Paleoenvironmental Recovery After the Cretaceous/ Paleogene Boundary Crisis: Evidence From the Marine Bidart Section (SW France)

LAIA ALEGRET

Department of Earth Sciences, University College London, London WC1E 6BT, United Kingdom, E-mail: laia@unizar.es

MICHAEL A. KAMINSKI

Department of Earth Sciences, University College London, London WC1E 6BT, United Kingdom

EUSTOQUIO MOLINA

Departamento de Ciencias de la Tierra, Facultad de Ciencias, Universidad de Zaragoza. 50009-Zaragoza, Spain

The study of Upper Cretaceous and Lower Paleogene benthic foraminifera from the Bidart section (SW France) provides detailed data on the paleobathymetry as well as paleoenvironmental conditions across the Cretaceous/Paleogene (K/Pg) boundary. A quantitative analysis of benthic foraminiferal assemblages from the Upper Maastrichtian Abathomphalus mayaroensis *Biozone and the Danian* Guembelitria cretacea*,* Parvularugoglobigerina eugubina*, and* Parasubbotina pseudobulloides *Biozones was performed. Benthic foraminifera indicate that the upper Maastrichtian and lower Danian sediments at Bidart were deposited in the upper–middle part of the slope.*

Benthic foraminiferal assemblages indicate mesotrophic conditions during the late Maastrichtian and a strong decrease in the food supply to the sea floor coincident with the K/Pg boundary. This change in the trophic regime was related to the collapse of the food web triggered by the mass extinction of calcareous primary producers. Benthic assemblages in the lower Danian are strongly dominated by few species, and suggest that primary productivity was dominated by blooms of non-calcareous primary producers, creating a stressful environment for the benthic fauna. The faunal turnover, together with the geochemical evidence, is compatible with an asteroid impact scenario. Benthic foraminiferal assemblages suggest that primary productivity had not completely recovered more than 200 kyr after the K/Pg boundary event.

INTRODUCTION

The Cretaceous/Paleogene (K/Pg) boundary marks one of the major mass extinctions in Earth's history. Most authors now accept that a large meteorite impacted the Yucatan Peninsula in Mexico (Alvarez et al., 1980; Smit and Hertogen, 1980; Hildebrand et al., 1991) and triggered the catastrophic mass extinction of calcareous plankton (e.g., Luterbacher and Premoli-Silva, 1964; Smit, 1982, 1990; Molina et al., 1998), as well as an anomalous enrichment in Ir and other extraterrestrial impact evidence, such as microspherules (interpreted as altered microtektites) and shocked quartz grains in the boundary sediments globally

(Alvarez et al., 1980; Smit and Hertogen, 1980; Smit and ten Kate, 1982; Sharpton et al., 1992). Furthermore, $\delta^{13}C$ and $\delta^{18}O$ values in bulk sediment and in tests of benthic and planktic foraminifera show abrupt changes just after the K/Pg extinction (Zachos and Arthur, 1986; Kaminski and Malmgren, 1989; Kaiho et al., 1999), and reflect important environmental changes that occurred immediately after the impact. Nevertheless, there are still some researchers who do not support a catastrophic mass extinction model (Keller, 1989 a, b; Keller et al., 1995; Abramovich and Keller, 2002), but an extended pattern of extinction generated by multiple causes that may be due to the Signor-Lipps effect and reworking processes affecting microfossils in the sediments immediately below and above the K/Pg boundary (Huber et al., 2002; Soria et al., 2001, Molina et al., 2002).

Whereas planktic foraminifera suffered a catastrophic mass extinction coincident with the K/Pg boundary (e.g., Molina et al., 1998), benthic foraminifera do not show significant extinctions, as reviewed by Culver (2003). Deep-sea benthic foraminifera show drastic, temporal changes in their community structure coincident with the K/Pg boundary, followed by a gradual, staggered pattern of recovery across the early Danian (see review by Culver, 2003). These temporary changes in benthic foraminiferal assemblages have been interpreted as resulting from the collapse of the pelagic food web and the subsequent drop in food supply to the benthos (e.g., Kuhnt and Kaminski, 1993; Thomas, 1990a, b; Alegret et al., 2001, 2003; Culver, 2003).

The Bidart section (southwestern France, Fig. 1) is considered as one of the most complete K/Pg boundary sections in southwestern Europe (Seyve, 1990; Haslett, 1994). Nevertheless, the paleoenvironmental turnover across the K/Pg boundary in this area remains unclear, and benthic foraminifera from Bidart have not been studied previously. Kuhnt and Kaminski (1993) analyzed the agglutinated benthic foraminiferal changes in the nearby Zumaya and Sopelana sections (Basque Basin, Northern Spain), and concluded that deep-water agglutinated foraminiferal turnover indicates a drastic decrease in surface productivity and a collapse of the food-web coincident with the K/Pg boundary. Apart from that study, no detailed analyses on benthic foraminifera have been performed in
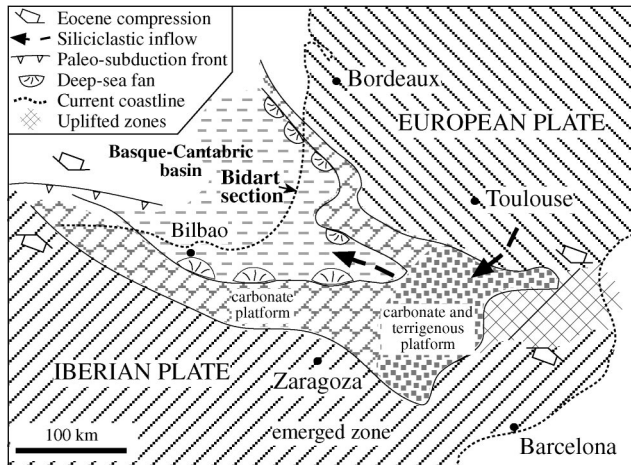
FIGURE 1—Paleogeographical reconstruction of the Pyrenean domain during the Paleocene (modified from Pujalte et al., 1994), and location of the Bidart section.

this area, so the results presented here provide important data to infer environmental changes across the K/Pg boundary.

In addition to its completeness and excellent exposure, the Bidart section is particularly important because of its paleogeographical location—between the Tethys and the North Atlantic—during the Late Cretaceous and Early Paleogene. According to Renard et al. (1982), the Maastrichtian of Bidart was deposited under Tethyan influences, whereas the Paleocene was influenced primarily by the North Atlantic. Consequently, the Bidart section has been the focus of various studies, such as stable isotope analysis (Romein and Smit, 1981; Renard et al., 1982; Nelson et al., 1991), iridium content (Smit and Ten Kate, 1982; Delacotte, 1982; Bonté et al., 1984), or biostratigraphy (Bonté et al., 1984; Delacotte et al., 1985), among others. Detailed biostratigraphical studies across the K–Pg interval have been based on calcareous nannofossils (Perch-Nielsen, 1979; Seyve, 1990) and planktic foraminifera (Haslett, 1994; Fondecave-Wallez et al., 1995; Apellaniz et al., 1997). Nevertheless, benthic foraminifera from Bidart have not been studied in detail, as pointed out by Haslett (1994).

The aim of this study is to perform a detailed, quantitative study of Upper Cretaceous and Lower Paleogene benthic foraminiferal assemblages from the Bidart section (SW France). Benthic foraminifera, which are closely related to the sea-bottom conditions, provide detailed data on the paleobathymetric setting of the uppermost Cretaceous and lowermost Paleogene sediments at Bidart, as well as on the paleoenvironmental changes across the K/Pg boundary.

MATERIAL AND METHODS

The Bidart section is situated between Hendaye and Biarritz (southwestern France), within the Basque-Cantabric Basin. The outcrop is located behind the beach of Bidart, towards the north of this village (for a more precise location of the outcrop, see Peybernès et al., 1996). The upper 4 m of the Maastrichtian and the lower 3.6 m of the Pa-

leogene were studied at Bidart. The Maastrichtian sediments correspond to the "Bidart marls" (Seunes, 1891), which consist of gray marls and calcareous marls containing abundant foraminifera and scarce macrofossils such as echinoids. The uppermost two centimeters of the Maastrichtian consist of gray clayey marls. The K/Pg boundary is marked by a sharp contact between the Maastrichtian marls and a 6-cm-thick layer of dark clays with a 2-mm-thick, red ferruginous level at its base (Fig. 2). The rest of this clay layer consists of brownish clays towards its lower part, and thinly laminated dark gray clays towards the top. Delacotte (1982) and Bonté et al. (1984) identified an iridium anomaly in the dark clay layer, coinciding exactly with a drop in the $\delta^{13}C$ curve and in the $\delta^{18}O$ values (Peybernès et al., 1996). Apellaniz et al. (1997) documented the presence of microspherules with Ni-rich crystals in the middle part of the clay layer. This layer is overlain by a ~25-cm-thick level of gray to brown clays, which become more grayish and calcareous towards the top, reflecting an increase in total bulk carbonate after a drastic reduction identified just above the K/Pg boundary (i.e., in the dark clay layer; Renard et al., 1982). Fish teeth were observed towards the upper part of this level, which is overlain by 1.30 m of massive gray limestones. Higher in the section, a 50-cm-thick, tabular breccia was identified (Fig. 2); the matrix has a mudstone texture, and the pebbles are calcareous, poorly sorted (the maximum length ranges from 1 mm to 10 cm), and subangular to rounded. This body is overlain by two tabular, 60-to-90-cm thick levels of massive gray limestones, each of which is strongly bioturbated towards the top.

The K/Pg boundary at Bidart, as well as in other K/Pg boundary sections from the Bay of Biscay, is included within a single depositional sequence (Maastrichtian–Danian Depositional Sequence; e.g., Apellaniz et al., 1997). According to these authors, the base of this sequence is located 10 m below the K/Pg boundary, whereas the top of the sequence is erosive.

Flysch deposition persisted from Albian to Eocene times in this area, which was situated in close proximity to a paleoslope to the northeast (Seyve, 1984). A distal deep-sea fan environment with a 40-mm/kyr sedimentation rate (Nelson et al., 1991) prevailed in this area during the Maastrichtian, whereas an increase in the activity on the slope is recorded in the Paleocene (Haslett, 1994), therefore, the Paleocene sediments are locally slumped (Seyve, 1990). According to Peybernès et al. (1996), the breccia identified at Bidart was deposited under conditions of low sea level, whereas the underlying limestones were deposited under high sea-level conditions. Alternatively, this breccia could be interpreted as a slump triggered by local tectonics during the early Danian. In spite of this geological context, the Paleocene foraminifera from Bidart are unlikely to have been affected by major reworking processes, although the microfossils found in the breccia have not been taken into account in the paleoenvironmental interpretations.

The studies by Hasslet (1994), Peybernès et al. (1996), and Apellaniz et al. (1997) have been followed for biostratigraphic control. These authors identified the upper Cretaceous *Abathomphalus mayaroensis* Biozone, as well as the Danian *Guembelitria cretacea*, *Parvularugoglobigerina eugubina* and *Parasubbotina pseudobulloides* Bio-
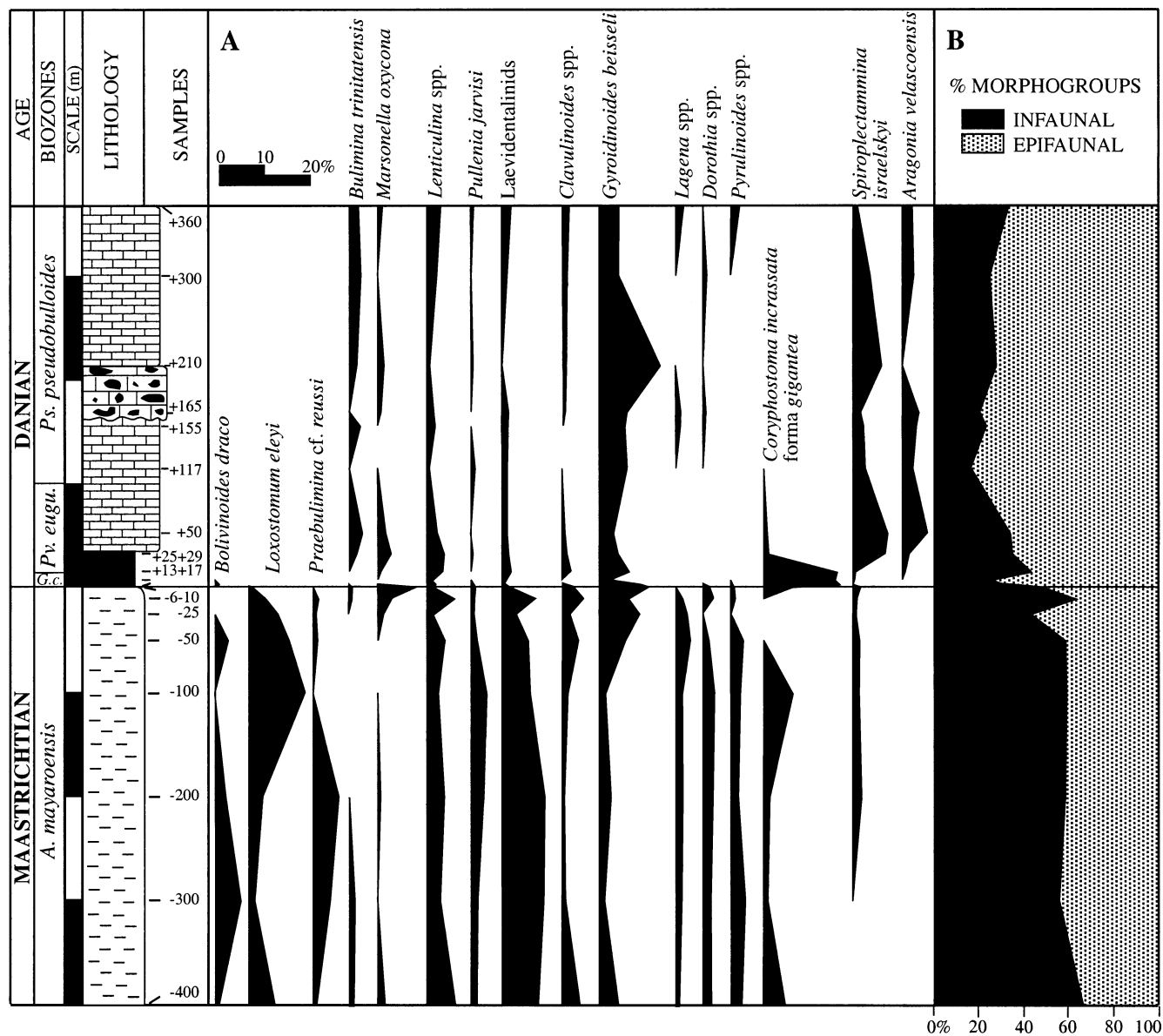
FIGURE 2—Occurrence and relative abundance of infaunal morphogroups across the K–Pg transition at Bidart. (A) Most-characteristic infaunal taxa. (B) Relative percentage of infaunal and epifaunal morphogroups. *G. c.= G. cretacea* Biozone; *Pv. eugu.= Pv. eugubina* Biozone. Biostratigraphy by Haslett (1994), Peybernès et al. (1996), and Apellaniz et al. (1997). See legend in Figure 4.

zones (Figs. 2–3). Foraminiferal assemblages from the lowermost 10 cm of the Danian are dominated by benthic foraminifera, and planktic foraminifera are almost absent. Haslett (1994) and Apellaniz et al. (1997) suggested that this level may correspond to the *Guembelitria cretacea* Biozone of Smit (1982); the first appearance of *Pv. eugubina* 10 cm above the K/Pg boundary marks the *Pv. eugubina* Biozone, and the base of the *Ps. pseudobulloides* Biozone is located ~1 m above the K/Pg boundary.

Twenty samples were studied in the upper 4 m of the Maastrichtian and the lower 3.5 m of the Danian. According to the biomagnetostratigraphic correlation and calibration recently proposed by Arenillas et al. (2004), the base of the *Ps. pseudobulloides* Biozone has an estimated age of 64.945 Ma (based on the calibration by Berggren et al., 1995, who placed the K/Pg boundary at 64.745 Ma) or

65.436 Ma (based on the astronomical calibration by Röhl et al., 2001, who placed the K/Pg boundary at 65.5 Ma). Arenillas et al. (2004) subdivided the *Ps. pseudobulloides* Biozone into the *Eoglobigerina trivialis* Interval Subzone, which has a duration of 171.5–201.1 kyr (based on the calibrations proposed by Berggren et al., 1995 and by Röhl et al., 2001, respectively) and the *Subbotina triloculinoides* Interval Subzone. Although these subzones have not been identified by Hasslet (1994), Peybernès et al. (1996), or Apellaniz et al. (1997) at Bidart, comparison of this section to the nearby Zumaya section, where the *E. trivialis* Subzone spans 2.75 m, suggests that at least this subzone is represented at Bidart. Further biostratigraphical studies are needed to test the presence of the *Subbotina triloculinoides* Subzone at Bidart. However, in the lack of a better biostratigraphical analysis, it may be tentatively inferred
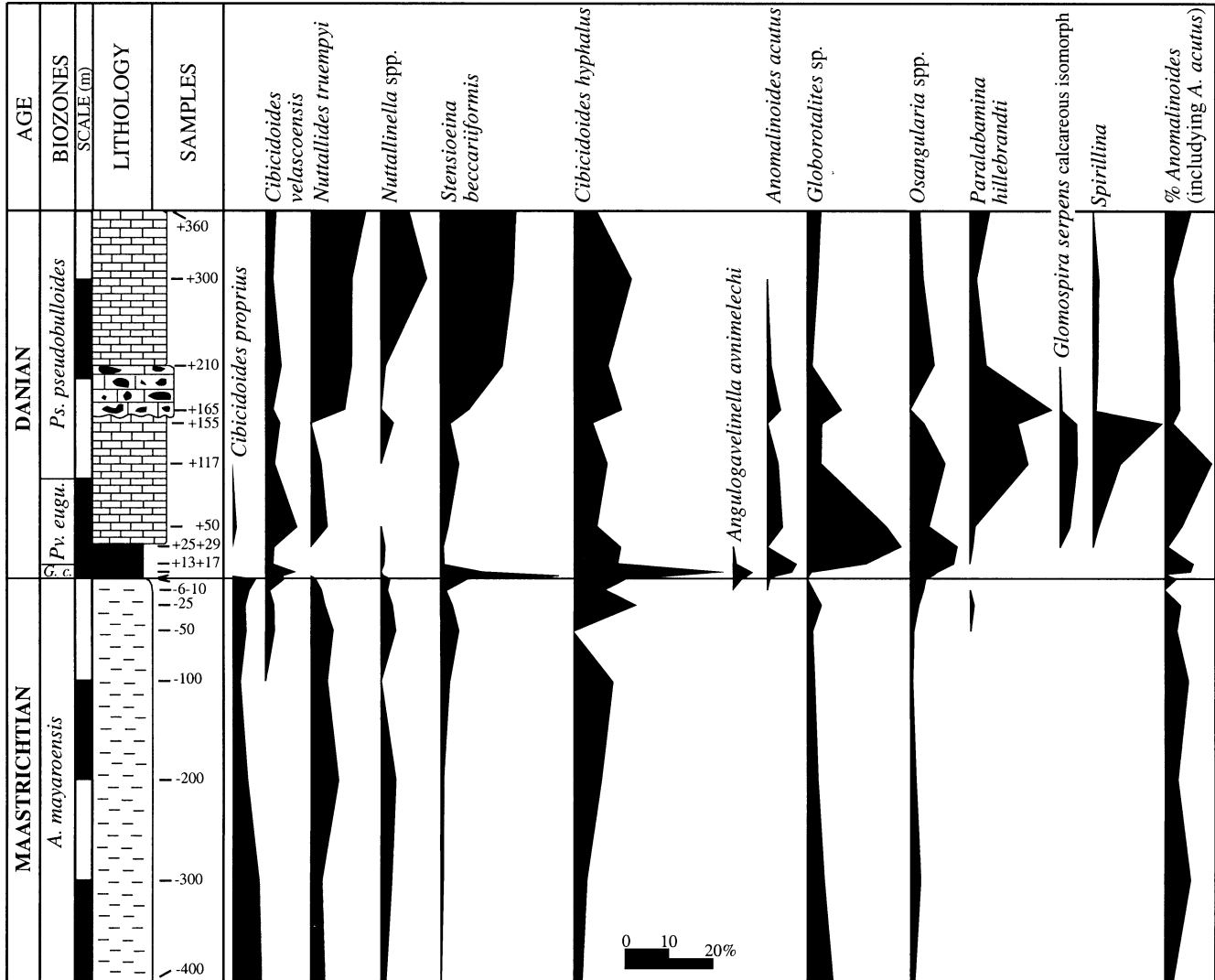
FIGURE 3—Occurrence and relative abundance of the most-characteristic epifaunal benthic foraminiferal taxa across the K–Pg transition at Bidart. *G. c.*= *G. cretacea* Biozone; *Pv. eugu.*= *Pv. eugubina* Biozone. Biostratigraphy by Haslett (1994), Peybernès et al. (1996), and Apellaniz et al. (1997). See legend in Figure 4.

that, at least, the whole *E. trivialis* Subzone is represented at Bidart. These data suggest that the top of the studied interval corresponds, approximately, to the top of the *E. trivialis* Subzone, 225.6–264.5 kyr after the K/Pg boundary (according to the calibrations proposed by Berggren et al., 1995 and by Röhl et al., 2001, respectively); if the *S. triloculinoides* Subzone were partially represented at Bidart, the top of the studied section would be even younger.

Samples were collected at one-meter intervals at the lower part of the section and at decimeter intervals towards the top, with closer sampling in the uppermost Maastrichtian and the lowermost Danian (Appendix 1). Only one micropaleontological sample from the basal 5 cm of the breccia was analyzed, but the results were not considered for paleoenvironmental interpretations due to the possible reworking processes affecting the microfossils in this unit. Samples were disaggregated in water with diluted H_2O_2, washed through a 63-µm sieve, and dried at 50°C. Species richness calculations and quantitative studies were based on representative splits (using a modified Otto micro-splitter) of approximately 300–400 specimens of benthic foraminifera larger than 63-µm. All representative specimens were mounted on microslides for a permanent record and identification. Classification at the generic level follows Loeblich and Tappan (1988); when possible, benthic foraminifers were identified to the specific level largely following the taxonomy of Alegret and Thomas (2001), since the Mexican faunas studied by these authors contain around 80% of the benthic foraminiferal species identified at Bidart. Moreover, 90% of the species identified in this study were reported from the Upper Cretaceous and lower Paleogene at the Agost section (southeastern Spain) by Alegret et al. (2003). Benthic foraminiferal counts are presented in Appendix 1.

The Fisher-α diversity index and the H(S) Shannon-Weaver information function, another index of diversity, were calculated in order to observe possible changes in diversity across the K–Pg interval. High values of H(S) indicate an even distribution of specimens over species;

Murray (1991) calls H(S) the index of heterogeneity, with high heterogeneity values indicating high diversity.

In order to infer probable microhabitat preferences and environmental parameters such as the nutrient supply to the sea floor and seawater oxygenation (e.g., Bernhard, 1986; Jorissen et al., 1995; Fontanier et al., 2002), all benthic foraminiferal taxa were allocated into morphogroups following Corliss (1985, 1991), Jones and Charnock (1985), and Corliss and Chen (1988). According to these authors, there is a general relationship between test morphology and the microhabitat preferences of benthic foraminifera. Thus, benthic foraminifera with plano-convex, biconvex, and rounded trochospiral tests, as well as tubular and coiled flattened tests, have an inferred epifaunal mode of life, living at the sediment surface. Infaunal foraminifera, living in deeper layers of the sediment, have cylindrical or flattened tapered, spherical, rounded planispiral, flattened ovoid, globular unilocular, or elongate multilocular tests. Major changes in percentages of these morphogroups (Fig. 2), as well as in the abundance of selected taxa (Figs. 2–3), and the comparison of fossil and recent communities of benthic foraminifera have been considered in this study to infer the paleoenvironmental turnover across the K/Pg boundary. Nonetheless, one should be careful with these interpretations due to the complex and not fully understood ecology of modern faunas, and their questionable comparison to Upper Cretaceous and lower Paleogene faunas (Alegret et al., 2003).

PALEOBATHYMETRY

Benthic foraminiferal assemblages are dominated by calcareous tests (~97%) through the whole section, except for the upper 10 cm of the Maastrichtian, where they make up 75% of the assemblages (Fig. 4). These values indicate deposition well above the calcite compensation depth. The planktic/benthic ratio is high (85–90%) in all samples except for those from the lowermost Danian, which are dominated by benthic foraminifera.

Paleobathymetric assignments were obtained mainly following the depth distributions and upper depth limits of benthic foraminiferal species, as reviewed by Alegret et al. (2003). Benthic foraminiferal assemblages contain abundant representatives of the bathyal and abyssal Velasco-type fauna (Berggren and Aubert, 1975), namely *Aragonia velascoensis*, *Cibicidoides velascoensis*, *Nuttallides truempyi*, or *Stensioeina beccariiformis*, as well as other deep-water species such as *Bulimina trinitatensis*, *Cibicidoides hyphalus*, or *Marssonella oxycona*. The upper depth limit of some of the most abundant species at Bidart (e.g., *Bulimina trinitatensis*, *Nuttallides truempyi*, *Stensioeina beccariiformis*) is located at 500–700 m depth (Alegret et al., 2003). These data suggest that the upper Maastrichtian and lower Danian sediments at Bidart were deposited in the upper–middle part of the slope.

An increase in the percentage of *Loxostomum eleyi* has been observed in the uppermost meter of the Maastrichtian (Fig. 2). The preservation of these specimens is very similar to that of other species in the same samples, and there is no apparent size sorting. These data indicate that the abundant specimens of *Loxostomum eleyi* identified in the uppermost Maastrichtian sediments are unlikely to have been reworked. Although *Loxostomum eleyi* is typical
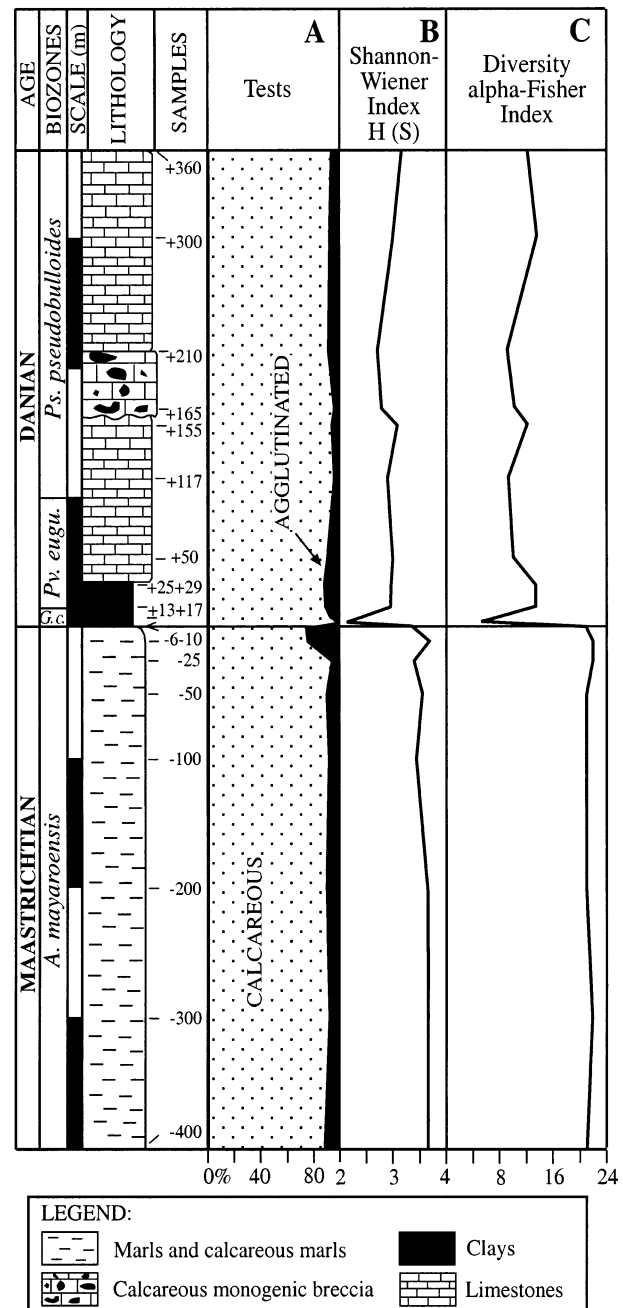

FIGURE 4—Characteristics of benthic foraminiferal assemblages across the K–Pg transition at Bidart. (A) Percentages of calcareous and agglutinated benthic foraminiferal tests. (B) Shannon-Weaver heterogeneity index. (C) Fisher-α diversity index. *G. c.* = *G. cretacea* Biozone; *Pv. eugu.* = *Pv. eugubina* Biozone. Biostratigraphy by Haslett (1994), Peybernès et al. (1996), and Apellaniz et al. (1997).

of outer-shelf environments (MacNeil and Caldwell, 1981; Nyong and Olsson, 1984), its depth occurrence may increase under a high food supply, as suggested by Alegret et al. (2003) at the Agost section. The high relative abundance of infaunal morphogroups in the Maastrichtian at Bidart (Fig. 2) indicates an abundant food supply to the sea-bottom floor, as in Agost. Under these conditions, the depth of occurrence of *L. eleyi* may have been somewhat greater than at other locations.

BENTHIC FORAMINIFERAL TURNOVER

Upper Maastrichtian assemblages are diverse and heterogeneous (Fisher-α index ~21, Shannon-Weaver index H(S) ~3.5; Fig. 4B, C), and they consist of a mixture of infaunal (~58%) and epifaunal morphogroups (Fig. 2B). Among the infaunal morphogroups, species with cylindrical-tapered (e.g., *Praebulimina* cf. *P. reussi*, laevidentalinids), flattened-tapered (e.g., *Loxostomum eleyi*, *Bolivinoides draco*), and spherical tests dominate (Fig. 2), whereas taxa with trochospiral-planoconvex (e.g., *Cibicidoides hyphalus*, *Cibicidoides proprius*) and biconvex (*Nuttallides truempyi*) tests dominate among the epifaunal morphogroups (Fig. 3). These data suggest mesotrophic conditions during the uppermost Maastrichtian, and a nutrient supply to the sea-bottom floor enough to sustain both infaunal and epifaunal morphogroups.

Only three species (*Bolivinoides draco draco*, *Loxostomum eleyi*, and *Praebulimina* cf. *P. reussi*) disappear at Bidart in coincidence with the K/Pg boundary (Fig. 2). Two specimens of *Bolivinoides draco draco* were found two centimeters above the K/Pg boundary, but the different color of the sediment inside their shells as compared to the other foraminifera in the same sample suggests that they are reworked. Although benthic foraminiferal assemblages were not significantly affected by the K/Pg extinctions, the percentage of infaunal morphogroups (Fig. 2) and the diversity of the assemblages (Fig. 4) drastically decreased just after the K/Pg boundary. Lowermost Danian assemblages (dark clay layer) contain up to 74% of epifaunal morphogroups, which are dominated mainly by the trochospiral planoconvex *Stensioeina beccariiformis* and *Cibicidoides hyphalus* (Fig. 3). Such a decrease in the abundance of infaunal taxa and the presence of peaks in the abundance of two epifaunal species suggest a drastic decrease in the food supply to the sea floor related to the catastrophic mass extinction of calcareous plankton at the K/Pg boundary (Zachos and Arthur, 1986; Thomas 1990a, b; Widmark and Malmgren, 1992; Kuhnt and Kaminski, 1993; d'Hondt et al., 1998; Widmark, 2000; Alegret et al., 2001, 2002a, b, 2003). Under oligotrophic conditions, the epifaunal *Stensioeina beccariiformis* and *Cibicidoides hyphalus*, living at the sediment surface, bloomed together with the infaunal species *Coryphostoma incrassata* forma *gigantea*.

Benthic foraminifera from the lower *Pv. eugubina* Biozone are still dominated by epifaunal morphogroups (Fig. 2B), especially by trochospiral biconvex (*Osangularia* spp.) and planoconvex (*Globorotalites* spp.) tests (Fig. 3). It may be argued that this interval is dominated by epifaunal taxa not because of the paleoecological characteristics at that time, but only due to the fact that they correspond to the solution-resistant forms. Nevertheless, both infaunal and epifaunal species show evidence of dissolution, not only in these samples but also in the upper two centimeters of the Maastrichtian and through the whole Danian part of the section. Moreover, in spite of the fact that epifaunal species are more susceptible to dissolution in the modern oceans, a peak in the abundance of epifaunal morphogroups is observed in the lower Danian, thus suggesting that the percentage of epifaunal morphogroups may have been even greater and that dissolution was present but not overwhelming. In addition, a wide range of sizes
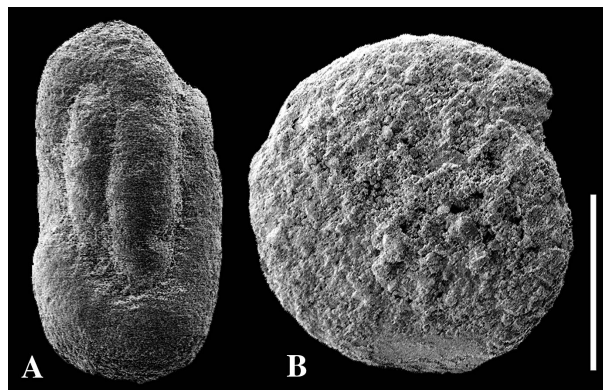
FIGURE 5—Scanning electron micrographs of two opportunistic benthic foraminiferal species. Scale bar = 50μm. (A) *Glomospira serpens* calcareous isomorph. (B) *Spirillina*.

may be observed in all the studied samples, which contain both thick-walled, solution-resistant forms, and thin-walled benthic foraminiferal tests. Two taxa, namely *Glomospira serpens* calcareous isomorph and *Spirillina* (Fig. 5), first appear during this interval. Both taxa morphologically are very similar to *Glomospira serpens* and *Ammodiscus*, respectively, which have been documented to be mobile epifaunal forms that feed on organic detritus (Ly and Kuhnt, 1994) and tolerate environmental instability, thus blooming whenever other taxa cannot compete (Kaminski et al., 1996). The *Glomospira serpens* calcareous isomorph and *Spirillina* were not the only taxa in the *Pv. eugubina* Biozone and in the lower part of the *Ps. pseudobulloides* Biozone, but their appearance and increase in abundance, together with the low diversity and low percentage of infaunal morphogroups, possibly indicate environmental instability at the sea floor (Figs. 2–3) An increase in the relative abundance of the infaunal *Spiroplectammina israelskyi* and *Aragonia velascoensis* also is recorded in the *Pv. eugubina* Biozone (Fig. 2). The percentages of *Spirillina* and *Paralabamina hillebrandti* significantly increase towards the lower part of the *Ps. pseudobulloides* Biozone, at which point, their abundance rapidly starts to decrease (Fig. 3).

Higher in the section, benthic foraminiferal assemblages from the rest of the *Ps. pseudobulloides* Biozone are dominated by the epifaunal *Stensioeina beccariiformis*, *Cibicidoides hyphalus*, *Nuttallides truempyi*, and *Nuttallinella* spp. (Fig. 3). The percentage of infaunal morphogroups increases slightly, but remains low (Fig. 2), as do the diversity and heterogeneity indices (Fig. 4B, C). The abundance of typically bathyal, oligotrophic species, together with the dominance of epifaunal morphogroups towards the top of the studied interval, suggest that the food supply to the sea floor had not completely recovered at that time, at least more than 200 kyr after the K/Pg boundary.

DISCUSSION

The dominance of calcareous benthic foraminifera through the whole section (Fig. 4A) may indicate a small supply of terrigenous sediment at Bidart as compared to the coeval north Spanish Sopelana and Zumaya sections

(Kuhnt and Kaminski, 1993), where agglutinated foraminifera make up two-thirds of the benthic foraminiferal assemblages. Upper Cretaceous benthic foraminiferal assemblages are diverse at Bidart, and consist of a mixture of both infaunal and epifaunal morphogroups, suggesting mesotrophic conditions during the late Maastrichtian.

The drastic decrease in the relative abundance of infaunal taxa and in the diversity and heterogeneity of the assemblages coincident with the K/Pg boundary indicates oligotrophic conditions, which are related to the decrease in the organic flux from surface waters as the result of the mass extinction of primary producers (e.g., Kuhnt and Kaminski, 1993; d'Hondt et al., 1998; Alegret et al., 2001, 2003). Under conditions of very limited food supply to the sea floor, food particles were consumed at the sediment surface by epifaunal species, whereas the percentage of infaunal species decreased due to the lack of organic matter in the underlying sediment. The drastic reorganization of benthic foraminiferal assemblages, together with the geochemical evidence at Bidart (e.g., Delacotte, 1982; Bonté et al., 1984; Peybernès et al., 1996), are compatible with an asteroid impact at the K/Pg boundary.

Peybernès et al. (1996) documented the rapid increase in the abundance of the dinoflagellates *Thoracosphaera operculata*, *Cyclagelosphaera reinhardii*, and *Braadurosphaera bigelowii* in the dark clay layer (*G. cretacea* Biozone and lower part of the *Pv. eugubina* Biozone) at Bidart. Such blooms would have provided large amounts of food that reached the sea floor even in the absence of pellet-producing zooplankton, which suffered a mass extinction (e.g., Ittekot, 1993; Verity et al., 1996). According to these data, the following questions arise: why do benthic foraminifera indicate oligotrophic conditions just after the K/Pg boundary, when phytoplankton blooms suggest an important food supply to the sea floor? Under these high-productivity conditions driven by non-calcareous phytoplankton blooms, why are lowermost Danian benthic foraminiferal assemblages apparently stressed, of low diversity, and dominated by few species? Speculatively, the observed peaks of the epifaunal species *Stensioeina beccariiformis* and *Cibicidoides hyphalus*, and the increase in the percentage of the infaunal *Coryphostoma incrassata* forma *gigantea* just after the K/Pg boundary (Figs. 2–3), may be related to the drastic increase in the abundance of dinoflagellates documented in the lowermost Danian at Bidart. Although the species composition of the assemblages and the low percentage of infaunal morphogroups (Fig. 2), as well as the drop in the δ¹³C curve and in total bulk carbonate (Renard et al., 1982; Bonté et al., 1984), indicate a drastic decrease in primary productivity just after the K/Pg boundary, some of the benthic foraminiferal species that bloomed just after the K/Pg boundary might have been able to feed on short-lived, local phytoplankton blooms that occurred even in the absence of carbonate-rich sediment contributed by nannoplankton, as described by Alegret et al. (2003) in the Agost section (southeastern Spain). In the Modern oceans, many organisms do not consume dinoflagellates, and the unusually low-diversity faunas live under a stressful environment because of this change in the composition of food directly supplied from the photic zone (Peryt et al., 2002). Therefore, most of the benthic foraminiferal species could not easily use the food nutrients supplied by the abundant dinoflagellates, thus

accounting for the low diversity and heterogeneity of the lowermost Danian benthic foraminiferal assemblages. It may be concluded that it was not only the drastic decrease in primary productivity, but also the changes in phytoplankton type (from calcareous to organic-walled phytoplankton) just after the K/Pg boundary that caused the low-diversity, high-dominance benthic foraminiferal assemblages from the lower part of the dark clay layer.

The appearance of the opportunistic taxa *Spirillina* and *Glomospira serpens* calcareous isomorph, together with the high percentages of epifaunal taxa such as *Globorotalites* or *Paralabamina hillebrandti* during the *Pv. eugubina* Biochron and the early *Ps. pseudobulloides* Biochron (Fig. 3), suggest that the food supply was still low, and probably dominated by non-calcareous phytoplankton.

The percentage of infaunal taxa increases slightly through the studied part of the *Ps. pseudobulloides* Biozone, although it does not reach the high values of the late Maastrichtian (Fig. 2). Benthic foraminiferal assemblages from this interval are dominated by the deep-water species *Nuttallides truempyi*, *Stensioeina beccariiformis*, and *Cibicidoides hyphalus* (Fig. 3), which are common in bathyal settings with a scarce nutrient supply to the sea floor (Van Morkhoven et al., 1986; Widmark and Malmgren, 1992; Speijer and Van der Zwaan, 1996; Alegret et al., 2001). The species composition, together with the low diversity and heterogeneity of the assemblages (Fig. 4 B–C), suggests that primary productivity had not completely recovered by that time—more than 200 kyr after the K/Pg boundary.

Kuhnt and Kaminski (1993) reported a similar faunal turnover in the northern Spanish Zumaya and Sopelana sections, including *Gavelinella* and *Stensioeina*-dominated calcareous assemblages in the lower part of the boundary clay and a strong increase in the abundance of *Spiroplectammina israelskyi* at the top of this clay layer. They documented a drastic increase in the relative abundance of opportunistic species just after the K/Pg boundary during a period of reduced primary productivity, and a gradual reestablishment of a normal trophic structure that took place, at least several hundred thousand years after the K/Pg boundary. A similar pattern of recovery has been reported from the South Atlantic (Widmark and Malmgren, 1992), Mexico (Alegret and Thomas, 2001; Alegret et al., 2001, 2002a, b), Austria (Peryt et al., 1997), Tunisia (Speijer and Van der Zwaan, 1996; Peryt et al., 2002), and southeastern Spain (Alegret et al., 2003). The benthic foraminiferal turnover is compatible with the collapse and recovery of surface productivity as the result of the K/Pg-boundary mass extinction of calcareous primary producers (Zachos and Arthur, 1986; Kuhnt and Kaminski, 1993; d'Hondt et al., 1998; Alegret et al., 2001, 2003). The lack of significant extinction of benthic foraminifera at a time of mass extinction of planktic fauna suggests a weak benthopelagic coupling at that time (Thomas et al., 1999; Alegret et al., 2001). Nevertheless, the drastic reorganization of benthic foraminiferal assemblages coincident with the K/Pg boundary at Bidart, and at many other sections worldwide is compatible with a geologically instantaneous, widespread, and catastrophic event, such as the impact of a large asteroid at the K/Pg boundary.

CONCLUSIONS

Upper Maastrichtian and lower Danian benthic foraminiferal assemblages from the Bidart section (southwestern France) are dominated by calcareous taxa, and indicate upper–middle bathyal depths of deposition for the whole studied interval.

Upper Maastrichtian benthic foraminiferal assemblages are diverse and heterogeneous, and contain a mixture of infaunal and epifaunal morphogroups, thus indicating mesotrophic conditions during the latest Cretaceous. The strong decrease in diversity and heterogeneity of the assemblages, as well as the drastic drop in the percentage of infaunal morphogroups, indicate a dramatic decrease in the food supply to the sea-bottom floor coincident with the K/Pg boundary, which is related to the collapse of the food web triggered by the mass extinction of primary producers. The benthic foraminiferal turnover, together with the geochemical and mineralogical evidence, is compatible with an asteroid impact at the K/Pg boundary.

Primary productivity during the early Danian was dominated by blooms of non-calcareous primary producers; such a change in phytoplankton composition induced a stressful environment for the benthic fauna. The low diversity of the assemblages, as well as the low percentage of infaunal morphogroups through the *Pv. eugubina* and *Ps. pseudobulloides* Biozones, suggests that primary productivity had not completely recovered more than 200 kyr after the K/Pg boundary.

ACKNOWLEDGEMENTS

REFERENCES

ABRAMOVICH, S., and KELLER, G., 2002, High stress late Maastrichtian paleoenvironment: inference from planktic foraminifera in Tunisia: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 178, p. 145–164.

ALEGRET, L., ARENILLAS, I., ARZ, J.A., LIESA, C., MELÉNDEZ, A., MOLINA, E., SORIA, A.R., and THOMAS, E., 2002a, The Cretaceous/Tertiary boundary: sedimentology and micropaleontology at El Mulato section, NE Mexico: Terra Nova, v. 14, p. 330–336.

ALEGRET, L., ARENILLAS, I., ARZ, J.A., and MOLINA, E., 2002b, Environmental changes triggered by the K/T impact event at Coxquihui (Mexico) based on foraminifers: Neues Jahrbuch für Geologie und Paläontologie, v. 5, p. 295–309.

ALEGRET, L., MOLINA, E., and THOMAS, E., 2001, Benthic foraminifera at the Cretaceous/Tertiary boundary around the Gulf of Mexico: Geology, v. 29, p. 891–894.

ALEGRET, L., MOLINA, E., and THOMAS, E., 2003, Benthic foraminiferal turnover across the Cretaceous/Tertiary boundary at Agost (southeastern Spain): paleoenvironmental inferences: Marine Micropaleontology, v. 48, p. 251–279.

ALEGRET, L., and THOMAS, E., 2001, Upper Cretaceous and lower Paleogene benthic foraminifera from northeastern Mexico: Micropaleontology, v. 47, p. 269–316.

ALVAREZ, L.W., ALVAREZ, W., ASARO, F., and MICHEL, H.V., 1980, Extraterrestrial cause for the Cretaceous–Tertiary extinction: Science, v. 208, p. 1195–1208.

APELLANIZ, E., BACETA, J.I., BERNAOLA-BILBAO, G., NÚÑEZ-BETELU, K., ORÚE-ETXEBARRÍA, X., PAYROS, A., PUJALTE, V., ROBIN, E., and ROCCHIA, R., 1997, Analysis of uppermost Cretaceous–lowermost Tertiary hemipelagic successions in the Basque Country (western Pyrenees): evidence for a sudden extinction of more than half planktic foraminifer species at the K/T boundary: Bulletin de la Societé Géologique de France, v. 168, p. 783–793.

ARENILLAS, I., ARZ, J.A., and MOLINA, E., 2004, A new high-resolution planktic foraminiferal zonation and subzonation for the lower Danian: Lethaia, v. 37, p. 79–95.

BERGGREN, W.A., and AUBERT, J., 1975, Paleocene benthonic foraminiferal biostratigraphy, paleobiogeography and paleoecology of Atlantic–Tethyan regions; Midway-type fauna: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 18, p. 73–192.

BERGGREN W.A., KENT D.V., SWISHER, C.C., and AUBRY, M.P., 1995, A revised Cenozoic geochronology and chronostratigraphy: *in* Berggren, W.A., Kent, D.V., Aubry, M.P., and Hardenbol, J., eds., Geochronology, Time Scales and Global Stratigraphic Correlation: Society of Economic Paleontologists and Mineralogists Special Publication 54, Tulsa, p. 129–212.

BERNHARD, J.M., 1986, Characteristic assemblages and morphologies of benthic foraminifera from anoxic, organic-rich deposits; Jurassic through Holocene: Journal of Foraminiferal Research, v. 16, p. 207–215.

BONTÉ, P., DELACOTTE, O., RENARD, M., LAJ, C., BOCHET, D., JEHANNO, C., and ROCCHIA, R., 1984, An iridium-rich layer at the Cretaceous/Tertiary boundary in the Bidart section (southern France): Geophysical Research Letters, v. 11, p. 473–476.

CORLISS, B.H., 1985, Microhabitats of benthic foraminifera within deep-sea sediments: Nature, v. 314, p. 435–438.

CORLISS, B.H., 1991, Morphology and microhabitat preferences of benthic foraminifera from the northeast Atlantic Ocean: Marine Micropaleontology, v. 17, p. 195–236.

CORLISS, B.H., and CHEN, C., 1988, Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications: Geology, v. 16, p. 716–719.

CULVER, S.J., 2003, Benthic foraminifera across the Cretaceous–Tertiary (K–T) boundary: a review: Marine Micropaleontology, v. 47, p. 177–226.

DELACOTTE, O., 1982, Étude magnetostratigraphique et géochemique de la limite Crétacé–Tertiaire de la coupe de Bidart (Pyrenees Atlantiques): Unpublished Ph.D. Dissertation, lÚniversité Pierre et Marie Curie, Paris 6, 162 p.

DELACOTTE, O., RENARD, M., LAJ, C., PERCH-NIELSEN, K., PREMOLI-SILVA, I., and CLAUSER, S., 1985, Magnètostratigraphie et biostratigraphie du pass Crétacé–Tertiaire de la coupe de Bidart (Pyrenees Atlantiques): Bulletin des Centres de Recherches Géologiques et Minières 1, Géologie de la France, v. 3, p. 243–254.

D'HONDT, S., DONAGHAY, P., ZACHOS, J.C., LUTTENBERG, D., and LINDINGER, M., 1998, Organic carbon fluxes and ecological recovery from the Cretaceous–Tertiary mass extinction: Science, v. 282, p. 276–279.

FONDECAVE-WALLEZ, M.J., PEYBERNÈS, B., and EICHÈNE, P., 1995, Mise en évidence micropaléontologique dún flysch ypréso-lutétien, excrétacé, à matériel triasique resédimenté, dans la coupe de Bidart Nord (Pyrénées atlantiques, Sud–Ouest de la France): Géologie de la France, v. 3, p. 47–56.

FONTANIER, C., JORISSEN, F.J., LICARI, L., ALEXANDRE, A., ANSCHUTZ, P., and CARBONEL, P., 2002, Live benthic foraminiferal faunas from the Bay of Biscay: faunal density, composition and microhabitats: Deep-Sea Research I, v. 49, p. 751–785.

HASLETT, S.K., 1994, Planktonic foraminiferal biostratigraphy and paleoceanography of the Cretaceous–Tertiary boundary section at Bidart, South-west France: Cretaceous Research, v. 15, p. 179–192.

HILDEBRAND, A.R., PENFIELD, G.T., KRING, D.A., PILKINGTON, M., CAMARGO, Z.A., JACOBSEN, S.B., and BOYNTON, W.V., 1991, Chicxulub crater: a possible Cretaceous–Tertiary boundary impact crater on the Yucatan Peninsula, Mexico: Geology, v. 19, p. 867–871.

HUBER, B.T., MacLEOD, K.G., and NORRIS, R.D., 2002, Abrupt extinction and subsequent reworking of Cretaceous planktonic foraminifera across the Cretaceous–Tertiary boundary: Evidence from the subtropical North Atlantic: *in* Koeberl, C., and MacLeod, K.G.,

eds., Catastrophic Events and Mass Extinctions: Impacts and Beyond: Geological Society of America Special Paper No. 356, Geological Society of America, Boulder, p. 227–289.

ITTEKOT, V., 1993, The abiotically driven biological pump in the ocean and short-term fluctuations in atmospheric CO_2 contents: Global and Planetary Change, v. 8, p. 17–25.

JONES, R.W., and CHARNOCK, M.A., 1985, "Morphogroups" of agglutinated foraminifera; their life positions and feeding habits and potential applicability in (paleo)ecological studies: Revue de Palèobiologie, v. 4, p. 311–320.

JORISSEN, F.J., STIGTER, H.C., and WIDMARK, J.G.V., 1995, A conceptual model explaining benthic foraminiferal microhabitats: Marine Micropaleontology, v. 26, p. 3–15.

KAIHO, K., KAJIWARA, Y., TAZAKI, K., UESHIMA, M., TAKEDA, N., KAWAHATA, H., ARINOBU, T., ISHIWATARI, R., HIRAI, A., and LAMOLDA, M.A., 1999, Oceanic primary productivity and dissolved oxygen levels at the Cretaceous/Tertiary boundary: their decrease, subsequent warming, and recovery: Paleoceanography, v. 14, p. 511–524.

KAMINSKI, M.A., KUHNT, W., and RADLEY, J.D., 1996, Paleocene–Eocene deep water agglutinated foraminifera from the Numidian Flysch (Rif, Northern Morocco): their significance for the paleoceanography of the Gibraltar gateway: Journal of Micropaleontology, v. 15, p. 1–19.

KAMINSKI, M.A., and MALMGREN, B.A., 1989, Stable isotope and trace element stratigraphy across the Cretaceous/Tertiary boundary in Denmark: Geologiska Föreningens i Stockholm Förhandlingar, v. 111, p. 305–312.

KELLER, G., 1989a, Extended Cretaceous/Tertiary boundary extinctions and delayed population changes in planktonic foraminifera from Brazos River, Texas: Paleoceanography, v. 4, p. 287–332.

KELLER, G., 1989b, Extended period of extinctions across the Cretaceous/Tertiary boundary in planktonic foraminifera of continental shelf sections: implications for impact and volcanism theories: Geological Society of America Bulletin, v. 101, p. 1408–1419.

KELLER, G., LE, L., and MACLEOD, N., 1995, The Cretaceous–Tertiary boundary stratotype section at El Kef, Tunisia: how catastrophic was the mass extinction?: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 119, p. 221–254.

KUHNT, W., and KAMINSKI, M.A., 1993, Changes in the community structure of deep water agglutinated foraminifers across the K/T boundary in the Basque Basin (Northern Spain): Revista Española de Micropaleontología, v. 25, p. 57–92.

LOEBLICH, A.R., and TAPPAN, H., 1988, Foraminiferal Genera and Their Classification: Van Nostrand Reinhold Company, New York, 1182 p.

LUTERBACHER, H.P., and PREMOLI-SILVA, I., 1964, Biostratigrafia del limite Cretaceo–Terziario nell'Appennino centrale: Rivista Italiana di Paleontologia, v. 70, p. 67–117.

LY, A., and KUHNT, W., 1994, Late Cretaceous benthic foraminiferal assemblages of the Casamanca Shelf (Senegal, NW Africa): indication of a late Cretaceous oxygen minimum zone: Revue de Micropaléontologie, v. 37, p. 49–74.

MACNEIL, D.H., and CALDWELL, W.G.E., 1981, Cretaceous rocks and their foraminifera in the Manitoba Escarpment: Geological Association of Canada Special Publication 21, 435 p.

MOLINA, E., ALEGRET, L., ARENILLAS, I., and ARZ, J.A., 2002, Taphonomy in analysis of the pattern of extinction at the Cretaceous/Tertiary boundary: in De Renzi, M., Pardo, M.V., Belinchón, M., Peñalver, E., Montoya, P., and Márquez-Aliaga, A., eds., Current Topics on Taphonomy and Fossilization: Encontres Collection, Barcelona, v. 5, p. 89–95.

MOLINA, E., ARENILLAS, I., and ARZ, J.A., 1998, Mass extinction in planktic foraminifera at the Cretaceous/Tertiary boundary in subtropical and temperate latitudes: Bulletin de la Societé Géologique de France, v. 169, p. 351–363.

MURRAY, J.W., 1991, Ecology and Palaeoecology of Benthic Foraminifera: Elsevier, Amsterdam, 397 p.

NELSON, B.K., MACLEOD, G.K., and WARD, P.D., 1991, Rapid change in strontium isotopic composition of sea water before the Cretaceous/Tertiary boundary: Nature, v. 351, p. 644–647.

NYONG, E.E., and OLSSON, R.K., 1984, A paleoslope model of Campanian to Lower Maestrichtian foraminifera in the North American basin and adjacent continental margin: Marine Micropaleontology, v. 8, p. 437–477.

PERCH-NIELSEN, K., 1979, Calcareous nannofossils at the Cretaceous/Tertiary boundary near Biarritz, France: in Christensen, W.K., ed., Cretaceous–Tertiary Boundary Events: University of Copenhagen, Copenhagen, v. 2, p. 151–155.

PERYT, D., ALEGRET, L., and MOLINA, E., 2002, The Cretaceous/Paleogene (K/P) boundary at Aïn Settara, Tunisia: restructuring of benthic foraminiferal assemblages: Terra Nova, v. 14, p. 101–107.

PERYT, D., LAHODYNSKY, R., and DURAKIEWICZ, T., 1997, Deep-water agglutinated foraminiferal changes and stable isotope profiles across the Cretaceous/Paleogene boundary in the Rotwandgraben section, Eastern Alps (Austria): Palaeogeography, Palaeoclimatology, Palaeoecology, v. 132, p. 287–307.

PEYBERNÉS, B., FONDECAVE-WALLEZ, M.J., EICHÈNE, P., BOST, J., SIBE, B., MARAIS, M., and QUILÈS, G., 1996, La Limite Crétacé–Paléocène: Phénomènes Biologiques, Événements Géologiques dÁprès les Sites de la Côte Basque: Centre Régional de Documentation Pédagogique dÁquitaine, Bordeaux, 91 p.

PUJALTE, V., BACETA, J.I., PAYROS, A., ORÚE-ETXEBARRIA, X., and SERRA-KIEL, J., 1994, Late Cretaceous–Middle Eocene sequence stratigraphy and biostratigraphy of the SW and W Pyrenees (Pamplona and Basque Basins, Spain): Field-Seminar of the Groupe d'étude du Paléogène and IGCP Project 286, Barcelona, 118 p.

RENARD, M., DELACOTTE, O., and LÉTOLLE, R., 1982, Le strontium et les isotopes stables dans les carbonates totaux de quelques sites de lÁtlantique et de la Tethys: Bulletin de la Societé Géologique de France, v. 14, p. 519–534.

RÖHL, U., OGG, J.G., GEIB, T.L., and WEFER, G., 2001, Astronomical calibration of the Danian time scale: in Kroon, D., Norris, R.D., and Klaus, A., eds., Western North Atlantic Palaeogene and Cretaceous Palaeoceanography: Geological Society Special Publication No. 183, p. 163–183.

ROMEIN, A.J.T., and SMIT, J., 1981, The Cretaceous/Tertiary boundary: calcareous nannofossil and stable isotopes: Proceedings Koninklijke Nederlandse Akademie van Wetenschappen, v. 84, p. 295–314.

SEUNES, J., 1891, Recherches géologiques sur les terrains secondaires et lÉocène inférieur de la région sous-pyrénéenne du Sud-Ouest de la France (Basses-Pyrénées et Landes): Annuales Minerales, Paris, v. 18, 250 p.

SEYVE, C., 1984, Le passage Crétacé–Tertiaire à Pont Labau: Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, v. 8, p. 385–423.

SEYVE, C., 1990, Nannofossil biostratigraphy of the Cretaceous–Tertiary boundary in the French Basque Country: Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, v. 14, p. 553–572.

SHARPTON, V.L., DALRYMPLE, G.B., MARÍN, L.E., RYDER, G., SCHURAYTZ, B.C., and URRUTIA-FUCUGAUCHI, J., 1992, New links between the Chicxulub impact structure and the Cretaceous/Tertiary boundary: Nature, v. 359, p. 819–821.

SMIT, J., 1982, Extinction and evolution of planktonic foraminifera after a major impact at the Cretaceous/Tertiary boundary: in Silver, L. T., and Schultz, P.H., eds., Geological Implications of Impacts of Large Asteroids and Comets on the Earth: Geological Society of America Special Paper, v. 190, p. 329–352.

SMIT, J., 1990, Meteorite impact, extinctions and the Cretaceous–Tertiary Boundary: Geologie en Mijnbouw, v. 69, p. 187–204.

SMIT, J., and HERTOGEN, J., 1980, An extraterrestrial event at the Cretaceous–Tertiary boundary: Nature, v. 285, p. 198–200.

SMIT, J., and TEN KATE, W.G.H.Z., 1982, Trace-element patterns at the Cretaceous–Tertiary boundary: consequences of a large impact: Cretaceous Research, v. 3, p. 307–332.

SORIA, A.R., LIESA, C., MATA, M.P., ARZ, J.A., ALEGRET, L., ARENILLAS, I., and 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, v. 29, p. 231–234.

SPEIJER, R.P., and VAN DER ZWAAN, G.J., 1996, Extinction and survivorship of Southern Tethyan benthic foraminifera across the Cretaceous/Paleogene boundary: in Hart, M. B., ed., Biotic Recovery

from Mass Extinction Events: Geological Society Special Publication 102, p. 343–371.

THOMAS, E., 1990a, Late Cretaceous through Neogene deep-sea benthic foraminifers (Maud Rise, Weddell Sea, Antarctica): *in* Barker, P.F., Kennett, J.P., O'Connell, S.B., and Pisias, N.G., eds., Proceedings ODP Scientific Results 113: College Station, Texas, Ocean Drilling Program, p. 571–594.

THOMAS, E., 1990b, Late Cretaceous–early Eocene mass extinctions in the deep sea: *in* Sharpton, V.L. and Ward, P.W., eds., Global Catastrophes in Earth History: The Proceedings of an Interdisciplinary Conference on Impacts, Volcanism and Mass Mortality: Geological Society of America Special Publication 247, Geological Society of America, Boulder, p. 481–495.

VAN MORKHOVEN, F.P.C.M., BERGGREN, W.A., and EDWARDS, A.S., 1986, Cenozoic cosmopolitan deep-water benthic foraminifera: Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, Pau, v. 11, 421 p.

VERITY, P.G., STOECKER, D.K., SIERACK, M.E., and NELSON, J.R., 1996, Microzooplankton grazing of primary production at 140°W in the equatorial Pacific: Deep Sea Research, v. 43, p. 1227–1255.

WIDMARK, J.G.V., 2000, Biogeography of terminal Cretaceous benthic foraminifera: Deep-water circulation and trophic gradients in the deep South Atlantic: Cretaceous Research, v. 21, p. 367–379.

WIDMARK, J., and MALMGREN, B., 1992, Biogeography of terminal Cretaceous deep-sea benthic foraminifera from the Atlantic and Pacific oceans: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 92, p. 375–405.

ZACHOS, J.C., and ARTHUR, M.A., 1986, Paleoceanography of the Cretaceous/Tertiary event: Inferences from stable isotope and other data: Paleoceanography, v. 1, p. 5–26.
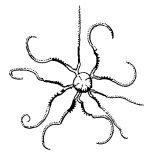
United States Postal Service

Statement of Ownership, Management, and Circulation

1. Publication Title	2. Publication Number	3. Filing Date
PALAIOS	0 8 8 3 - 1 3 5 1	08/31/2004

4. Issue Frequency	5. Number of Issues Published Annually	6. Annual Subscription Price
6 times a year	6	$200.00

7. Complete Mailing Address of Known Office of Publication *(Not printer) (Street, city, county, state, and ZIP+4)*
6128 East 38th St., Ste 308; Tulsa, OK 74135-5814 (Tulsa County)
Contact Person: Theresa Scott
Telephone: 918-610-3361 x 11

8. Complete Mailing Address of Headquarters or General Business Office of Publisher *(Not printer)*
6128 East 38th St., Ste 308; Tulsa, OK 74135-5814 (Tulsa County)

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor *(Do not leave blank)*
Publisher *(Name and complete mailing address)*
SEPM (Society for Sedimentary Geology)
6128 East 38th St., Ste 308
Tulsa, OK 74135-5814
Editor *(Name and complete mailing address)*
Dr. Christopher G. Maples
Dept of Geological Sciences, Indiana University, 1001 e 10th Street
Bloomington, IN 47405-1405
Managing Editor *(Name and complete mailing address)*
SEPM (Society for Sedimentary Geology)
Mrs. Theresa Scott
6128 East 38th St., Ste 308, Tulsa, OK 74135-5814

10. Owner *(Do not leave blank. If the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as those of each individual owner. If the publication is published by a nonprofit organization, give its name and address.)*

Full Name	Complete Mailing Address
SEPM (Society for Sedimentary Geology)	6128 East 38th St., Ste 308 Tulsa, OK 74135-5814

11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box. ▶ ☒ None

Full Name	Complete Mailing Address
None	None

12. Tax Status *(For completion by nonprofit organizations authorized to mail at nonprofit rates) (Check one)*
The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes:
☒ Has Not Changed During Preceding 12 Months
☐ Has Changed During Preceding 12 Months *(Publisher must submit explanation of change with this statement)*

PS Form **3526**, October 1999   *(See Instructions on Reverse)*

13. Publication Title	14. Issue Date for Circulation Data Below
PALAIOS	August 2004

15.		Extent and Nature of Circulation	Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a.		Total Number of Copies *(Net press run)*	1700	1700
b. Paid and/or Requested Circulation	(1)	Paid/Requested Outside-County Mail Subscriptions Stated on Form 3541 *(Include advertiser's proof and exchange copies)*	849	879
	(2)	Paid In-County Subscriptions Stated on Form 3541 *(Include advertiser's proof and exchange copies)*	----	----
	(3)	Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Non-USPS Paid Distribution	----	----
	(4)	Other Classes Mailed Through the USPS	498	525
c.		Total Paid and/or Requested Circulation *[Sum of 15b. (1), (2),(3),and (4)]* ▶	1347	1404
d. Free Distribution by Mail *(Samples, compliment ary, and other free)*	(1)	Outside-County as Stated on Form 3541	6	6
	(2)	In-County as Stated on Form 3541	----	----
	(3)	Other Classes Mailed Through the USPS	69	6
e.		Free Distribution Outside the Mail *(Carriers or other means)*	----	----
f.		Total Free Distribution *(Sum of 15d. and 15e.)* ▶	75	12
g.		Total Distribution *(Sum of 15c. and 15f)* ▶	1422	1416
h.		Copies not Distributed	278	284
i.		Total *(Sum of 15g. and h.)* ▶	1700	1700
j.		Percent Paid and/or Requested Circulation *(15c. divided by 15g. times 100)*	95%	99%

16. Publication of Statement of Ownership
☐ Publication required. Will be printed in the _____ issue of this publication.   ☐ Publication not required.

17. Signature and Title of Editor, Publisher, Business Manager, or Owner
Theresa L Scott, Business Mgn SEPM   Date 9-1-04

I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanctions (including fines and imprisonment) and/or civil sanctions (including civil penalties).

Instructions to Publishers

1. Complete and file one copy of this form with your postmaster annually on or before October 1. Keep a copy of the completed form for your records.

2. In cases where the stockholder or security holder is a trustee, include in items 10 and 11 the name of the person or corporation for whom the trustee is acting. Also include the names and addresses of individuals who are stockholders who own or hold 1 percent or more of the total amount of bonds, mortgages, or other securities of the publishing corporation. In item 11, if none, check the box. Use blank sheets if more space is required.

3. Be sure to furnish all circulation information called for in item 15. Free circulation must be shown in items 15d, e, and f.

4. Item 15h., Copies not Distributed, must include (1) newsstand copies originally stated on Form 3541, and returned to the publisher, (2) estimated returns from news agents, and (3), copies for office use, leftovers, spoiled, and all other copies not distributed.

5. If the publication had Periodicals authorization as a general or requestor publication, this Statement of Ownership, Management, and Circulation must be published; it must be printed in any issue in October or, if the publication is not published during October, the first issue printed after October.

6. In item 16, indicate the date of the issue in which this Statement of Ownership will be published.

7. Item 17 must be signed.

Failure to file or publish a statement of ownership may lead to suspension of Periodicals authorization.

PS Form **3526**, October 1999 *(Reverse)*

APPENDIX

Benthic foraminiferal species counts in the studied samples from Bidart. The number of each sample (above) corresponds to the centimeters below (−) or above (+) the K/Pg boundary.

Species	K−400	K−300	K−200	K−100	K−50	K−25	K−6−10	K−0−2	T+0+2	T+3+6	T+13+17	T+25+29	T+50	T+117	T+155	T+165	T+210	T+300	T+360
Alabamina cf. mudwayensis								1											
Allomorphina cf. navarroana							5												
Allomorphina sp.	5			2	3	2													
Allomorphina velascoensis	6	4	1	1	1	1													
Ammodiscus cretaceus	1					1		1			3								
Ammodiscus glabratus						1	7	2			2								
Ammodiscus sp.	1	1	1	1	1	1													
Angulogavelinella avninelechi								5	12	6							3		
Anomalinoides acutus		4	6					5	3	27	25		14	9		9			
Anomalinoids ammonoides	2	8	1	10	5	5		4		36	2		3			3	9	7	1
Anomalinoides spp.	4			5	2	5		2		3		2		28	2		2		
Aragonia sp.															5		2		22
Aragonia velascoensis		2		2	2		2	3			2	7	20	8	10	12	2	8	6
Arenobulimina sp.											1	1	3		1	2		2	
Astacolus cf. jarvisi	4																		
Astacolus spp.	2	2	2	1		1	1									1			
Bathysiphon sp.		1	2	1		1		1		7	1	4					1		
Bathysiphon sp. C				1						2	1								
Bolivinoides delicatulus	11	2	1	4		7	4	2		4	5	12	3	4			1	1	1
Bolivinoides draco	1	11	6		7							1							
Bolivinoides sp.									3	2									
Bulimina midwayensis						7	1		2										
Bulimina paleocenica						5	3												
Bulimina spp.				1	1		1	1				4			3	4	4	4	15
Bulimina trinitatensis	1	1					1	1				8	11		8		6	9	8
Bulimina velascoensis				1			4												
Buliminella cf. beaumonti			3				4												
Buliminella sp.		1	7	1	2	4													
Caudammina sp.					1		1	1		2		2							
Cibicidoides cf. abudurbensis					1														
Cibicidoides cf. ekblomi				8											13				
Cibicidoides cf. naranjoensis			3																
Cibicidoides dayi	1		3	1				2	10				1			2	5	1	1
Cibicidoides howelli		1	2	1	3			2	2	6									
Cibicidoides hyphalus	5	7	15	25	3	41	24	35	90	221	41	51	20	27	15	36	31	45	19
Cibicidoides proprius	23	12	10	6	9	8	14	15					4						
Cibicidoides sp.		1	3				6	6			8	12	21		12	31	6	23	2
Cibicidoides velascoensis					5	4	1	12	17	41	5	9	24	7	12	5	15	5	8
Clavulinoides amorpha					6		1		5										
C. amorpha juvenile form							15												
Clavulinoides sp.		1	1	1								4							
Clavulinoides trilatera	3			1	4	5		2			3					2	4	7	
C. trilatera juvenile form	12			2							5						3		
Canorbina sp.															10				
Coryphostoma decurrens												2							
Coryphostoma incrassata		3					3												
C. incrassata forma gigantea	16	1	3	18				19	69	100	65	7	5						
Coryphostoma sp.	8	1		1	2			1				1	1			4		1	
Dentalina sp.	2	1				1	1	1		1		1							
Dorothia bulleta		1	3																

APPENDIX Continued.

	K−400	K−300	K−200	K−100	K−50	K−25	K−6−10	K−0−2	T+0+2	T+3+6	T+13+17	T+25+29	T+50	T+117	T+155	T+165	T+210	T+300	T+360
Dorothia bulleta juvenile form	4																		
Dorothia pupa	2							1											
Dorothia pupa juvenile form		3			2			3											
Dorothia spp.	5			7	1	1	8	1							1	1		2	
Ellipsodimorphina sp.		1		3	1	1									1	1		2	
Fissurina spp.			2	2	1	1	4												
Fursenkoina sp.			1		4	4	4												
Gaudryina pyramidata	3	2	2	2	1	2	4						2	2	1			1	4
Gaudryina sp. juvenile form			6	2									2		1			1	
Gavelinella danica	2																		
Glandulina sp.		3							1									1	
Globorotalites sp.	18	8	6	5	4	10	5		2	6	55	100	66	10	11	24	4	8	12
Globulina prisca	1			1			1												
Globulina spp.	6	5		3	5	3	1	2			1				2			2	
Glomospira gordialis							1												
Glomospira serpens calcareous isomorph													9	15	14	1			
Glomospira spp.							1												
Glomospirella grzybouzki		3		2	1	3	1			3	2	1						1	3
Guttulina sp.			4		2	2	3				2	1							
Gyroidinoides beisseli	14	2	6	4	15	24	22	32	39	16	28	22	12	20	17	18	53	15	16
Gyroidinoides cf. *goudkoffi*								5	5						2			2	
Gyroidinoides depressus	5	3	2	2	2	4	4	1	5		2	6		8	1			2	5
Gyroidinoides girardanus	4	1	5	3	1	3	3	2		1	2	4	3	4	2	5	5	2	7
Gyroidinoides globosus	2	2	4	8	6	5	1	1	2		1	2		2	3	7	2	4	3
Gyroidinoides sp.			3				1	1				1		6	3		1	6	
Haplophragmoides proteus										5									
Haplophragmoides sp.			1	1			1				1								
Heronallenia lingulata															2	2			
Hormosina velascoensis			1		1		1	5											
Hyperammina sp.	1					1		1		3		3	1						
Insculptarenula sp.							2												
Laevidentalina spp.	26	19	25	16	14	9	24	5	3	5	8	7	5	3	4	4	2	4	8
Lagena globosa				2															
Lagena spp.	1	2	4	4	10	7	5	5						2	2	2		7	7
Lenticulina spp.	21	6	10	7	11	4	20	4	6	7	13	17	8	2	5	4	2	7	12
Lingulina spp.	1																		
Loxostomum eleyi	18	3	9	34	24	18	14	1	1								1		
Marginulina sp.				3															
Marssonella oxycona	5	1	1		3	3	11	24			2	14	7			1	5	4	4
M. oxycona juvenile form	2	2	2	1			6						2					2	2
Marssonella sp.	1	3			2	2		2							2				
Neoflabellina sp.		3			1	1	1												
Nonionella cretacea	1	1																	
Nonionella sp.	1	1																	
Nuttallides spp.	5	12	13	12	27	29	19	8	10	16	18	41	38	50	38	19	61	8	14
Nuttallides truempyi	12	5	16	11	13	9	8	3					15	8	24	24	37	33	45
Nuttallinella coronula			10	3															
Nuttallinella florealis									1										7
Nuttallinella spp.	3	5	5	9	9	7	5	6	1	3	3	5	9		9	4	4	36	18
Oolina spp.		1	1	4	4														

APPENDIX Continued.

	K−400	K−300	K−200	K−100	K−50	K−25	K−6−10	K−0−2	T+0+2	T+3+6	T+13+17	T+25+29	T+50	T+117	T+155	T+165	T+210	T+300	T+360
Oridorsalis plummerae	5	4										2							
Oridorsalis sp.								1											
Oridorsalis umbonatus	3	3		1		2		2			12	6			1		2	2	3
Osangularia cf. velascoensis																		3	
Osangularia cf. cordieriana								3		20	1							2	
Osangularia cf. plummerae	3	4	3	1	2	2	5					16		8					
Osangularia spp.		1				2	6	8	22	19	39	35	18	21	11		22	6	8
Paliolatella orbignyana		2	2	3	3														
Paliolatella sp.	2						3												2
Paralabamina hillebrandti						2						2	4	47	35	58	17	5	17
Planulina sp.										2									
Pleurostomella sp.			2	2	2		1							1		1			4
Praebulimina cf. reussi	2		14		3	2	5												
Praebulimina sp.				8	1														
Praeglobobulimina spp.		1																	
Pseudouvigerina plummerae	2	2	1	1								3			2				
Pseudouvigerina sp.																1	1		
Pullenia cretacea			1	1															
Pullenia jarvisi	3	2	7	9	3	1	3	3				1		2		1			1
Pyramidina rudita							6												
Pyramidina sp.													6						
Pyrulinoides sp.	7	7	4	6	7		2												6
Quadrimorphina allomorphinoides			1	2										1					2
Quadrimorphina sp.	2	2																	
Quinqueloculina sp.	2																		
Ramulina spp.	1																		
Recurvoides sp.						1	2												
Repmania charoides			2	3	1	1	4			3	1	1							
Reusella sp.	3																		
Rhizammina sp.	1						1	1			1		1						
Saccammina placenta									1	3									
Saccammina spp.										4	1								
Saracenaria sp.	1							1				1							2
Scheibnerova sp.							3												
Sitella sp.	1			1															
Sliteria varsoviensis			1																
Spiroplectammina cf. dentata										5	11								
Spiroplectammina cf. israelskyi			4	3	3	1	3	6		1	3	34	29	9	7	5	25	15	3
Spiroplectammina spectabilis	2		1			1					8	1						1	2
Spiroplectammina spp.										1	5	3						2	
Spiroplectinella sp.	1					1								2					
Spirillina sp.													5	21	51	1	4	4	
Stensioeina beccariiformis		1	1	6	12	8	4	19	112	64	4	3	7	15	7	20	57	58	63
Stensioeina excolata	6	2	2	3	1	2	1	2									1		
Stillostomella sp.		4	2	1	1	1	1				3	2	2	1	3	1	1	1	
Tappanina selmensis														2					
Thalmannammina sp.				1			1												
Trochammina sp.	3	1	1		3	1	6	6		7	3	1	3						
Vaginulina trilobata						1	4	4				1							
Valvalabamina lenticula	1				1											1			
TOTAL	321	197	254	273	258	283	325	238	416	651	401	462	373	343	328	310	393	345	370