Is there evidence for Cretaceous-Tertiary boundary–age deep-water deposits in the Caribbean and Gulf of Mexico?

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ABSTRACT

Over most of the Gulf of Mexico and Caribbean a hiatus is present between the lower upper Maastrichtian and lowermost Tertiary deposits; sedimentation resumed ~200 ka (upper zone P1a) after the K-T boundary. Current-bedded volcaniclastic sedimentary rocks at Deep Sea Drilling Project (DSDP) Sites 536 and 540, which were previously interpreted as impact-generated megawave deposits of K-T boundary age, are biostratigraphically of pre–K-T boundary age and probably represent turbidite or gravity-flow deposits. The top 10 to 20 cm of this deposit at Site 536 contains very rare *Micula prinsii*, the uppermost Maastrichtian index taxon, as well as low values of Ir (0.6 pbb) and rare Ni-rich spinels. These indicate possible reworking of sediments of K-T boundary age at the hiatus. Absence of continuous sediment accumulation across the K-T boundary in the 16 Gulf of Mexico and Caribbean sections examined prevents their providing evidence of impact-generated megawave deposits in this region. Our study indicates that the most complete trans–K-T stratigraphic records may be found in onshore marine sections of Mexico, Cuba, and Haiti. The stratigraphic records of these areas should be investigated further for evidence of impact deposits.

INTRODUCTION

Recently, the buried circular structure at Chicxulub in northern Yucatan has been described as a possible impact crater (Pope et al., 1991; Hildebrand et al., 1991) of precisely K-T boundary age on the basis of $^{39}Ar/^{40}Ar$ dating (Swisher et al., 1992; Sharpton et al., 1992). This date is in conflict with the reported early to middle Maastrichtian paleontologic age of overlying bedded marls and limestones (Lopez Ramos, 1973). Possible explanations for the age discrepancy include incorrect identification of diagnostic microfossils, crater infilling, secondary alteration of the glass used for the $^{39}Ar/^{40}Ar$ dates, and the possibility that the dated rocks represent igneous intrusions. Of these explanations, crater infilling is the least satisfactory because such deposits should not be of uniform bedded lithologies but instead should consist of mixed and principally granitic basement debris. No samples are available to us from the Chicxulub cores; therefore, we cannot reexamine the paleontology and sedimentology. Yet, if a large impact did occur on Yucatan, impact debris and tsunami deposits should be present throughout the Gulf of Mexico and Caribbean (Hildebrand and Boynton, 1990). Such deposits have recently been described from Mimbral, northeast Mexico, and the Gulf of Mexico Deep Sea Drilling Project (DSDP) Sites 536 and 540 (Alvarez et al., 1992; Smit et al., 1992). We have reexamined these sections (Stinnesbeck et al., 1993) and cores and included data from all other deep-sea sections that cored the K-T boundary in the Gulf of Mexico, Caribbean, and the western side of the Atlantic Ocean. These data enable the evaluation of the stratigraphy of these K-T boundary sections in a comprehensive regional context.

METHODS

Planktic foraminifera from Site 536 (core-sections 9-3 to 9-5), Site 540 (core-sections 31-1 to 31-2), Site 95 (core-sections 12-4 to 13-3), and Site 153 (core-sections 12-1 to 12-2) have been quantitatively analyzed (size fraction >63 μm) in 10 cm spaced samples, and at closer sample intervals across the K-T boundary in Site 536.[1] In addition, all other Caribbean and Gulf of Mexico deep-sea sections that span Cretaceous to Tertiary deposits have been reexamined on the basis of published literature as well as new sample analyses (see sample list and stratigraphic data in Thierstein and Woodward, 1982).

STRATIGRAPHY OF DSDP SITES 536 AND 540

Site 536 is located on a submarine ridge at the base of the Campeche Escarpment (2790 m depth), and Site 540 is located 93 km across a channel on the Florida Escarpment of the Florida platform (2926 m depth, Fig. 1). Buffler, Schlager, et al. (1984) and Worzel, Bryant, et al. (1973) have noted that this area probably funneled currents through the Straits of Florida since Cretaceous time, resulting in numerous hiatuses, submarine slumps, and turbidite deposits as previously recognized at Sites 94, 95, 536, and 540. Our analysis of Sites 536 and 540 is consistent with these previous investigations.

[1]Data Repository item 9331, containing data of these analyses, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

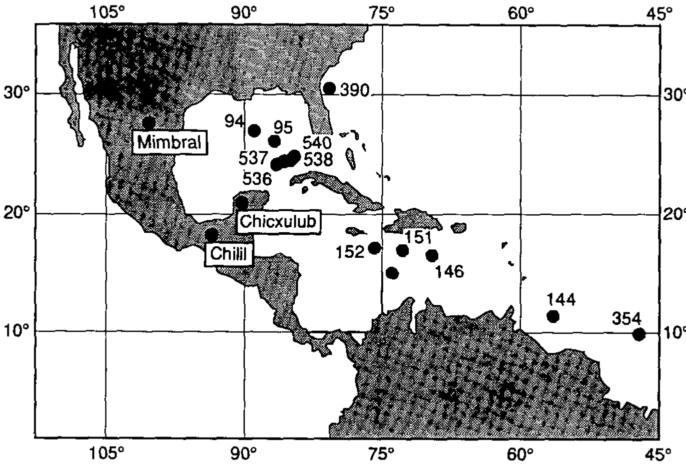

Figure 1. Location map of DSDP sites and Mexican sections studied.

Note: Data Repository item 9331 contains additional material related to this article.

How Complete is the K-T Transition?

We have restudied Site 536 with closely spaced samples. Results revealed the presence of at least four major hiatuses between the Paleocene and Maastrichtian, including an upper Paleocene hiatus (Zones P2 to P4), a lower Paleocene hiatus (upper Zone P1a to P1b), a K-T boundary hiatus from zone P1a (*P. eugubina*) into at least the upper Maastrichtian, and a lowermost Maastrichtian to upper Albian hiatus (Fig. 2). All but the K-T boundary hiatus were previously recognized by shipboard scientists (Premoli Silva and McNulty, 1984). They considered the K-T boundary transition to be complete on the basis of (1) the presence of the early Tertiary planktic foraminifer Zone P1a index taxon *Parvularugoglobigerina eugubina* and (2) the presence of the late Maastrichtian nannofossil index taxa *Micula prinsii* and *Lithraphidites quadratus* in the core catcher at the base of the only 70 cm of Maastrichtian sedimentary deposits. They explained the absence of the upper Maastrichtian index taxa *Abathomphalus mayaroensis*, *Rosita contusa*, and *Globotruncanita conica* as possibly due to ecologic exclusion or dissolution. We believe that this is unlikely, because these three species are dissolution resistant and are present in the Mendez Formation of Mexico (Pessagno, 1967; Keller et al., 1993). Shipboard scientists, noting the absence of a lithological change, tentatively placed the K-T boundary in Site 536 core 9-5 at 70 cm (Premoli Silva and McNulty, 1984). Reexamination of this section indicates that *P. eugubina* and *P. longiapertura* are abundant (27%–40%) in a 27 cm interval (core 9-5, 50 to 77 cm), and sharp drops in abundance above and below mark hiatuses (Fig. 2). Moreover, the fossil assemblage at 77 cm includes taxa that first appear in the upper part of Zone P1a (*P. compressus, C. midwayensis, G. pentagona*), indicating that ~200 ka of the basal Tertiary is missing (Fig. 3). At 80 cm, 3 cm below, no Tertiary species are present, but a well-developed Maastrichtian fauna was observed (Figs. 2 and 3). This indicates that the K-T boundary is between 77 and 80 cm in core 9-5. It also indicates that the basal Tertiary boundary clay, or Zone P0 is missing, in addition to the lower part of Zone P1a.

How Complete is the Maastrichtian?

Upper Cretaceous sedimentary strata in core 9-5, between 80 cm and 150 cm, of Site 536 are rich in volcanic debris and pyrite spherules and contain a very diverse (38 species) Maastrichtian planktic foraminiferal fauna (Fig. 3). Alvarez et al. (1992) claimed that these sedimentary rocks are of K-T boundary age and contain only small foraminifers that represent "the finest fraction of sediment stirred up by a K-T impact wave, which was suspended and then settled out" (p. 698). Our investigation shows, however, that both small- and large-sized species are present throughout this interval (~20% large globotruncanids and 30% large pseudoguembelinids) and that no size sorting is apparent (Figs. 2 and 3). The precise K-T boundary age for this 70 cm interval is very difficult to assess, however, considering the Danian hiatus above and the lower Maastrichtian to Albian hiatus below.

This interval contains common globotruncanid taxa that are restricted to the lower and lower upper Maastrichtian *G. aegyptiaca* and *G. gansseri* Zones (e.g., *Globotruncana falsostuarti, G. ventricosa, G. linneiana, Rosita fornicata, R. patelliformis*; Fig. 3). Upper Maastrichtian index taxa are missing, as noted also by earlier investigators (Premoli Silva and McNulty, 1984), with the exception of an isolated, single *R. fructicosa* specimen and the nannofossil *Micula prinsii* in the top 10 cm interval (J. Pospichal, 1993, written commun.). Watkins and Bowdler (1984) originally noted *M. prinsii* in the core-catcher. However, since Pospichal could not confirm the presence of *M. prinsii* below the top 10 cm (core 9-5, 90 cm), its presence in the core-catcher may be due to downcore contamination, which is frequent in core-catchers. R. Rocchia and E. Robin (1993, personal commun.) found rare Ni-rich spinels in the top 10 cm interval and low diffuse values of Ir (0.5 ppb) in the top 30 cm. These rare uppermost Maastrichtian and K-T boundary markers in an otherwise lower Maastrichtian planktic foraminiferal assemblage suggest two alternative interpretations. First, on the basis of rare *M. prinsii*, Ni-rich spinels, and low Ir concentrations in the topmost (10 to 20 cm) sedimentary strata, the 70 cm of Upper Cretaceous sediments may be of *M. prinsii* Zone age (uppermost Maastrichtian) but contain predominantly reworked lower Maastrichtian sedimentary deposits. Second, on the basis of the presence of common early Maastrichtian planktic foraminiferal species, the 70 cm interval may be of *G. aegyptiaca* Zone age (upper lower Maastrichtian) with reworked uppermost Cretaceous age sediments in the topmost 20 cm below the K-T boundary hiatus. We believe that the latter is the most parsimonious interpretation, on the basis of (1) the current faunal

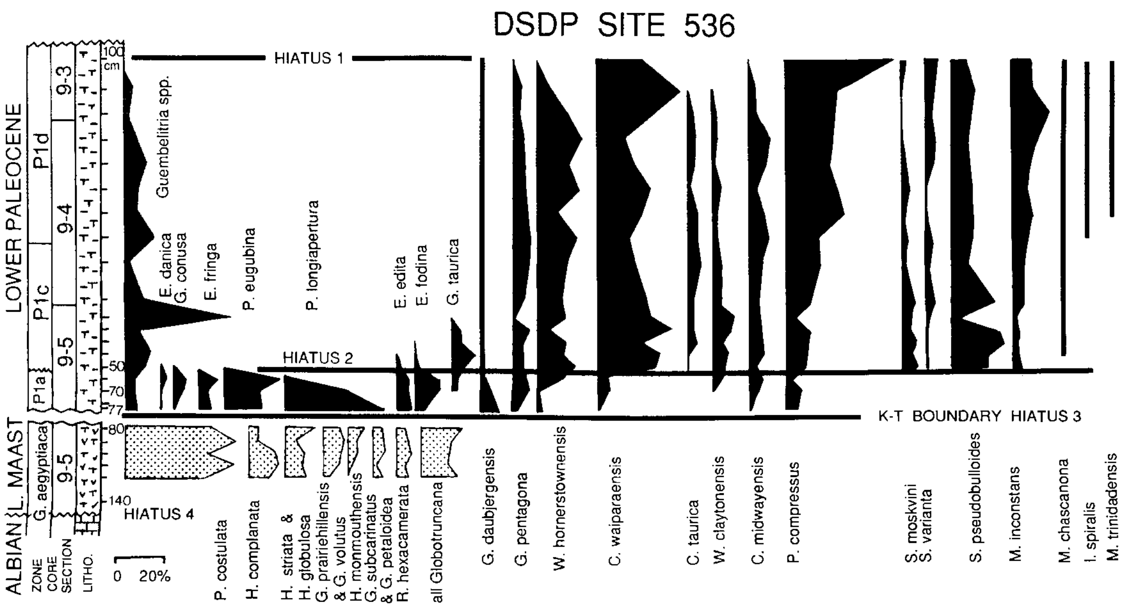

Figure 2. Planktic foraminiferal biostratigraphy and relative species abundances of Cretaceous-Tertiary sedimentary units at Site 536. Black = Tertiary taxa; dot pattern = Cretaceous taxa.

data and restriction of K-T boundary indices to the topmost 20 cm; (2) the unlikely case that erosion at Site 536 stopped precisely at the K-T boundary, and (3) the fact that in all other Caribbean deep-sea sections erosion spans an interval across the K-T boundary to at least the lower Maastrichtian (Fig. 4). Similar to Site 536, Site 540 contains a lower Maastrichtian species assemblage in cores 31-1 and 31-2 with ~2.6 m of volcaniclastic and current-bedded sandstones. This suggests that the Maastrichtian intervals at Sites 536 and 540 are nearly coeval.

MINERALOGY AND PETROLOGY

Alvarez et al. (1992, p. 699) reported the presence of shocked quartz in Site 540 (31-1, 53–55 cm) and smectitized impact spherules, glass, and K-feldspar in Site 536 (9-cc), similar in composition to those found at Mimbral, Mexico, and in Haiti. Our investigations recovered no microspherules (except pyrite spherules) and no glass except for volcanic glass shards.

Site 536, core 9-5, 60 cm and 9-5, 70 cm (upper Zone P1a), contains rare unshocked quartz, pristine plagioclase (oligoclase and calcic andesine), and biotite. Also present is basaltic glass (n = 1.591; SiO_2 = 50%), which is considerably lower in SiO_2 content than the andesitic glass found at Beloc, Haiti (n = 1.539; SiO_2 = 63%), with which it is presumed to be correlative (Lyons and Officer, 1992). Another major distinction between the two deposits is that the palagonite-zeolite-calcite spherules so abundant in the Haiti and Mimbral deposits (Smit et al., 1992; Stinnesbeck et al., 1993) are absent from Site 536, even though smectitized volcanic rocks are present.

At Site 540, core 31 consists of abundant fossils, clasts of pyritic, smectitized volcanic rocks and argillaceous limestones (31-2, 115–123 cm and 130–145 cm), coarse secondary calcite, and minor zeolite (principally clinoptilolite). Most of these are replaced by coarse (up to 2 mm in diameter) gypsum porphyroblasts. There are concentrically zoned radial growths of secondary smectite. Again, none of the spherules characteristic of both sections at Beloc and Mimbral are present. Alvarez et al. (1992) reported that "abundant shocked grains were recovered from Site 540 (31-1, 29–30 cm and 53–55 cm)" (p. 699). We have not found any shocked grains. Quartz with multiple irregularly spaced trains of fluid inclusions have been seen in the HCl residues, but no deformation lamellae. Glass(?) is too smectitized to yield reliable microprobe analyses. Glass analyses reported by Alvarez et al. (1992, Table 1) for glasses at Sites 540 and 536 are of dubious igneous composition, as they are abnormally low in FeO and MgO and too high in alkalis and Al_2O_3 for their respective SiO_2 compositions.

An Ir anomaly of up to 0.6 ppb in the volcaniclastic debris flow of Sites 536 and 540 has been taken as further evidence of a cosmic impact (Alvarez et al., 1992; R. Rocchia and E. Robin, 1993, unpublished data). This is in contrast to values as high as 28 ppb in a clay layer above the spherule beds in Haiti (Jéhanno et al., 1992).

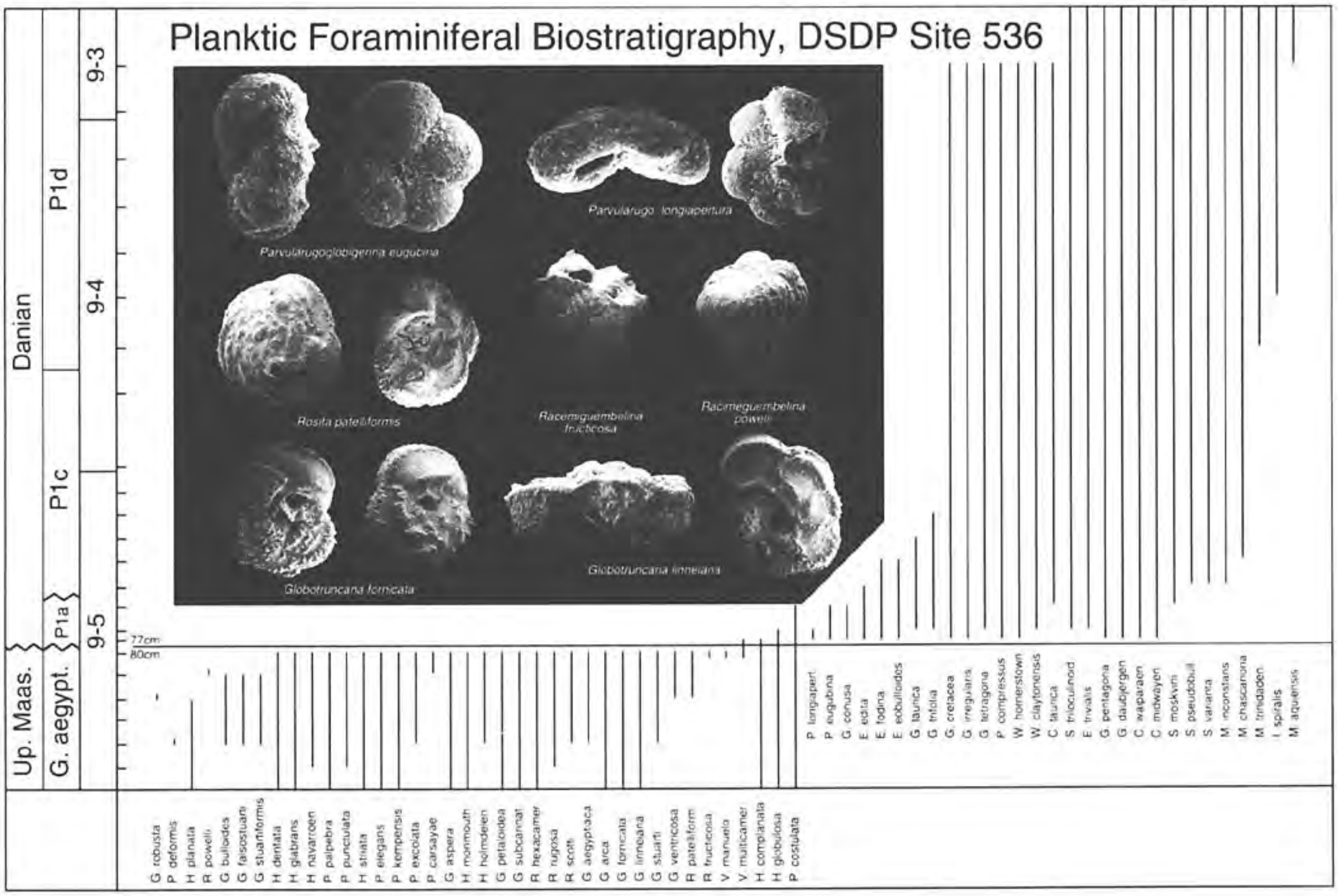

Figure 3. Ranges of planktic foraminifera across K-T boundary at DSDP Site 536 along with SEM illustrations of key stratigraphic taxa. Note K-T boundary hiatus marked by abrupt species assemblage change from topmost Cretaceous assemblage of *G. aegyptiaca* Zone, upper lower Maastrichtian in core 9-5 at 80 cm to first Tertiary assemblage of *P. eugubina* (P1a) Zone in core 9-5, 77 cm. SEM illustrations show *P. eugubina, P. longiapertura*, 9-5, 77 cm; *Rosita patelliformis, Globotruncana linneiana, G. fornicata*, 9-5, 80 cm; and *R. powelli*, 9-5, 90 cm.

The reason for these orders-of-magnitude differences is unclear. One likely explanation is that the two Ir anomalies are not coeval, as indicated by the paleontology, and may be due to reworking at the K-T boundary hiatus at Sites 536 and 540.

HOW COMPLETE ARE OTHER K-T BOUNDARY SECTIONS?

We have reexamined the biostratigraphy of 16 deep-sea and onshore marine sections from the Caribbean, Gulf of Mexico, Mexico, and western Atlantic region to evaluate the stratigraphy and sedimentation patterns and identify possible impact-generated megawave deposits (Fig. 4). Of all sections examined, only Mimbral appears to exhibit relatively continuous sediment accumulation across the K-T boundary, including the presence of the late Maastrichtian *A. mayaroensis* Zone, a 4-cm-thick boundary clay and thin red layer representing Zone P0, and a 1.5-m-thick P1a (*eugubina*) Zone (Keller et al., 1993). All other sections and cores appear to be characterized by major boundary hiatuses (Fig. 4), and none has current-bedded clastic deposits at or near the K-T boundary similar to the sections in Mimbral, Haiti, and Cuba. Nonetheless, clastic deposits, usually described as turbidites, are common in older Cretaceous sedimentary units.

At Mimbral, the clastic channel-fill deposit reported by Smit et al. (1992) as an impact-generated megawave deposit appears to have accumulated over an extended time interval that probably coincided with the latest Maastrichtian sea-level lowstand. This is indicated by benthic foraminiferal depth inferences, the presence of three lithologically distinct units and subunits, three disconformities, burrowing, short intervals of normal pelagic sedimentation, the presence of spherules of multiple origins (volcanic, precipitational, and organic), the absence of common shocked quartz, and the absence of glassy spherules (Stinnesbeck et al., 1993; Keller et al., 1993). No rigorous biostratigraphic analysis from Haitian outcrops has been published. Therefore, the precise age of the Haitian clastic deposit must be regarded as unknown. The impact origin of that deposit has also been questioned by Jéhanno et al. (1992) and Lyons and Officer (1992). Cuban K-T boundary sections are characterized by conglomerates and volcaniclastic deposits overlain by sedimentary units of early Tertiary Zone P1a (*P. eugubina*) age with Zone P0 and the lower part of Zone P1a missing, similar to Site 536 (Fernández et al., 1991). In DSDP Site 354 core (18-5, 136 cm), we found a layer with abundant spherules in lower Maastrichtian sedimentary deposits. These spherules, however, are concretions of the mineral siderite which form in anoxic, reducing, and organic-rich environments where they generally nucleate on foreign substances, such as small mineral grains, fecal pellets, or microfossils (Eh = −0.2 to −0.4; pH = 7.0 to 7.8). Spherules of this type are particularly widespread in Cretaceous black shales.

Our stratigraphic analyses show that none of the deep-sea sites cored to date exhibit continuous sediment accumulation across the K-T boundary and that the best records may be preserved in onshore marine sections in Mexico, Cuba, and Haiti. These sections will require further stratigraphic, petrologic, and mineralogic investigations to determine the nature and origin of their clastic Cretaceous deposits.

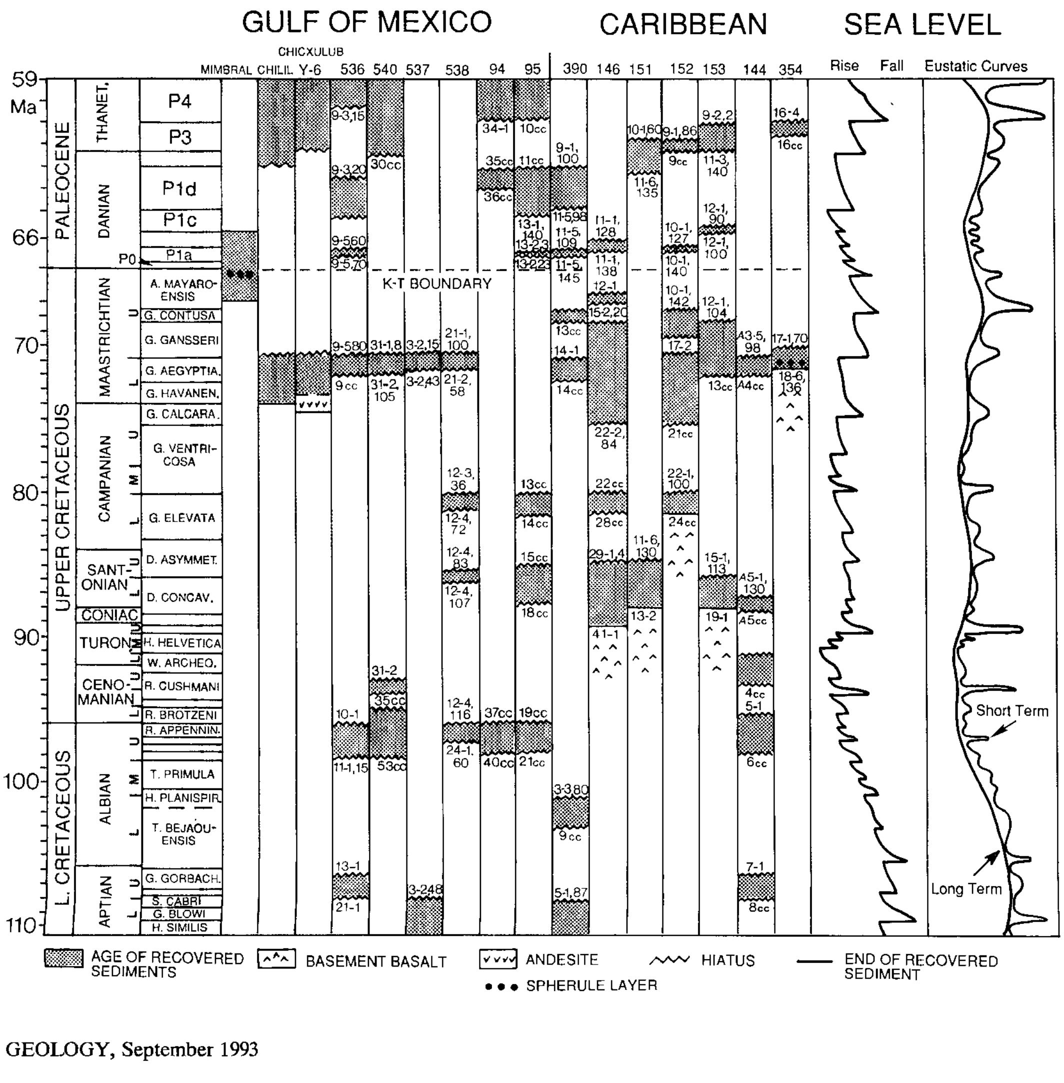

Figure 4. Sea-level changes, Cretaceous to Paleocene sedimentation, and hiatus patterns based on planktic foraminiferal evidence in Gulf of Mexico, Mexico, Caribbean, and western Atlantic. Note absence of K-T boundary-age sedimentary deposits, except at Mimbral, northeastern Mexico. Time scale and sea-level curves from Haq et al. (1987).

REGIONAL HIATUS PATTERNS

Patterns of sediment accumulation during the Cretaceous to early Paleocene in the Gulf of Mexico, including Mexico, the Caribbean, and western Atlantic, are illustrated in Figure 4 along with the sea-level curves of Haq et al. (1987). These 16 deep-sea and onshore marine sections represent a comprehensive history of sediment deposition and erosion in this region. The most conspicuous pattern is that of a highly fragmented sedimentary record, with more sediment missing than is deposited, due to repeated hiatuses and erosion. Moreover, erosion and net deposition patterns seem to be systematic, rather than random, suggesting that they originated as a response to regional oceanographic events. Within this long-term pattern of repeated hiatuses, the K-T boundary hiatus is not unusual and shows no unique erosional features. In fact, an evaluation of the K-T boundary transition worldwide has revealed that a hiatus is present in nearly all deep-sea sections below 1000 m depth, whereas sediment deposition is more continuous in continental shelf regions (MacLeod and Keller, 1991a, 1991b). This differential pattern of hiatus distribution across the K-T boundary appears to be linked to eustatic sea-level fluctuations. During the late Cretaceous to Paleocene, these repeated patterns of sediment deposition and erosion in the Gulf of Mexico and Caribbean region may also be linked to current circulation as well as sea-level fluctuations. Present limitations in dating, however, prevent correlation of these hiatuses to specific eustatic sea-level falls.

CONCLUSIONS

Biostratigraphic, sedimentologic, and petrologic studies of deep water Gulf of Mexico, Mexico, and Caribbean sections indicate a regional depositional hiatus that spans an interval from the lower upper Maastrichtian to lower Tertiary, or ~200 ka after the K-T boundary. This hiatus is found throughout the Caribbean and Gulf of Mexico and appears to be related to intensified current circulation associated with a sea-level lowstand. In contrast, trans–K-T sediment accumulation in the shallower northeastern Mexico section (e.g., Mimbral) appears to have been nearly continuous across the K-T boundary. The current-bedded clastic sedimentary deposits of DSDP Sites 536 and 540, as well as Mimbral, all of which were previously interpreted as impact-generated megawave deposits, are of pre–K-T boundary age and were probably deposited by turbidite or gravity flows. These deposits contain no unequivocal evidence of impact origin. As a result of this regional boundary hiatus, none of the 16 K-T boundary sections examined for this report can provide evidence for impact-generated megawave deposits.

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