# Ejecta layer at the Cretaceous-Tertiary boundary, Bass River, New Jersey (Ocean Drilling Program Leg 174AX)

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## ABSTRACT

**A continuously cored borehole drilled at Bass River, New Jersey, recovered a Cretaceous-Tertiary (K-T) succession with a 6-cm-thick spherule layer immediately above the boundary. Below the spherule layer, the Cretaceous glauconitic clay is extensively burrowed and contains the uppermost Maastrichtian *Micula prinsii* calcareous nannofossil zone. Spherical impressions of spherules at the top of the Cretaceous indicate nearly instantaneous deposition of ejecta from the Chicxulub impact. The thickest ejecta layer shows clearly that a single impact occurred precisely at K-T boundary time.**

**Above the spherule layer, the glauconitic clay contains the planktonic foraminiferal P0 and Pα Zones, indicating (1) a complete K-T succession and (2) continuous deposition interrupted only by fallout of the ejecta layer. Clay clasts within a 6 cm interval above the spherule layer contain Cretaceous microfossils and may be rip-up clasts from a tsunami or possibly a megastorm event. Extinction of the Cretaceous planktonic foraminifers and burrowing organisms occurs abruptly at the K-T boundary. Thus, the Bass River K-T succession unequivocally links the Chicxulub bolide impact to the mass extinctions at the end of the Mesozoic.**

## INTRODUCTION

Cretaceous-Tertiary (K-T) boundary stratigraphic sections in the Gulf Coastal Plain are characterized by two kinds of deposits, a spherule bed or beds and a deep-water siliciclastic succession including exotic clasts of varying sizes. The spherule layers are interpreted as ejecta fallout from a bolide impact at Chicxulub, Yucatán, Mexico (Smit et al., 1992a), although this interpretation has been questioned (Stinnesbeck et al., 1993; Keller et al., 1994a). The siliciclastic succession is interpreted as the result of backwash off the adjacent land mass from a bolide impact–generated megatsunami. This explanation has been questioned by Bohor (1996), López-Oliva and Keller (1996), Keller et al. (1993, 1994a), and Stinnesbeck and Keller (1996), who interpret the siliciclastic succession as due to turbidity currents during an episode of lower sea level. Although many workers maintain a K-T boundary age for the Chicxulub crater, the spherule beds, and the siliciclastic succession (Hildebrand et al., 1991; Sharpton et al., 1992; Swisher et al., 1992; Smit et al., 1992a, 1996; Pêcheux and Michaud, 1997), others argue for a late Maastrichtian age (Meyerhoff et al., 1994; Ward et al., 1995, Keller et al., 1997). These disagreements apparently stem from the complexity of the structural, stratigraphic, and paleontologic relationships of the Chicxulub crater and the stratigraphic-paleontologic relationships of the spherule and siliciclastic succession, which have been interpreted differently by these workers.

In November 1996, the New Jersey Coastal Plain Drilling Project (Ocean Drilling Program Leg 174AX) recovered a 596.5 m continuously cored section at Bass River, New Jersey (Fig. 1) (Miller et al., 1997). The K-T boundary was recovered at 384.2 m within a 1.5 m core barrel and occurs in a marine glauconitic clay succession, the paleodepth of which was about 100 m. The succession includes a 6-cm-thick spherule bed overlain by a 6 cm zone that includes clay clasts of varying sizes (Fig. 1). This is the farthest from the Chicxulub crater (~2500 km) that a distinct spherule layer (i.e., one that is >2 cm in thickness) has been identified and it is the first confirmed nonturbidite spherule bed outside the Gulf of Mexico. In contrast to the K-T boundary succession in the Gulf Coastal Plain, the placement of the K-T boundary in the Bass River borehole is unequivocal, and its relationship to the spherule layer is clear.

## K-T BOUNDARY STRATIGRAPHY

In the Bass River borehole, the lowermost Paleocene is separated from the Maastrichtian by a 6-cm-thick spherule layer (Fig. 2). Foraminifera are present in the lower Paleocene Hornerstown Formation, but they are much fewer in number than in the upper Maastrichtian New Egypt Formation. Calcareous nannofossils are present but poorly preserved, although dinoflagellates are well preserved and common. Body fossils of invertebrates are absent in the basal 10 cm of the Hornerstown Formation, although echinoid spines and fecal pellets indicate their presence. Marine invertebrates are represented by a few fish teeth. The uppermost Maastrichtian is richly fos-

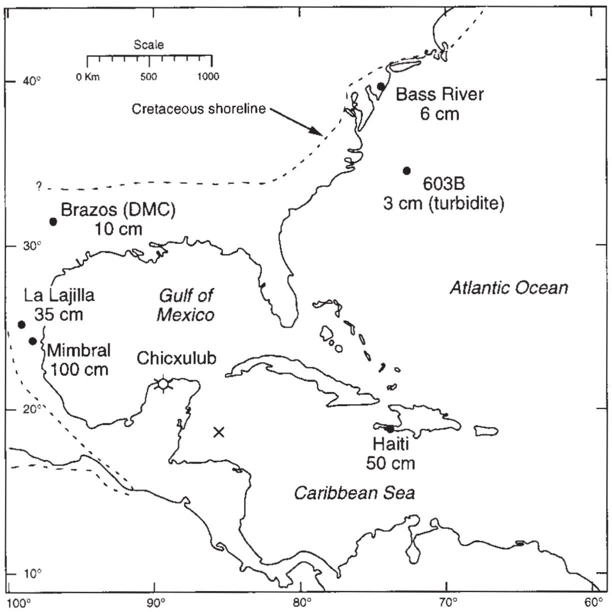


**Figure 1. Location of Bass River borehole and location and thicknesses of identified spherule layers in marine setting. Brazos (DMC)—Darting Minnow Creek. Site 603 spherules are from a turbidite. Haiti was located about 700 km south of Chicxulub (X) at Cretaceous-Tertiary (K-T) time.**

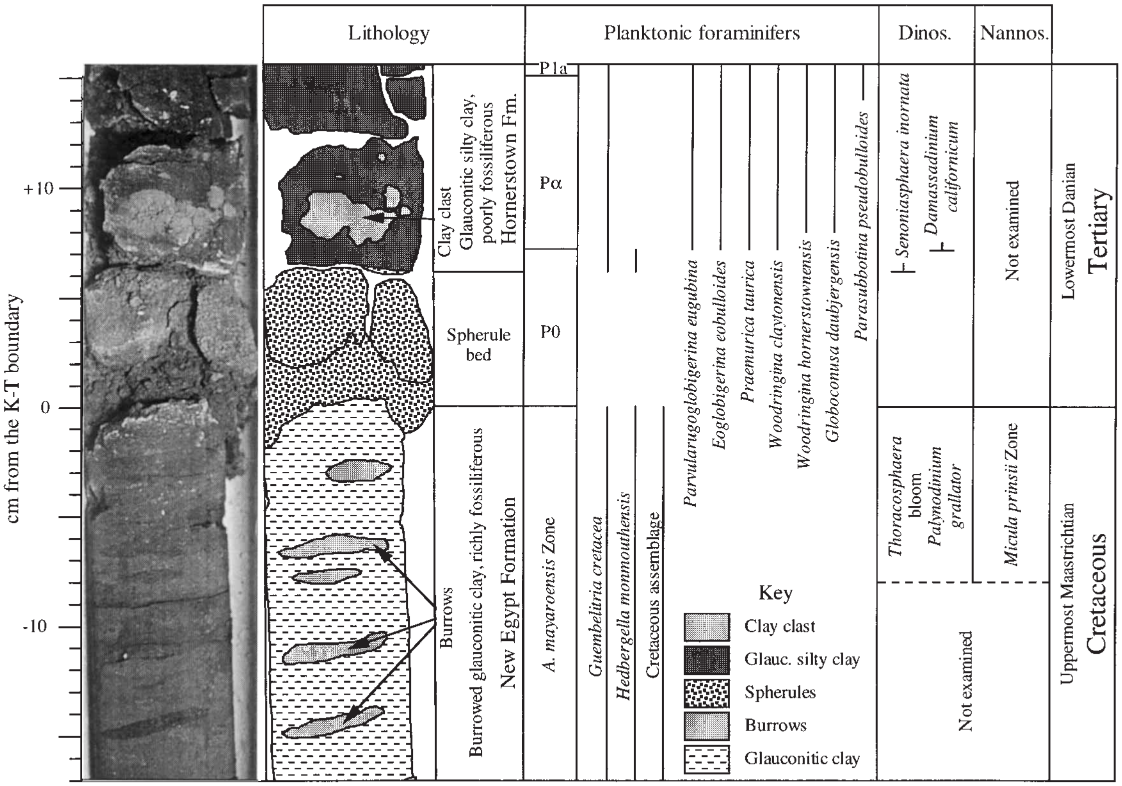


**Figure 2. Bass River borehole Cretaceous-Tertiary boundary core showing spherule layer and microfossil biostratigraphy. Note burrows in Maastrichtian and clay clasts in lower 6 cm of the Paleocene.**

siliferous in foraminifera, calcareous nannofossils, and dinoflagellates. It is heavily burrowed (Fig. 2). Above the spherule layer, calcareous clay clasts occur in the basal 6 cm of the Paleocene. The clasts appear to have been redeposited on the spherule bed, and even reworked during subsequent burial by the Hornerstown sediments. They contain Cretaceous foraminifera and calcareous nannofossils, indicating that they were derived from the underlying Cretaceous glauconitic clays.

## BIOSTRATIGRAPHY AT THE K-T BOUNDARY

A complete K-T boundary section at Bass River is indicated by the presence of the uppermost Maastrichtian calcareous nannofossil *Micula prinsii* Zone below the spherule layer and the basal Danian planktonic foraminiferal *Guembelitria cretacea* P0 Zone in the 1 cm immediately overlying the spherule bed. The dinoflagellate *Palynodinium grallator,* which has an uppermost Maastrichtian first occurrence (FO), is also present in the 8 cm immediately below the spherule layer. The planktonic foraminiferal assemblage, although lacking the upper Maastrichtian marker, *Abathomphalus mayaroensis*, contains an associated assemblage that includes *Globotruncana aegyptiaca, Globotruncanita conica, Globotruncanita stuarti,* and *Rugoglobigerina reicheli,* among others. *Abathomphalus mayaroensis* apparently lived at deeper depths than occurred during deposition of the uppermost Cretaceous at Bass River. In the New Jersey region, this taxon has only been found in deep-water locations (e.g., Site 605 on the New Jersey continental slope; Jansen and Kroon, 1987).

In the basal Paleocene, Zone P0 is overlain by Zone Pα (=*Parvularugoglobigerina eugubina* Zone), which is about 8 cm thick. The dinoflagellate *Senoniasphaera inornata,* the FO of which is associated with Zone P0 (Habib et al., 1996), occurs immediately above the spherule layer. The FO of dinoflagellate *Damassadinium californicum,* whose FO is associated with the base of Pα (Habib et al., 1996), coincides with the FO of *P. eugubina*. Thus, the K-T section at Bass River is biostratigraphically complete and deposition is interrupted only by the occurrence of the spherule layer.

## SPHERULE BED

The spherule bed at Bass River, which represents diagenetically altered (smectite?) impact ejecta, consists of a coarse, poorly graded, poorly sorted, and poorly cemented unit. The sand-sized component contains white oval-shaped spherules, gray irregularly shaped intraclasts, and dark gray spherical-shaped spherules (Fig. 3). Gray matrix, similar to the intraclasts, surrounds some of the spherules along with euhedral pyrite crystals. The white spherules (175–1100 µm in diameter) have a smooth outer surface that consists of a thin solid rind. Internally, they consist of fine matrix that includes spherical globules (50–150 µm in diameter). They are similar to the spherules that occur in K-T turbidites at Deep Sea Drilling Project Site 603B in the western North Atlantic southeast of New Jersey (Klaver et al., 1987), Gulf of Mexico outcrops at El Mimbral and La Lajilla, Mexico (Smit et al., 1992b; Keller et al., 1994b), and at Darting Minnow Creek, Texas (Smit et al., 1992b). The gray irregular intraclasts (475–1250 µm in diameter) are subangular, and some have a vesicular surface (Fig. 3). The dark gray spherical-shaped spherules (375–875 µm in diameter) are uniformly smooth; pyrite replaces them in varying degrees (Fig. 3).

The contact of the spherule bed with the uppermost Cretaceous is interesting, if not spectacular. The top surface of the Cretaceous contains spherical impressions, 750 to 1125 µm in diameter (Fig. 4). The impressions are soft-sediment deformation features that probably formed by settling of glassy spherical droplets into a soft substrate and indicate deposition on a surface undergoing sedimentation (i.e., nonerosional). In contrast, the upper contact of the spherule layer is sharp and the layer is more fine grained. The upper centimeter of the spherule layer contains shocked quartz (G. Izett, 1997, personal commun.) and may represent in part the “impactor-rich” layer.

## SEA LEVEL AT K-T BOUNDARY TIME

The depth of the Bass River Site at the end of the Cretaceous was ~100 m, judging from the benthic foraminiferal assemblage. Characteristic species include *Alabaminina midwayensis* Brotzen, *Anomalinoides acuta* (Plummer), *Buliminella carseyae* Plummer, *Coryphostoma plai-*

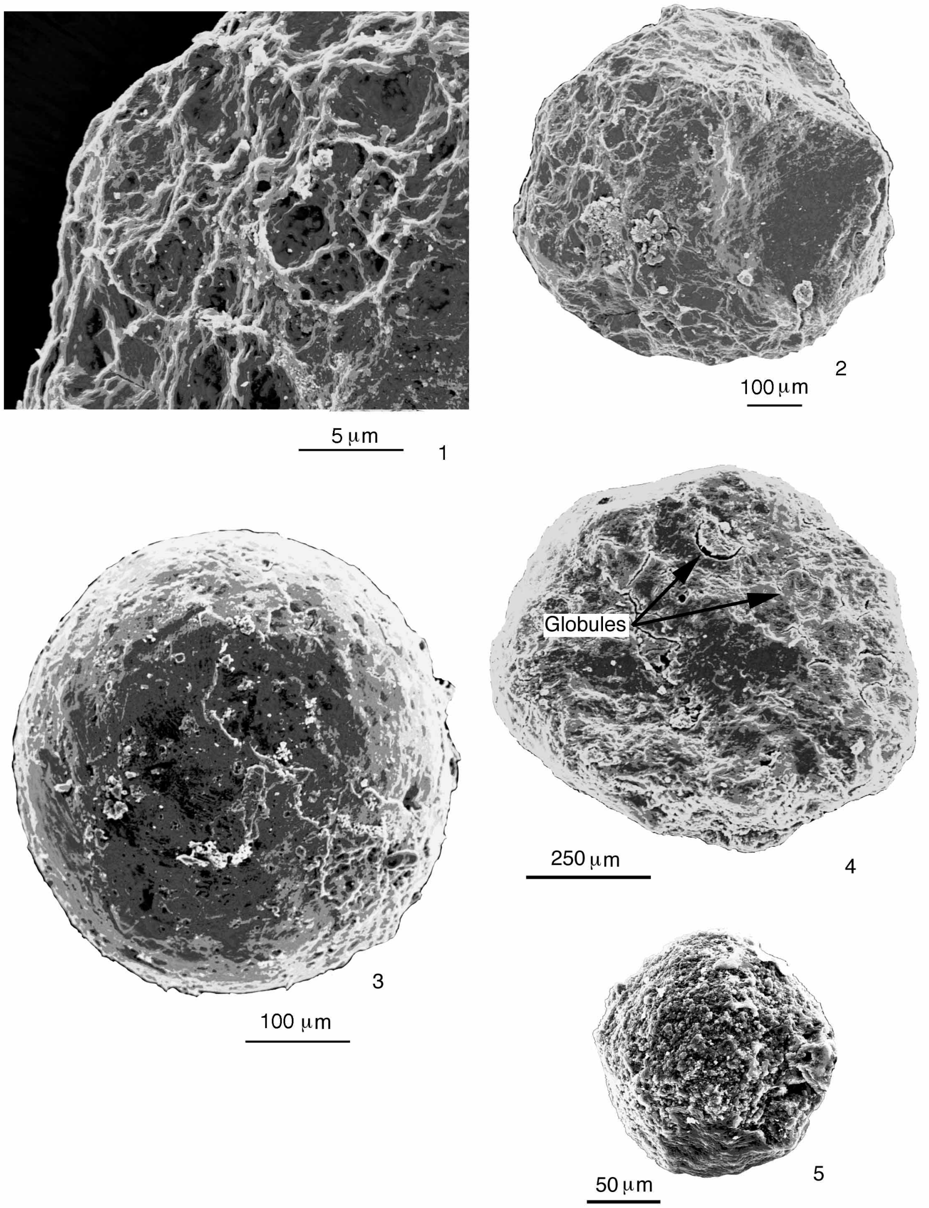


**Figure 3. Scanning electron microscope photographs of spherules, globules, and intraclasts. 1 and 2: Gray, subangular-shaped intraclast; 1 is enlargement of 2 showing vesicular surface. 3: Dark gray spherule. 4: Oval-shaped white spherule showing outlines of internal globules (arrows). 5: Globule separated from interior of a white spherule.**

*tum* (Carsey), *Osangularia navarroana* (Cushman), *Pulsiphonina prima* (Plummer), and *Valvulineria depressa* (Alth). Planktonic foraminifera compose about 35%. This benthic assemblage lived in middle-shelf environments with paleodepths of ~100 m (Olsson and Nyong, 1983). The assemblage continues into the Paleocene with much lower percentages (~4%) of planktonic foraminifera, due to planktonic extinctions. The percentage of planktonic foraminifera is higher (71%) 16 cm below the K-T boundary, suggesting somewhat deeper shelf paleodepths. Thus, sea level appears to have fallen before the K-T boundary but remained at middle-shelf depths across the K-T.

## DISCUSSION AND CONCLUSIONS

The K-T boundary succession at Bass River unequivocally shows that the formation of a spherule layer caused a brief interruption of deposition in a middle-shelf environment. The derivation of the spherule layer had to have come from fallout of a ballistic vapor cloud generated by a bolide impact at Chicxulub, Yucatán, at K-T boundary time. Geophysical data presented by Schultz and D'Hondt (1996) showed asymmetries in the Chicxulub structure that suggested a low-angle (20°–30° from the horizon), southeast-to-northwest trajectory for the Chicxulub bolide. As a consequence, "devastation may have been most severe and catastrophic in the Northern Hemisphere" (Schultz and D'Hondt, 1996, p. 963). At locations closest to the Chicxulub crater, such as El Mimbral, Mexico, the spherule layer is as thick as 100 cm (Fig. 1). Farther to the north, the spherule layer at Darting Minnow Creek at Brazos, Texas, is about 10 cm thick and at Bass River, New Jersey, is 6 cm thick. The thickness of the spherule layer is consistent with the southeast low-angle impact hypothesis for the Chicxulub impactor (Schultz and D'Hondt, 1996), but it should be noted that there is little data on the occurrence of spherule beds south of Chicxulub. A 6 cm spherule layer about 2500 km north of the Chicxulub crater indicates that large volumes of ejecta material were spread great distances down range from the Chicxulub impact. Velocities of ejecta from the impactor, calculated by Alvarez (1996) and Schultz and D'Hondt (1996), indicate that re-entry of ballistic ejecta would have reached Bass River within about 10 min and, applying Stokes' Law, would have settled to the sea floor within a matter of minutes to less than an hour. In a geologic sense, deposition of the spherule layer was instantaneous.

The calcareous clay clasts in the basal 6 cm of the Paleocene may have originated from the erosive action of an impact-generated tsunami (Bourgeois et al., 1988) on the Cretaceous sea bed or possibly by another process, such as megastorms (Emanuel et al., 1995). Because only small pieces of Cretaceous clay were involved (Fig. 2) the mechanism of their emplacement needs further study.

The biologic effects of the Chicxulub impact are clearly marked by the spherule bed (Fig. 2). The richly fossiliferous beds of the Cretaceous give way to more sparsely fossiliferous beds in the Danian. Among the foraminifera, there is a reduction in size among the benthic foraminifera and the mass extinction of the Cretaceous planktonic foraminifera assemblage. *Guembelitria cretacea, Hedbergella holmdelensis,* and *H. monmouthensis* were the only survivor planktonic foraminifera. Thus, the stratigraphic section at Bass River establishes that deposition of the spherule layer derived from the impact at Chicxulub and the mass extinction of marine biota are linked unequivocally to the K-T boundary. It is also clear that a single devastating impact event occurred at this critical time in Earth history, and that killing mechanisms (see D'Hondt et al., 1994) apparently operated on a very short time scale.

## ACKNOWLEDGMENTS

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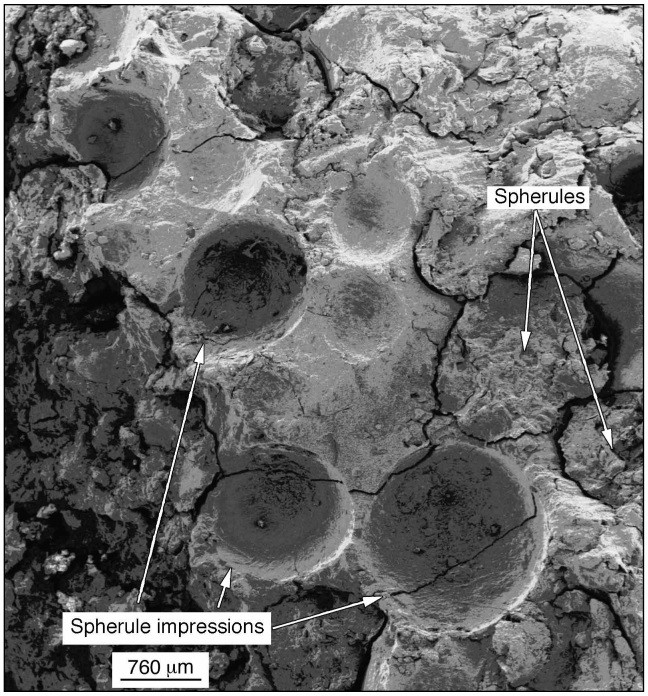


**Figure 4. Scanning electron microscope photograph of top of Maastrichtian showing soft-sediment deformation made by settling of spherules into somewhat soupy substrate. Note spherical depressions and depressions containing replaced spherules (arrows).**

photograph. This is Lamont-Doherty Earth Observatory Contribution number 5650.

**REFERENCES CITED**

Alvarez, W., 1996, Trajectories of ballistic ejecta from the Chicxulub Crater, *in* Ryder, G., et al., eds., The Cretaceous-Tertiary event and other catastrophes in Earth history: Geological Society of America Special Paper 307, p. 141–150.

Bohor, B. F., 1996, A sediment gravity flow hypothesis for siliciclastic units at the K/T boundary, northeastern Mexico, *in* Ryder, G., et al., eds., The Cretaceous-Tertiary event and other catastrophes in Earth history: Geological Society of America Special Paper 307, p. 183–196.

Bourgeois, J., Hansen, T. A., Wiberg, P. L., and Kauffman, E. G., 1988, A tsunami deposit at the Cretaceous-Tertiary boundary in Texas: Science, v. 241, p. 567–570.

D'Hondt, S., Pilson, M. E. Q., Sigurdsson, H., Hanson, A. K., Jr., and Carey, S., 1994, Surface-water acidification and extinction at the Cretaceous-Tertiary boundary: Geology, v. 22, p. 983–986.

Emanuel, K. A., Speer, K., Rotunno, R., Srivastava, R., and Molina, M., 1995, Hypercanes: A possible link in global extinction scenarios: Journal of Geophysical Research, v. 100, p. 13,755–13,765.

Habib, D., Olsson, R. K., Liu, C., and Moskovitz, S., 1996, High-resolution biostratigraphy of sea-level low, biotic extinction, and chaotic sedimentation at the Cretaceous-Tertiary boundary in Alabama, north of the Chicxulub Crater, *in* Ryder, G., et al., eds., The Cretaceous-Tertiary event and other catastrophes in Earth history: Geological Society of America Special Paper 307, p. 243–252.

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 Yucatán Peninsula, Mexico: Geology, v. 19, p. 867–871.

Jansen, H., and Kroon, D., 1987, Maestrichtian foraminifers from Site 605, Deep Sea Drilling Project Leg 93, northwest Atlantic, *in* van Hinte, J. E., Wise, S. W., et al., Initial reports of the Deep Sea Drilling, Project Volume 93: Washington, D.C., U.S. Government Printing Office, p. 555–576.

Keller, G., MacLeod, N., Lyons, J. B., and Officer, C. B., 1993, Is there evidence for Cretaceous-Tertiary boundary-age deep-water deposits in the Caribbean and Gulf of Mexico?: Geology, v. 21, p. 776–780.

Keller, G., Stinnesbeck, W., and Lopez-Oliva, J. G., 1994a, Age, deposition, and biotic effects of the Cretaceous/Tertiary boundary event at Mimbral, NE Mexico: Palaios, v. 9, p. 144–157.

Keller, G., Stinnesbeck, W., Adatt, T., MacLeod, N., and Lowe, D. R., 1994b, Field guide to Cretaceous-Tertiary boundary sections in northeastern Mexico: Lunar and Planetary Institute Contribution 827, 110 p.

Keller, G., Lopez-Oliva, J. G., Stinnesbeck, W., and Adatt, T., 1997, Age, stratigraphy, and deposition of near-K/T siliclastic deposits in Mexico: Relation to bolide impact?: Geological Society of America Bulletin, v. 109, p. 410–428.

Klaver, G. T., van Kempen, T. M. G., Bianchi, F. R., and van der Gaast, S. J., 1987, Green spherules as indicators of the Cretaceous/Tertiary boundary in Deep Sea Drilling Project Hole 603B, *in* van Hinte, J. E., Wise, S. W., Jr., et al., Initial reports of the Deep Sea Drilling Project, Volume 93, Washington, D.C., U.S. Government Printing Office, p.1039–1056.

López-Oliva, J. G., and Keller, G., 1996, Age and stratigraphy of near-K/T boundary siliciclastic deposits in northeastern Mexico, *in* Ryder, G., et al., eds., The Cretaceous-Tertiary event and other catastrophes in Earth history: Geological Society of America Special Paper 307, p. 227–242.

Meyerhoff, A. A., Lyons, J. B., and Officer, C. B., 1994, Chicxulub structure: A volcanic sequence of Late Cretaceous age: Geology, v. 22, p. 3–4.

Miller, K. G., Sugarman, P. J., et al., 1997, ODP, Initial reports of the Ocean Drilling Program, Leg 174X: College Station, Texas, Ocean Drilling Program (in press).

Olsson, R. K., and Nyong, E. E., 1984, A paleoslope model for Campanian-lower Maestrichtian foraminifera of New Jersey and Delaware: Journal of Foraminiferal Research, v. 14, p. 50–68.

Pêcheux, M., and Michaud, F., 1997, Yucatán subsurface stratigraphy: Implications and constraints for the Chicxulub impact: Comment and Reply: Geology, v. 25, p. 92.

Schultz, P. H., and D'Hondt, S., 1996, Cretaceous-Tertiary (Chicxulub) impact angle and its consequences: Geology, v. 24, p. 963–967.

Sharpton, V. L., Dalrymple, G. B., Marin, L. E., Ryder, G., Schuraytz, B. C., and Urrutia-Fucugauchi, J., 1992, New links between the Chicxulub impact structure and the Cretaceous-Tertiary boundary: Science, v. 359, p. 819–821.

Smit, J., and eight others, 1992a, Tektite-bearing, deep-water clastic unit at the Cretaceous-Tertiary boundary in northeastern Mexico: Geology, v. 20, p. 99–103.

Smit, J., Alvarez, W., Montanari, A., Swinbourne, N. H. M., Van Kempen, T. M., Klaver, G. T., and Lustenhouwer, W. J., 1992b, Tektites and microcrystites at the Cretaceous Tertiary boundary: Two strewn fields, one crater?: Lunar and Planetary Science Proceedings, v. 22, p. 87–100.

Smit, J., Alvarez, W., Claeys, P., Montanari, A., and Roep, Th. B., 1994, Misunderstandings regarding the K/T boundary deposits in the Gulf of Mexico, *in* New developments regarding the KT event and other catastrophes in Earth history: LPI Contribution 825, Lunar and Planetary Institute, Houston, Texas, p. 116–117.

Smit, J., Roep, Th. B., Alvarez, W., Montanari, A., Claeys, P., and Grajales-Nishimura, J. M., 1996, Coarse-grained, clastic sandstone complex at the K/T boundary around the Gulf of Mexico: Deposition by tsunami waves induced by the Chicxulub impact?, *in* Ryder, G., et al., eds., The Cretaceous-Tertiary event and other catastrophes in Earth history: Geological Society of America Special Paper 307, p. 151–182.

Swisher, C. C., and 11 others, 1992, Coeval $^{40}Ar/^{39}Ar$ ages of 65.0 million years ago from Chicxulub crater melt rock and Cretaceous-Tertiary boundary tektites: Science, v. 257, p. 954–958.

Stinnesbeck, W., and Keller, G., 1996, K/T boundary coarse-grained siliciclastic deposits in northeastern Mexico and northeastern Brazil: Evidence for mega-tsunami or sea-level changes?, *in* Ryder, G., et al., eds., The Cretaceous-Tertiary event and other catastrophes in Earth history: Geological Society of America Special Paper 307, p. 197–210.

Stinnesbeck, W., and 10 others, 1993, Deposition of channel deposits near the Cretaceous-Tertiary boundary in northeastern Mexico: Catastrophic or "normal" sedimentary deposits?: Geology, v. 21, p. 797–800.

Ward, W. C., Keller, G., Stinnesbeck, W., and Adatte, T., 1995, Yucatán subsurface stratigraphy: Implications and constraints for the Chicxulub impact: Geology, v. 23, p. 873–876.

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