

Environmental changes triggered by the K/T impact event at Coxquihui (Mexico) based on foraminifera

Laia Alegret, Ignacio Arenillas, José Antonio Arz and Eustoquio Molina, Zaragoza

With 4 figures

ALEGRET, L., ARENILLAS, I., ARZ, J. A. & MOLINA, E. (2002): Environmental changes triggered by the K/T impact event at Coxquihui (Mexico) based on foraminifera. – N. Jb. Geol. Paläont. Mh., **2002**: 295–309; Stuttgart.

Abstract: The benthic and planktic foraminifera across the Cretaceous/Tertiary (K/T) boundary at Coxquihui (Mexico) undergo significant changes, which coincide with the K/T boundary. Planktic foraminifera underwent a catastrophic mass extinction at the K/T boundary. Benthic foraminifera in the lower part of the slope did not undergo any major extinctions but their communities were reorganised. Infaunal morphogroups drastically decreased at the K/T boundary reflecting a sudden drop in the food supply to the sea-bottom floor, probably due to the collapse in primary productivity. This drastic change in benthic foraminiferal communities, their staggered recovery during the lowermost Paleogene and the extinction of planktic foraminifera are all compatible with a unique and catastrophic event. A meteoritic impact that triggered a drop in primary productivity, affecting foraminifera from the surface and, less severely, those from deep sea environments, may explain the faunal turnover at the K/T boundary.

Zusammenfassung: Am Übergang von der Kreide zum Tertiär erleiden die benthonischen und planktonischen Foraminiferen im Profil von Coxquihui (Mexiko) einschneidende Veränderungen. Bei den planktonischen Foraminiferen kommt es an der Kreide/Tertiär-Grenze zu einem katastrophalen Massenaussterben. Bei den benthonischen Foraminiferen des unteren Kontinentalhanges findet sich kein entsprechendes Aussterbe-Ereignis, doch werden die Vergesellschaftungen neu geordnet. An der Kreide/Tertiär-Grenze nimmt die Zahl der für Infaunen typischen Morphogruppen drastisch ab. Dies zeigt vermutlich eine durch den Zusammenbruch der primären Produktion verursachte plötzliche Abnahme der Nährstoff-Zufuhr am Meeresboden an. Dieser starke Wechsel in den benthonischen Foraminiferen

Vergesellschaftungen, deren schrittweise Erholung während des frühesten Paleogens und das Massenaussterben der planktonischen Foraminiferen an der Kreide/Tertiär-Grenze lassen sich mit einem einzigen katastrophalen Ereignis erklären. Die Verminderung der primären Produktion durch den Einschlag eines Meteoriten traf die an der Wasseroberfläche lebenden Foraminiferen unmittelbar, während sie sich bei den Tiefsee-Formen abgeschwächt auswirkte.

Introduction

Ever since ALVAREZ et al. (1980) suggested that a meteoritic impact was the main cause of a world-wide mass extinction recorded at the K/T boundary, numerous researchers have focused their attention on this period of Earth's history. Although most paleontological, sedimentological and geochemical data strongly support this hypothesis (e.g. ZACHOS et al., 1989; THOMAS, 1990; COCCIONI et al., 1993; SPEIJER & VAN DER ZWAAN, 1994; PERYT et al., 1997; D'HONDT et al., 1998) some authors continue to suggest that the K/T evidence has multiple causes (e.g. KELLER & STINNESBECK, 1996). K/T sections from around the Gulf of Mexico and adjacent areas are the main points of controversy. These sections consist of Upper Cretaceous and lower Paleogene marly sediments belonging to the Méndez and the Velasco formations, respectively; and a metric-scale clastic unit located between them. Recently, the origin of the K/T clastic unit has been related to the K/T boundary event, resulting from mass wasting and deposition into the deep basin triggered by the K/T impact around the Gulf of Mexico (BOHOR, 1996; BRALOWER et al., 1998; SORIA et al., 2001).

We analysed the Upper Cretaceous and lower Paleogene marly sediments from the Coxquihui section (Mexico) and documented the faunal turnover across the K/T boundary. Whereas planktic foraminiferal mass extinction is widely accepted and documented in sections around the world (e.g. SMIT, 1990; MOLINA et al., 1996, 1998; KAIHO & LAMOLDA, 1999), studies on benthic foraminifera and their response to the K/T event are more scarce, especially in Mexican sections. Benthic foraminifera are closely related to the sea-bottom floor and are generally used as tracers to mark changes in ocean productivity (THOMAS & GOODAY, 1996). Benthic communities are therefore useful to infer environmental changes. Moreover, the integration of data from surface and bottom marine taxa may contribute to the understanding of the K/T event.

The aim of this paper is to demonstrate the environmental changes across the K/T boundary based on foraminifera, which supports the impact theory

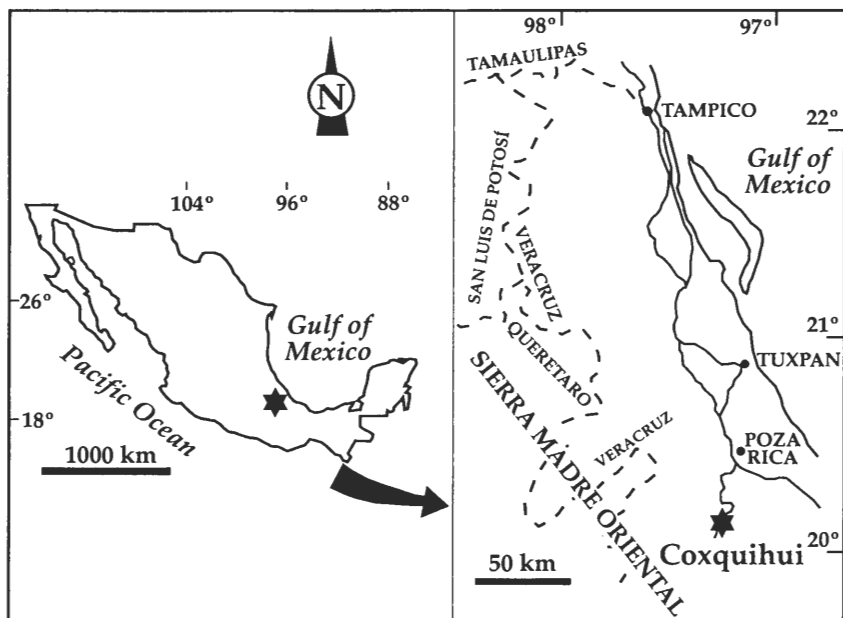


Fig. 1. Geographical location of the Coxquihui section.

as an explanation for faunal and environmental turnovers at the K/T boundary.

Material and methods

We performed a quantitative study of benthic and planktic foraminifera from Upper Cretaceous and Lower Paleogene marly sediments belonging to the Méndez and Velasco formations, respectively, at the Coxquihui section (Central-East Mexico). This section is East of the Coxquihui village (23°07'N, 97°32'W), in the State of Veracruz (Fig. 1). Its stratigraphy was described in SMIT *et al.* (1996) and CEDILLO & GRAJALES (1997). More recently, ARZ *et al.* (2001) reported the sedimentology of the K-T transition sediments and also documented a catastrophic mass extinction of planktic foraminifera at Coxquihui in coincidence with the K/T boundary.

The Méndez Formation at Coxquihui consists of red marls that are intercalated by two centimeter levels of gypsum and bentonites. It is overlain by a metric-scale clastic complex, which is characterized by a 20 cm to 1 m thick spherule-bearing bed containing marly and calcareous boulders (Fig. 2). Similar spherules from other Mexican sections have been reported by several authors as microtektites (SMIT et al., 1996). Higher in the section, towards the top of the clastic unit, we find an 18 cm-thick sandy unit with lenticular geometry and cross-bedding. Finally, the Velasco Formation consists of gray marls that alternate with gray calcareous marls. Both the Méndez and the Velasco Formations were deposited in the lower part of the slope, at a depth of 1000-1500 m (ARZ et al., 2001). These authors suggest an allochthony of the clastic unit, with elements (sand, spherules, foraminifera) from shallow environments that are transported and redeposited along the slope.

We carried out a detailed sampling of both the Méndez and the Velasco Formations. Samples were taken at decimetre-intervals well above and below the clastic unit and at centimetre-intervals close to the complex. All samples were disaggregated in tap water, diluted in H₂O₂ and washed through a 63 µm sieve. After drying at 50°C, we took at least 300 planktic and 300 benthic foraminifera from the > 63 µm fraction of each sample. All specimens were mounted on slides, identified to the species level and counted for quantitative studies. The genus richness (number of genera), the α -Fisher index and the H(s) Shannon-Weaver index were calculated in order to detect possible changes in diversity across the K-T transition (Fig. 2). All taxa were allocated into morphogroups, largely following CORLISS (1985), JONES & CHARNOCK (1985) and CORLISS & CHEN (1988). An infaunal or epifaunal mode of life was also attributed to each morphogroup, mainly according to these authors. Nevertheless, the species *Gyroidinoides beisseli*, which these authors would include into the epifaunal group, was considered to be infaunal, following ALEGRET et al. (2001). The most abundant morphogroups and their inferred microhabitat preferences at Coxquihui are shown in Fig. 3.

Planktic foraminiferal biozonation and assemblages turnovers

Following the biozonation proposed by MOLINA et al. (1996), ARZ et al. (2001) identified the *Plummerita hantkeninoides* biozone in the Upper Cretaceous, and the *Guembelitra cretacea*, *Parvularugoglobigerina eugubina* and *Parasubbotina pseudobulloides* biozones in the Lower Paleo-

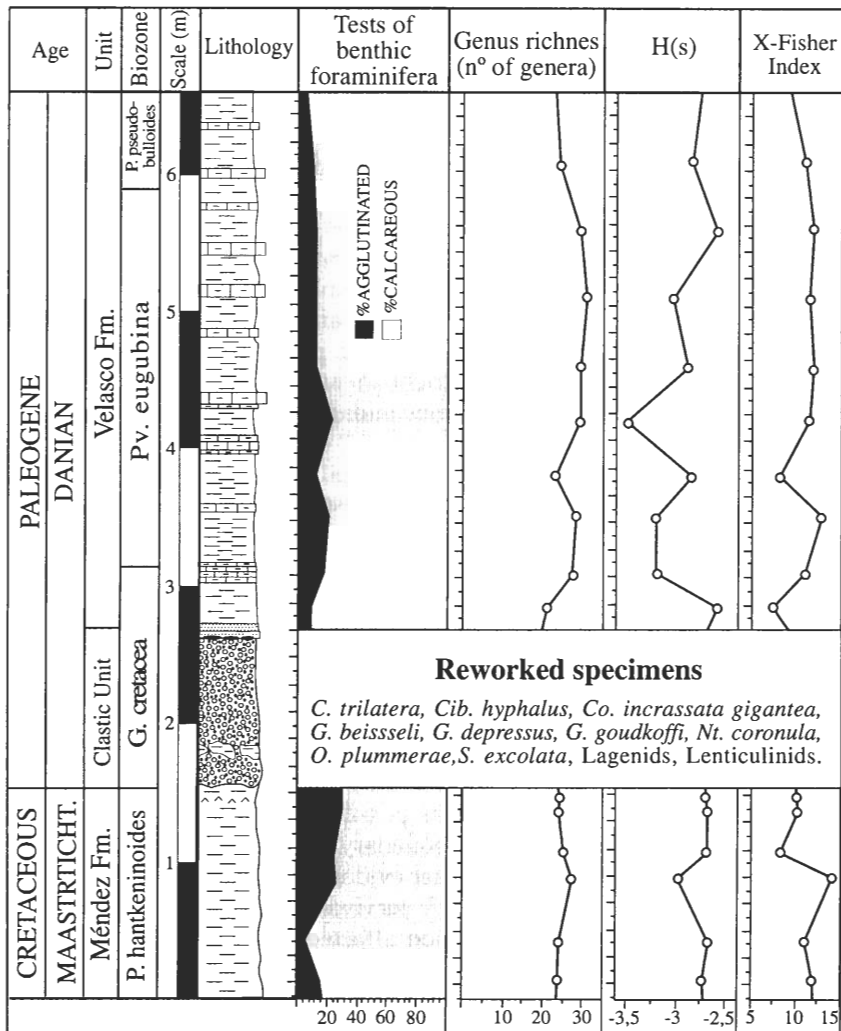


Fig. 2. Percentages of agglutinated and calcareous benthic foraminifera, genus richness, H (s) Shannon-Weaver index and α -Fisher index across the K/T boundary at Coxquihui.

gene. According to the definition of the K/T boundary, these authors place it at the base of the clastic unit, i. e., just under the first appearance of impact markers. A short stratigraphical lacune comprising the lower part of the *G. cretacea* Biozone has been biostratigraphically identified between the clastic unit and the Velasco Fm.

Uppermost Maastrichtian planktic foraminiferal assemblages at Coxquihui were diverse and dominated by simple heterohelicids species, mainly *Heterohelix*, and other cosmopolitan groups. Large, complex, tropical-subtropical species of globotruncanids (*Globotruncana*, *Globotruncanita*, *Abathomphalus*, *Contusotruncana*) and complex heterohelicids (*Racemi-guembelina*, *Planoglobulina* and *Gublerina*) are relatively numerous in the Maastrichtian assemblages. The quantitative planktic foraminiferal index suggests that the uppermost Maastrichtian assemblages are quite stable, except for a slight increase in globotruncanids in the terminal *P. hantkeninoides* Biozone (see ARZ et al., 2001).

A drastic reduction of planktic foraminiferal diversity is found above the clastic unit (ARZ et al., 2001), due to the catastrophic mass extinction at the K/T boundary (SMIT, 1982, 1990; MOLINA et al., 1998). At Coxquihui, the planktic foraminiferal assemblages below and above the Clastic Unit are different. The first Danian species belong to typical assemblages of the upper part of the *G. cretacea* Biozone, with abundant *Parvularugoglobigerina* and *Globoconusa*. Only some smaller, cosmopolitan Cretaceous planktic foraminiferal species - *Guembelitra cretacea*, *Heterohelix globulosa*, *H. navarroensis*, *H. planata*, *Hedbergella holmdelensis*, *H. monmouthensis*, *Globigerinelloides yaucoensis*, *G. volutus* and *G. prairiehillensis* - have been identified in the lowermost Danian, but only *G. cretacea* is certainly a survivor. If we count all these species as possible survivors, 84,7 % of them seem to have gone extinct at the K/T boundary at Coxquihui, coinciding with the base of the clastic unit with impact evidence. If we discount the Cretaceous planktic species whose post-K/T survival is doubtful or unproved (all except *G. cretacea*), the K/T extinction affected 98,3 % of the Cretaceous planktic species at Coxquihui.

Benthic foraminiferal turnover across the K/T boundary

Both benthic and planktic foraminifera were affected by the K/T boundary event, but with different responses. Whereas planktic foraminiferal communities were affected by a catastrophic mass extinction in coincidence with the K/T boundary, no major extinction events are reported for benthic foraminifera (e. g. BIGNOT, 1984; THOMAS, 1990; SPEIJER & VAN DER ZWAAN,

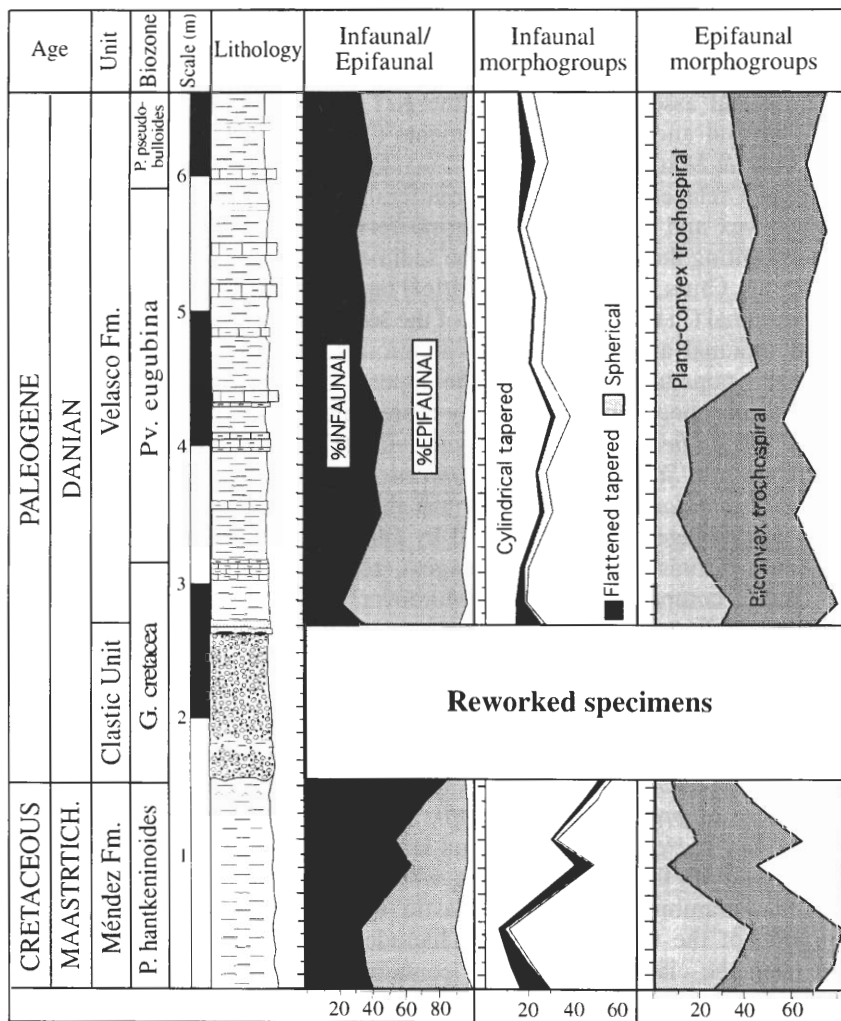


Fig. 3. Infaunal and epifaunal morphogroups at Coxquihui and their evolution across the K/T boundary.

1994; ARENILLAS et al., 2000). The main change experienced by benthic foraminiferal assemblages was a reorganization of the community structure. Moreover, the extinction rate and the degree of restructuring of benthic foraminiferal assemblages across the K/T boundary were less intense in deep, bathyal and abyssal environments (THOMAS, 1990; NOMURA, 1991; WIDMARK & MALMGREN, 1992).

Upper Cretaceous benthic foraminiferal assemblages are dominated by planoconvex and biconvex trochospiral forms with an epifaunal mode of life -inhabiting the upper 2 cm of the sediment- (JONES & CHARNOCK, 1985; CORLISS & CHEN, 1988), and cylindrical tapered forms, which are supposed to be infaunal (in the deepest layers of the sediment). Thus, assemblages have mixed infaunal and epifaunal morphogroups, although the percentage of infaunal groups increases toward the uppermost *P. hantkeninoides* Biozone. Infaunal morphogroups were mainly represented by *Clavulinoides trilatera*, *Gyroidinoides beisseli* and *laevidentalinids* (Fig. 4). Among the epifaunal morphogroups, *Stensioeina beccariiiformis*, *G. depressus*, *Nuttallides truempyi* and *Osangularia* spp. were the most abundant taxa (Fig. 5). Upper Cretaceous assemblages were dominated by calcareous taxa (up to 70-75 % of the benthic foraminiferal assemblages), reflecting deposition well above the calcite compensation depth. Moreover, the presence of 25-30 % of agglutinated foraminifers reflects a clastic input towards the deep basin.

No major extinctions of benthic foraminifera were recorded at the K/T boundary. Diversity indexes, such as α -Fisher, H (s) and the genus richness do not change significantly across the K/T boundary (Fig. 2) except for a slight decrease after the boundary. Scarce, reworked specimens, namely *C. trilatera*, *Cibicidoides hyphalus*, *Coryphostoma incrassata gigantea*, *G. beisseli*, *G. depressus*, *G. goudkoffi*, *Nuttalinella coronula*, *Osangularia plummerae*, *S. excolata*, lagenids and lenticulinids, were found in the clastic unit mixed with the microspherules, which are interpreted as altered microtektites. Foraminifers from the clastic unit usually show different preservation of the tests. We did not include quantitative data on foraminifera from the clastic unit since it contains allochthonous, shallower fauna transported and mixed with deep-water fauna.

In contrast to the Upper Cretaceous assemblages, benthic foraminiferal assemblages from the lowermost Danian (*G. cretacea* Biozone) are dominated by epifaunal morphogroups, mainly *Osangularia* spp. and *Cb. hyphalus*, and lower percentages of *Cb. velascoensis*, *S. beccariiiformis* and *Gyroidinoides* spp. (Fig. 5). Minor percentages of *G. beisseli* and *Gaudryina pyramidata* are recorded at the base of the Velasco Formation; *C. trilatera* also reappears toward the basal part.

A slight recovery of infaunal morphogroups is recognised toward the upper *G. cretacea* and lower *P. eugubina* biozones, where we observed the

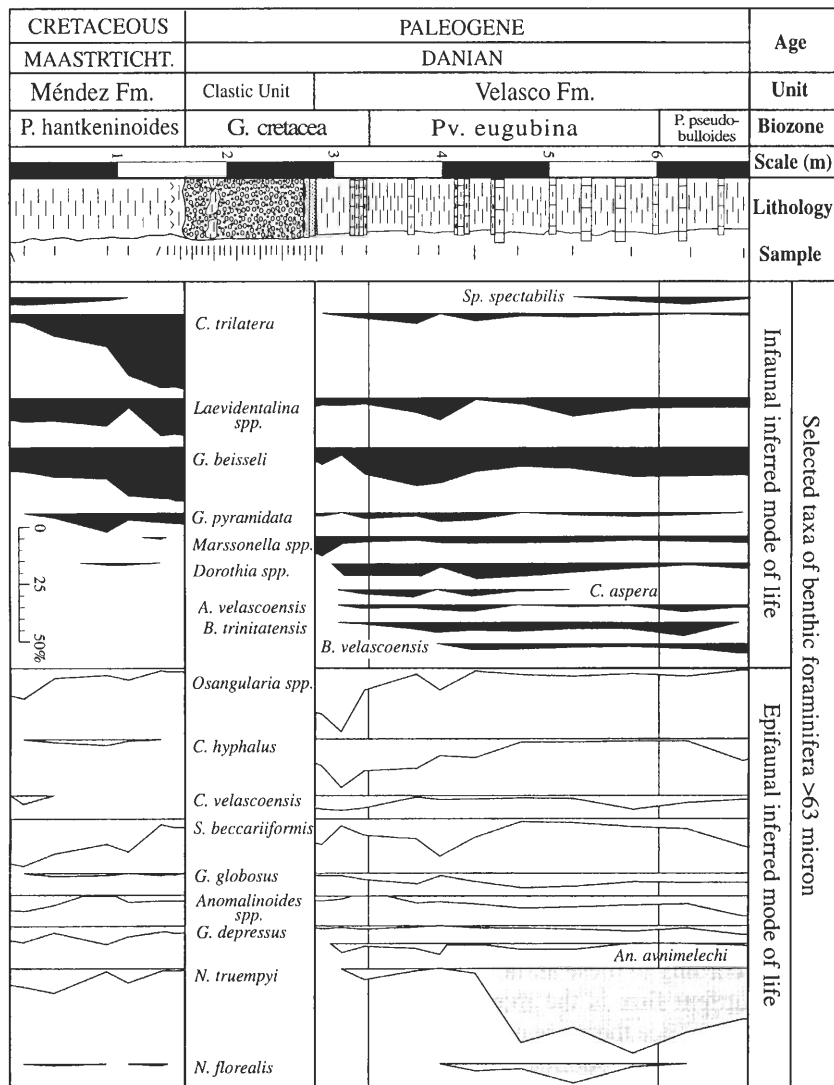


Fig. 4. Faunal turnover of selected infaunal and epifaunal benthic foraminifera across the K/T boundary at Coxquihui.

first appearance of new infaunal species, such as *C. aspera*, *Aragonia velascoensis*, *Bulimina trinitatensis* (Fig. 4). Nevertheless, assemblages are still dominated by epifaunal morphogroups. A slight increase in diversity is also recorded during this period (Fig. 2). Toward the middle part of the *Pv. eugubina* Biozone, the epifaunal *N. truempyi* is the most abundant species along with the presence of infaunal *B. velascoensis* and the reappearance of *S. spectabilis*. Toward the top of the section (*P. pseudobulloides* Biozone), epifaunal morphogroups dominate the assemblages (60-67 %), and the percentages of agglutinated foraminifera are low (5,7-12 %).

Environmental turnover: A staggered pattern of recovery

Upper Cretaceous benthic foraminiferal assemblages are composed of mixed infaunal and epifaunal morphogroups. The percentage of infaunal groups progressively increases toward the uppermost *P. hantkeninoides* Biozone, making up 65-85 % of the assemblages. This general trend may be due to an increase in the food supply toward the sea-bottom floor (JORISSEN et al., 1995) in the uppermost Maastrichtian. Such an extraordinary nutrient flux is also found in other Mexican K/T sections (ALEGRET & MOLINA, 2000; ALEGRET et al., in press), and might be the result of changes in oceanic currents. The percentage of agglutinated foraminifera indicates a considerable input of fine-grained sediment toward the lower part of the slope.

No extinctions or significant changes in diversity indexes of benthic foraminifera were observed at Coxquihui in coincidence with the K/T boundary. The most important change across the boundary was a drastic reorganisation of benthic foraminiferal communities. The percentage of infaunal morphogroups decreased by 50 %. Thus, lowermost Paleogene assemblages were dominated by epifaunal morphogroups, mainly biconvex and plano-convex trochospiral forms. This pattern can be explained in terms of oxygenation and food supply toward the sea-bottom floor (JORISSEN et al., 1995). According to these authors, under a normal oxygenation of the bottom waters, nutrient flux is the most important parameter determining benthic assemblages. Since there are no markers of oxygen depleted bottom waters at the time of the K/T boundary at Coxquihui, we propose that there was a drastic decrease in the food supply toward the sea-bottom floor, which led to reorganised benthic communities. Infaunal groups suffered from starvation, whereas epifaunal species on sediment surface were more efficient in taking the scarce food particles of the sea-bottom floor. This drop in nutrient flux has been reported in other Mexican sections (ALEGRET & MOLINA, 2000; ALEGRET et al., 2001) and also from K/T sections all over the world (THOMAS, 1990; KUHN & KAMINSKI, 1993; PERYT et al., 1997).

According to several authors (ZACHOS et al., 1989; D'HONDT et al., 1998, KUHNT & KAMINSKI, 1993), this generalised drop in the food supply might be related to a collapse in the primary productivity in surface waters, which was nearly instantaneous with the K/T event. A negative excursion of $\delta^{13}\text{C}$ at the K/T boundary has been observed world-wide (SMIT, 1982, ZACHOS et al., 1989; KAIHO et al., 1999), implying a dramatic reduction in primary productivity. The period with decreased productivity and subsequent reduced zoo-plankton activity is termed the "Strangelove Ocean" and "Respiring Ocean" respectively by HSÜ & MCKENZIE (1985). The drastic reduction of the carbon-isotope gradient signified a breakdown in the photosynthesis/respiration cycle, causing mass mortality and a drastic reduction of plankton production (HOLLANDER et al., 1993), including a catastrophic planktic foraminiferal mass extinction (SMIT, 1982; MOLINA et al., 1998). The ceasing of photosynthesis and severe disruption of the food chain were caused by a sudden atmospheric darkening and a global climatic cooling -"impact winter"- due to K/T impact-generated dust in the atmosphere (MILNE & MCKAY, 1982). The most significant benthic foraminiferal turnovers agree with these paleoceanographic and climatic changes.

A staggered pattern of recovery of benthic foraminiferal assemblages is observed after the K/T boundary at Coxquihui. In the lowermost Paleogene sample (*G. cretacea* Biozone), infaunal communities appear decimated and reflect oligotrophic conditions at the sea-bottom floor. Afterwards, during the upper *G. cretacea* and the lower *Pv. eugubina* biozones, the abundance of infaunal groups slightly increases but not as high as in the uppermost Cretaceous. In the middle part of the *Pv. eugubina* Biozone, *Nuttallides truempyi* dominates among epifaunal benthic foraminifers. This species indicates oligotrophic conditions (NOMURA, 1995; THOMAS et al., 1999). Its abundance within the upper *Pv. eugubina* Biozone suggests an incomplete recovery of primary productivity by that time. The slight decrease in the abundance of *N. truempyi* in the lowermost *P. pseudobulloides* Biozone might indicate the beginning of the food web recovery.

Conclusions

Benthic foraminiferal assemblages at Coxquihui reflected normal environmental conditions with an increasing food supply toward the sea-bottom floor in the uppermost Maastrichtian. There were enough food particles on the sea-bottom floor to sustain both infaunal and epifaunal communities. These mesotrophic conditions were interrupted by the K/T boundary event. The sudden catastrophic mass extinction of planktic foraminifera and the

restructuring of benthic foraminiferal assemblages in coincidence with the K/T boundary are recorded at Coxquihui. These events seem to be inter-related and have the same primary cause. The death of the marine plankton would cease primary productivity. Scarce food particles in the deep basin were used by epifaunal species living close to the surface of the sediment. Since the food was consumed at the sediment surface, little was left for infaunal species who starved after the K/T boundary. A staggered pattern of recovery is recorded at Coxquihui. This faunal turnover was probably triggered by the collapse of the food web (and primary productivity) caused by the K/T boundary impact.

Acknowledgements

We thank Morris Villarroel (Ph.D. in Biology, McGill University, Canada) for correcting the English. This study was funded by the DGES project PB97-1016.

References

- ALEGRET, L. & MOLINA, E. (2000): Evolución paleoecológica de las asociaciones de foraminíferos bentónicos durante el tránsito Cretácico/Terciario en La Ceiba, México. – *Geotemas*, **1** (2): 327-330.
- ALEGRET, L., MOLINA, E. & THOMAS, E. (2001): Benthic foraminifera at the Cretaceous/Tertiary boundary around the Gulf of Mexico. – *Geology*, **29**: 891-894.
- ALVAREZ, A.L., ALVAREZ, W., ASARO, F. & MICHEL, H. V. (1980): Extraterrestrial cause of the Cretaceous-Tertiary extinction. – *Science*, **208**: 1095-1108.
- ARENILLAS, I., ALEGRET, L., ARZ, J. A. & MOLINA, E. (2000): Foraminíferos planctónicos y bentónicos del límite Cretácico/Terciario de Aïn Settara, Tunicia: dos patrones de extinción diferentes y una misma causa. – *Geotemas*, **1** (2): 331-334.
- ARZ, J. A., ALEGRET, L., ARENILLAS, I., LIESA, C. L., MOLINA, E. & SORIA, A. R. (2001): Extinción de foraminíferos en el límite Cretácico/Terciario de Coxquihui (México) y su relación con las evidencias de impacto. – *Rev. Esp. Micropal.*, **33** (2): 221-236.
- BIGNOT, G. (1984): Les foraminifères benthiques n'ont pas subi de crise majeure à l'extrême fin du Crétacé. – In: *Le passage Mésozoïque-Cénozoïque; point de vue paléontologique.* – *Bulletin de la Section des Sciences*, **6**: 27-55.
- BOHOR, B. F. (1996): A sediment gravity flow hypothesis for siliciclastic units at the K/T boundary, northeastern Mexico – In: RYDER, G., FASTOVSKY, D. & GARTNER, S. (Eds.): *The Cretaceous-Tertiary event and other catastrophes in Earth history.* – *Geol. Soc. America Spec. Paper* **307**: 183-196.
- BRALOWER, T. J., PAULL, C. K. & LECKIE, R. M. (1998): The Cretaceous-Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sediment gravity flows. – *Geology*, **26**: 331-334.

- CEDILLO, E. & GRAJALES-NICHIMURA, J. M. (1997): Las rocas de impacto del cráter Chicxulub y el límite Cretácico-Terciario en México y áreas vecinas de America del Norte y el Caribe. – In: CARREÑO, A. L. and MONTELLANO-BALLESTEROS, M. (Eds.): Extinción masiva del límite Cretácico-Terciario: mitos y realidades, **4**: 147-164. (Unión Geofísica Mexicana).
- COCCIONI, R., FABBRUCCI, L. & GALEOTTI, S. (1993): Terminal Cretaceous deep-water benthic foraminiferal decimation, survivorship and recovery at Caravaca (SE Spain).- *Paleopelagos*, **3**: 3-24.
- CORLISS, B. H. (1985): Microhabitats of benthic foraminifera within deep-sea sediments. – *Nature*, **314**: 435-438.
- CORLISS, B. H. & CHEN, C. (1988): Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications. – *Geology*, **16**: 716-719.
- D'HONDT, S., DONAGHAY, P., ZACHOS, J. C., LUTTENBERG, D. & LINDINGER, M. (1998): Organic Carbon Fluxes and Ecological Recovery from the Cretaceous-Tertiary Mass Extinction. – *Science*, **282**: 276-279.
- HOLLANDER, D. J., MCKENZIE, J. A. & HSÜ, K. J. (1993): Carbon isotope evidence for unusual plankton blooms and fluctuations of the surface water CO₂ in "Strangelove Ocean" after terminal Cretaceous event. – *Palaeogeogr., Palaeoclimat., Palaeoecol.*, **104**: 229-237.
- HSÜ, K. J. & MCKENZIE, J. (1985): A "Strangelove" ocean in the earliest Tertiary. In BROECKER, V.S. & SUNDSQUIST, T. (Eds.): *The carbon cycle an atmospheric CO₂: Natural variation Archian to Present*, American Geophysic Union Monography, **32**: 487-492.
- JONES, R. W. & CHARNOCK, M. A. (1985): "Morphogroups" of agglutinating foraminifera. Their life positions and feeding habits and potential applicability in (paleo)ecological studies. – *Revue Paléobiol.*, **4**: 311-320.
- JORISSEN, J. J., DE STIGTER, H. C. & WIDMARK, J. G. V. (1995): A conceptual model explaining benthic foraminiferal microhabitats. – *Mar. Micropaleont.*, **26**: 3-15.
- KAIHO, K. & LAMOLDA, M. (1999): Catastrophic extinction of planktonic foraminifera at the Cretaceous-Tertiary boundary evidenced by stable isotopes and foraminiferal abundance at Caravaca, Spain. – *Geology*, **27** (4): 355-358.
- KAIHO, K., KAJIWARA, Y., TAZAKI, K., UESHIMA, M., TAKEDA, N., KAWAHATA, H., ARINOBU, T., ISHIWATARI, R., HIRAI, A. & LAMOLDA, M. A. (1999): Oceanic primary productivity and dissolved oxygen levels at the Cretaceous/Tertiary boundary: Their decrease, subsequent warming, and recovery. – *Paleoceanography*, **14**: 511-524.
- KELLER, G. & STINNESBECK, W. (1996): Sea-level changes, clastic deposits, and mega-tsunamis across the Cretaceous-Tertiary boundary. – In: MACLEOD, N. & KELLER, P. (Eds.): *Cretaceous-Tertiary Mass Extinctions: biotic and environmental crises*: 415-449. New York-London, (W. W. Norton and Company).
- KUHNT, W. & KAMINSKI, A. (1993): Changes in the community structure of deep water agglutinated foraminifers across the K/T boundary in the Basque Basin (northern Spain). – *Rev. Esp. Micropal.*, **25**: 57-92.
- MILNE, D. H. & MCKAY, C. P. (1982): Response of marine plankton communities to a global atmospheric darkening. – *Geol. Soc. America Spec. Paper*, **190**: 297-303.

- MOLINA, E., ARENILLAS, I. & ARZ, J. A. (1996): The Cretaceous/Tertiary boundary mass extinction in planktic foraminifera at Agost, Spain. – *Rev. Micropaléontologie*, **39**: 225-243.
- (1998): Mass extinction in planktic foraminifera at the Cretaceous / Tertiary boundary in subtropical and temperate latitudes. – *Bulletin Soc. Géol. France*, **169** (3): 351-363.
- NOMURA, R. (1991): Paleoceanography of Upper Maestrichtian to Eocene benthic foraminiferal assemblages at sites 752, 753 and 754, Eastern Indian Ocean. – *Proceedings of the ODP, Scientific Results* **121**: 3-29.
- (1995): Paleogene to Neogene deep-sea paleoceanography in the eastern Indian Ocean: Benthic foraminifera from ODP Sites 747, 757 and 758. – *Micro-paleontology*, **41**: 251-290.
- PERYT, D., LAHODYNSKY, R. & DURAKIEWICZ, T. (1997): Deep-water agglutinated foraminiferal changes and stable isotope profiles across the Cretaceous-Paleogene boundary in the Rotwandgraben section, Eastern Alps (Austria). – *Palaeogeogr., Palaeoclimat., Palaeoecol.*, **132**: 287-307.
- SMIT, J. (1982): Extinction and evolution of planktonic foraminifera after a major impact at the Cretaceous/Tertiary boundary. – *Geol. Soc. America Spec. Paper* **190**: 329-352.
- (1990): Meteorite impact, extinctions and the Cretaceous-Tertiary boundary. – *Géologie en Mijnbouw*, **69**: 187-204.
- SMIT, J., ROEP, TH. B., ALVAREZ, W., MONTANARI, A., CLAEYS, P., GRAJALESNISHIMURA, J. M. & BERMUDEZ, J. (1996): Coarse-grained, clastic sandstone complex at the Cretaceous/Tertiary boundary around the Gulf of Mexico: Deposition by tsunami waves induced by the Chicxulub impact?. – In: RYDER, G., FASTOVSKY, D. & GARTNER, S. (Eds.): *The Cretaceous-Tertiary Event and Other Catastrophes in Earth History: Boulder, Colorado, Geol. Soc. America Spec. Paper* **307**: 151-182.
- SORIA, A. R., LIESA, C., MATA, M. P., ARZ, J. A., ALEGRET, L., ARENILLAS, I. & MELÉNDEZ, A. (2001): Slumping and a sandbar deposit at the K/T boundary in the El Tecolote section (northeastern Mexico): An impact-induced sediment gravity flow. – *Geology*, **29**: 231-234.
- SPEIJER, R. P. & VAN DER ZWAAN, G. J. (1994): Extinction and survivorship patterns in southern Tethyan benthic foraminiferal assemblages across the Cretaceous/Paleogene boundary. – In: (R. P. SPEIJER, Ed.): *Extinction and recovery patterns in benthic foraminiferal paleocommunities across the Cretaceous/Paleogene and Paleocene/Eocene boundaries*. – *Geologica Ultraiectina*, **124**: 19-64.
- THOMAS, E. (1990): Late Cretaceous through Neogene deep-sea benthic foraminifera (Maud Rise, Weddell Sea, Antarctica). – In: BARKER, P. F., KENNETT, J. P. et al., (Eds.): *Proceedings ODP, Scientific Results*, **113B**: 751-594.
- THOMAS, E. & GOODAY, A. J. (1996): Cenozoic deep-sea benthic foraminifera: Tracers for changes in oceanic productivity?. – *Geology*, **4**: 355-358.
- THOMAS, E., ZACHOS, J. C. & BRALOWER, T. J. (1999): Deep-sea environments on a warm Earth: latest Paleocene-early Eocene. – In: HUBER, B. T. et al. (Eds.): *Warm climates in Earth history: 132-160*. Cambridge (Cambridge University Press).

- WIDMARK, J. G. W. & MALMGREN, B. (1992): Benthic foraminiferal changes across the Cretaceous-Tertiary boundary in the deep-sea; DSDP sites 525, 527, and 465. – *Journ. Foraminiferal Res.*, **22**: 1-113.
- ZACHOS, J. C., ARTHUR, M. A. & DEAN, W. E. (1989): Geochemical evidence for suppression of pelagic marine productivity at the Cretaceous/Tertiary boundary. – *Nature*, **337**: 61-64.

Bei der Tübinger Schifffahrt eingegangen am 5. Juni 2001.

Zum Druck angenommen am 20. Dezember 2001.

Address of the authors:

Dr. LAIA ALEGRET, Dr. IGNACIO ARENILLAS, Dr. JOSÉ ANTONIO ARZ, Prof. Dr. EUSTOQUIO MOLINA, Departamento de Ciencias de la Tierra, Universidad de Zaragoza, E-50009 Zaragoza, Spain; laia@posta.unizar.es.