)
Planularia sp. A 7 (4)
Plectina cenomana Carter and Hart 6 (2)
Plectina mariae (Franke) 6 (1)
Pleurostomella sp. A 16 (3)
Praebulimina sp. A 16 (1)
Pseudonodosaria humilis (Roemer) 7 (15)
Pseudospiroplectinanta plana (Gorbenko) 5 (15)
Psilocytharella costulata (Roemer) var. A 8 (11)
Psilocytharella costulata (Roemer) var. B 8 (12)
Psilocytharella costulata (Roemer) var. C 8 (13)
Psilocytharella costulata (Roemer) var. D 8 (14)
Psilocytharella sp. indet. -
Pyramidulina obscura (Reuss) 8 (15)
Pyramidulina paupercula (Reuss) -
Pyrulina sp. A -
Quadromorphina allomorphinoides (Reuss) 7 (11)
Quinqueloculina antiqua (Franke) 7 (5)
Ramulina aculeata Wright 8 (10)
Reophax sp. A 8 (1)
Saracenaria bronni (Roemer) -
Saracenaria jarvisi (Brotzen) 7 (14)
Spiroloculina cretacea Reuss 5 (5)
Spiroplectammina praelonga (Reuss) 5 (10)
Textularia chapmani (Lalicker) 8 (6)
Textularia sp. A 8 (7)
Textularia sp. B 9 (9)
Tristix excavata (Reuss) 5 (11)
Tristix maertensi (Reuss) 5 (12)
Tritaxia macfadyeni (Cushman) 6 (3)
Tritaxia pyramidata (Reuss) 6 (9)
Tritaxia tricarinata (Reuss) 9 (13)
Tritaxia tricarinata var. *jongmansi* (Schijfsma) 9 (4)
Valvulineria lenticula (Reuss) 9 (10-11)
Verneuilinoides sp. A -

B: FULL NAMES OF PLANKTIC FORAMINIFERA REFERRED TO IN THE TEXT

Dicarinella algeriana (Caron) 12 (6)
Dicarinella hagni (Scheibnerova) 12 (5)
Dicarinella imbricata (Mornod) -
Globigerinelloides bentonensis (Morrow) 16 (1)
Guembelitria cenomana (Cushman) 16 (6)
Hedbergella delrioensis (Carsey) 12 (2)
Hedbergella planispira (Tappan) 11 (11)
Hedbergella simplex (Morrow) 11 (12)
Helvetoglobotruncana praehelvetica (Trujillo) -
Heterohelix moremani (Cushman) 16 (5)

Marginotruncana renzi (Gandolfi) 12 (7-9)
Praeglobotruncana gibba (Claus) -
Praeglobotruncana sp. A 12 (10-12)
Praeglobotruncana stephani (Gandolfi) 11 (10)
Rotalipora cushmani (Morrow) 11 (7-9)
Rotalipora deeckei (Franke) 11 (1-3)
Rotalipora greenhornensis (Morrow) 11 (4-6)
Schakoina cenomana (Schacko) -
Schakoina sp. A 16 (8-9)
Whiteinella aprica Loeblich and Tappan 12 (4)
Whiteinella archaeocretacea (Pessagno) 12 (3)
Whiteinella baltica (Douglas and Rankin) -
Whiteinella brittonensis (Loeblich and Tappan) 12 (1)
Whiteinella inornata (Bolli) -
Whiteinella paradubia (Sigal) -

C: FULL NAMES OF OSTRACODS REFERRED TO IN THE TEXT

Bairdoppilata pseudoseptentrionalis Mertens 15 (1)
Bairdoppilata southerhamensis Weaver 15 (2)
Bythoceratina herrigi Weaver 14 (8)
Bythoceratina umbonata (Williamson) 15 (10)
Bythoceratina umbonatoides (Kaye) 13 (6)
Cornicythereis sp. A 15 (9)
Curfsina derooi Weaver 13 (3)
Cythereis longaeva Porkorny -
Cythereis sp. A 15 (4)
Cytherella chathamensis Weaver 14 (10)
Cytherella concava Weaver 15 (5)
Cytherella contracta van Veen 15 (6)
Cytherella ovata Roemer 15 (11-12)
Cytherelloidea bonnemai Weaver 13 (1)
Cytherelloidea hindei Kaye 14 (12)
Cytherelloidea kayei Weaver 14 (11)
Cytherelloidea stricta (Jones and Hinde) 13 (2)
Dolocytheridea sp. A 14 (13)
Habrocythereis sp. A -
Herrigocythere donzei (Weaver) 13 (11)
Imhotepia euglyphea Weaver 13 (4)
Isocythereis elongata Weaver 15 (3)
Macrocypris siliqua (Jones) 13 (12)
Mosaeleberis sp. A 15 (7-8)
Neocythere kayei Weaver 13 (5)
Oertliella alata Weaver 13 (8)
Oertliella donzei Weaver 13 (7)
Paracypris wrothamensis Kaye 14 (7)
Phodeucythere cuneiformis Weaver -
Pontocyprella harrisiana (Jones) 14 (5-6)
Pontocyprella hindei Weaver 14 (4)
Pontocyprella robusta Weaver 14 (1-2)
Pterygocythereis diminuta Weaver 14 (9)
Pterygocythereis laticristata (Bosquet) 13 (9)
Pterygocythereis robusta (Jones and Hinde) 13 (10)