Foraminiferal palaeoecology of the Upper Maastrichtian, Danish Central Graben

M-10X (Dan Field), E-5X (Tyra SE Field)

Jan A. Rasmussen & Susanne Lassen

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Contents

Abstract

Foraminiferal palaeoecological analyses carried out on the Late Maastrichtian of the M-10X well (Dan Field) and the E-5X well (Tyra SE Field), demonstrate similar trends, although some differences occur. Both wells are dominated by planktic Foraminifera, of which the small, biserial *Heterohelix globulosa* is by far the most common species. In addition, both wells are characterised by an outer shelf benthic fauna comprising only very few agglutinated species. The faunal and palaeoenvironmental changes observed during the Late Maastrichtian period were in most places, especially in the lower part, not very distinct, and it is believed that the palaeoenvironment during the majority of the interval was a mostly stable, deep outer shelf environment characterised by mainly pelagic sedimentation under temperate, aerobic to slightly dysaerobic conditions.

The combined use of planktic/benthic (P/B) ratio and epifaunal/infaunal ratios, and the palaeoecological significance of both benthic and planktic taxa have revealed that small but important palaeoenvironmental changes occurred during the interval. Based on this, the faunal succession has been subdivided into 6 different biofacies, each typified by characteristic faunal indices. The development of biofacies indicates that the palaeoenvironment was relatively stable during the lower part of the analysed interval in both M-10X and E-5X, but that more unstable and fluctuating conditions appeared during the latest Maastrichtian of both wells. The influx of abundant *Pseudotextularia elegans* (three acmes) together with the typical Tethyan species *Abathomphalus mayaroensis* and *Pseudoguembelina hariaensis* (in E-5X only) indicate that relatively warmer conditions prevailed during the latest part of the Late Maastrichtian

High-resolution sampling was undertaken in a short interval in the lower part of the M-10X core to investigate palaeoecological changes across laminated–bioturbated chalk cycles; only minor faunal differences were observed. There seems to be no clear correlation between changes in the planktic foraminiferal fauna and the nature of the sediment (laminated *versus* bioturbated chalk). Only very sporadic benthic Foraminifera were observed in this interval.

Introduction

Foraminiferids are unicellular marine organisms that have often been used as watermass indicators both in the present-day oceans and in ancient sediments. The actual assemblage of foraminiferids observed at a specific time and locality (Recent) or in a specific sample (fossil) is the result of the interaction between biological – e.g. food supply – physical and chemical factors such as temperature, dissolved oxygen, salinity and turbidity (Hemleben *et al.* 1989). Every species, or occasionally genus, is adapted to a certain range of these factors; this forms the basis of the following interpretation of changing palaeoenvironments in the Upper Maastrichtian interval of the Dan and Tyra SE fields.

Location and geological setting

The M-10X well is situated in the Dan Field of the southern Salt Dome Province, located in the southern part of the Danish Central Graben (Fig. 1). The Dan Field developed over a diapiric structure, which explains its overall circular structure. The E-5X well is situated in the Tyra SE Field located in the Central Graben approximately 30 km NW of the Dan Field in an area known as the Southern Compression Zone Province (Oakman & Partington 1998). In this area, the structures were initially formed by the inversion of a major Jurassic half-graben. The Maastrichtian biostratigraphy and chronology used in this study is shown in Fig. 2.

The Maastrichtian Tor Formation and the Danian Ekofisk Formation of the Central Graben form the uppermost part of the Chalk Group, a thick succession of calcareous, mainly pelagic deposits, which were deposited during the Late Cretaceous to Early Paleocene (Cenomanian–Danian). The Maastrichtian chalk consists of very fine-grained calcium carbonate. About 90% of the sediment grains are < 63 µm across. The grains are derived from mainly coccoliths, which constitute up to 60% of the grains between 5 and 20 µm (Håkansson et al. 1974). In addition, most grains with a diameter of < 5 µm (about 90% of the fraction < 63 µm) are remains of disintegrated coccoliths. Foraminifera, bryozoans and fragments of other calcareous organisms constitute the majority of the chalk sediment > 63 µm in size (Håkansson et al. 1974).

The chalks of north-west Europe were deposited in a temperate epicontinental shelf sea (Surlyk 1997), which extended from the Atlantic Ocean and the North Sea in the west across Denmark, The Netherlands, Belgium, France and northern Germany to Poland in the east. It is suggested that the Central Graben area was situated more than 300 km from the nearest shore during the Maastrichtian (see palaeogeographical map by Ziegler 1990).
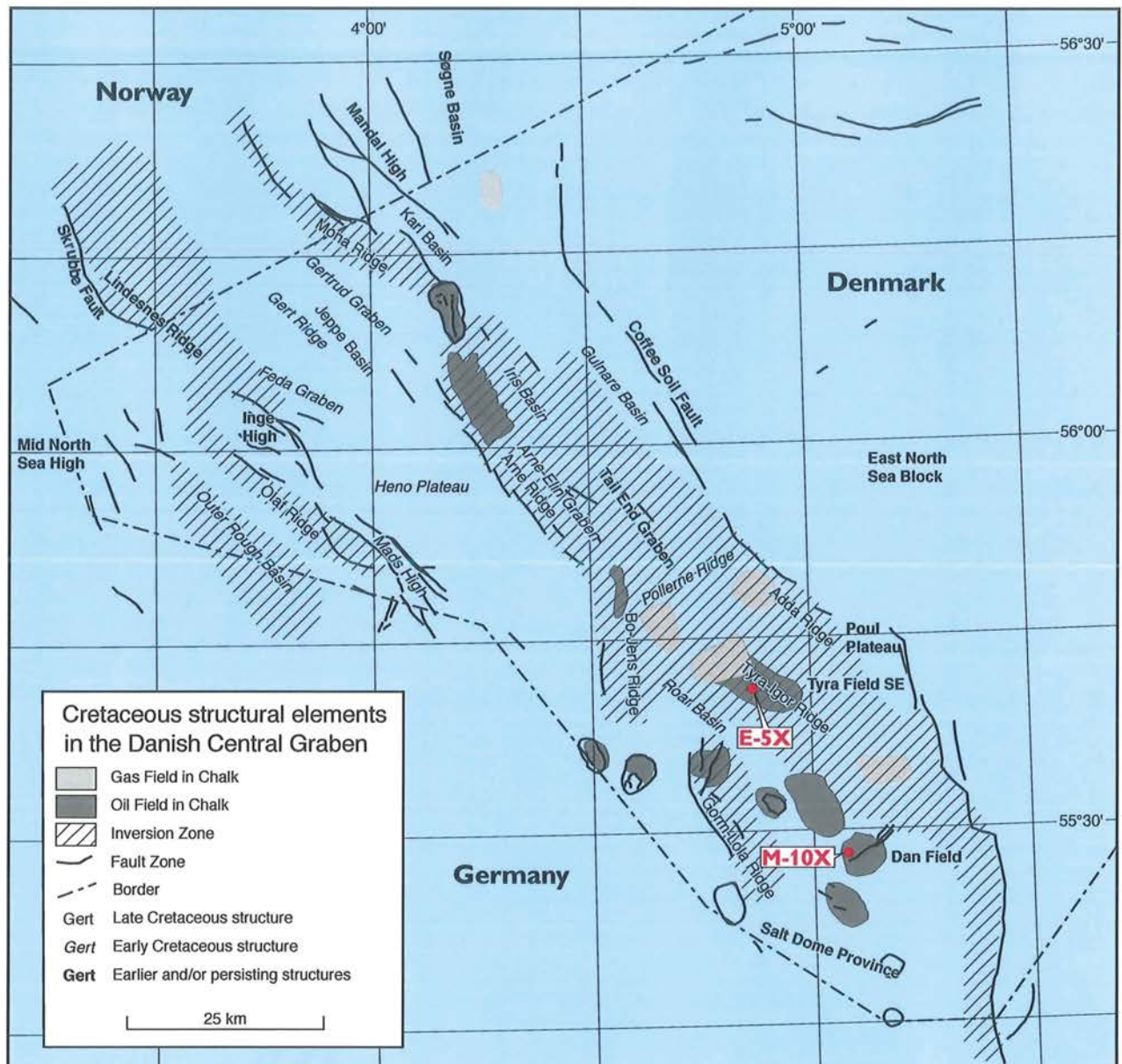
Fig. 1. Late Cretaceous structural framework of the Danish Central Graben showing the position of the M-10X and E-5X wells within the Dan and Tyra SE Fields, respectively.

Hardenbol et al. (1998)	Koch (1977), Germany			King et al. (1989), North Sea	Hart et al. (1989), England		Stenestad (1971), Denmark	Li et al. (1999), Tunisia	Lassen & Rasmussen (this volume) E-5X, M-10X, Danish North Sea
Maastrichtian — Early	Late	*B. casimirovensis*	*P. elegans*	23b	*A. mayaroensis*		*S. esnehensis*	*P. hantken-inoides* (CF1)	*P. hariaensis* ⟵ *A. mayaroensis* ⟵ *P. elegans* (acme 3) ⟵
				P. elegans (FCS 23)			*P. elegans*	*P. palpepra* (CF2)	*P. elegans* (acme 2) ⟵
								P. haria-ensis (CF3)	*P. laevis* (acme 2) ⟵
	Early	*B. junior*	*G. danica*	23a	*R. patelliformis/ R. contusa*	UKB. 22	*P. rugosa*	*R. fructi-cosa* (CF4)	*P. elegans* (acme 1) ⟵ *P. laevis* (acme 1) ⟵ P/B ratio >90 %
							P. cimbrica	*P. inter-media* (CF5)	
Late 69.4	Late	*B. occi-dentalis*	*B. draco draco*		*G. havanensis*	UKB.21		*R. contusa* (CF6)	
	Early	*B. lan-ceolata*	*N. reticu-lata*	*B. miliaris* (FCS 22) 22b / 22a		UKB. 20		*G. gansseri* (CF7)	
								R. hexa-camerata (CF8a)	

Scale (Ma): 65.0 — 66.0 — 69.0 — 69.4 — 70.0 — 71.0 — 71.3

Material and methods

The 139 analysed samples were collected from the M-10X and E-5X drill cores. Fifty grams of each sample were washed through a 0.063 mm sieve. The fraction between 0.063 and 0.5 mm was subsequently separated in heavy liquid (ρ = 1.8 g/cm^3) to reduce the amount of sediment to pick. Splits containing *c.* 100–200 foraminiferal specimens (when possible) were analysed by use of a light microscope, identified, counted and stored in microfossil slides. It was shown by Fatela & Taborda (2002) that counting 100 individuals has satisfactory statistical reliability in most palaeoceanographic studies, although the 95% confidence level error is about twice the size it would be if 300 specimens were counted.

For this study, 139 samples covering the Upper Maastrichtian to Lower Danian interval were examined, 103 from M-10X and 36 from E-5X (Appendices I-IV). An approximately 222 feet (68 m) thick section was studied from M-10X, including a very closely sampled interval from the lower part. The studied interval in E-5X was 165 feet (*c.* 50 m) thick. The variable fossil abundance in the samples has only allowed for quantitative data analysis in a number of the analysed samples. Samples with less than 30 foraminiferal specimens have not been used for P/B (planktic/benthic) ratio and biofacies calculations and samples with less than 15 benthic specimens have not been used to calculate the epifaunal/infaunal ratio. Thus, 67 samples from M-10X and 3 samples from E-5X were excluded from calculation of the epifaunal/infaunal ratio. In particular, the closely sampled interval between 6619.41′ and 6612.33′ in M-10X was characterised by a very low abundance of benthic foraminiferids.

Faunal characteristics

The calcareous microfauna in the 0.063–1 mm fraction of the investigated intervals is dominated by small, calcareous planktic and benthic foraminiferids while calcispheres are only locally common. Remains of inoceramid bivalves, ostracods and siliceous radiolarians and diatoms are present in scattered occurrences.

Planktic Foraminifera are much more common than benthic Foraminifera in both M-10X and E-5X, representing c. 82% and 70% respectively, of the total foraminiferal fauna in the two wells. Thus, the planktic/benthic (P/B) ratio is below 50% in only 14 out of 139 samples (Figs 3 and 4).

The benthic fauna is characterised by two main groups of calcareous Foraminifera: an epifaunal to shallow infaunal deposit feeding group dominated by *Cibicidoides, Cibicides, Stensioeina, Gavelinella, Osangularia* and *Pullenia*, and an infaunal group of deposit feeders dominated by buliminids, *Brizalina, Pyramidina* and *Bolivinoides*. Agglutinated Foraminifera occur only very sparsely.

Foraminiferids have been known to be useful in palaeoecological interpretations for several decades (e.g. Bandy 1960), and many taxa are known to prefer particular palaeoenvironments restricted by e.g. salinity, temperature, oxygen, the nature of the sea-floor sediments and food-supply, some of which are depth-related parameters. They have been widely used as palaeobathymetric indicators, by comparing fossil assemblages with recent analogues. Other methods include calculation of the planktic/benthic (P/B) ratio, the epifaunal/infaunal ratio and calculation of diversity indices.

Recent isotopic and morphological studies on planktic Foraminifera have shown that different taxa lived in different levels of the water-column. It has been known for some decades that Cretaceous planktic taxa preferred different palaeoenvironments (e.g. Malmgren, 1981; Haslett, 1994), but the understanding of Cretaceous planktic foraminiferal palaeoecology has expanded greatly with the recent improvements in stable isotope analyses of foraminiferal tests (e.g. Keller *et al.* 2002b; Abramovich *et al.* 2003).

The present study has taken advantage of several of these methods, and the combined results have led to the palaeoenvironmental interpretation presented below.

Limiting factors

The behaviour and habitats of living foraminiferids are controlled by several physical, chemical and biological parameters, and it is usually a combination of these limiting factors that affects the composition of the different foraminiferal assemblages. The limiting factors influenced the foraminiferid throughout its life, whereas taphonomical processes influenced the tests (both individuals and assemblages) from their deposition to the present day discovery. It is beyond the scope of the present paper to consider taphonomy in detail, but it may be mentioned that some of the important processes, which also have had an effect on the foraminiferal assemblages presented here, include post-mortem transportation, sorting, dissolution and physical damage.

Temperature

Temperature is one of the most important limiting factors, and it had a strong effect on the large-scale palaeogeographic distribution of Foraminifera and other organisms in the Maastrichtian period. Temperature is in general latitudinally dependent; biogeographical provinces (e.g. the Tethyan Province and the Boreal Province during the Maastrichtian) are founded primarily using this phenomenon.

Oxygen

Oxygen is essential for cellular respiration in organisms and vital in the marine realm. It is renewed to the deep parts of the sea by widespread ocean circulation patterns. Cold surface waters sink downwards near the poles and move towards the equatorial areas as bottom and intermediate watermasses.

It has been suggested that a greatly expanded oxygen minimum layer existed in regions of the Cretaceous seas compared to that of present-day oceans (Schlanger & Jenkyns 1976). It was situated above the well-oxygenated deep-sea pelagic sediments and below the well-oxygenated, mixed surface waters. This situation was believed to develop a temporary and local oxygen minimum zone ("anoxic") near the shelf margin in water depths as shallow as 300–400 m but often down to *c.* 1000 m, and was especially well-developed during transgressive periods (Nyong & Olsson 1984). It was characterised by the deposition of organic-rich sediments. Dark, organic-rich clays or shales deposited in an anoxic palaeoenvironment do not occur in the cored intervals analysed in the present study, and it is suggested that the Maastrichtian palaeoenvironments in E-5X and M-10X shifted between dominantly aerobic settings (in general between 6 and 1 ml O_2/l) and weakly dysaerobic conditions (approximately or below 1 ml O_2/l). Kaiho (1991) and Kaiho *et al.* (1993) used the epifaunal/infaunal ratio of benthic Foraminifera as a tool for calculating the relative amount of dissolved oxygen at the sea bottom. Kaiho (1991) concluded that benthic faunas of the oxygen minimum zone (< 0.1 ml O_2/l) mainly consist of elongate-flattened genera such as *Bolivina*, and unornamented, elongate–conical types such as *Bulimina* and *Buliminella*. The epifaunal/infaunal ratio is further described below.

Water depth

Water depth affects the distribution of species indirectly through a number of depth-related parameters, e.g. temperature, light intensity, salinity, oxygen and food supply. For example, light penetration decreases with depth and thus limits autotrophic and symbiotic activity to the photic zone.

The base of the photic zone often extends down to 150 m below sea level in the tropics but markedly less towards higher latitudes. In the present-day North Sea, the photic zone is only about 20 m thick (Johns & Reid 2001). Whereas the majority of plankton preferred to live in the photic zone, carnivores and deposit feeders thrived beneath the photic zone.

Substratum and food supply

There is a broad generalised correlation between community distribution and grain size and between sediment type and feeding mechanism in benthic organisms. Sanders (1956) showed that deposit feeders are more abundant than suspension feeders in muddy sediments, while the opposite situation occurs in sandy sediments. The reason for this is that fine-grained organic matter (food) accumulates at the sea bottom together with mud particles in low energy areas but is removed from coarse-grained sands in agitated waters. Deposit-feeding Foraminifera were much more common in the Maastrichtian chalk of the North Sea than suspension feeders partly because the primarily soft and fine-grained mud on the bottom of the Late Cretaceous North Sea contained more food than the overlying bottom waters. The fine-grained, soft and "soupy" surface layer of the muddy chalk sea may also have had an obstructing influence on the feeding apparatus of many suspension feeders (Rhoads & Young 1970). In addition, it was shown by Jones & Charlock (1985) that agglutinated suspension feeders dominate the middle bathyal to abyssal environments (depths from c. 1000 m to >2250 m), while agglutinated deposit feeders are more common in inner neritic to upper bathyal environments at depths from c. 100 m to 1000 m. The very low abundance of agglutinated Foraminifera in E-5X and M-10X indicates a low influx of terrigenous material, which is consistent with the present palaeogeographic maps (e.g. Ziegler 1990) that place the southern Central Graben area far from the nearest shoreline.

Salinity

It is suggested that most Maastrichtian North Sea Foraminifera were stenohaline and thus had a narrow tolerance range concerning salinity. They occupied offshore habitats more than 300 km from the nearest shoreline, and thus were never subjected to significant changes in salinity.

Nutrients

It has been proposed that the soft, muddy sea bottom recorded by the upper Lower Maastrichtian chalks at Rügen, North Germany, was characterised by oligotrophic conditions (Reich 2000). It was confirmed by Schiøler (2004, this report) based on dinoflagellate

studies and Sheldon (2004, this report) on calcareous nannoplankton that similar conditions with relatively low nutrient levels prevailed in most – but not all – of the Upper Maastrichtian deposits analysed in the drill cores included in the present study.

Palaeoecological methods

P/B ratios

P/B ratios are expressed as (P / (P + B))*100, where P = number of planktic Foraminifera and B = number of benthic Foraminifera. Thus, the P/B ratios show the percentages of planktic Foraminifera in the total foraminiferal assemblages. The P/B ratio have been used as a proxy for palaeodepth estimates for almost fifty years (e.g. Barr 1961; Flexer 1971) and it has been shown that the ratio usually increases with depth although the absolute values may be different at different locations (Gibson 1989). Present-day studies have shown that the P/B-ratios display a steady increase with depth in slope environments. Offshore Puerto Rico, Schmucker (2000) observed the minimum P/B ratio at 435 m water depth (the shallowest sample), where the P/B was 63%. At 1813 m water depth, the P/B-ratio increased to 99%. Higher values at shallower depths were reported by Gibson (1989) who observed 20% planktic Foraminifera at a minimum depth of 70 m, 50% at 85 m and 70% at 100 m offshore the present-day, temperate, Atlantic coast of USA. Gibson (1989) concluded that this area was characterised by a slow increase in P/B ratios across the inner shelf (from shoreline to 80–100 m), which exhibited a lowered salinity and higher turbidity. Further from the shore, at depths from 80 m to 200 m or slightly deeper, the outer shelf was typified by a very rapid increase in P/B ratios. The third, or slope to deep oceanic segment was characterised by a relatively slow increase in P/B ratios. Alegret & Thomas (2001) studied the benthic assemblages from the K-T boundary beds in Mexico and reported P/B ratios at about 80–90%, which they interpreted as characterising an open oceanic, probably upper or middle bathyal palaeoenvironment.

Although the P/B ratio is a fairly reliable method for palaeobathymetric interpretations across the shelf-slope transition and further offshore, it should be kept in mind that waves and currents may cause significant transportation and mixing of the microfaunal assemblages on the continental shelf. Thus, the P/B ratio should only be taken as a very rough method of estimating the palaeodepth in these palaeoenvironments, and should be supported by other methods.

Epifaunal/infaunal ratio in benthic Foraminifera

Kaiho (1991) established a dissolved oxygen index based upon the ratio between aerobic and anaerobic calcareous benthic Foraminifera: OI = (aerobic / (aerobic + anaerobic) *100). Aerobic morphotypes were characterised by spherical, planoconvex and lenticular forms, and were supposed to prefer environments with > 0.5 ml O_2 /l. These forms were epifaunal or shallow infaunal and lived within 0–2 cm below the sea-bottom. The anaerobic morphotypes (or dysaerobic in Kaiho et al. 1993) were typically elongated–flattened (such as *Bolivinoides* and *Brizalina*) or elongate–conical such as *Bulimina, Praebulimina,* and *Pleurostomella*. This group was infaunal and was believed to live down to 7–15 cm below the sea floor in an environment with very little dissolved oxygen (< 0.1 ml O_2 /l *sensu* Kaiho 1991).

Kaiho (1991) and Kaiho *et al.* (1993) were thus of the opinion that dissolved oxygen was the main controlling factor of the epifaunal/infaunal ratio.

Dominance of infaunal taxa was recorded from areas with a high content of organic carbon flux to the ocean floor by Bernard (1986), and this indicates that at least two factors – dissolved O_2 in bottom waters and organic carbon at the ocean floor – controlled the epifaunal/infaunal ratio within the upper 15 cm of the sediment. It is possible to test these models relatively easily in deep water areas with only little variation in additional chemical and physical factors, but the epifaunal/infaunal ratio must be used with care in marginal marine and shelf environments, where factors other than food supply and oxygen also affect the distribution of Foraminifera (Murray, 2001). The primarily very deep shelf environment that characterised the Danish Central Graben area during the Maastrichtian was situated perhaps up to 3–400 km from the nearest shore, and it is supposed that both dissolved oxygen and food supply had an effect on the epifaunal/infaunal ratio in this palaeoenvironment.

The epifaunal/infaunal ratios of E-5X and M-10X (Figs 3 and 4) are based on the habitat preferences of benthic foraminiferal morphogroups reported by Widmark (1995) and Alegret *et al.* (2003).

Depth ranking in planktic Foraminifera

The upper part of the water column in oceans

Oceanographers refer to the surface layer of the oceans with consistent hydrographic properties, as the surface mixed layer. This layer serves as a transfer of heat and freshwater between the atmosphere and the ocean. Usually, it spans the uppermost 50–150 m of the water column, but can be deeper in winter when cooling at the sea surface produces convective overturning of water, releasing heat stored in the ocean to the atmosphere. The underlying thermocline is a zone of rapid temperature transition, where temperature decreases rapidly with depth. The thermocline is situated below the layer of active mixing and is commonly shallow in spring and summer, deep in autumn, and disappears in winter.

Palaeoecological significance of planktic Foraminifera

The majority of planktic Foraminifera live in the upper 200–400 m of the water column but prefer different depth ranges. Thus, it has been known for decades that some planktic species occupied the surface layers of the oceans and other species were deeper-dwelling (e.g. Malmgren 1981; Haslett 1994). The understanding of Cretaceous planktic foraminiferal palaeoecology has expanded greatly in recent years (e.g. Keller *et al.* 2002b; Abramovich *et al.* 2003) and some of the knowledge concerning the planktic species observed in the present study is presented below. In short, the planktic fauna within the investigated interval in E-5X and M-10X consist mainly of small specimens of ecological generalists (Keller *et al.* 2002b). *Heterohelix globulosa* in particular, but also *Hedbergella mon-*

mouthensis and *Globigerinelloides* spp. are common. The triserial genus *Guembelitria* is rare in both wells, but is relatively more common in M-10X than in E-5X. Keeled globotruncanids were observed only in E-5X.

Abramovich *et al.* (2003) distinguished between three main groups of planktic foraminiferids based on depth ranking: Deep dwellers, thermocline dwellers and mixed layer dwellers. The depth ranking subdivision was based on isotopic measurements and the assumption that $\delta^{18}O$ values of foraminiferal calcite generally increase with depth due to decreasing temperatures (Fairbanks *et al.* 1982) and $\delta^{13}C$ values decrease with depth because of selective removal of ^{12}C by photosynthesis in the photic zone and accumulation of ^{12}C in deeper water due to decay of organic material.

The ratio between *Guembelitria* (G) and *Heterohelix* (H) was used as a palaeobathymetric indicator by Keller *et al.* (1993) based on data from the latest Maastrichtian of Nye Kløv, Denmark. They reported high G/H values (increasing from less than 10% to *c*. 35%) about 0.7 m below the K-T boundary, which was interpreted as a shallowing peak. All samples studied in the present study showed a G/H ratio lower than 12% (in average 2.2% in E-5X and 2.0% in M-10X), and the abundance of *Guembelitria* is too small to allow the use of the G/H ratio in the present study.

Deep dwellers

This group is characterised by their heavily calcified tests, thickened keels and large size (Keller *et al.* 2002b). It occupied the relatively deep waters below the thermocline. Late Maastrichtian species from this group observed in the present study include *Abathomphalus mayaroensis* and *Globotruncanella havanensis* (Abramovich *et al.* 2003).

Thermocline dwellers

The depth of the thermocline varies during the year and differs from low latitudes to high latitudes. The present day thermocline at the Goban Spur area near the NW European shelf break (*c*. 300 km southwest of Ireland and 600 km west of Brittany, France) ranges from 40 m to 60 m below the sea surface during the Spring bloom (Hydes *et al.* 2001), but the annual depth of the thermocline varies considerably. In the central Arabian Sea, the January thermocline usually ranges from 100 m to 150 m (Wiggert *et al.* 2002).

The foraminiferids living in this zone probably included most keeled globotruncanids, *Globigerinelloides* spp. and *Heterohelix globulosa* (Abramovich *et al.* 2003), but their mutual habitats changed between localities and climate modes. *Heterohelix globulosa* probably lived slightly deeper in the colder waters of the South Atlantic than at equatorial localities (Abramovich *et al.* 2003), and a similar situation may be expected for the Maastrichtian succession of the temperate North Sea.

Mixed layer dwellers

The mixed layer dwellers lived within the usually warmer waters above the thermocline. *Pseudoguembelina* (including *P. hariaensis* which was observed in E-5X in the present study) probably lived in the shallowest parts of the mixed layer (Abramovich *et al.* 2003), possibly sharing this part of the water column with *Guembelitria* (Keller *et al.* 2002b). The relative abundance of *Guembelitria*, however, was influenced also by ecological stress, as this genus is interpreted as a opportunistic disaster genus which showed increasing abundance during periods of severe biotic stress (Keller & Pardo in press). $\delta^{18}O$ records suggest that *Rugoglobigerina* and *Pseudotextularia* inhabited depths slightly deeper than *Pseudoguembelina* within the lower part of the mixed layer (Abramovich *et al.* 2003).

It was suggested by Troelsen (1955) that *Pseudotextularia elegans* and the keeled globotruncanid *Rosita contusa* found within the Kjølby Gård Marl in northern Jutland, were brought to Denmark during the Late Maastrichtian by a warm current from a southern direction, because these taxa were more common in subtropical and tropical areas.

Foraminiferal Biofacies of the Upper Maastrichtian succession and their palaeoenvironmental significance

This chapter comprises an interpretation of the palaeoenvironment during Late Maastrichtian times in E-5X and M-10X. The interpretation is based on a combination of the palaeoecological methods summarised above including P/B (planktic/benthic) ratios, epifaunal/infaunal ratios, and palaeoenvironmental significance of selected depth-dependent benthic and, to a lesser degree, planktic Foraminifera (Figs 3, 4). The palaeoecological interpretations by van Morkhoven *et al.* (1986), Murray (1991), Sikora & Olsson (1991), Schmitz *et al.* (1992), Widmark & Speijer (1997), Widmark (2000) and Alegret & Thomas (2001, 2004) have been followed to a great extent concerning the benthic assemblages. The combined results from all these methods form the basis for the following subdivision in biofacies (or foraminiferal assemblages) and the subsequent palaeoenvironmental interpretation.

Biofacies 1

Characteristics

Biofacies 1 has a very high dominance of planktic Foraminifera, resulting in P/B ratios usually higher than 92% (average 96%). Very small, biserial planktic specimens of *Heterohelix globulosa* is by far the most common species and constitute 87% on average of the total foraminiferal fauna. *H. globulosa* has been interpreted as a ecological generalist, which tolerated significant fluctuations in temperature and/or salinity, oxygen and nutrients (Keller 2002b). Sporadic occurrences of *Gavelinella* spp. comprise the dominating benthic component, but never exceeds 3% of the total foraminiferal fauna. The amount of indeterminable Foraminifera is large due to the generally small size and poor preservation.

Only three out of 31 samples within Biofacies 1 contained more than fifteen benthic specimens, which thus precluding reliable calculations of the epifaunal/infaunal ratio of this biofacies. The three samples, however, contained between 53% and 83% epifaunal components.

Distribution

M-10X: 6647′ – 6610′
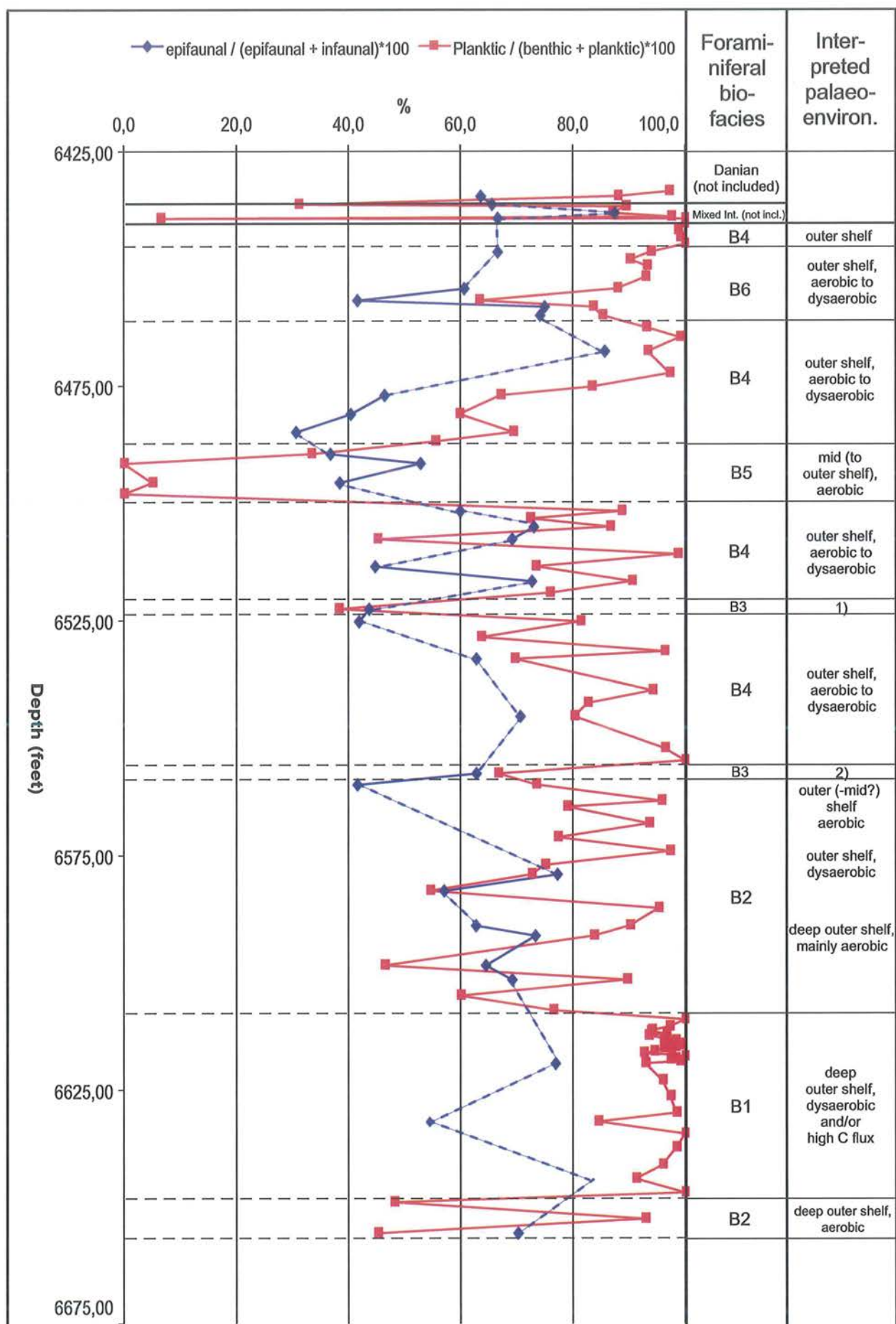
Fig. 3: Planktic/Benthic (P/B) ratio, epifaunal/infaunal ratio and foraminiferal biofacies of M-10X.

Palaeoenvironmental interpretation

The very high P/B ratios (> 90%) indicate normal pelagic deposition in an open oceanic palaeoenvironment, probably the deepest encountered in the present study. Similar P/B ratios were reported from upper to middle bathyal palaeoenvironments of northeastern Mexico (Alegret & Thomas, 2001). Alegret & Thomas, however, reported a higher abundance of benthic Foraminifera typical of bathyal settings. The benthic fauna of the 6647' – 6610' interval is very depleted, which indicates hostile bottom settings. It may have been caused by relatively high organic carbon flux and/or lowered oxygen conditions during this period, suggesting that it was probably not only the palaeobathymetric conditions that caused the very high P/B ratios.

Consequently, Biofacies 1 is interpreted as a relatively deep, outer shelf assemblage, which may have characterised a basinal, probably dysaerobic palaeoenvironment, relatively rich in organic carbon. The palaeodepth was deeper than 200 m, possibly as deep as 400–500 m.

Biofacies 2

Characteristics

The P/B ratio is usually high and averages 72% in E-5X and 74% in M-10X, but it varies notably, especially in M-10X. The epifaunal/infaunal ratio is high and fluctuates from an average of 64% in M-10X to 77% in E-5X. The benthic fauna of E-5X is generally scanty and both the diversity and abundance are low. *Cibicides succedens* is relatively common in E-5X comprising up to 30% of the benthic fauna, while *Osangularia navarroana* comprises up to 17% of the benthic fauna. M-10X is characterised by a relatively rich benthic fauna in the lower levels of the biofacies unit while the upper 17 feet of this unit is poor in benthic Foraminifera, probably because of poor bottom conditions or taphonomical processes. *Stensioeina* ex gr. *beccariformis*, *Gavelinella* spp. and *Pyramidina minuta* characterise the lower and middle part of Biofacies 2 of M-10X, the former constituting up to half of the total benthic assemblage (at 6655.58' in M-10X). *Nutalinella* spp. was recorded in low numbers in the middle part of the biofacies. *Pyramidina cimbrica* is common in the uppermost sample. Biofacies 2 is characterised by a large amount of indeterminable Foraminifera (especially in E-5X) due to the generally small size and poor preservation. Calcispheres are relatively common.

Distribution

E-5X: 6975.2'– 6926.6'
M-10X: 6655.6'–6648.5', 6608.1'–6560.8'

Palaeoenvironmental interpretation

The high frequency of epifaunal elements compared to infaunal may suggest a relatively low food supply to the sea-bottom floor and/or a well-oxygenated palaeoenvironment, slightly more pronounced in E-5X than in M-10X. The P/B ratios are lower than those from Biofacies 1, suggesting slightly shallower palaeodepths and/or more tolerable bottom conditions. The benthic assemblage, including the fairly high occurrence of *S*. ex gr. *beccariformis* (most notably in the lower and middle part of the interval in M-10X), suggests a relatively deep outer shelf palaeoenvironment, possibly between 200 m and 3–400 m. A relatively deep palaeoenvironment is further shown by the appearance of *Nuttallinella* spp. in the middle of Biofacies 2 of M-10X, as this species normally is reported from bathyal settings (e.g. van Morkhoven *et al.* 1986). The incoming of common *Pyramidina cimbrica* in the uppermost Biofacies 2 sample in M-10X (sample 6560.8′) may, according to the palaeoecological interpretation of this species by Schmitz *et al.* (1992), suggest a shallowing towards mid-shelf conditions, although the abundance of benthic components at this level is too low to allow for reliable interpretation. In general, the palaeoenvironment was probably slightly deeper and/or more nutrient-rich in M-10X than in E-5X.

Biofacies 3

Characteristics

The P/B ratio is on average 52% in M-10X and 64% in E-5X and thus is lower than both B1, B2 and B4. The epifaunal/infaunal ratio is relatively low and varies from an avarage of 51% in M-10X to 59% in E-5X. Biofacies 3 is characterised by common *S*. ex gr. *beccariformis*, which may constitute up to 20% of the benthic fauna, *Praebulimina laevis* (max. 29% of the total benthic assemblage), cibicids (incl. *Cibicides succedens*) and *Osangularia navarroana*.

The planktic assemblage is dominated by *Heterohelix globulosa*. The individual samples of Biofacies B3 are distinguished by P/B ratios that are quite similar to the epifaunal/infaunal ratios.

Distribution

E-5X: 6916.3′–6910.3′, 6875.3′–6859.8′
M-10X: 6557.6′ and 6522.3′

Palaeoenvironmental interpretation

The relatively low P/B ratio and benthic assemblage comprising relatively common *Praebulimina laevis*, *O. navarroana* and *C. succedens* indicates a palaeoenvironment relatively more shallow than Biofacies 1 and 2, as these species are common in Upper Maastrichtian
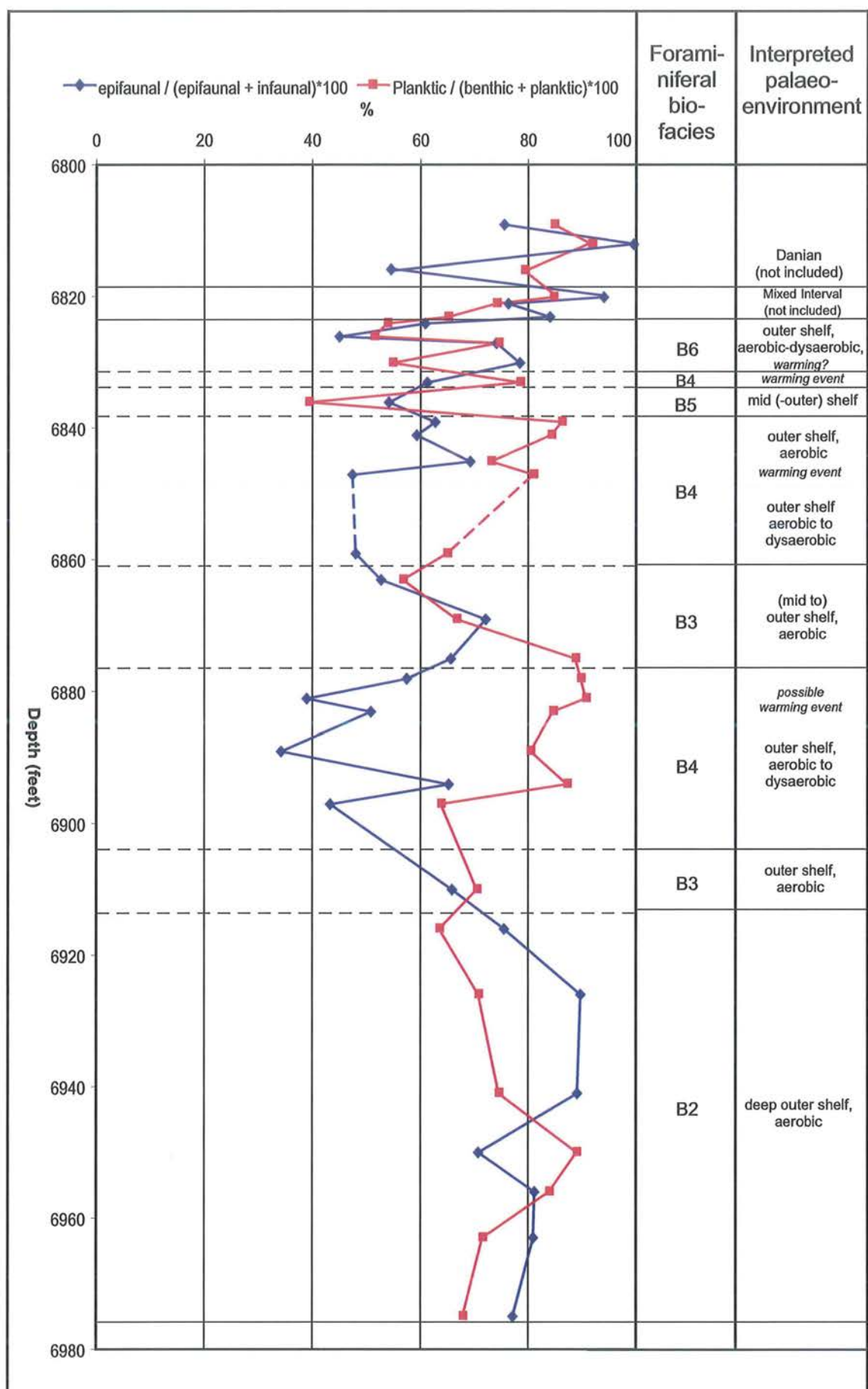
Fig. 4: Planktic/Benthic (P/B) ratio, epifaunal/infaunal ratio and foraminiferal biofacies of E-5X.

deposits of eastern Denmark in the more proximal part of the shelf (J.A. Rasmussen, unpublished). The presence of relatively common *S*. ex. gr. *beccariformis*, however, suggests that the palaeoenvironment was still under open oceanic influence, indicating outer neritic conditions, possibly in the neighbourhood of 200 m in palaeodepth. The low epifaunal/infaunal ratio indicates a relatively high organic carbon flux and/or lowered oxygen conditions.

Biofacies 4

Characteristics

This is the most common biofacies in both wells. The P/B ratio is high, on average 83% in M-10X and 76% in E-5X. The epifaunal/infaunal ratio is also relatively low in this biofacies and varies from an average of 57% in M-10X to 49% in E-5X. The benthic assemblage is highly diverse and dominated by *Pyramidina minuta* (M-10X), *Praebulimina laevis*, *Gavelinella* spp. (M-10X), and occasionally *Brizalina incrassata*, *Osangularia navarroana* (E-5X), *Gyroidinoides nitidus* (E-5X), *Dentalina* spp. (E-5X), and *Cibicides* spp. (M-10X). Calcispheres occur commonly in this biofacies.

The planktic assemblage is overwhelmingly dominated by *Heterohelix globulosa*, but *Hedbergella monmouthensis* is common in some samples. *Pseudotextularia elegans* shows acmes at three levels of this biofacies and may constitute up to 50% of the planktic fauna in E-5X. It is much more abundant in E-5X than in M-10X, but three less distinct acmes of *P. elegans* were also observed in M-10X (two in Biofacies 4 and one in Biofacies 6). *Guembelitria cretacea* occurs consistently, but with low abundances.

Distribution

E-5X: 6897.3′–6878.6′, 6859.8′–6839.3′, 6833.5′
M-10X: 6554.8′–6525.3′, 6519.1′–6502.3′, 6487.3′–6463.0′, 6444.8–6441.9′

Palaeoenvironmental interpretation

The generally high P/B ratios and low epifaunal/infaunal ratios indicate open oceanic conditions and a relatively high organic carbon flux and/or lowered oxygen conditions. The benthic assemblage is somewhat similar to that of Biofacies 2, but it is distinguished by its more common occurrences of *Praebulimina laevis*, *Osangularia navarroensis* and *Gyroidinoides* spp. and fewer speciments of *Stensioeina* ex gr. *beccariformis*. Alegret & Thomas (1991) interpreted *Gyroidinoides nitidus* as junior synonym of *G. globosus*, which they - together with *Stensioeina becarriformis* forma *parvula* - regarded as an upper bathyal indicator commonly found at 200–300 m depth. It is probable that Biofacies 4 is indicative of similar palaeobathymetric conditions, although the depositional setting was more likely a deep neritic setting than upper bathyal in the Central Graben area. The influxes of *Pseu-*

dotextularia elegans at 6883.9′, 6847.8′ and 6833.5′ in E-5X may be related to the periodical invasion of warmer waters from the south (Troelsen 1955), or climatic warming periods, as this species is more common in the Tethyan region than at northern high latitudes.

Biofacies 5

Characteristics

The P/B ratio is very low, especially in M-10X, and averages 10% in M-10X and 35% in E-5X. The epifaunal/infaunal ratio is also low and varies from an average of 44% in M-10X to 50% in E-5X.

The benthic assemblage are characterised by *Osangularia navarroana* and *Cibicides succedens* in E-5X (the latter also in M-10X) and *Praebulimina laevis*, *Brizalina incrassata*, *Alabamina midwayensis* and *Stensioeina* ex gr. *beccariformis* in M-10X. Only few planktic specimens dominated by *Heterohelix globulosa* are present.

Distribution

E-5X: 6836.8′
M-10X: 6499.0′ – 6489.5′

Palaeoenvironmental interpretation

The very low P/B ratios, especially in M-10X, indicates a neritic depositional palaeoenvironment with only a restricted oceanic influence. It may be speculated that the overall absence of planktic specimens is due to taphonomical processes, but as the benthic specimens show no signs of particular dissolution or transportation, we believe that the planktic component was never high. The dominance of *O. navarroana* and *C. succedens* in E-5X and the occurrence of *A. midwayensis* in M-10X further support the proposal that Biofacies 5 characterised a shelf environment, probably situated somewhere between the outer and mid shelf. The relatively high occurrence (16% of the benthic fauna) of *Stensioina* ex gr. *beccariformis* in sample M-10X (sample 6491.5′) is difficult to explain. The species normally characterises upper bathyal or outer neritic conditions (van Morkhoven *et al.* 1986; Keller *et al.* 2002a). It may be speculated that relatively lower temperatures in the Central Graben area may have allowed the species to migrate to the intermediate parts of the shelf during this period, but taphonomic processes such as transportation and sorting might also have influenced the assemblage. The palaeodepth may have been about 200 m or even lower in this part of the wells, probably shallowest in M-10X.

It is unlikely that the low epifaunal/infaunal ratios indicate lowered oxygen conditions in this relatively shallow palaeoenvironment. It is suggested that it instead is related to a relatively high organic carbon flux. The interval corresponding to this biofacies in M-10X is known as

a high porosity interval, and the data shows that the high porosity correlates with a lowered pelagic (planktic) content in the foraminiferal fauna.

Biofacies 6

Characteristics

The P/B ratio varies from an average of 83% in M-10X to 55% in E-5X. The epifaunal/infaunal is relatively high and varies from 63% on average in M-10X to 61% in E-5X. Biofacies 6 is characterised by *Stensioeina* ex gr. *becarriformis*, *Brizalina incrassata*, *Cibicides* cf. *simplex* in both wells. *Gavelinella* spp. and *Pyramidina minuta* are common in M-10X. The planktic species *Abathomphalus mayaroensis* occurs consistently but in very low numbers in E-5X.

Distribution

E-5X: 6830.0′–6824.8′
M-10X: 6460.0′–6446.5′

Palaeoenvironmental interpretation

The P/B ratios are markedly higher in M-10X than in E-5X. This contrasts with the generally similar benthic assemblages of the two wells. The incoming of rare specimens of the planktic species *A. mayaroensis* in Biofacies 6 of E-5X, which is much more common in more equatorial settings than farther North, may indicate that warmer conditions reached the Central Graben area (especially E-5X) during this period. *A. mayaroensis* has been interpreted as a subsurface dweller that lived below the thermocline (Abramovich *et al.* 2003). This, in combination with the common occurrence of the benthic species *Stensioina* ex gr. *beccariformis* in both wells, indicates that Biofacies 6 in general characterised a relatively deep, outer shelf palaeoenvironment, probably deeper than 200 m. The occurrence of *A. mayaroensis* and *Pseudoguembelina hariaensis* in E-5X may indicate warmer conditions in this part of the Late Maastrichtian. This is in accordance with the hypothesis mentioned above (Biofacies 5), that if *S.* ex gr. *beccariformis* was able to migrate to the more shallow parts of the shelf during relatively cold periods, it should be expected to migrate to the deeper, more oceanic, parts during warmer periods.

Sample 6456.8′ from M-10X and the samples 6826.7′ and 6824.8′ from E-5X display significantly lower P/B ratios and a higher infaunal component than the other samples from this biofacies. The low epifaunal/infaunal ratios indicate a relatively high organic carbon flux and/or lowered oxygen conditions in these intervals compared to the remaining part of Biofacies 6, which is characterised by a higher epifaunal content. It is possible that the palaeodepth decreased slightly during these periods within Biofacies 6, although the difference may also have been due to other palaeoenvironmental changes.

High resolution foraminiferal palaeoecology of the 6620′–6610′ interval of M-10X

The interval between 6620′ and 6610′ was sampled densely in order to shed light on the palaeoecology during deposition of the laminated–bioturbated cycles present in the well at these levels. In general, the foraminiferal faunas are very uniform with very high numbers of planktic foraminiferids in relation to benthic. The ratio between planktic and benthic Foraminifera (P/B) is always higher than 92% (Fig. 5). The planktic faunas are dominated by more than 70% *Heterohelix globulosa*. However, small faunal differences occur and based on these it has been possible to subdivide the interval into two foraminiferal biofacies (PB1, PB2), which display a cyclic pattern in the studied interval. The three main parameters we have used to show this pattern are P/B ratios and the relative abundance of *Guembelitria cretacea* and *Hedbergella monmouthensis*. Keller (2003, p. 94)) regarded *Guembelitria* as an opportunistic species, which tends to bloom in high stress environments, most notably during times of high nutrient, eutrophic conditions (high content of organic carbon) and disruption of water mass stratification. Keller & Pardo (in press) showed that the largest *Guembelitria* blooms took place in low and middle latitudes, and only smaller blooms occurred in high latitudes. The latter authors also suggested that a major ecologic crisis, which may have lead to the exclusion of ecological specialists and most generalists, would be followed by 1) bloom of *Guembelitria*, 2) increase of small low-O_2-tolerant heterohelicids followed by 3) an increase of small trochospiral and planispiral species.

Biofacies PB1

Characteristics

This biofacies is characterised by the lowest P/B ratios in the interval together with minor increases in the relative abundance of *Guembelitria cretacea* (up to 7%). The sparse benthic foraminiferal faunas are characterised by *Stensioeina* ex gr. *beccariformis*, gavelinellids and *Pyramidina minuta*.

Distribution

6619.41′, 6617′– 6616.25′, 6614.41′– 6611.58′

Palaeoenvironmental interpretation

Gumbelitria species were restricted to the surface layer above the thermocline and occurred in both open marine and shallow neritic nearshore environments. The genus seems to have tolerated a fluctuating palaeoenvironment with regard to salinity, temperature, oxygen and nutrients. Thus, opportunistic blooms of *Guembelitria* have been reported from
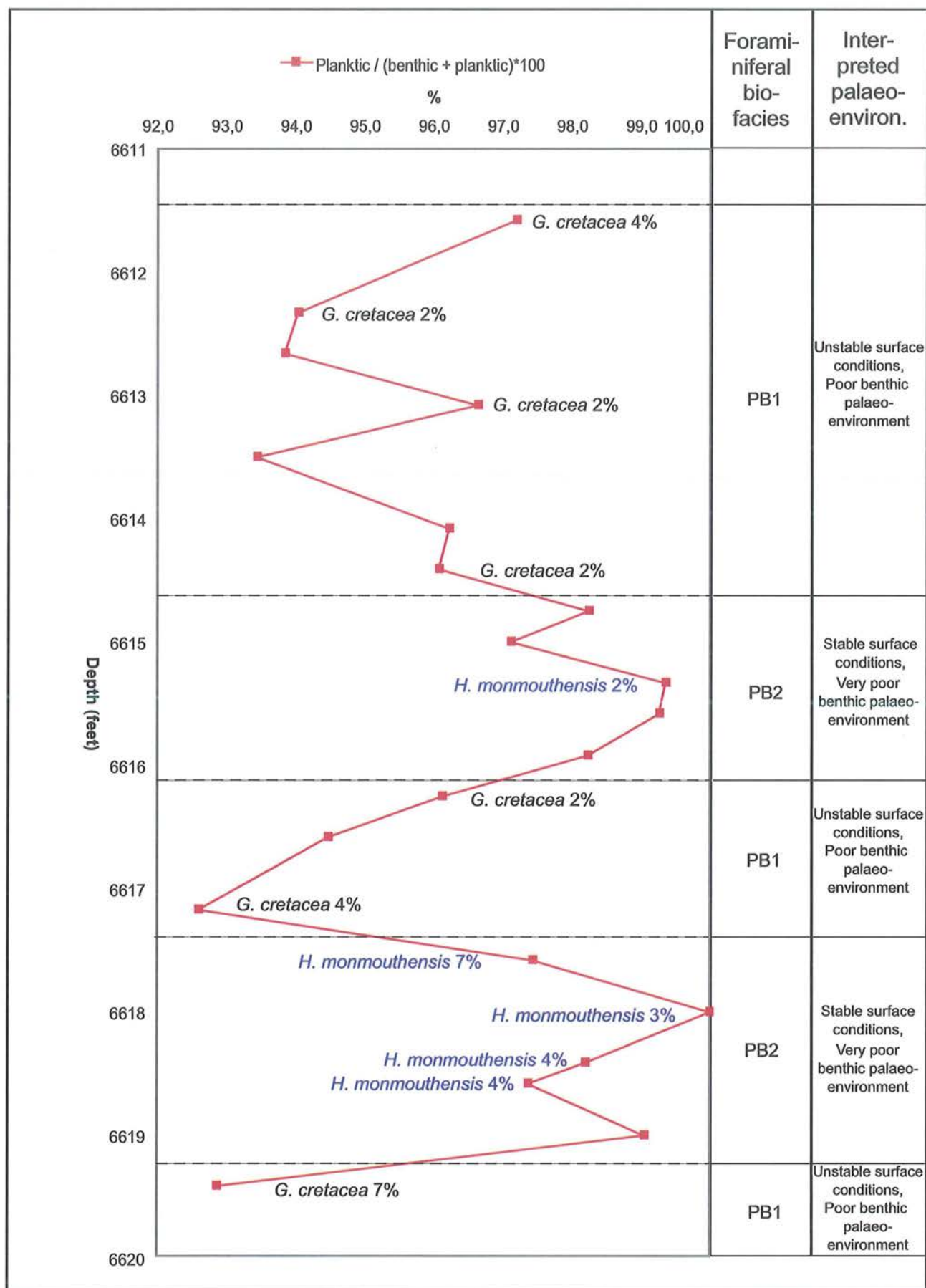
Fig. 5: Planktic/Benthic (P/B) ratio and foraminiferal biofacies of the 6620´ and 6610´ interval of M-10X.

neritic palaeoenvironments reaching a crisis level, characterised by a strong decrease in the normal population (Keller *et al.* 2002b).

The increase of *Guembelitria* found in this biofacies is diminutive, and does not reach the same degree as seen at, e.g. the K-T boundary and at the Cenomanian-Turonian transition in other regions (Keller, 2003). In PB1 of the closely sampled interval, however, its relative abundance seems to increase weakly in the intervals with relatively low (but still more than 92%) P/B ratios. This situation does not correspond to the severe ecological stress that occurred around the K-T and Cenomanian-Turonian boundaries but might indicate that the surface system was stressed possibly by unstable conditions during these periods. In contrast, the sparse benthic fauna suggests that the sea bottom conditions were slightly better during PB1 biofacies times than during PB2, when the benthic fauna was almost absent.

Biofacies PB2

Characteristics

The highest P/B ratios are found in this biofacies (>97%), resulting from an almost complete lack of benthic foraminiferids. Besides the dominant planktic foraminiferal species *H. globulosa*, the biofacies is characterised by *Hedbergella monmouthensis*, comprising up to 7% of the planktic assemblage.

Distribution

6619′–6617.58′, 6615.92′–6614.75′

Palaeoenvironmental interpretation

H. monmouthensis is not regarded as an opportunistic species as is the case for *G. cretacea* (Keller *et al.* 2002b). Thus, the increase of this species within the lowermost part of Biofacies PB2 might point toward more stable surface conditions compared to Biofacies PB1. The extremely low numbers of benthic foraminiferids suggests very poor conditions on the sea floor during the PB2 period.

Palaeoenvironmental development during the 6620′–6610′ high resolution interval

Heterohelix globulosa is by far the most common species in the closely analysed interval, and relative changes in the abundance of other species are difficult to detect. Although highly tentative, it seems possible to subdivide the section into five intervals, based on changes in P/B ratios, and the relative abundances of *G. cretacea* and *H. monmouthensis*. Thus, the high resolution interval comprises two and a half cycles from biofacies PB1 to

PB2. The PB1 biofacies are characterised by a relatively low P/B ratio averaging 95%, an increased number of *Guembelitria* (2–7%), and the occurrence of benthic (although very few) Foraminifera. Following the model of Keller & Pardo (in press), we interpret PB1 as the first slightly opportunistic stage in the cyclic development. The following PB2 biofacies is only slightly different from PB1, being characterised by a slightly higher P/B ratio averaging 98%, an increased number of the low trochospiral *Hedbergella monmouthensis* (2–7%), and the virtual absence of guembelitrids and benthic Foraminifera. PB2 is interpreted as representing more stable conditions above the thermocline, but very poor conditions at the sea bottom.

Thus, unstable conditions in the surface system were contemporaneous with a slightly improved sea bottom environment whereas relatively stable surface conditions were associated with very poor conditions for the benthic community.

Three laminated–bioturbated chalk cycles were recorded in the high resolution interval. None of the transitions from laminated to bioturbated intervals correspond to the transitions between biofacies PB1 and PB2. Instead the deteriorated benthic conditions occurred within the bioturbated interval and continued through the lower part of the laminated interval. The slight recovery then began during the deposition of the laminated interval and ended within the bioturbated interval.

The less pronounced lamination–bioturbation cycles in the upper part of the high resolution interval are also less pronounced in terms of the foraminiferal faunas and contain elements of both biofacies, i.e. input of *G. cretacea* together with low numbers of benthic foraminiferids.

Palaeoenvironmental summary of E-5X and M-10X

The development of biofacies indicates that the palaeoenvironment was relatively stable during the lower part of the analysed interval in both M-10X and E-5X, but that more unstable and fluctuating conditions appeared during the latest Maastrichtian period of both wells. Both wells are dominated by planktic Foraminifera, of which the small, biserial *Heterohelix globulosa* is the dominating species, and both wells are characterised by an outer shelf benthic fauna comprising only very few agglutinated species. The average epifaunal/infaunal ratios are very similar, reaching 61% in M-10X and 60% in E-5X. The faunal and palaeoenvironmental changes that occurred during the Late Maastrichtian period were in most places not very distinct, and it is believed that the palaeoenvironment during the interval was a predominantly stable, deep outer shelf environment characterised by mainly pelagic sedimentation under temperate, aerobic to slightly dysaerobic conditions. The combined use of P/B and epifaunal/infaunal ratios, and the palaeoecological significance of both benthic and planktic taxa has revealed that small but important palaeoenvironmental changes occurred during the interval. It is thus indicated that the palaeoenvironment was relatively stable during the lower part of the analysed interval in both M-10X and E-5X, but that more unstable and fluctuating conditions prevailed during the latest Maastrichtian.

Relatively minor faunal and palaeoenvironmental changes occurred during the 6655'–6520' interval of M-10X and the 6975'–6880' interval of E-5X. This interval is represented by Biofacies 1, 2, 3 and 4 (*pars*) in M-10X and Biofacies 2, 3 and 4 (*pars*) in E-5X. M-10X was cored to a deeper stratigraphic level than E-5X, and Biofacies 1 was only recorded from this well (Fig. 6). Biofacies 1 probably represents the deepest and/or most offshore interval encountered in the present study, although its extremely high P/B ratios and exceptionally sparse benthic fauna may also reflect very poor sea-floor conditions at the time of deposition. Thus, it is possible that a relatively high influx of organic carbon or a reduction of dissolved oxygen at the sea floor may have taken place during this period.

The P/B ratio decreases slightly in the overlying Biofacies 2 (B2) inferred by the incoming of principally epifaunal and shallow infaunal benthic taxa, although many benthic specimens are small and badly preserved. The ecological generalist, *Heterohelix globulosa*, is the most abundant planktic taxon during almost all of the analysed core intervals, and Biofacies 2 is no exception. The palaeoenvironment is believed to have been represented by a deep outer shelf setting in the lower part, probably replaced by slightly more shallow conditions in the upper part, indicated by the appearance of *Cibicides succedens* and *Osangularia navarroana* in E-5X and *Pyramidina cimbrica* in M-10X. A high oxygen level and/or a low organic carbon flux characterised B2 in E-5X, whereas these parameters fluctuated in B2 of M-10X.

The outer shelf setting continued within the overlying B3 and B4 biofacies intervals up to the 6520' level in M-10X and the 6880' level in E-5X. It was typified by temperate, slightly dysaerobic but mostly aerobic conditions and/or a slightly higher influx of organic carbon. Relatively small regressive events may have taken place during B3 at around 6557.8' and 6522.3' in M-10X, and possibly 6916.5'–6910.3' in E-5X as seen by a conspicuous lowering of the P/B ratio in these levels.
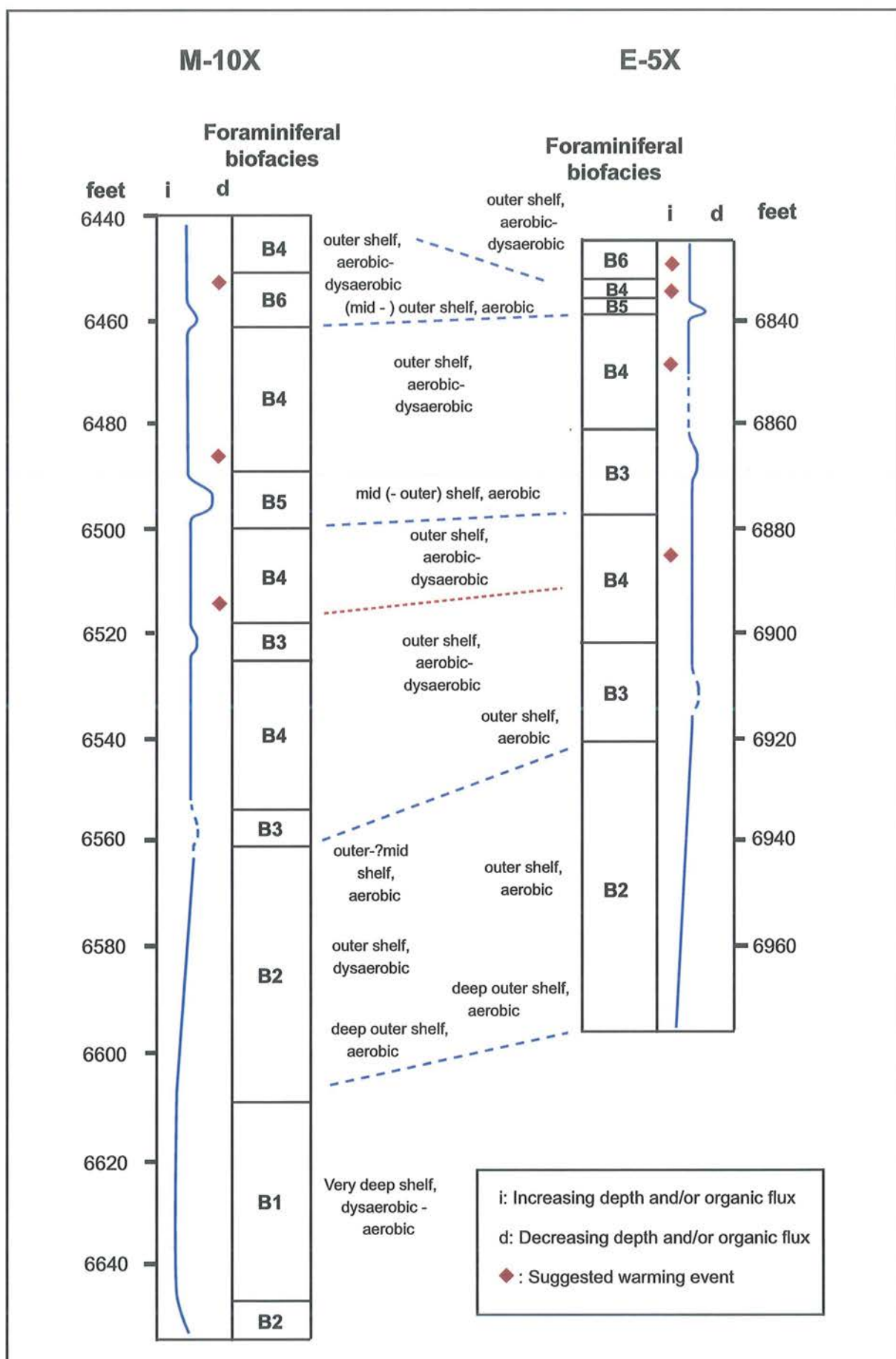
Fig. 6: Correlation of foraminiferal biofacies and palaeoenvironmental events in M-10X and E-5X.

The first indications of a probable warming event were recorded in E-5X at 6883.9′, where the first of three acmes of *Pseudotextularia elegans* appears (12% of the total planktic fauna). *P. elegans* was much more common in the Maastrichtian warmer oceans at low and intermediate latitudes, e.g. the former Tethyan Sea, the deposits of which are today widely exposed at localities around the present-day Mediterranean Sea. The influx of *P. elegans* to temperate seas, e.g. the Central Graben area, may thus be taken as a sign of an invasion of warmer conditions (Troelsen 1955). *P. elegans* is consistently less common in M-10X than in E-5X, but a small acme appears at 6519.1′, where it comprises 8% of the total planktic fauna.

The probable warming event marked the beginning of a depositional phase with more unstable palaeoenvironmental conditions than earlier. The faunal evidence from this upper phase, which is represented within the 6519′–6442′ interval of M-10X and the 6883′–6824′ interval of E-5X, shows that substantial palaeoecological fluctuations occurred.

The most remarkable regressive event, judging from the foraminiferal evidence, occurred during the time of deposition of Biofacies 5 in M-10X (6499′–6489′). The P/B level dropped to zero in two of the four samples and the planktic fauna may have experienced very poor ecological conditions within the upper part of the water column. The benthic fauna, however, indicates that low organic carbon influx conditions occurred at the sea floor. As noted earlier, the exceptional decrease in the planktic foraminiferal fauna corresponds to a significant increase in the chalk porosity (Ineson *et al.*, this report). At present, we have no convincing explanation for this relationship, but it is likely that it is related to a conspicuous regressive event. Evidence for a regression at this level was observed in E-5X, albeit less dramatic. The relatively low P/B ratios together with the incoming of cibicidids and *Praebulimina laevis* indicates a drop in sea level within the 6869.3′–6863.3′ interval of Biofacies 3.

The second probable warming event took place shortly after this shallowing, when the following transgressive event was accompanied by a new influx of *Pseudotextularia elegans* at 6847.8′ in E-5X (28% of the planktic fauna) and at 6481′ (8%) in M-10X. Foraminiferal evidence indicates that the overall palaeoenvironment was an outer shelf setting from this level to the top of the Maastrichtian, only interrupted by a probable shallower or less oceanic palaeoenvironment in the lower part of the Biofacies 6 interval of M-10X (6456.2′) and in the Biofacies 5 interval of E-5X (6836.8′). The palaeoenvironment probably changed to an aerobic, mid to outer shelf setting during this short period.

The third and very distinct acme of *Pseudotextularia elegans* was recorded from the uppermost Biofacies 4 sample of E-5X (6836.8′: 50% of the planktic fauna) and, less distinctively, from the uppermost Biofacies 6 sample in M-10X (6446.5′: 3%). To judge from the values in E-5X, this is the most significant of the three probable warming events, and *P. elegans* is more abundant than even *Heterohelix globulosa*, which comprises only 33% of the planktic fauna in this sample. It may be speculated that this and the previous distinct *P. elegans* acme may signal the phase of climate warming that has been related to e.g. the uppermost Maastrichtian Deccan volcanism and dated at *c.* 65.4–65.1 Ma (Keller *et al.* 2003).

The keeled globotruncanid *Abathomphalus mayaroensis* migrated into the E-5X area immediately after the last *P. elegans* acme and occurs in small numbers in the Biofacies 6 interval of E-5X (Fig. 6). *A. mayaroensis* was a subsurface dweller that lived in relatively deep waters below the thermocline (Abramovich *et al.* 2003). The occurrence of common *Stensioeina* ex gr. *beccariformis* in this interval together with *A. mayaroensis* and *Pseudoguembelina hariaensis* indicate that the warmer conditions continued into the uppermost part of the Late Maastrichtian of E-5X (Biofacies 6). The oceanic palaeoenvironment was probably slightly warmer than average Late Maastrichtian temperatures in the area, but most likely cooler than during the last *P. elegans* acme, as the keeled globotruncanids only occur in very small numbers. The geological setting was probably a deep, outer shelf palaeoenvironment, with depths more than 200 m. The fact that keeled globotruncanids were recorded from the uppermost part of E-5X, but not from M-10X, may indicate either that rather dissimilar palaeoenvironmental settings occurred, perhaps related to a restricted current pathway, or that a hiatus exists within the uppermost part of the Maastrichtian of M-10X.

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Appendices 1–4

Appendix I. Percentages of the benthic and planktic taxa in E-5X calculated separately

E-5X (%)

Sample depth (feet)	6809.25	6812.41	6817.58	6820.00	6821.08	6823.33	6824.83	6826.66	6827.92	6830.00	6833.50	6836.83	6839.25	6841.92	6845.83	6847.83	6859.83	6863.33	6869.33	6875.33	6878.58	6881.41	6883.92	6889.33	6894.00	6897.92	6910.25	6916.33	6920.75	6926.58	6941.17	6950.41	6956.83	6963.17	6968.58	6975.17
Alabamina ex gr. limbata																																		3		
Anomalinoides spp.	5			8							3				5		2	4						5						2						
Aragonia velascoensis	5										3								8																	
Astacolus mundus																																				
Astacolus spp.					1													3			2															
Bolivinoides draco						5	1							7	1	9	7	2		3	6					8			7				7		7	7
Bolivinoides giganteus				3		5																														
Bolivinoides paleocenicus	5																																			
Bolivinoides peterssoni			26							1																										
Brizalina cf. decurrens											3			3																						
Brizalina decurrens						4												4		4																
Brizalina incrassata			4		3	6	4	17	3	8	14	3	7		2	5	5	5	2		7	9	5	8	5		4									
Brizalina spp.																										2										
Brozenella acuta																				5		3														
Brozenella welleri							4																			2										
Bulimina? paleocenica							3						2	3																	6					
Cibicides aff. burlingtonensis														4	3																					
Cibicides mariae				8	3						3			2	5			4				4				7										
Cibicides cf. simplex			4		3		9		18	3	2		10		2		5	24			5		5	8												14
Cibicides succedens	5		7		3	6		1	3	4	10	9			3	3	2				5		21	30											33	1
Cibicides velascoensis					1														5			8														7
Cibicides spp.							1																													33
Cibicidoides alleni					2																															
Cibicidoides involutus							3																													
Cibicidoides sp. A					1																															
Cibicidoides spp.	24	2	15		3	13			3			4	1		2		5			4	6	9	10			4	24	4								
Coleites reticulosus																																				3
Coryphostoma limonense													3	2																						
Coryphostoma plaita																				13																
Coryphostoma spp.						1	3		2										3				2	8												3
Dentalina alternata																																				
Dentalina catenula					1																															
Dentalina spp.			4			1		4				3	3			1				17	12	7	5	4	3	4			6				7		3
Ellipsoidella gracillima														1																						
Ellipsodimorphina divergens																				4																
Eouvigerina hispida				3																																
Eouvigerina sculptura				3		2	4	5																												
Eouvigerina spp.											2																									
Eponides sp.					4																															
Fissurina laticarinata																					2															
Fissurina spp.																				3																
Frondicularia spp.				6																																
Fursenkoina tegulata				3																																
Gavelinella cf. danica					1																															
Gavelinella laevigata																															7					
Gavelinella nacetochensis					3																															
Gavelinella pertusa					3	5		1																												
Gavelinella whitei				3		9																														
Gavelinella sp. A					5																															
Gavelinella spp.											3										2				4						3	7				
Gavelinopsis bembix				4											3																					
Globorotalites subconicus											3						6		3																	
Globorotalites spp.																4			3																	
Guttulina spp.											3				2																					
Guttulina trigonula														2																						
Gyroidinoides nitidus						3			19		3		10	9	8	5	8	7		3	4		2			3										3
Gyroidinoides octocamerata					6	2	1		3					3		3	2	4		5																
Gyroidinoides sp. A									1																											
Gyroidinoides spp.																					2		4				3									
Lagene acuticosta															1	2				3																
Lagena amphora																								7												
Lagena geometrica										3																										
Lagena isabella																				4	3	5														
Lagena paucicostata										3																										
Lagena semiinterrupta						1																														
Lagena sphaerica				3																4	8															
Lagena spp.																				4				5												
Loxostomum sp.						3																														
Neoflabellina reticulata					3										5	1																				
Neoflabellina rugosa																																3				
"Nodosaria" sp.					1																															
Nonionella spp.			4																																	
Osangularia navarroana	33	6	15	17	4	13		4	5	14	5	11	14	16	27	3	13	8	1	8	13	4		2	26	4		19		4			7		17
Paralabamina lunata	5				5			3		1																										
Paralabamina sp. A											3								3																	
Pleurostomella subnodosa						2					3																									
Praebulimina laevis					6	2	12	5	1	10	3	3	13	4	1	13	18	13		10	4	3	19		24	3	8		4	6	7					
Praebulimina cf. reussi					6	1	3						3	2			6	3																		
Praebulimine spp.										1		2																								
Praebulimina? sp. A					1	4		5																												
Praebulimina? sp. B					1																															
Praebulimina? spp.					2																															
Pseudonodosaria proboscidea					1																															
Pseudonodosaria pseudoscripta				3		4	3	3	2		7	3		3		1					3															
Pseudonodosaria spp.	5			5																																
Pseudouvigerina cristata					1									3							3		2													
Pseudouvigerina rugosa																																				
Pullenia cretacea					1	1							2	3																						
Pullenia jarvisi				8		2							2	3		1		3		9		2	4								7					
Pullenia spp.	5																						5			5										
Pyramidina cimbrica					1																3		3													
Pyramidina minuta					1				1			4	3	13		5	5	3		7					3							3				
Pyramidina spp.									1							3																				
Pyrulina cylindroides									2						3		3	3	4				3	7		3	4			7					
Pyrulina spp.																	2																			
Pyrulinoides acuminatus																1	1		2			3	4		2											3
Quadrimorphina allomorphinoides				3				3			3										5															
Reussoolina apiculata									2																											
Reussoolina simplex														3	2																					
Rosalina spp.											3																									
Robulus macrodiscus						1																														
Robulus spp.				3		1		1		5		3			3		5	2			5		4						7		7					
Saracenaria triangularis																		4																		
Spirillina subornata					1																															
Spirillina spp.													3																							
Stensioeina ex gr. beccariiformis				1		18	17	18	3		3					10	13				15			14		33					3	7			3	
Stensioeina pommerana			4						6	2	1		3	4	5																	3				
Tappanina selmensis	10								2		7				5									5								3				
Veginulinopsis sp.								3						3																						
Gen. et sp. indet. A																																	11			
Calcareous benthic indet. total		2	19	58	15	38	18	5	23	12	21	13	3	10	29	2	13	2	28	12	26	17	15	9	37	32	14	42		64	36	67	83	43	33	3
Calcareous benthic indet. Epifaunal			7	42	1	31	5	1	18	6	19	5	3	3	2	1	9	5	14	8	19	17	10	5	16	16	3	15	5	64	38	4	51	36		3
Calccareous benthic indet. Infaunal			11			4	3	5	5	2	3	3		3	4	3	2	1	2	4	3		2	16	8	5	8	17				7	11			
Total calcareous benthic	**21**	**5**	**27**	**12**	**38**	**16**	**82**	**72**	**40**	**78**	**42**	**95**	**29**	**31**	**45**	**40**	**58**	**73**	**57**	**26**	**31**	**23**	**31**	**41**	**19**	**25**	**36**	**26**	**6**	**28**	**47**	**15**	**35**	**14**	**3**	**29**
Ammodiscus spp.								1																												
Bathysiphon spp.								1																5												
Karrerulina conversa			3																																	
Orbignyna spp.																			2			3														
Rhabdammina spp.										1																										
Spiroplectammina spp.												3																								
Agglutinated indet.							4														3															
Total agglutinated benthic				1			5						1		1					1			2	2			1									
epifaunal/(epifaunal+infaunal)*100	71		54		72	80	57	41	70	74	57	50	59	55	65	43	44	49	58	62	53	35	47	30	61	39	82	71		86	85	67	77			73
Total benthic	**21**	**5**	**27**	**12**	**39**	**16**	**82**	**78**	**40**	**78**	**42**	**96**	**29**	**31**	**45**	**40**	**58**	**73**	**58**	**26**	**31**	**23**	**33**	**43**	**19**	**25**	**37**	**26**	**6**	**28**	**47**	**15**	**35**	**14**	**3**	**29**
Abathomphalus mayaroensis									1	2		4																								
Chiloguembeline spp.	4		5	6																																
Eoglobigerina edita					3																															
Eoglobigerina eobulloides			10	12	2																															
Globanomaline compressa	4	3																																		
Globigerinelloides asperus									6			2	3	5	7	12	6	4	3	2	4															
Globigerinelloides multispina					6	1	2	8	2	6	3	6	18	14	16	20	8	11	9	9	1	4	2	43	7			23	6	2	5	3				6
Globoconusa daubjergensis	32	56	46	6	33	12																														
Globotruncana arca																1																				
Globotruncana spp.											1														1											
Globotruncanella havanensis																					2	1														
Guembelitria cretacea						1	1			1	4	1	1	1	1			1	1	3	1		4		1	8		1		1		1	7			
Hedbergella monmouthensis				8		10	17	12	13	6	17	7	12	7	13	16	9	8	7	5	13	17	4	5	32	7		5	9		9	7				14
Heterohelix dentata							2	3	2	3	5		1	1	1	1	1	1																		
Heterohelix globulosa					20		4	64	58	66	64	33	54	84	75	54	40	61	54	73	72	73	59	45	76	80	22	77	82	4	71	82	89	81	69	4	59
Heterohelix punctulata												2								1	3																
Heterohelix spp.														2																						
Parasubbotina pseudobulloides	15		8	1	2																															
Parasubbotina cf. varianta	17	14	17	8	22																															
Parvularugoglobigerina? spp.	2	8																																		
Praemurica sp.	2	6																																		
Pseudoguembelina harieensis				2	4	2																														
Pseudotextularia elegans					1			2	4	50	8			8	28		4			2		12														
Racemiguembelina fructicosa					4																															
Rugoglobigerina spp.			1					2		1									1	1		5	2		1											8
Subbotina triloculinoides	5	6	3		5	8																														
Total planktic	**84**	**36**	**105**	**50**	**91**	**25**	**81**	**69**	**95**	**80**	**122**	**52**	**134**	**128**	**100**	**133**	**90**	**81**	**97**	**144**	**186**	**150**	**137**	**139**	**94**	**37**	**73**	**38**	**8**	**56**	**112**	**85**	**139**	**29**	**10**	**51**
Planktic/(benthic+planktic)*100	80	88	80	81	70	61	50	47	70	51	74	35	82	80	69	77	61	53	63	85	86	87	81	76	83	60	66	59	57	67	70	85	80	67		64
Total foraminifera	**105**	**41**	**132**	**62**	**130**	**41**	**163**	**146**	**135**	**158**	**164**	**148**	**163**	**157**	**145**	**173**	**148**	**154**	**155**	**170**	**217**	**173**	**170**	**182**	**113**	**62**	**110**	**64**	**14**	**84**	**159**	**100**	**174**	**43**	**13**	**80**
Bivalve fragment								1																											1	
Calcispheres			1	2	9	9	1			6	1	18		1		2	9	3		2	1	1	14							7	11	8	11			
Cenodiscus / Cenosphaera																										26				2		16	2			
diatom indet.									1																1											
inoceramus fragments										1																										1
ostracod indet.				2	2					1		1								1	2															
radolaria indet.																				3																
sponge spicules							1	1	4			1		1		1					1															
dinoflagellate cysts													3																							

Appendix II. Percentages of total foraminiferal abundance in E-5X

E-5X — Sample depth (feet)	6809.25	6812.41	6817.58	6820.00	6821.08	6823.33	6824.83	6826.66	6827.92	6830.00	6833.50	6836.83	6839.25	6841.92	6845.83	6847.83	6859.83	6863.33	6869.33	6875.33	6878.58	6881.41	6883.92	6889.33	6894.00	6897.92	6910.25	6916.33	6920.75	6926.58	6941.17	6950.41	6956.83	6963.17	6968.58	6975.17
Alabamina ex gr. Limbata																																	1			
Anomalinoides spp.	5			2										1		2			1	1			1													
Aragonia velascoensis	5													1																						
Astacolus mundus																	1																			
Astacolus spp.							1													1			1													
Bolivinoides draco							2	1							3	2	3	3	1	1					3			2				2			3
Bolivinoides giganteus				1																																
Bolivinoides paleocenicus	5									5																										
Bolivinoides peterssoni			5									1																								
Brizalina cf. decurrens											1																									
Brizalina decurrens							2												1		1															
Brizalina incrassata					1	2	2	9	1	4	4	20	1		1	1	2	3	1		1	2	1	3	2		1									
Brizalina spp.			1																				1													
Brozenella acuta																								1	1											
Brozenella welleri								2																						3						
Bulimina? paleocenica													1	1																	1					
Cibicides aff. burlingtonensis																				1	1															
Cibicides mariae			2	1							1				1	3									1											
Cibicides cf. simplex			1		1		4		5	1	1		2		1		2	4				1		2	3										5	
Cibicides succedens	5		2		1	2		1	1	2	2	7			1	1	1							2			7	9							8	3
Cibicides velascoensis						1																	2			3										
Cibicides spp.								1																											8	
Cibicidoides alleni					1																															
Cibicidoides involutus					1																															
Cibicidoides sp. A					1																															
Cibicidoides spp.	24	2	3		1	5		1			3	2		1		2			1	1	1	2			2	8	2									
Coleites reticulosus											1	1																								1
Coryphostoma limonense																						2														
Coryphostoma plaita																			1																	
Coryphostoma spp.						1	1		1																1	3										1
Dentalina alternata						1																														
Dentalina catenula																																				1
Dentalina spp.			1			1		2			1	1		5					2	2	2	1	2	1	2		2			2		1
Ellipsoidella gracillima																	1																			
Ellipsodimorphina divergens																					1															
Eouvigerina hispida					1																															
Eouvigerina sculptura					1		1	3	1																											
Eouvigerina spp.													1																							
Eponides sp.							3																													
Fissurina laticarinata																								1												
Fissurina spp.																						1														
Frondicularia spp.					2																															
Fursenkoina tegulata					1																															
Gavelinella cf. danica					1																													2		
Gavelinella laevigata								1																												
Gavelinella nacatochensis							1	1																												
Gavelinella pertusa				1			4																	1			2					1	2		
Gavelinella whitei						2																														
Gavelinella sp. A						2																														
Gavelinella spp.								2					1					1					1			2						1	2		
Gavelinopsis bembix							1			5	1		2	3	2	2	4	3		1	1		1		1										1
Globorotalites subconicus										1						1		1																		
Globorotalites spp.									1				1																							
Guttulina spp.							1						1					1																		
Guttulina trigonula											1									1	1															
Gyroidinoides nitidus							2	1	1			1		1	1	1		1	1		1	2											1
Gyroidinoides octocamerata											1											1															
Gyroidinoides sp. A												1			1																			
Gyroidinoides spp.																		1			1			1	2						1				
Lagena acuticosta																		1	1																	
Lagena amphora																													1							
Lagena geometrica													1																							
Lagena isabella																				1	1	2														
Lagena paucicostata													1																							
Lagena semiinterrupta							1																													
Lagena sphaerica					1															1	1															
Lagena spp.																					1				2											
Loxostomum sp.							1																													
Neoflabellina reticulata												1						1																		
Neoflabellina rugosa																																		1		
"Nodosaria" sp.						1																														
Nonionella spp.			1																																	
Osangularia navarroana	33	7	3	3	9	5		3	1	7	1	7	2	3	8	1	5	4	4	1	2	1		1	4	2		8		1		2		6
Paralabamina lunata	5						2			1		1																								
Paralabamina sp. A														1						1																
Pleurostomella subnodosa						1						1																								
Praebulimina laevis					2	1	6	1	1	2	1	1	3	1	2	5	8	5		1	1	1	4		10	1	3		1	2	1	
Praebulimina cf. reussi					2	1	1			1			1		1	1		1		1												
Praebulimina spp.										1			1																				
Praebulimina? sp. A						1	3		1			1																				
Praebulimina? sp. B						1	1																									
Praebulimina? spp.						1																										
Pseudonodosaria proboscidea						1																										
Pseudonodosaria pseudoscripta					1		3	1	1		1	1		1		1		1		1												
Pseudonodosaria spp.	5				2																											
Pseudouvigerina cristata							1							1					1													
Pseudouvigerina rugosa							1																									
Pullenia cretacea						1	1						1	1																		
Pullenia jarvisi			2			1							1	1		1		1		1		1		1	2					2	1
Pullenia spp.	5																									1						
Pyramidina cimbrica						1															1				1							
Pyramidina minuta						1			1		3	1	3		1	2	3	1		1											1	
Pyramidina spp.									1					1																		
Pyrulina cylindroides															1	1	1														
Pyrulina spp.									1				1								1	2		1	2						
Pyrulinoides acuminatus																																
Quadrimorphina allomorphinoides					1			1			1			1		1	1	1		1										1
Reussoolina apiculata									1														2								
Reussoolina simplex													1	1																	
Rosalina spp.											1																				
Robulus macrodiscus							1																									
Robulus spp.					1				1		3		1		1							2		2			1		2	
Saracenaria triangularis																		1												
Spirrillina subornata						1																								
Spirrillina spp.																	1												
Stensioeina ex gr. beccariformis					4		9	9	5	1							5	5		3			5	14				1	2	1
Stensioeina pommerana			1						3	1	1		1	1	1														
Teppanina selmensis	10									1		1		1			2							1				1	
Vaginulinopsis sp.								1							1														
Gen. et sp. indet. A																1												2	
Calcareous benthic indet. total		2	4	11	5	15	9	3	7	6	5	8	4	2	9	5	5	5	1	2	4	2	3	2	6	13	5	17	21	11	1	13	14	8	6
Calcareous benthic indet. Epifaunal		2	2	9	4	12	2	1	5	3	3	4	1	6	2	3	5	1	3	2	2	2	3	6	1	6	21	21	11	6	1	12	5	3
Calcareous benthic indet. infaunal		2				2	1	1	3	1	1	1	1		1	1	0	1	1	2			3	3	2	3	7		1	2	1
Total calcareous benthic	**21**	**5**	**27**	**12**	**38**	**16**	**82**	**72**	**40**	**78**	**42**	**95**	**29**	**30**	**45**	**40**	**58**	**73**	**57**	**26**	**31**	**23**	**31**	**41**	**19**	**25**	**36**	**26**	**6**	**28**	**47**	**15**	**35**	**14**	**3**	**29**
Ammodiscus spp.								1																								
Bathysiphon spp.								1																	5							
Karrerulina conversa					3																											
Orbignyna spp.																							2			3					
Rhabdammina spp.													1																		
Spiroplectammine spp.														3																	
Agglutinated indet.								4														1									
Total agglutinated benthic					1			6					1					1				2	2		3			1			
epifaunal / (epifaunal + infaunal)*100	71		54		72	80	57	41	70	74	57	50	59	55	65	45	44	49	68	62	53	35	47	30	61	39	62	71		86	85	67	77			73
Total benthic	**21**	**5**	**27**	**12**	**39**	**16**	**82**	**78**	**40**	**78**	**42**	**96**	**29**	**31**	**45**	**40**	**58**	**73**	**58**	**26**	**31**	**23**	**33**	**43**	**19**	**25**	**37**	**26**	**6**	**28**	**47**	**15**	**35**	**14**	**3**	**29**
Abathomphalus mayaroensis								1	1	1																					
Chiloguembelina spp.	3		4	5																											
Eoglobigerina edita					2																										
Eoglobigerina eobulloides			8	10	2																										
Globanomalina compressa	3	2																													
Globigerinelloides asperus									3				1	3	5	6	4	4	3	2	3										
Globigerinelloides multispina							4	5	1	4	2	2	2	4	12	2	9	1	5	9	7	8	8	3	1	26	5		15	4	2	4	2
Globoconusa deubjergensis	26	49	36	48	24	7																									
Globotruncana arca																			1												
Globotruncana spp.												1														1					
Globotruncanella havanensis																				1											
Guembelitria cretacea	1						1	1	3		1	1	1	1	1			1	1	3	3	1		4		1	5		1		1	5
Hedbergella monmouthensis						5		5	8	8	6	4	7	6	10	5	10	9	5	5	6	5	12	13	3	4	19	5		4	6		7	5	9
Heterohelix dentata								1	1	4	1	4			1		1		1	1		3	5	7	2		2				
Heterohelix globulosa					14	24	32	27	47	32	24	19	69	60	37	4	37	28	46	61	63	51	36	58	66	13	6	46		48	58	76	65	47	4	38
Heterohelix punctulata																						1	2								
Heterohelix spp.												1																			
Parasubbotina pseudobulloides	12		7	9	1																										
Parasubbotina cf. varianta	13	12	14	6	15																										
Parvularugoglobigerina? spp.		7																													
Praemurica spp.	2	5																													
Pseudoguembelina hariaensis					1	2	1																								
Pseudotextularia elegans							1		1	2	37	3			6	21			1		1									
Racemiguembelina fructicosa						2																									
Rugoglobigerina spp.			1					1		1								1	1		4	2		1						
Subbotina triloculinoides	4	5	2		4	5																2	3		3	6	2	5	5	3	
PlIanktic indet.	16	7	10	3	4	20	6	4	7	1	2	3	4	3	4		2		2	3		3	6	2	5	5	5		7	2	9	6	9
Total planktic	**84**	**36**	**15**	**5**	**91**	**25**	**81**	**69**	**95**	**8**	**122**	**52**	**134**	**126**	**1**	**133**	**9**	**81**	**97**	**144**	**166**	**15**	**137**	**139**	**94**	**37**	**73**	**38**	**8**	**56**	**112**	**85**	**139**	**29**	**1**	**51**
Planktic / (benthic + planktic)*100	80	88	80	61	70	61	50	47	70	51	74	35	82	80		69	17	61	53	63	85	86	87	81	76	83	60	66	59	57	67	70	85	80	67	64
Total foraminifera	**15**	**41**	**132**	**62**	**13**	**41**	**163**	**146**	**135**	**158**	**164**	**148**	**163**	**157**	**145**	**173**	**148**	**154**	**155**	**17**	**217**	**173**	**17**	**182**	**113**	**62**	**11**	**64**	**14**	**84**	**159**	**1**	**174**	**43**	**13**	**6**
Bivalve fragment									1																						1
Calcispheres			1	2	9	9	1		6	1	18					2	9	3		2	1	1	14			7	11	8	11
Cenodiscus / Cenosphaera																									28			2		16	2
diatom indet.										1														1						
Inoceramus fragments													1																	1
ostracod indet.					2	2				1		1						1	2								
radolaria indet.																			3								
sponge spicules							1	1	4				1		1			1								
dinoflagellate cysts												3															

Appendix III. Percentages of the benthic and planktic taxa in M-10X calculated separately

M-10X (%)

Sample depth (feet): 6433,58 · 6434,58 · 6436,33 · 6436,83 · 6438,17 · 6438,83 · 6439,00 · 6439,33 · 6440,50 · 6441,92 · 6443,41 · 6444,83 · 6446,50 · 6448,17 · 6449,50 · 6451,83 · 6454,33 · 6456,75 · 6458,17 · 6460,00 · 6463,00 · 6465,25 · 6467,66 · 6472,33 · 6475,17 · 6477,00 · 6481,00 · 6483,83 · 6487,25 · 6489,50 · 6491,50 · 6495,60 · 6498,00 · 6502,33 · 6503,25 · 6505,08 · 6507,66 · 6511,50 · 6514,50 · 6516,65 · 6519,14 · 6522,25 · 6525,25 · 6526,92 · 6528,92 · 6531,00 · 6533,17 · 6539,92 · 6542,58 · 6546,41 · 6552,25 · 6554,83 · 6557,58 · 6560,75 · 6563,66 · 6564,66 · 6566,25 · 6571,17 · 6573,66 · 6577,08 · 6579,83 · 6582,58 · 6586,25 · 6590,00 · 6592,17 · 6598,50 · 6601,58 · 6604,92 · 6608,08 · 6610,00 · 6611,58 · 6612,33 · 6612,66 · 6613,08 · 6613,50 · 6614,08 · 6614,41 · 6614,75 · 6615,00 · 6615,33 · 6615,58 · 6615,92 · 6616,25 · 6616,58 · 6617,17 · 6617,58 · 6618,00 · 6618,41 · 6618,58 · 6619,00 · 6619,41 · 6623,00 · 6626,41 · 6629,33 · 6631,66 · 6634,41 · 6637,33 · 6641,00 · 6644,00 · 6647,00 · 6648,50 · 6652,58 · 6655,58

Benthic taxa

Agglutinated spp.
Alabamina midwayensis
Alabamina cf. midwayensis
Ammodiscus cretaceus
Angulogavelinella avnimelechi
Aragonia aff. ouezzanensis
Bathysiphon spp.
Bolivinoides draco
Bolivinoides cf. draco
Bolivinoides peterssoni
Bolivinoides spp.
Brizalina incrassata
Brizalina spp.
Cibicides cf. simplex
Cibicides spp.
Cibicidoides velascoensis
Cibicidoides cf. velascoensis
Cibicidoides succedens
Cibicidoides cf. succedens
Cibicidoides alleni
Cibicidoides cf. alleni
Dentalina spp.
Dentalina cf. alternata
Dorothea spp.
Eponides spp.
Fissurina spp.
Gaudryina spp.
Gavelinella danica
Gavelinella cf. danica
Gavelinella pertusa
Gavelinella spp.
Globorotalites michelliniana
Guttulina sp.
Gyroidinoides octocamerata
Gyroidinoides spp.
Lagena cf. sulcatiformis
Lagena spp.
Lenticulina pseudocultrata
Lenticulina cf. pseudocultrata
Lenticulina cf. velascoensis
Lenticulina inhabilis
Lenticulina spp.
Melonis spp.
Neoflabellina reticulata
Neoflabellina spp.
"Nodosaria" spp.
Nonionella spp.
Nuttalinella spp.
Osangularia navarroana
Osangularia cf. navarroana
Osangularia cf. cordieriana
Osangularia spp.
Paralabamina lunata
Planularia liebusi
Praebulimina leavis
Praebulimina spp.
Pseudouvigerina cimbrica
Pseudouvigerina cristata
Pullenia quaternaria
Pullenia jarvisi
Pullenia sp. A
Pullenia spp.
Pyramidina minuta
Pyrulina spp.
Saracenaria cf. triangularis
Stensioeina pommerana
Stensioeina ex gr. beccariiformis
Stensioeina spp.
Stilostomella spp.
Tappanina selmensis
Vaginulina spp.
Vaginulina trilobata
Trochospiral spp.
Benthic foraminifera indeterminata

(epifaunal/(epifaunal+infaunal))*100
Total benthic

Planktic taxa

Eoglobigerina eobulloides
Globigerinelloides asperus
Globigerinelloides cf. asperus
Globoconusa daubjergensis
Guembelitria cretacea
Hedbergella monmouthensis
Heterohelix cf. globulosa
Heterohelix complanata
Heterohelix dentata
Heterohelix globulosa
Heterohelix spp.
Heterohelix spp./chiloguembelina morsel indiff.
Heterohelix glabrans
Parasubbotina cf. varianta
Parasubbotina pseudobulloides
Planktonic foraminifera indeterminata
Praemurica taurica
Pseudotextularia elegans
Rugoglobigerina rugosa
Subbotina cf. trivialis
Subbotina spp.
Subbotina triloculinoides
Subbotina trivialis
trochospiral

Total planktic
(Planktic/(benthic+planktic))*100
Total foraminifera

Calcisphere
Ostracod
Radiolaria

Appendix IV. Percentages of total foraminiferal abundance in M-10X

M-10X (%)

Sample depth (feet): 6433,58; 6434,58; 6436,33; 6436,83; 6438,17; 6438,83; 6439,00; 6439,33; 6440,50; 6441,92; 6443,41; 6444,50; 6446,50; 6448,17; 6449,50; 6451,83; 6454,33; 6456,75; 6458,17; 6460,00; 6463,00; 6465,25; 6467,66; 6472,33; 6475,17; 6477,00; 6481,83; 6483,83; 6487,25; 6489,50; 6491,50; 6495,50; 6499,00; 6502,33; 6503,25; 6505,08; 6507,66; 6511,50; 6514,50; 6516,65; 6519,14; 6522,25; 6525,25; 6528,92; 6531,00; 6533,17; 6539,92; 6542,58; 6546,41; 6552,25; 6554,83; 6557,58; 6560,75; 6563,41; 6564,66; 6568,25; 6571,17; 6573,66; 6577,08; 6579,83; 6582,58; 6586,25; 6590,50; 6592,17; 6598,50; 6601,58; 6604,92; 6608,08; 6610,00; 6611,50; 6612,33; 6612,66; 6613,08; 6613,50; 6614,08; 6614,41; 6614,75; 6615,00; 6615,33; 6615,58; 6615,92; 6616,58; 6616,58; 6617,17; 6618,00; 6618,41; 6618,58; 6619,00; 6619,41; 6623,00; 6626,41; 6629,33; 6631,66; 6634,41; 6637,33; 6641,00; 6644,00; 6647,00; 6648,50; 6652,58; 6655,58

Taxa (row labels):

- Agglutinated spp.
- Alabamina midwayensis
- Alabamina cf. midwayensis
- Ammodiscus cretaceus
- Angulogavelinella avnimelechi
- Aragonia aff. ouezzanensis
- Bathysiphon spp.
- Bolivinoides draco
- Bolivinoides cf. draco
- Bolivinoides peterssoni
- Bolivinoides spp.
- Brizalina incrassata
- Brizalina spp.
- Cibicides cf. simplex
- Cibicides spp.
- Cibicidoides velascoensis
- Cibicidoides cf. velascoensis
- Cibicidoides succedens
- Cibicidoides cf. succedens
- Cibicidoides alleni
- Cibicidoides cf. alleni
- Dentalina spp.
- Dentalina cf. alternata
- Dorothea spp.
- Eponides spp.
- Fissurina spp.
- Gaudryina spp.
- Gavelinella danica
- Gavelinella cf. danica
- Gavelinella pertusa
- Gavelinella spp.
- Globorotalites micheliniana
- Guttulina sp.
- Gyroidinoides octocamerata
- Gyroidinoides spp.
- Lagena cf. sulcatiformis
- Lagena spp.
- Lenticulina pseudocultrata
- Lenticulina cf. pseudocultrata
- Lenticulina cf. velascoensis
- Lenticulina inhabilis
- Lenticulina spp.
- Melonis spp.
- Neoflabellina reticulata
- Neoflabellina spp.
- "Nodosaria" spp.
- Nonionella spp.
- Nuttalinella spp.
- Osangularia navarroana
- Osangularia cf. navarroana
- Osangularia cf. cordieriana
- Osangularia spp.
- Paralabamina lunata
- Planularia liebusi
- Praebulimina leavis
- Praebulimina spp.
- Pseudouvigerina cimbrica
- Pseudouvigerina cristata
- Pullenia quaternaria
- Pullenia jarvisi
- Pullenia sp. A
- Pullenia spp.
- Pyramidina minuta
- Pyrulina spp.
- Saracenaria cf. triangularis
- Stensioeina pommerana
- Stensioeina ex gr. beccariiformis
- Rhabdammina spp.
- Stensioeina spp.
- Stilostomella spp.
- Tappanina selmensis
- Vaginulina spp.
- Vaginulina trilobata
- Trochospiral spp.
- Benthic foraminifera indeterminata
- (epifaunal/(epifaunal+infaunal))*100
- Total benthic
- Eoglobigerina eobulloides
- Globigerinelloides asperus
- Globigerinelloides cf. asperus
- Globoconusa daubjergensis
- Guembelitria cretacea
- Hedbergella monmouthensis
- Heterohelix cf. globulosa
- Heterohelix complanata
- Heterohelix dentata
- Heterohelix globulosa
- Heterohelix spp.
- Heterohelix spp./chiloguembelina morsei indiff.
- Heterohelix glabrans
- Parasubbotina cf. varianta
- Parasubbotina pseudobulloides
- Planktonic foraminifera indeterminata
- Praemurica taurica
- Pseudotextularia elegans
- Rugoglobigerina rugosa
- Subbotina cf. trivialis
- Subbotina spp.
- Subbotina triloculinoides
- Subbotina trivialis
- Plankt. Foram. indeterminata trochospir.
- Total planktic
- (Planktic/(benthic+planktic))*100
- Total foraminifera
- Calcisphere
- Ostracod
- Radiolaria