

Benthic foraminifera at the Cretaceous-Tertiary boundary around the Gulf of Mexico

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ABSTRACT

Cretaceous-Tertiary (K-T) boundary sections in northeastern Mexico contain marly formations separated by a controversial clastic unit. Benthic foraminifera in seven sections indicate middle and lower bathyal depths of deposition for the marls, with the exception of the upper bathyal northernmost section. Mixed neritic-bathyal faunas were present in the clastic unit, indicating redeposition in the deep basin by mass-wasting processes resulting from the K-T bolide impact in the Gulf of Mexico. Benthic foraminifera in the Mexican sections, and at other deep-sea locations, were not subject to major extinction at the time of impact, but there were temporary changes in assemblage composition. Benthic faunas indicate well-oxygenated bottom waters and mesotrophic conditions during the late Maastrichtian and increased food supply during the latest Maastrichtian. The food supply decreased drastically just after the K-T boundary, possibly because of the collapse of surface productivity. Cretaceous and early Paleogene benthic foraminifera, however, did not exhibit the benthic-pelagic coupling of present-day faunas, as documented by the lack of significant extinction at the K-T collapse of surface productivity. Much of the food supplied to the benthic faunas along this continental margin might have been refractory material transported from land or shallow coastal regions. The decrease in food supply at the K-T boundary might be associated with the processes of mass wasting, which removed surface, food-rich sediment. Benthic faunas show a staggered pattern of faunal recovery in the lowermost Paleogene, consistent with a staged recovery of the vertical organic flux but also with a gradual buildup of organic matter in the sediment.

Keywords: benthic foraminifera, K-T boundary, paleobathymetry, evolution.

INTRODUCTION

Since Alvarez et al. (1980) proposed that a bolide impact occurred at the Cretaceous-Tertiary (K-T) boundary, this time of mass extinctions has attracted much attention. Documented effects of the impact include the mass extinctions of planktic foraminifera and calcareous nannoplankton, global Ir anomalies, the crater in Chicxulub (Yucatán, Mexico), and the presence of controversial clastic deposits close to the impact crater.

In the latest Maastrichtian and earliest Danian, the northeast Mexican basin received fine-grained clastic material from the rising Laramide orogeny and Sierra Madre Oriental (e.g., Galloway et al., 1991). The K-T boundary in the Tampico-Misantia basin is marked by a controversial clastic deposit intercalated between the hemipelagic marls of the Upper Cretaceous Méndez Formation and the lower Paleogene Velasco Formation (Longoria and Gamper, 1993). An unconformity of variable duration is present above this unit (e.g., Keller et al., 1997; Arz et al., 2001).

The hemipelagic marls have been interpreted as deep-water deposits, as indicated by the low abundance or absence of invertebrate macrofossils and the high abundance of planktic foraminifera (e.g.,

White 1928a, 1928b, 1929; Berggren and Aubert, 1975; van Morkhoven et al., 1986; Longoria and Gamper, 1993). The clastic unit, as well as similar deposits in the Gulf of Mexico (Bralower et al., 1998) and the North Atlantic (Klaus et al., 2000), was interpreted as resulting from mass wasting and deposition in the deep basin at the time of the K-T impact (Bralower et al., 1998; Klaus et al., 2000; Arenillas et al., 2000; Arz et al., 2001; Soria et al., 2001).

In contrast, others suggested that the clastic unit was deposited at outer-shelf to at most upper-slope depths (200–400 m) by gravity flows or turbidity currents in channel fill or fans during a latest Maastrichtian sea-level lowstand (Keller and Stinnesbeck, 1996; Keller et al., 1997). Paleodepth estimates for the Méndez and Velasco Formations are thus crucial for the paleoenvironmental interpretation of the clastic unit. Benthic foraminifera in these sections have not been studied in detail, although they are excellent paleobathymetric markers, as well as indicators of ocean productivity and oxygenation (e.g., van der Zwaan et al., 1999).

At the K-T boundary, benthic foraminifera in upper bathyal settings such as the El Kef section (Tunisia) show disappearances of up to ~50% of species, linked to local low-oxygen conditions just above the boundary (Speijer and van der Zwaan, 1996). At some middle bathyal locations (e.g., Caravaca, Spain) faunas were affected by low-oxygen conditions but recovered within less than 10 k.y. (Cocconi and Galeotti, 1994). Benthic foraminifera from middle bathyal and greater depths show relatively minor net faunal turnover across the K-T boundary (Thomas, 1990; Kaiho, 1995).

The observation of insignificant benthic extinction at a time of mass extinction of planktic fauna appears to be in conflict with the benthic-pelagic coupling in recent deep-sea faunas (e.g., Gooday, 1993); one would expect the collapse of surface-water productivity to have major effects on the benthic faunas (e.g., Zachos and Arthur, 1986; d'Hondt et al., 1998). However, surface-bottom linkages and the dominant supply of food to the benthos may have been different in the Cretaceous-Paleogene oceans (Thomas et al., 1999).

We examined benthic foraminifera in seven Cretaceous-Tertiary sections in northeastern Mexico (Fig. 1), ~1000 km from the Chicxulub crater. Several species of common deep-water benthic foraminifera (including *Clavulinoides amorpha*, *Stensiöina beccariiiformis*, *Nuttallinella florealis*, and *Pullenia coryelli*) were first described from the Velasco Formation (Cushman, 1926; White, 1928b) and were later recognized in material recovered by deep-sea drilling from all major ocean basins (e.g., van Morkhoven et al., 1986). For determinations at the specific level, we compared our material with specimens in White's (1928a, 1928b, 1929) collection in the American Museum of Natural History (New York), and in Cushman's (1926) collection at the Smithsonian Institution (Washington, D.C.).

MATERIAL AND METHODS

We studied 136 samples from the Méndez and Velasco Formations at seven sections (Fig. 1), and we present micropaleontological data for a composite section (Fig. 2), constructed from the La Ceiba and La Lajilla sequences. Samples were collected at 2 cm intervals close

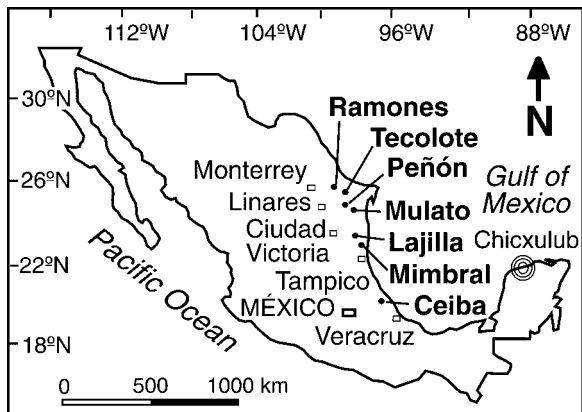


Figure 1. Location of Cretaceous-Tertiary sections around Gulf of Mexico.

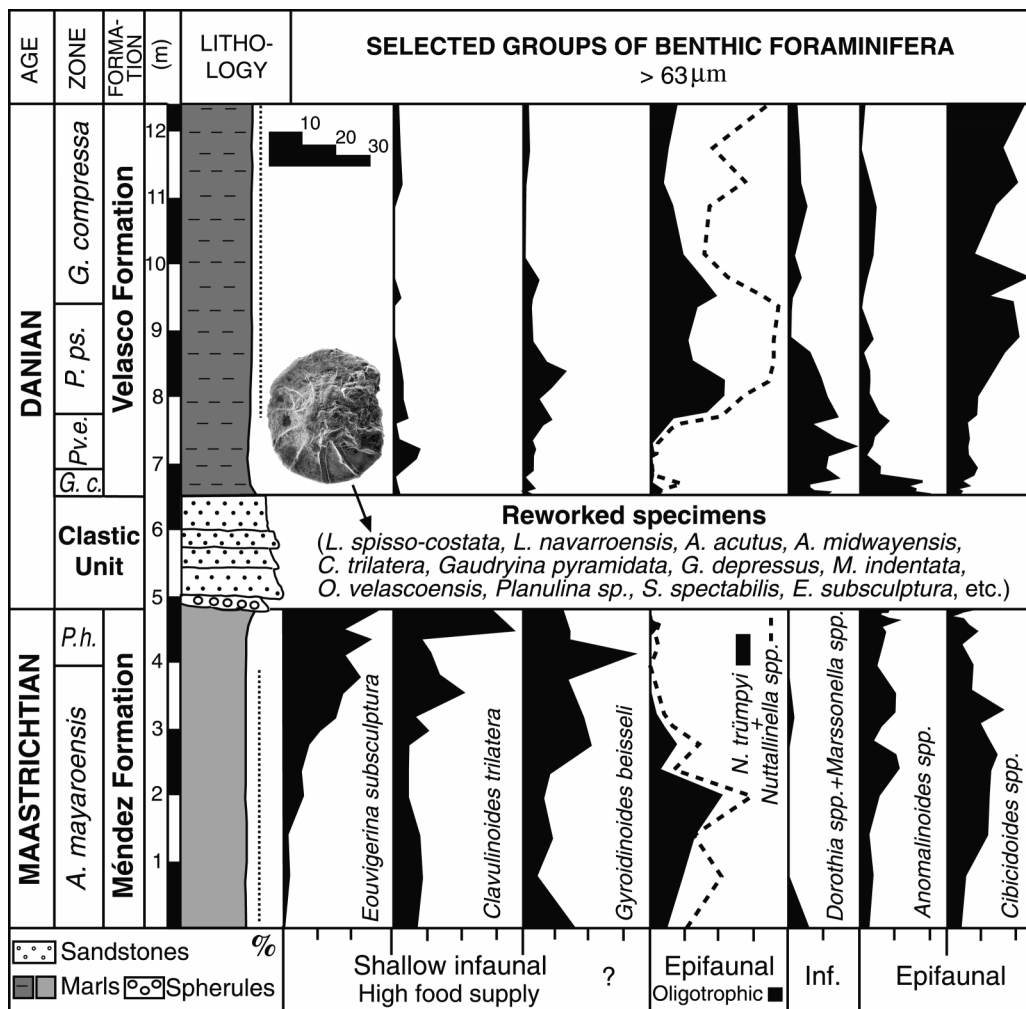
to the K-T boundary clastic unit and at 10 to 30 cm intervals well below and above this unit. All samples were disaggregated in tap water, diluted in H₂O₂, and washed through a 63 μm sieve. After they were dried at 50 °C, we picked at least 300 benthic foraminifera from the >63 μm fraction from each sample. All specimens were mounted on slides, identified to the species level, and counted. Benthic foraminiferal microhabitat preferences, based mainly on morphological features (Corliss, 1985), were explained in terms of nutrient supply to the seafloor (Jorissen et al., 1995), which allowed us to infer the environmental turnover across the K-T boundary.

PALEOBATHYMETRY

Faunas from the Velasco and Méndez Formations are dominated by calcareous taxa; agglutinated species (mainly of *Clavulinoides*) commonly constitute ~25%–30% of the faunas, rarely up to >60%. The species composition is similar to that of the bathyal, mixed agglutinated-calcareous faunas at deep-water locations around the North Atlantic—e.g., in Trinidad (Kaminski et al., 1988). The assemblages are highly diverse, common species including *Bulimina trinitatensis*, *B. velascoensis*, *Cibicoides dayi*, *C. hyphalus*, *Clavulinoides trilatera*, *Eouvierina subsculptura*, *Gyroidinoides beisseli*, *G. depressus*, *G. globosus*, *Marssonella oxycona*, *Nuttallides triumpyi*, *Nuttallinella coronula*, *Nt. florealis*, *Spiroplectammina spectabilis*, and *Stensioina beccariiformis*. Most of these belong to the bathyal to abyssal Velasco fauna (Berggren and Aubert, 1975). Species with an upper depth limit of ~1000 m are most abundant, suggesting that most sections are lower bathyal (van Morkhoven et al., 1986). The high percentage of calcareous and calcareous-agglutinated species (38% to 70%) indicates paleodepths well above the calcite compensation depth (CCD).

Benthic foraminiferal assemblages at El Peñón and El Tecolote contain higher percentages of middle bathyal *E. subsculptura*, *Bolivinoidea draco*, *C. pseudoacutus*, and *Sitella cushmani* (Widmark, 2000). Los Ramones, the northernmost section, contains common *Alabama midwayensis* and lenticulinids, which occur in the neritic to upper bathyal Midway Formation (Berggren and Aubert, 1975). We conclude that paleodepths for both the Méndez and Velasco Formations were between 1000 and 1500 m (the upper part of the lower bathyal zone) for most sections. El Peñón and El Tecolote sections were middle

Figure 2. Faunal turnover of common benthic foraminiferal taxa across K-T boundary. Stratigraphic column is composite section. Vertical dotted line—La Lajilla section; no line—La Ceiba. Biostratigraphy (López-Oliva et al., 1998; Arz et al., 2001) is based on planktic foraminiferal biozones (Molina et al., 1998). *P.h.*—*Plummerita hantkenoides*, *G. c.*—*Guembeltria cretacea*, *Pv.e.*—*Parvularugoglobigerina eugubina*, *P. Ps.*—*Parasubbotina pseudobulloides*.



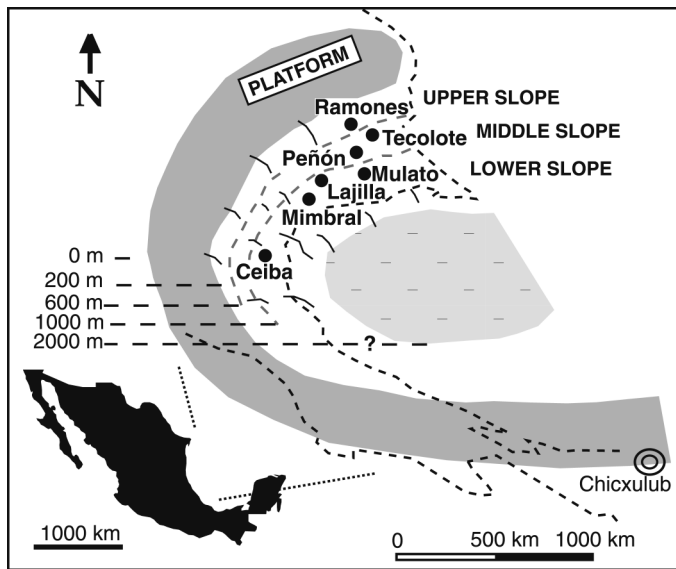


Figure 3. Paleobathymetry of Cretaceous-Tertiary sections around Gulf of Mexico.

bathyal (600–1000 m), and Los Ramones was uppermost middle bathyal to lower upper bathyal (upper bathyal, 200–600 m; Fig. 3).

Various other observations support these depth assignments. The percentage of planktic foraminifera is higher than 80% in all samples (except from the clastic unit), similar to that in assemblages at depths below ~1000 m in the present Gulf of Mexico (van der Zwaan et al., 1990). There is considerable overlap in species between the Mexican sections and the coeval, deep-water faunas in Trinidad (Kaminski et al., 1988). In addition, the benthic foraminifera in the Velasco and Méndez Formations have morphotypes similar to those of benthic foraminifera in recent deep-water environments in the Gulf of Mexico, where there is a large influx of fine terrigenous sediments from the Mississippi. The distribution of *Clavulinoides* species, for instance, resembles that of *Martinotiella occidentalis* in the bathyal modern Gulf of Mexico (Pflum and Frerichs, 1976).

The spherule-bearing layer toward the base of the clastic unit in the lower bathyal sections contains reworked neritic foraminifera, indicative of paleodepths <200 m (e.g., large specimens of *Lenticulina navarroensis* and *L. spisso-costata*), mixed with lower bathyal species (Fig. 2). Material from neritic regions was thus transported into the bathyal zone only during a geologically instantaneous event (e.g., Soria et al., 2001).

FAUNAL TURNOVER AT THE K-T BOUNDARY

The highly diverse late Maastrichtian benthic faunas indicate well-oxygenated bottom waters and mesotrophic surface waters. The high percentage of agglutinated foraminifera (30% to 62%; *Cl. trilatera*, *Gaudryina pyramidata*, *Spiroplectammia israelskyi*, *S. spectabilis*) indicates a considerable input of fine-grained clastic material, similar to the Trinidad faunas (Kaminski et al., 1988). The detrital flux was higher in the southern sections (agglutinated foraminifera up to 62%).

Toward the uppermost Maastrichtian (Fig. 2), infaunal taxa (*Cl. trilatera*, *E. subsculptura*, *G. beisseli*) increased in relative abundance, whereas *N. triümpyi* decreased. The latter species has been suggested to reflect oligotrophic conditions (Nomura, 1995; Thomas et al., 1999). *E. subsculptura* has been related to regions with high abundance of organic matter and reasonably oxygenated sea-bottom waters (Widmark, 2000). These data, together with the general increase in infaunal morphogroups, suggest an increase in the food supply toward the end of the Maastrichtian. We speculate that *G. beisseli* may be a shallow infaunal species, because of its resemblance to *O. umbonatus* (Rath-

burn and Corliss, 1994). If this is indeed the case, the increase of this species toward the uppermost Maastrichtian might be related to an increase in the nutrient flux (Mackensen et al., 1995).

Benthic foraminifera did not undergo a major extinction at the K-T boundary in the Mexican sections. For only two species, *E. subsculptura* and *B. draco*, is the last occurrence close to the K-T boundary in all sections. Changes across the boundary consist of a drastic decrease in infaunal morphogroups, which probably reflects changes in the availability of organic carbon (e.g., Loubère and Fariduddin, 1999). The percentage of infaunal taxa in the lowermost Paleogene is 25% to 45% lower than that in the uppermost Maastrichtian, indicating more oligotrophic conditions (Widmark, 2000). Samples from the basal Velasco Formation contain few foraminifera, which are a mixture of neritic and bathyal taxa with evidence of reworking. Benthic foraminiferal communities recovered through the lowermost Paleogene in several steps (Fig. 2), not all of which are represented in all sections because of the occurrence of unconformities of varying duration.

Just above the unconformity at the base of the Velasco Formation (*G. cretacea* biozone), epifaunal taxa (*A. acutus*, *C. hyphalus*, *St. beccariiiformis*) dominated the assemblages, indicating oligotrophic conditions. *Coryphostoma incrassata* and *C. incrassata gigantea* were abundant within the infaunal community. After this interval, agglutinated species such as *Dorothia bulleta*, *D. pupa*, and *M. oxycona* occupied the infaunal niche, and the epifaunal niche was taken over by *Globorotalites* spp. first, and by *N. triümpyi*, *Nt. coronula*, and *Nt. florealis* later (up to 40%).

The benthic faunas thus document increasing food supplies in the latest Maastrichtian, a sudden decrease at the K-T boundary, and a staggered recovery in food supply in the Paleogene. In the earliest Danian, the percentage of infaunal groups did not reach the high numbers of the latest Maastrichtian, indicating that environmental conditions did not completely recover. We suggest that food supply was the main factor controlling benthic foraminifera after the K-T boundary, because in northeastern Mexico there is no evidence for low-oxygen conditions, as prevailed elsewhere (Speijer and van der Zwaan, 1996; Coccioni and Galeotti, 1994).

What caused the decrease in food supply to the benthic foraminifera in northeastern Mexico at the K-T boundary? The collapse of surface-water productivity could be the cause (e.g., Zachos and Arthur, 1986; d'Hondt et al., 1998), but why would benthic foraminifera worldwide show no significant extinction at the almost total collapse of surface-water productivity if they relied mainly upon a direct flux of organic matter from the surface? The lack of extinction of benthic foraminifera at the collapse of productivity suggests that benthic-pelagic coupling in the warm oceans of the Cretaceous and Paleogene was weak (e.g., Thomas et al., 1999), and species that used fresh phytoplankton may not have existed (Thomas and Gooday, 1996).

We speculate that in the northeastern Mexican sections, as in regions in the modern Gulf of Mexico where clastic material is provided by the Mississippi River, lateral transfer of organic matter from shelf and coastal regions may have contributed substantially to the food eaten by benthic foraminifera, who could use either refractory organic material or bacteria growing on this material (e.g., Loubère and Fariduddin, 1999). The mass wasting at the end of the Cretaceous deposited the clastic unit (consisting of organic-poor sediments) in the lower bathyal region. The influx of these nutrient-impoor sediments, in combination with the collapse of surface-water productivity, may have starved benthic foraminifera.

CONCLUSIONS

Benthic foraminiferal assemblages indicate middle to lower bathyal paleodepths for most northeastern Mexican sections, but the northernmost section was upper bathyal. A mixture of neritic and bathyal

species is present in the clastic unit only, confirming an interpretation of this unit as transported into the deep basin at the K-T boundary bolide impact.

Deep-sea benthic foraminifera in northeastern Mexico, as in other deep-sea sections, show minor net extinction at the K-T boundary, but the faunas changed in species composition. Benthic foraminiferal assemblages indicate mesotrophic conditions during the Maastrichtian and increasing food supply during the latest Maastrichtian. Just after the K-T boundary event, the food supply decreased drastically, followed by a slow and staggered recovery in the Paleogene. This decrease and recovery could be explained by the collapse and recovery of surface productivity as the result of the K-T mass extinction of plankton, in combination with the removal of organic-rich sediments by mass wasting, followed by the deposition of sandy neritic material containing little food. K-T benthic faunas were sheltered from extinction because of their use of sedimentary organic material, rather than fresh phytoplankton.

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