

THE LATE PALEOCENE BENTHIC FORAMINIFERAL EXTINCTION AS OBSERVED IN THE MIDDLE EAST

by

R.P. SPEIJER¹

ABSTRACT

The microfossil content of the upper Paleocene parts of the Nahal Avdat section (Negev Desert, Israel) and the Abu Rudeis section (Sinai Desert, Egypt) was studied. Direct correlation of planktonic foraminiferal and calcareous nannofossil zonations results in positioning the NP9/NP10 zonal boundary within the top part of Zone P6a. Benthic foraminiferal assemblages in the two areas are diverse and very similar: 92 % of the more abundant species are observed at both sites. These sites were situated in the deeper parts of a NE-SW trending basin at a paleodepth of 500-700 m. The well-known deep-sea benthic extinction (within Zones P6a, NP9) is easily recognized by the sudden disappearance of *Gavelinella beccariiiformis*, *Angulogavelinella avnimelechi*, *Pullenia coryelli* and other species within a 50 Kyr. timespan. In contrast to deep ocean sites, simple diversity drops only 17 %, since the abundant shallow-water species in the assemblages are not affected. Post-extinction faunas are dominated by *Nuttallides truempyi* (up to 29 %). In addition to this species a number of other species occur which seem to invade the deeper parts of the basin from shallow waters, immediately after the extinction. Infaunal morphotype abundance does not increase across the extinction level, indicating stable bottom water oxygenation. On the basis of these data, it is concluded that the hypothesis involving a temporal shift of bottom water formation from high to low latitude, inducing warm saline bottom water to spread through all oceanic basins, is tenable. However, oxygen deficiency of this postulated watermass originating at low latitudes, can not be the controlling factor in the worldwide extinction. A change in other properties, e.g. salinity and/or temperature, must at least have played a role as well.

KEY WORDS

Paleocene/Eocene boundary, upper Paleocene, benthic foraminifera, extinction, Egypt, Israel.

1. INTRODUCTION

The late Paleocene is characterised by a major turnover in deep-sea benthic foraminiferal assemblages (Tjalsma and Lohmann, 1983). This event was first described by Beckmann (1960) for the Lizard Springs Formation in Trinidad. Subsequently it was recorded in the Alps (Hillebrandt, 1962; Braga *et al.*, 1975), in Japan and New Zealand (Kaiho, 1988) and in many deep-sea cores, recovered by the Deep Sea Drilling Project and the Ocean Drilling Program, from all the world's oceans (e.g. Tjalsma, 1977; Schnitker, 1979; Thomas, 1990; Katz and Miller, 1991; Nomura, 1991). Many cosmopolitan Cretaceous species that apparently easily survived the biotic crisis at the Cretaceous/

Paleogene (K/P) boundary (Beckmann, 1960; Webb, 1973; Dailey, 1983), became extinct near the end of the Paleocene (Tjalsma and Lohmann, 1983; Thomas, 1990; Nomura, 1991). In fact, the late Paleocene extinction can be regarded as the largest turnover in deep-sea benthic foraminifera of the last 90 million years (Tjalsma and Lohmann, 1983). A drop in species diversity of 35-50 % has been observed at several locations in the Southern Ocean (Thomas, 1990; Katz and Miller, 1991; Nomura, 1991). Ever since the recognition of this event, it has been difficult to assess its exact timing within a rigid biostratigraphic framework (Tjalsma and Lohmann, 1983). Tjalsma (1977) and

¹ Department of Geology, Institute of Earth Sciences, Budapestlaan 4, P.O. Box 80.021 - NL-3508 TA Utrecht, The Netherlands.

Schnitker (1979) observed a post-extinction fauna within the lowermost part of Zone P6a, following the foraminiferal zonal scheme of Berggren (1969). Therefore, Tjalsma and Lohmann (1983) concluded that the faunal turnover coincided with the P5/P6a zonal boundary. Because of the occurrence of a pre-extinction fauna within Zone P6a in a Pacific deep-sea core, Miller *et al.* (1987) suggested that the turnover should be placed within Zone P6a and probably just below the P6a/P6b zonal boundary (Berggren and Miller, 1989), often referred to as the Paleocene/Eocene boundary (Berggren *et al.*, 1985).

Recently, the benthic turnover has been linked to a calcareous nannofossil zonal scheme. Both at Maud Rise, Weddell Sea, (Thomas, 1989) and at Broken Ridge, Indian Ocean (Nomura, 1991) it is placed within the top part of Zone NP9, following the zonal scheme of Martini (1971). Because of the scarcity of the NP10 zonal marker *Tribraehiatus bramlettei* within oceanic sediments, the NP9/NP10 zonal boundary is often drawn at the last occurrence (LO) of *Fasciculithus* (Aubry *et al.*, 1988). This LO is sometimes correlated with the benthic turnover (Katz and Miller, 1991). Of course, the use of this LO should be used with great care because of the easy reworking of *Fasciculithus*.

The benthic extinction event has often been referred to as a Paleocene/Eocene boundary event (Boersma, 1984; Rea *et al.*, 1990). However, Aubry *et al.* (1988) pointed out that the Paleocene/Eocene boundary, as it was originally defined by Von Koenen (1885), corresponds to the upper part of Zone NP10. Therefore, the extinction is merely a late Paleocene feature. Whatever the exact timing might be, Kennett and Stott (1991) clearly demonstrated, by means of high resolution sampling, that it was a rather rapid event spanning only a few thousand years, at least at Maud Rise. Furthermore, these authors showed that it was accompanied by a sudden decline in carbonate $\delta^{18}\text{O}$ values, which is immediately followed by a strong decrease in $\delta^{13}\text{C}$ values. These isotopic shifts are superimposed on longer term trends towards lighter values starting in the late Paleocene, which have been observed in many other areas (e.g. Shackleton *et al.*, 1984, 1985; Katz and Miller, 1991; Barrera and Huber, 1991; Nomura, 1991; Hovan and Rea, 1992).

Four main hypotheses have been proposed in explaining stable isotope excursions and the benthic extinction. The first two emphasize excursions of oxygen and carbon stable isotopes, whereas the other two more strongly lean on the change in $\delta^{13}\text{C}$ values. Shortly summarized the explanations are:

1 - Rapid global warming would induce intense formation of warm saline bottom water (WSBW), after the model of Brass *et al.* (1982); the high temperature of this watermass would be lethal to many benthic species (Miller *et al.*, 1987).

2 - In essence the same as mentioned above, but pointing to oxygen deficiency of the WSBW as the lethal factor (Thomas, 1989, 1990).

3 - In sharp contrast with the previous explanations, this one invokes a cessation of WSBW formation induced by reduction of evaporation in marginal seas (Brass, *et al.*, 1982; Barron *et al.*, 1981). This would lead to aged and oxygen-depleted bottom water causing the extinction (Nomura, 1991).

4 - The strong negative $\delta^{13}\text{C}$ excursion has been interpreted as a signal of a global decrease in primary production (Shackleton *et al.*, 1985). This would lead to a decrease in organic carbon flux to the bottom, resulting in starvation for benthic organisms (Miller *et al.*, 1987).

The causal mechanism for the global changes in oceanic chemistry and/or circulation in the first three hypotheses mentioned is still a matter of speculation. It is suggested that a sharp increase in atmospheric CO_2 , causing an extreme greenhouse effect, was induced by extensive volcanism and hydrothermal activity at a time of plate-tectonic reorganization (e.g. Rea *et al.*, 1990; Thomas and Varenkamp, 1992).

In order to evaluate the merit of the models for low latitude areas, samples from two sections (Nahal Avdat, Negev Desert, Israel and Abu Rudeis, Sinai Desert, Egypt) have been investigated. Both sections display an almost continuous sequence of Upper Cretaceous through lower Eocene deposits. In this paper some preliminary results concerning the benthic foraminiferal patterns from the upper Paleocene parts of the sections are presented.

2. REGIONAL GEOLOGY

The deposits studied, belong to the Taqiye Formation for the Israelian Nahal Avdat section (Romein, 1979) and to the Esna Shales, first described by Beadnell (1905), for the Egyptian Abu Rudeis section (for location see fig. 1). Both are however partially lateral equivalents with very similar, predominantly marly, lithologies (Arkin *et al.*, 1972). These deposits are widely distributed all over Egypt (e.g. Leroy, 1953; Nakkady, 1957; Luger, 1985) and within a NE-SW trending area across the central Sinai between the Dead Sea and the Gulf of Suez (Bartov and Steinitz, 1977). This area delineates a basin which developed during the Late Cretaceous Laramide orogeny, creating the Syrian Arc System (Bartov and Steinitz, 1977; El Shazly, 1977). Based on isopach maps, the two sections studied are thought to be situated in the deeper parts of this basin (Bartov and Steinitz, 1977). Small-scale fold structures with the same NE-SW direction are observed in the area around Nahal Avdat causing basinal highs and lows. The upper part of the Taqiye

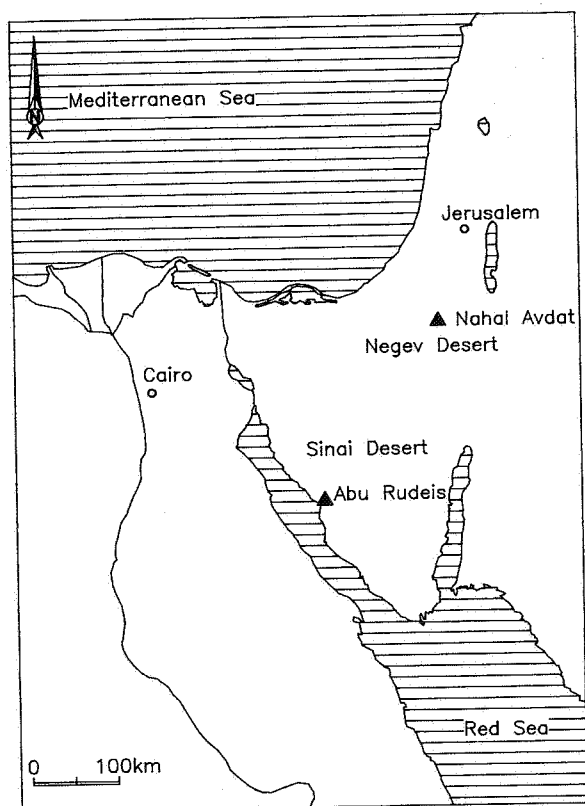


Figure 1. Location of the two studied sections (triangles) in the Middle East.

Formation, i.e. the Hafir Member, clearly wedges out against the structural highs (Arkin *et al.*, 1972). Based on lithofacies and clay mineral distributions, these authors argued that, these highs were emerged during late Paleocene-early Eocene time, forming longitudinal peninsulas within a shallow sea.

Most papers dealing with late Paleocene-early Eocene microfossils, obtained from the Sinai/Negev region, focused on (regional) stratigraphic correlations (e.g. : Reiss, 1952 ; Said and Kenawy, 1956 ; Nakkady, 1957 ; Abdelmalik *et al.*, 1978 a,b), of course strongly relying on pelagic fossils. Unfortunately, useful paleoenvironmental analyses based on either benthic and/or pelagic microfossils are extremely scarce. An example is the paper by Shahin (1990) discussing an area somewhat south of Abu Rudeis. More paleoenvironmental studies are needed, however, in order to test the validity of the above-mentioned basin-configurations ; in that way it would be easier to distinguish local from regional and global events.

3. MATERIAL AND METHODS

Data on calcareous nannofossil distributions of the Nahal Avdat section were obtained from Romein (1979). For the Abu Rudeis section, analyses on cal-

careous nannofossils were carried out separately. Special attention was paid to marker species. All samples, except IR106 were desintegrated in water for a few days and were subsequently washed over a 63- and 125- μm mesh sieve. Afterwards samples were dried at 60°C in a stove. Benthic foraminifera showed a reasonable preservation, whereas in many samples the planktonic foraminifera showed more or less severe signs of dissolution. Because Israeli samples were extremely small, the planktonic foraminiferal assemblages were sometimes rather poor. Only the 125- μm fraction was employed both for planktonic and benthic foraminiferal analyses. For planktonic foraminiferal biostratigraphy the samples were only searched for several marker species. In contrast, all benthic foraminiferal specimens (about 200-300) were picked from a split of the sample and were subsequently stored and sorted in a Chapman-slide. These pickings were used in quantitative analyses of the benthic assemblages. Most specimens were determined at species level, in closed or open nomenclature ; a minor part was assigned to a higher taxonomic level. The standard zonations of Berggren (1969) and Martini (1971), for planktonic foraminifera and calcareous nannofossils respectively, were used for biostratigraphy.

4. BIOSTRATIGRAPHIC RESULTS

In figure 2 the ranges of several nannofossil (Romein, 1979) and planktonic foraminiferal marker species in the Nahal Avdat section are displayed. *Discoaster multiradiatus* is observed in all samples ; this implies that the base of Zone NP9 (Martini, 1971) is not encountered in this part of the section. The zonal boundary between NP9 and NP10 which is defined by the first occurrence (FO) of *Tribrachiatus bramlettei* (Martini, 1971) is observed between samples IR106 and IR107. This level coincides with a sharp decrease in *Fasciculithus* spp.. Possibly, the *Fasciculithus tympaniformis* found in higher samples are reworked; if so, then the last common occurrence (LCO) of *Fasciculithus* approximates the NP9/NP10 zonal boundary (Berggren *et al.*, 1985 ; Perch-Nielsen, 1985). In samples IR104 and IR105 only a few specimens resembling *Morozovella subbotinae* were observed ; therefore the boundary between Zones P5 and P6a (Berggren, 1969) was tentatively placed between samples IR103 and IR104. The FO of *Pseudohastigerina wilcoxensis* coincides with the FO of *Tribrachiatus bramlettei*. The LO of *Morozovella velascoensis* is encountered in IR108 ; therefore IR109 belongs to the basal part of Zone P6b. The extinction of many benthic species, e.g. *Gavelinella beccariiformis* and *Pullenia coryelli* falls between IR105 and IR107, thus within Zone P6a and near the NP9/NP10 zonal boundary. Ranges of marker species in the Abu Rudeis section

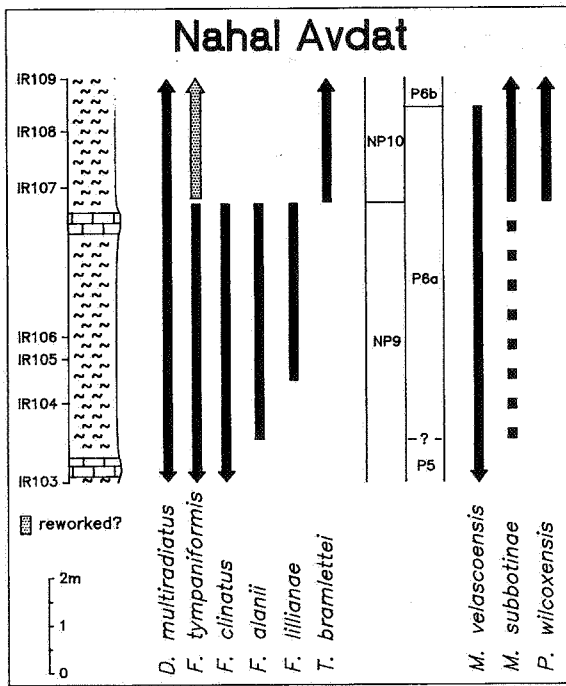


Figure 2. Lithologic column and studied samples (IR codes) of the Nahal Avdat section; biozonation is based on ranges of selected calcareous nannofossil species (left, after Romein, 1979) and planktonic foraminifera (right).

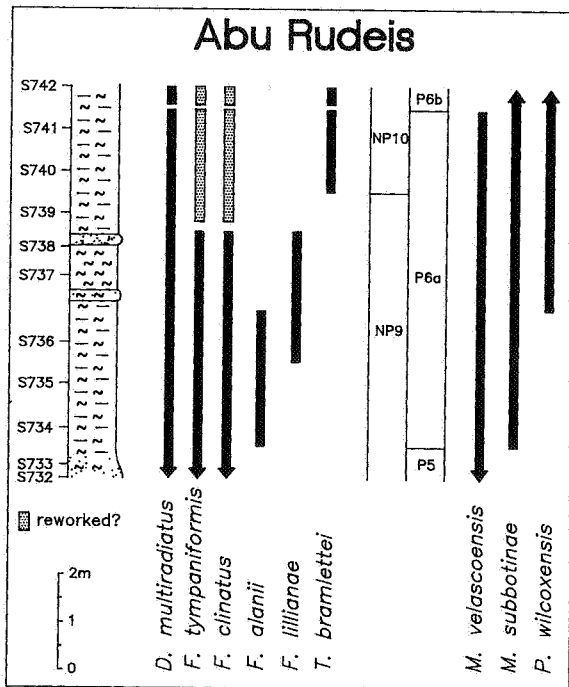


Figure 3. Lithologic column and studied samples (S codes) of the Abu Rudeis section; biozonation is based on ranges of selected calcareous nannofossil species (left) and planktonic foraminifera (right).

(fig. 3) reveal essentially the same pattern as in the Nahal Avdat section ; moreover, they add some biostratigraphic resolution. Again, *Discoaster multiradiatus* has been observed in all samples, thus the base of Zone NP9 is not reached. A clear lag separates the LCO of *Fasciculithus* spp. and the FO of *Tibrachiatus bramlettei*. Thus it seems that the probable extinction of *Fasciculithus* is just below the NP9/ NP10 zonal boundary. Distinct *Morozovella subbotinae* appear from sample S734 onwards, defining the P5/P6a zonal boundary just below this sample. *Pseudohastigerina wilcoxensis* appears well below the FO of *Tibrachiatus bramlettei*, at about the same level of the benthic extinction. Based on the LO of *Morozovella velascoensis*, the P6a/P6b zonal boundary is situated near the top of the section. Again the benthic extinction falls within P6a and just below the NP9/ NP10 zonal boundary.

Evidently the Abu Rudeis section displays a higher biostratigraphic resolution. This probably results from the better sample coverage in this section. Figure 4 shows that the two sections can easily be correlated using all faunal events. If figure 4 is compared with the integrated Paleogene geochronological scheme of Aubry *et al.* (1988), it appears that these authors propose quite a different sequence of faunal events : they correlated the NP9/NP10 zonal boundary with a level within Zone P6b. Probably the reason for this discrepancy is the scarcity of NP10 zonal marker *Tibrachiatus bramlettei* in oceanic sediments (Aubry *et al.*, 1988) and/or reworking of *Fasciculithus* above its supposed extinction level. These results, however, are not completely new. In fact, the FO of *Tibrachiatus bramlettei* within the *Morozovella velascoensis* Zone (i.e. Zone P5 or P6a, following Berggren, 1969) was already proposed by Hay and Mohler (1969) and Abdelmalik *et al.* (1978 a,b) for some epicontinental deposits exposed in land sections. The latter authors based this idea on studies on a parallel-section of the Abu Rudeis section. Our study indicates that the extinction event should be placed below the NP9/NP10 zonal boundary (fig. 4), either based on the FO of *Tibrachiatus bramlettei* or approximated by the LCO of *Fasciculithus*. This agrees well with recent ODP data (Thomas, 1989 ; Katz and Miller, 1991 ; Nomura, 1991). It is also clearly demonstrated that the benthic extinction occurs within Zone P6a. This is in agreement with the suggestion of Miller *et al.* (1987). In the study area the FO of *Pseudohastigerina wilcoxensis* is the best coeval faunal event in the pelagic realm to approximate the benthic extinction (Figures 2, 3, 4). Whether this is just a local feature, remains to be investigated. However, there is some proof that this is a global feature for (sub-)tropical areas (Berggren and Miller, 1988).

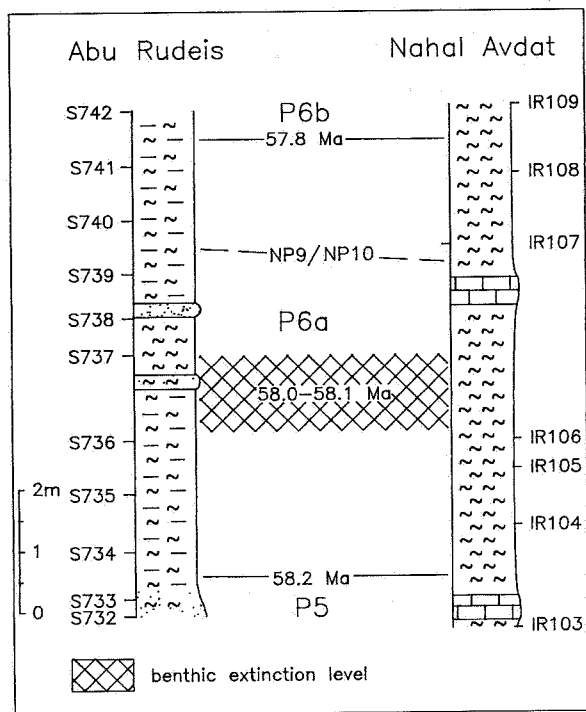


Figure 4. Correlation of the two sections based on foraminiferal and nannoplankton events, introducing numerical age estimates (after Aubry *et al.*, 1988) for the foraminiferal zonal boundaries. Constant sedimentation rates are assumed for the correlation of the benthic extinction level.

.When numerical age estimates for the P5/P6a (58.2 Myr) and P6a/P6b (57.8 Myr) zonal boundaries are used (Aubry *et al.*, 1988), the average sedimentation rates in both sections can be estimated at about 1,75 cm/Kyr. By extrapolation this implies that the benthic extinction occurred between 200-300 Kyr before the extinction of *Morozovella velascoensis*, thus at 58.1-58.0 Ma. Furthermore, this sedimentation rate implies that in the Abu Rudeis area the turnover in the benthic assemblage took less than 50 Kyr. This is not surprising since Kennett and Stott (1991) already denoted a time span of less than 3 Kyr (!) for the enormous drop in benthic foraminiferal diversity at Maud Rise. The relative rapidity of this event places constraints on the various hypotheses put forward to explain this extinction.

5. QUANTITATIVE ANALYSIS OF BENTHIC ASSEMBLAGES

Within the 16 samples treated in this paper, 118 different taxa were encountered; this number would have been much higher if the complete washed residue would have been searched for rare specimens and if certain species (e.g. *Nodosariids*) were not lumped together.

The taxa found can be grouped into three categories.

- 64 species are more or less common and compose 81-92 % of the specimens in each sample.

- 37 species are very scarce and compose up to 5 % of the specimens in each sample.

- Other species are lumped into 17 taxa, composing 7-17 % of the specimens in each sample.

92 % of the common species were encountered in samples from both sections. The quantitative patterns of the 36 most common species are displayed in figure 5.

The Paleocene (pre-extinction) benthic assemblages are highly diversified: each sample contained about 50 different taxa; 97 taxa were encountered in all samples together (Nahal Avdat: 75; Abu Rudeis: 83). Many common species (figure 5) can be regarded as belonging to the Velasco-type fauna (VF) of Berggren and Aubert (1975). This fauna was named after the lower Paleocene Velasco Shale Formation, Mexico; its foraminiferal contents have first been described by Cushman (1925, 1926) and White (1928, 1929). The VF is commonly recognized in bathyal and abyssal deposits (Berggren and Aubert, 1975). Many VF species were cosmopolitans and range from the Campanian or Maastrichtian onward, straddling the K/P boundary into the Paleocene (Tjalsma and Lohmann, 1983). This assemblage is very often easily recognizable by the presence of *Gavelinella beccariiiformis*, a very distinct species. In both sections this species dominates (up to 31%) the Paleocene assemblages until its abrupt disappearance.

Many other common species in the assemblages can be regarded as Midway-type fauna (MF) elements (Berggren and Aubert, 1975); this fauna was named after the benthic foraminiferal assemblages observed in the lower Paleocene Midway Formation, Texas (Plummer, 1927; Kellough, 1965). All species commonly occurring in neritic marl/shale deposits in Europe and North Africa (e.g. Brotzen, 1948; Leroy, 1953; Aubert and Berggren, 1976; Salaj *et al.*, 1976; Luger, 1985; personal observations), are considered to belong to this MF assemblage (fig. 5), thus using this term in its widest sense. Having a mixture of VF and MF suggests that the VF and MF are not strictly separate entities, but more the two extremes of a range of different assemblages. Similar mixed MF/VF assemblages were described by earlier workers in Israel (Reiss, 1952) and the Sinai (Said and Kenawy, 1956). In fact, many typical MF species, e.g. *Bulimina midwayensis* and *Coryphostoma midwayensis*, are often observed in bathyal and abyssal deposits (Tjalsma and Lohmann, 1983; Van Morkhoven *et al.*, 1986). In contrast, most VF species never occur in neritic deposits indicating that these species have bathyal upper depth limits (Morkhoven *et al.*, 1986). This is visualised in figure 6: bathymetrical ranges of the most common species are displayed. This graph shows that the minimum depth of deposition should have been about 500 m, because of the occurrence of *Nuttallides truempyi* and *Bulimina trinitatensis* in both areas. In all samples

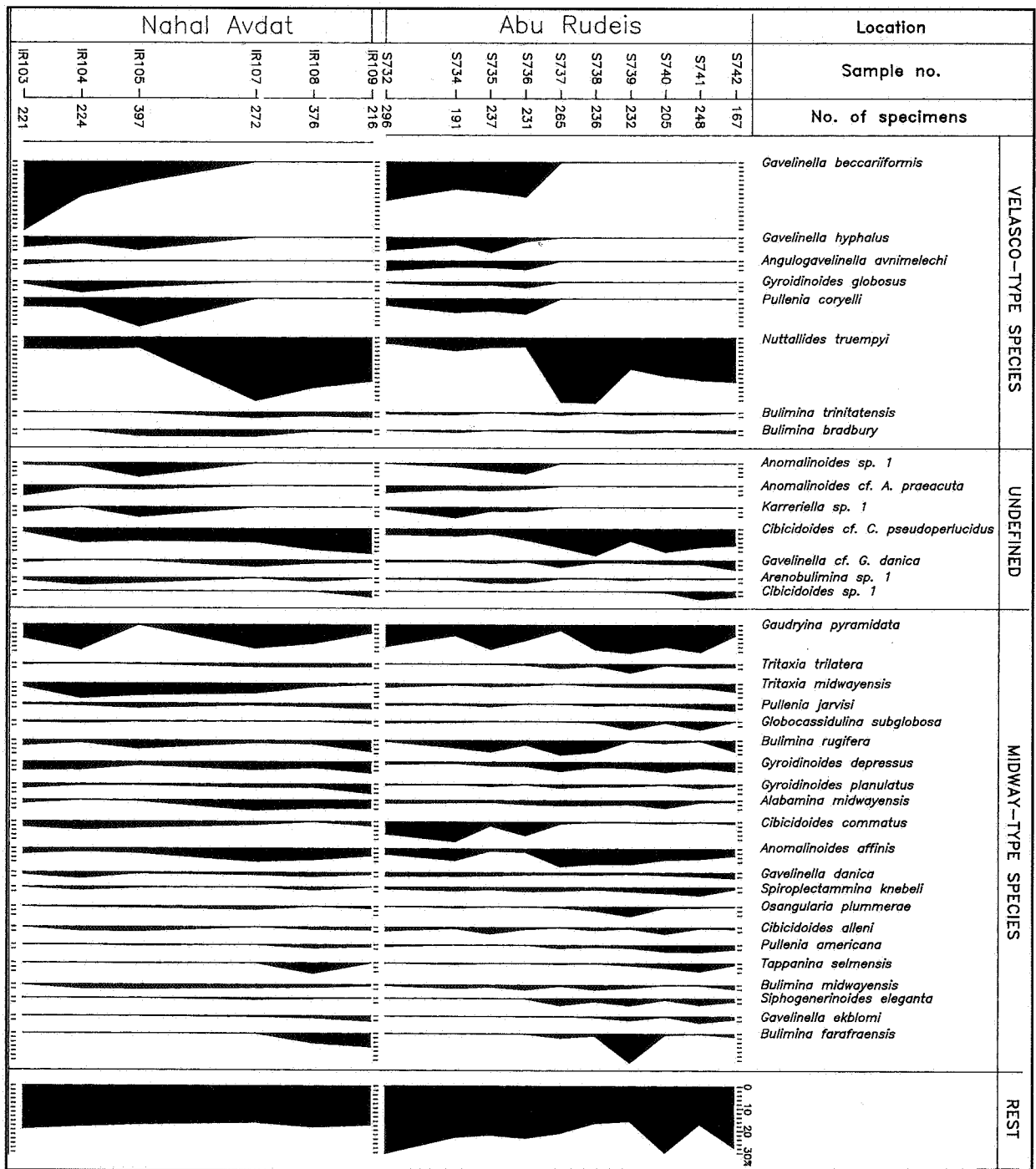


Figure 5. Frequencies of the 36 most common species in the >125 μ m fraction, grouped according bathyal (Velasco-type) and neritic (Midway-type) biofacies. One bar equals 2% of the total assemblage.

planktonic foraminifera dominate the assemblages (50-70 %), despite some loss by dissolution. When this value is compared with regression curves of modern %P versus depth as compiled in Van der Zwaan *et al.* (1990), the proposed minimum paleodepth appears realistic. However, since the total abundance of MF and VF is about equal (fig. 7), it seems reasonable to assume that the basin was not much deeper than 500-700 m at the two locations studied. Latest Paleocene, post-extinction, assemblages differ

significantly from the earlier Paleocene ones. They are slightly impoverished; each picking contained about 45 taxa, with a total of 80 recorded taxa (Nahal Avdat: 63; Abu Rudeis: 73). Simple diversity (total number of taxa) drops with 17%. 14 species have last appearances, whereas 7 common species are newly appearing within the studied interval (fig. 8). Few common VF species persist in the Eocene assemblages (fig. 5), although *Nuttallides truempyi* is now most dominant (up to 29%). In contrast many MF species

Depth ranges of diagnostic species	NERITIC			BATHYAL			ABYSSAL	
	inner 30	middle 100	outer 200	upper 600	middle 1000	lower 2000	upper 3000	lower
<i>Nuttallides truempyi</i>				■	■	■	■	■
<i>Bulimina trinitatensis</i>				■	■	■	■	■
<i>Angulogavelinella avnimelechi</i>				■	■	■		
<i>Aragonia aragonensis</i>				■	■	■	■	■
<i>Gyroidinoides globosus</i>				■	■	■	■	■
<i>Gavelinella beccariiiformis</i>				■	■	■	■	■
<i>Coryphostoma midwayensis</i>			■	■	■	■	■	
<i>Tappanina selmensis</i>			■	■	■	■	■	
<i>Gavelinella hyphalus</i>			■	■	■	■	■	■
<i>Loxostomoides applinae</i>		■	■	■	■			
<i>Gavelinella danica/rubiginosa</i>		■	■	■	■	■	■	■

Figure 6. Paleobathymetric ranges of observed species (modified after Van Morkhoven *et al.*, 1986) indicate an upper to middle bathyal (500-700m) paleodepth for the examined deposits.

remain or become important constituents, on the average 50 % of the total abundance (figures 5, 7). A similar fauna was described earlier in Israel (Reiss, 1952). Using the paleobathymetric ranges in figure 6, it seems that depth of deposition did not change during the late Paleocene i.e. remained at approximately 500-700 m, despite the high total abundance of MF. High frequencies of well preserved planktonic foraminifera (> 90 %) could even indicate slightly deeper deposition (Van der Zwaan *et al.*, 1990).

Several ways of quantifying the benthic assemblages have been applied in order to assess what changes took place during the late Paleocene. Figure 9 shows that a drastic change in the faunal composition occurred in both studied areas. Although only 14 (25 %) of the common species disappeared (fig. 8), they composed almost half of the total assemblage during the Paleocene. During the latest Paleocene their position is primarily taken over by species already extant during the earlier Paleocene. This however, could partly be a closed sum effect. Newly appearing species play a very subordinate, but upward increasing, role. At least 7 disappearing species belong to the VF (fig. 8). In contrast, only one certain MF species (at least in the early Paleocene), namely *Coryphostoma midwayensis*, died out simultaneously. The remainder cannot be assigned to one of the faunal assemblages. Thus it appears that in particular species restricted to the bathyal/abyssal realm did not survive the late

Paleocene event. This idea is substantiated by observations of typical MF assemblages in the uppermost Paleocene and lower Eocene of Egypt (Luger, 1985) and Rockall Bank (Berggren, 1974). Thus the MF remains rather unaffected and lingers on in the early Eocene (Berggren and Schnitker, 1983). I speculate that before the extinction event the paleobathymetric range of *Coryphostoma midwayensis* was restricted to the bathyal/abyssal realm, thus being a VF species in the late Paleocene. The changes in total abundance of VF versus MF (fig. 7) could of course indicate a rapid shallowing of the basin during the late Paleocene. This seems highly unlikely, as pointed out earlier. The increase of MF abundance might again partly be a closed sum effect. On the other hand, the first appearance of *Bulimina farafraensis*, a MF species in the upper Paleocene (P4) of Central Egypt (Leroy, 1953 ; Berggren and Aubert, 1975), indicates immigration of bathyal environments from shallower shelf areas. Such a shift might as well be applicable to other MF species, such as *Siphogene-rinoides eleganta* and *Gavelinella ekblomi* ; further comparison of regional distribution patterns will be needed to confirm this idea.

The quantitative analyses mentioned above unravel the changes in composition clearly, but do not render any clues to the mechanism leading to these changes. An actualistic approach to deduce environmental changes related to oxygen content and organic carbon flux implies the use of benthic morphotype ratios. In gen-

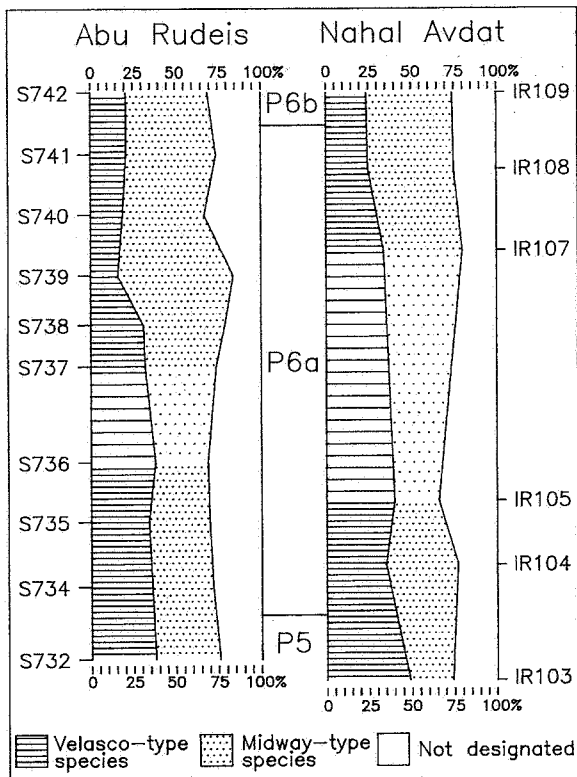


Figure 7. Total abundances of VF and MF species through the sections. Wider hatching indicates benthic turnover interval. Note the gradual increase in MF species after the benthic extinction.

eral all bottom dwelling benthic foraminifera can be divided into two groups (Corliss, 1985).

1. Epifaunal morphotypes : species living at the sediment-water interface usually having a test morphology with a low surface area to volume ratio (plano-, or biconvex trochospiral forms), only able to live within well-oxygenated bottom water.
2. Infaunal morphotypes : species living primarily within the sediment usually having a test morphology with a high surface area to volume ratio (slender uni-, bi-, triserial and planispiral forms) able to live in an oxygen-deficient environment.

The ratio of these morphotypes could reveal paleoxygenation of the bottom environment. Changes in the ratio would then suggest circulation and/or organic carbon flux changes.

Although this approach is even in recent environments still controversial and at best simplistic, especially in shallow marine and/or seasonally influenced areas (Wetmore, 1991 ; Barmawidjaja *et al.*, 1991), it has been applied to Paleogene benthic assemblages (Thomas, 1990 ; Kaiho, 1991 ; Kaminski, pers. comm., 1991). To facilitate an easy comparison with the data of Thomas (1990), the same morphotype criteria have been applied: cylindrical species are included within the infaunal group, agglutinants are completely excluded. Unfortunately, Thomas analysed the 63-mm

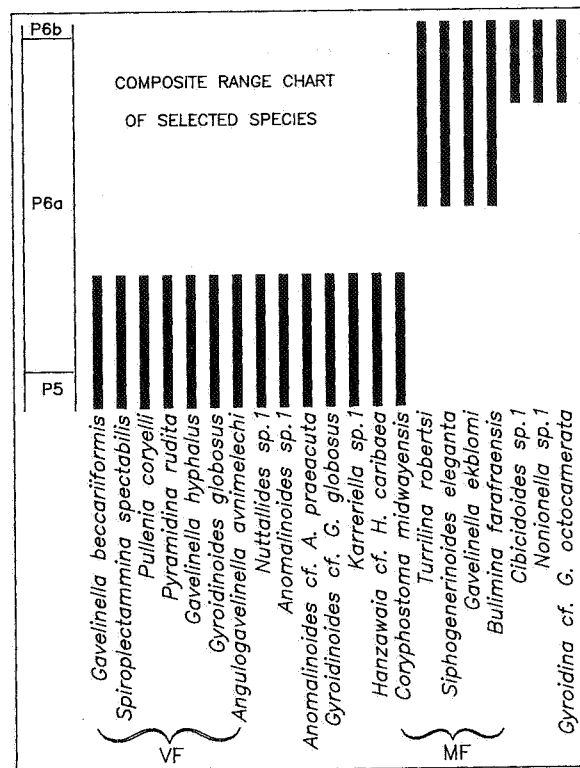


Figure 8. Ranges of all common species that either appear or disappear in the studied interval. Note the sudden first appearances of several MF species after the extinction of mainly typical VF species.

fraction, therefore absolute figures cannot directly be compared. Nevertheless observed trends should still be comparable. Figure 10 displays the total abundance of epi- and infaunal morphotypes. The epifaunal group constitutes between 70 and 90 % of the Paleocene pre-extinction assemblages in both studied areas. This value decreases only slightly during the latest Paleocene. To check the pattern, two 63µm pickings have been performed on samples S736/S737, both showing about 50 % infaunal morphotypes. Therefore, in the studied basin no change in bottom water oxygenation can be inferred. This is in sharp contrast with the results from the Weddell Sea (Thomas, 1990), the Pacific (Kaiho, 1991), the Southern Indian Ocean (pers. obs.) and the Barents Sea (Kaminski, pers. comm., 1991), where infauna dominates latest Paleocene assemblages and indicates low oxygen conditions. Especially at Maud Rise peak values of more than 90% infauna just after the extinction point to oxygen deficiency (Thomas, 1990).

6. DISCUSSION

Because of the striking similarity between the faunas in the two studied areas, both before and after the benthic crisis, it seems evident that the two depositional sites were situated in a very similar physical/chemical

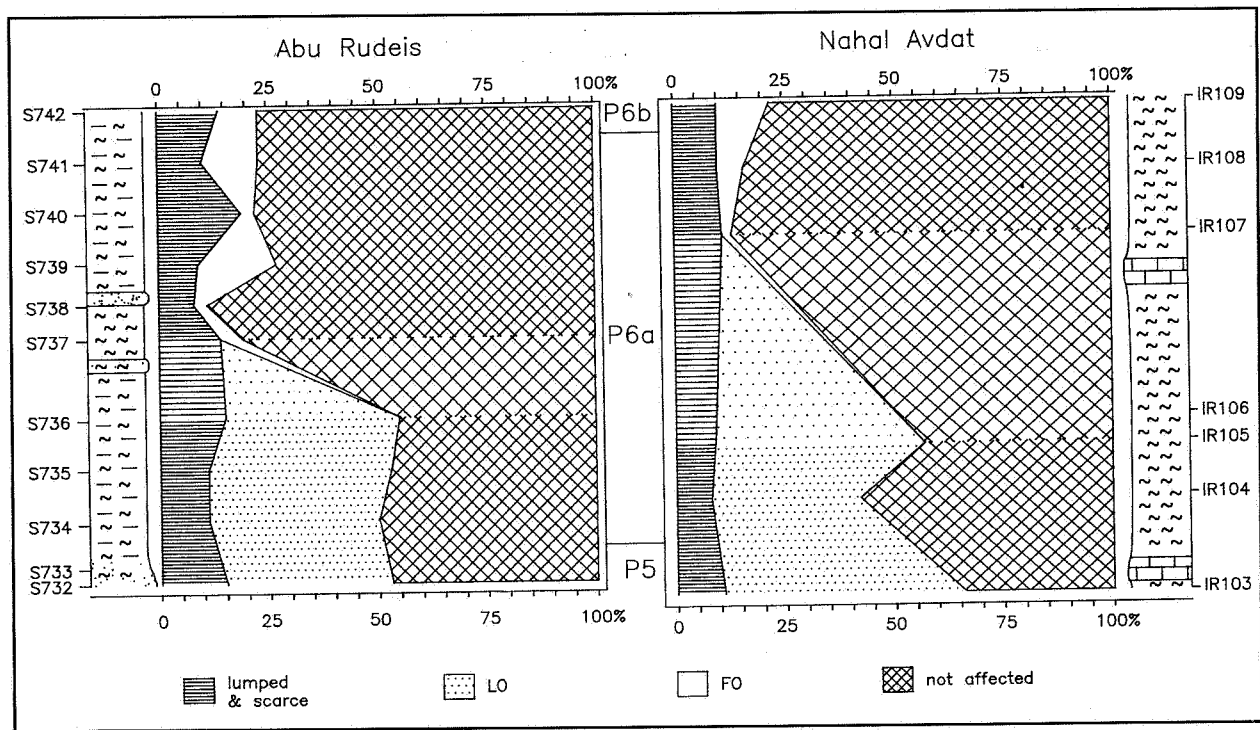


Figure 9. Total abundance grouping according lumped and scarce taxa, taxa with last occurrences (LO), taxa with first occurrences (FO) and not affected taxa, before and after the extinction event. Wider hatching indicates benthic turnover interval.

environmental setting, during the studied part of the Paleocene. Both sites belonged to the deeper part of a NE-SW trending trans-Sinai basin. Little is known about paleogeography of the Abu Rudeis area; the Nahal Avdat area, however, has been studied more extensively in this respect (Arkin *et al.*, 1972). On their paleo-geographic maps these authors suggest that the Nahal Avdat section was within 5 km distance from the ancient shoreline of a NE-SW peninsula during the late Paleocene and early Eocene. This idea conflicts with the estimated paleobathymetry and the widespread and rather uniform lithofacies of the Taqiye Formation, pointing at open marine epipelagic sedimentation. Possibly this peninsula was in fact a submerged basinal high, a few hundred meters below sea-surface. Sediment accumulation on top of this elevation could have been stripped of during subsequent regional uplift or sea level lowering. Consequently, only deposits in the structural lows were preserved. The basin as a whole was probably well connected with the Tethys and other oceans. This can be concluded from the predominance of the cosmopolitan deep-water VF and its successor. A more isolated basin would have shown much more endemic benthic taxa; instead very few such elements have been observed.

The fact that many common Paleocene VF species are cosmopolitans and have large depth ranges (Tjalsma and Lohmann, 1983; Van Morkhoven *et al.*, 1986) could suggest a rather uniform intermediate- and deep watermass, dominating the world's oceans (cf.

Thomas, 1992). This watermass may have originated in a single source-area, e.g. at the margins of the Southern Ocean or the Tethys. This idea is substantiated by comparisons of stable isotope values from different oceans (Pak *et al.*, 1991). Late Paleocene $\delta^{18}\text{O}$ profiles are very gentle, indicating equable temperature of intermediate and deep waters. In contrast, $\delta^{13}\text{C}$ values seem to point to the occurrence of the most nutrient-depleted, young bottomwater in the Southern Ocean, and nutrient contents increasing towards the other oceans. From this it appears that intermediate and deep waters could have originated somewhere around the Austral-Antarctic continent (see also Barrera *et al.*, 1987; Barrera and Huber, 1991). However, the high amount of infaunal morphotypes at Maud Rise (Thomas, 1990) and Broken Ridge (pers. obs.) seem to contradict this latter concept. This discrepancy can best be explained when a high latitude strong seasonal cycle in primary production is taken into account. At times of maximum insolation before the seasonal thermocline build-up (Kennett and Barker, 1990), high levels of nutrients are available for primary producers such as diatoms. Subsequently an increased organic carbon flux will reach the seafloor. This organic matter will preferentially be advantageous for infaunal benthics, because at the same time dissolved oxygen is consumed in the process of organic decay. When the thermocline is developed surface water nutrients will soon be depleted and primary production diminishes. As a consequence the normal equilibrium fauna will re-establish until the next surface bloom. Since a non-laminated sample contains a mixed

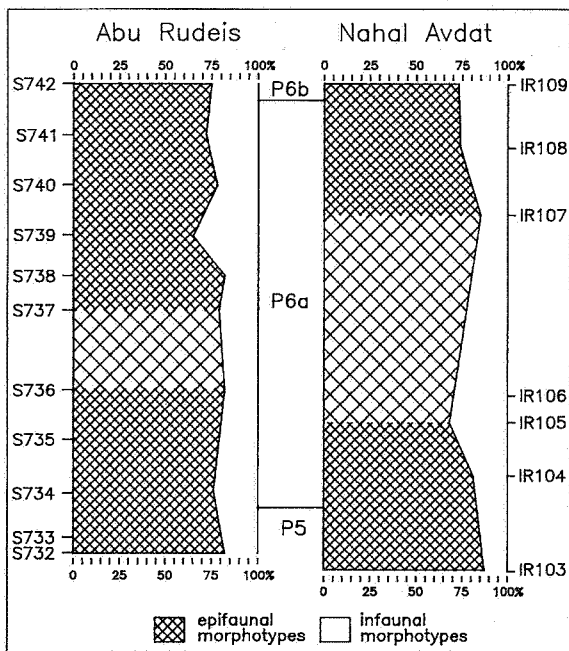


Figure 10. Total abundances grouped according epifaunal and infaunal morphotypes (same criteria as in Thomas, 1990). Wider hatching indicates benthic turnover interval. No dramatic change can be observed in the studied sections.

assemblage of at least a few thousand years, the result will be that infauna is relatively enriched compared with assemblages obtained from low latitude areas where no seasonal bloom occurs. Substantial evidence for (seasonal) high productivity can be found at Broken Ridge site 752 where high amounts of diatoms and radiolarians are preserved (Fourtanier, 1991; pers. obs.). Unfortunately this has not been observed at Maud Rise, which might well be a preservational artifact, because biogenic opal easily dissolves at the seafloor (Broecker and Peng, 1982).

What could have happened to disturb the very stable Paleocene deep-sea benthic foraminiferal composition? Since all well-known late Cenozoic climatic/oceanographic events had only a minor effect on deep-sea benthic foraminifera, a very dramatic but still rather elusive climatic/oceanographic perturbation must have occurred during the late Paleocene.

The various hypotheses and ideas proposed to solve this problem, should at least account for the following:

1. The importance of *Gavelinella beccariiformis* c.s. in the bathyal environment does not diminish up to the moment of its abrupt disappearance; there is no sign of a gradual restriction to southern high latitudes, as has been suggested by Katz and Miller (1991).
2. Most species becoming extinct were VF deep-sea dwellers; the shallow-water MF biofacies was (almost?) not affected.
3. Diversity decrease in the Middle East is much less than in other areas, because of the richness of MF species during the entire time interval.

4. A temporal oxygen deficiency of bottom water of the Tethys-margin can not be deduced by means of benthic morphotype analyses.

5. Immediately after the extinction at least three common MF species migrated from the neritic to the bathyal environment.

Combining this with data available from various sources and areas I conclude that:

1. It seems unlikely that the benthic extinction was directly caused by a decrease in primary production and restricted food supply to the deep-sea (Miller *et al.*, 1987), mainly because the K/P boundary productivity crisis hardly had any impact on approximately the same benthic fauna (Tjalsma and Lohmann, 1983; Thomas, 1990; Nomura, 1991), and because the vertical $\delta^{13}\text{C}$ -gradient does not change (e.g. Stott and Kennett, 1989).

2. Because of $\delta^{13}\text{C}$ trends (Pak *et al.*, 1991) it seems unlikely that WSBW originating at the Tethys margin dominated the oceans and that the disappearance of VF was caused by a cessation in WSBW formation (Nomura, 1991).

3. The currently most likely extinction scenario includes a change from high to low latitude domination of bottomwater formation, thus to an initiation, or a major increase in the influence, of WSBW formation (Miller *et al.*, 1987; Thomas, 1990, 1992).

The last-mentioned scenario would at modern PO_4 nutrient levels and atmospheric oxygen content lead to extensive anoxia (Herbert and Sarmiento, 1991), comparable with the proposed mid-Cretaceous situation (Arthur and Natland, 1979). There are however only few indications of regional dysoxic conditions at the moment of the extinction (Thomas, 1990; pers. obs.). Probably Paleocene atmospheric oxygen content was slightly higher than at present (Berner, 1989) and possibly more importantly, PO_4 levels were much reduced, because of storage in shallow marginal marine deposits (Oberhänsli and Hsü, 1979). Thus anoxic bottomwaters could be much more constrained to locally high productive areas and/or areas very remote from the source area. Since no indications of temporal dysoxic conditions are found in the studied area, a short term global WSBW oxygen deficiency can not be the sole controlling factor for the benthic extinction. Probably another (combination of) watermass property(ies) e.g. temperature and/or salinity must be directly responsible for the extinction of many deep-sea benthic foraminifera.

The ultimate cause for high latitude warming and the reversed poleward deep circulation remains elusive, but could be a sudden pulse of atmospheric CO_2 increase through extensive volcanism related to the opening of the North Atlantic (Thomas and Vahrenkamp, 1992), superimposed on a longer term warming trend. How long this reversed circulation persisted remains

unclear, although Thomas (1990) suggested it to last about 350 Kyr. (the period of prevalence of the oxygen-deficient benthic assemblage). This however has not been noted elsewhere, whereas the reversal to normal circulation should well be visible from the benthic assemblage. In the studied area this can be explained by having a too short post-extinction record of only about 300 Kyr. (fig. 4). Here immigration of newly appearing MF species took place within 50 Kyr. after the extinction. Possibly they were accompanied by earlier extant MF species which temporarily disappeared from an inhospitable bathyal environment but were able to sustain at apparently environmentally more stable neritic depths. More detailed records of both bathyal and neritic deposits in the studied basin will result in a more conclusive viewpoint.

7. CONCLUSIONS

Two Middle East sections contain a continuous upper Paleocene sequence. Direct correlation of planktonic foraminiferal and calcareous nannofossil zonal schemes has resulted in the establishment of the NP9/ NP10 zonal boundary within the top part of Zone P6a. The deep-sea benthic foraminiferal extinction is observed in the middle part of Zone P6a, and thus does not mark the Paleocene/Eocene boundary. Faunal paleobathymetric analyses leads to a proposed paleodepth of 500-700 m for both depositional sites, which were situated in the deeper parts of a NE-SW trending trans-Sinai basin. The benthic foraminiferal assemblages contain a mixture of shallow- and deep-water species, of which several very common, exclusively bathyal/abyssal species became extinct, whereas none of the neritic/bathyal species were affected. Therefore simple diversity drops only 17%. After the extinction event several neritic species known from surrounding areas, extended their depth range into deeper bathyal environments. This study does not conflict with the hypothesis that the major bottom water source area temporarily shifted from high to low latitude, inducing intensified WSBW formation. However, simple WSBW oxygen-deficiency can not be the sole controlling factor of the worldwide extinction.

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