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Yucatán subsurface stratigraphy: Implications and constraints for the Chicxulub impact

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ABSTRACT

Much of the discussion about the effects of an end-of-Cretaceous impact by a large extraterrestrial body in northwestern Yucatán has been done in the context of limited and partly erroneous published data on the Mesozoic stratigraphy of that area. Reexamination of cores and geophysical logs taken in several Pemex wells has produced improved lithologic and biostratigraphic correlation of the Jurassic to Maastrichtian section across the northern Yucatán peninsula. These data suggest that major disturbance of strata by an impact would have been confined to within about 100 km of the proposed impact center near Chicxulub. The only unusual lithologic unit is polymict breccia, which apparently was penetrated at or near the top of the Cretaceous section in all the deep wells of northern Yucatán. This breccia in Pemex wells Yucatán 1, 2, 4, 5A, and 6 is composed predominantly of detrital dolomite, limestone, and anhydrite clasts set in dolomitized carbonate mud matrix, which contains upper Maastrichtian foraminifers. These constituents, mixed with fragments of altered glass or melt rock, shocked quartz and feldspar, and basement rock, suggest an impact as the most likely origin for the breccia. The timing of brecciation is poorly constrained by biostratigraphic data. There is some evidence, however, that the breccia unit is overlain by about 18 m of uppermost Maastrichtian marls, suggesting an impact before the Cretaceous-Tertiary boundary. In addition, there may have been more than one episode of breccia deposition.

INTRODUCTION

Impact by a large extraterrestrial body near Chicxulub in northwestern Yucatán is widely credited with causing mass extinctions at the Cretaceous-Tertiary (K-T) boundary. In this paper we reexamine the stratigraphic and biostratigraphic context of the Chicxulub structure (Fig. 1) in order to (1) address the significance of the fragments of sedimentary rock within a widespread breccia near the top of the Cretaceous strata; (2) provide a better stratigraphic framework for estimating the extent of an impact structure (e.g., Camargo and Suárez, 1994; Pilkington and Hildebrand, 1994; Sharpton et al., 1996) and constraining postulations about the amount of carbonate and sulfate sedimentary rock that could have been vaporized by a large impact (e.g., Pope et al., 1994); and (3) evaluate estimates of the timing of an impact in the Chicxulub area in light of the limited core data near the K-T boundary.

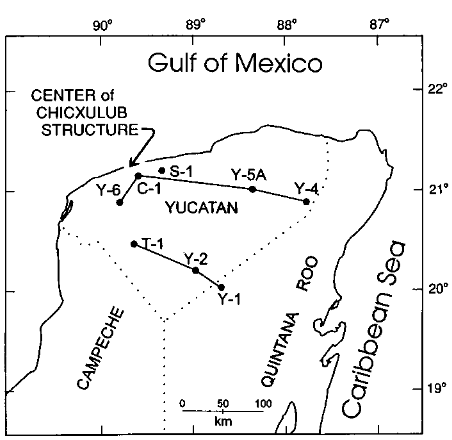

Figure 1. Map showing location of Pemex wells discussed in text, lines of cross section shown in Figure 2, and approximate location of center of Chicxulub structure (center according to Pilkington and Hildebrand, 1994).

The Chicxulub structure is thought to be the location of the K-T boundary impact because of the presence of shocked quartz and feldspar grains within some breccia samples (e.g., Hildebrand et al., 1991; Sharpton et al., 1992, 1994), anomalously high iridium values in isolated rock fragments previously described as andesites (Sharpton et al., 1992), the similarity in chemical compositions between Chicxulub glass within "andesitic" rocks and the tektite-like glasses in Haiti and northeastern Mexico (Smit et al., 1992; Stinnesbeck et al., 1993; Koeberl et al., 1994), $^{40}Ar/^{39}Ar$ age of 65 Ma in particles of altered(?) glass (Sharpton et al., 1992; Swisher et al., 1992), reversed polarity in two samples assumed to indicate paleomagnetic chron 29R (Sharpton et al., 1992), and the presence of concentric geophysical anomalies associated with breccia and andesitic rocks or melt rocks (Sharpton et al., 1993). Sharpton et al. (1992, p. 819) stated that this evidence from Chicxulub core samples apparently can "account for all the evidence of impact distributed globally at the K-T boundary." Although biostratigraphic timing of K-T events may be determined more precisely at some other places in the world, there are only limited stratigraphic and biostratigraphic data near the K-T boundary of northern Yucatán.

DATABASE

The stratigraphy of the northern Yucatán platform can be inferred primarily from Petróleos Mexicanos (Pemex) exploration wells drilled across the peninsula (Fig. 1) in the 1950s and 1960s (Murray and Weidie, 1962; López Ramos, 1973, 1975; Marshall, 1974; Weidie, 1985; Meyerhoff et al., 1994). Our rock and fossil data are from small pieces of the 3–5-m-long cores taken in Pemex wells Yucatán 1, 2, 4, 5A, and 6. Core coverage near the K-T boundary is not good (Fig. 2). In addition to the cores, for each well there are resistivity-spontaneous potential logs and various lithologic logs made from cuttings. The electric logs are of variable quality, but they can be used for stratigraphic correlations in the lower two-thirds of the logged intervals.

We were unable to obtain access to samples in the lower part of well Y6 and therefore relied primarily on published information (López Ramos, 1973, 1975; Meyerhoff et al., 1994). Furthermore, we were unable to examine samples from wells Sacapuc 1 (S1) and Chicxulub 1 (C1), near the center of the postulated impact structure, nor from Ticul 1 (T1), 95 km to the south (Fig. 1). We relied on electric logs and published lithologic and paleontological descriptions for these wells.

STRATIGRAPHY

The Pemex wells we examined penetrated about 1300–3500 m of stratified Tertiary, Cretaceous, and Jurassic sedimentary rocks. Paleozoic metamorphic rocks were encountered at 2418 m in well Y4 and at 3202 m in well Y1 (Fig. 2). "Volcanic rock" (e.g., López Ramos, 1975; Meyerhoff et al., 1994) or "impact-melt rock" (e.g., Sharpton et al., 1992; Schuraytz et al., 1994) was encountered in the lower parts of wells Y6, C1, and S1 (Fig. 2). We identified and correlated

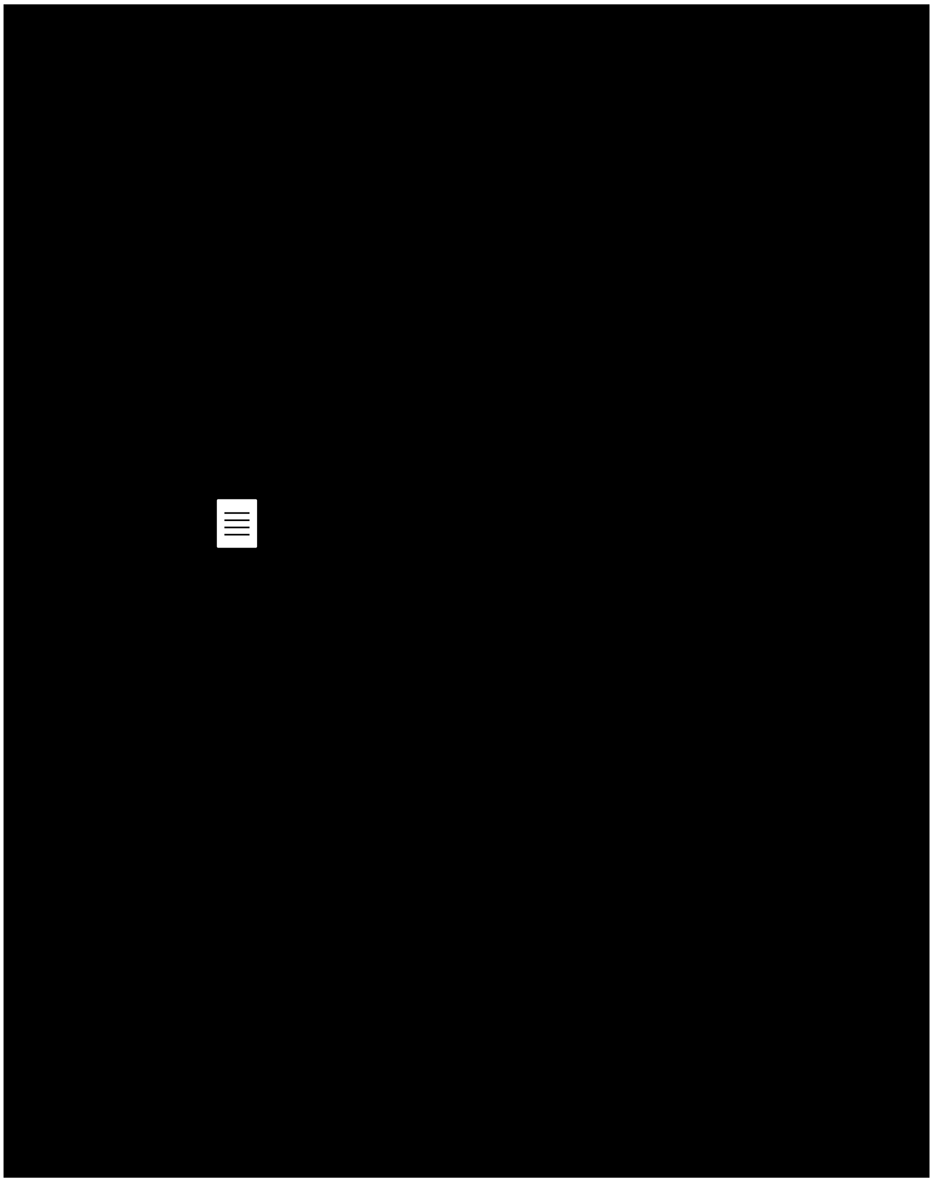

Figure 2. Correlation sections through Pemex wells of northern Yucatan Peninsula. Datum is ground level, which is within several metres above sea level at all locations. Y wells = Yucatán Nos. 1, 2, 4, 5A, and 6; C well = Chicxulub No. 1; T well = Ticul No. 1. Large-scale units of Mesozoic (units A–G) are based on lithology, correlative fossil zones, and electric-log characteristics. Unit boundaries are defined by log correlation. Approximate ages of units: A—Jurassic–Early Cretaceous, B—Albian, C—Albian-Cenomanian, D—Cenomanian-Turonian, E—Turonian, F—Coniacian?-Maastrichtian, G—late Maastrichtian.

seven major biostratigraphic-lithostratigraphic units in the Mesozoic section overlying basement rocks (Fig. 2).

Unit A consists of red and gray sandstone, shale, and silty dolomite that was penetrated near the base of wells Y1, Y2, and Y4. This unit is Jurassic to Early Cretaceous in age (López Ramos, 1975).

Unit B is predominantly dolomite in the lower part and becomes rich in anhydrite and dolomite upward. Rock salt was cored in this unit in T1 at 2378–2381 m (Murray and Weidie, 1962, p. 38). *Nummoloculina* was identified in Y2-40 (Fig. 2), and was reported to occur in this unit in T1 (Murray and Weidie, 1962), suggesting an Albian age for unit B.

Unit C is predominantly shallow-water limestone in the lower part, becoming more dolomitic upward. At the base of unit C in wells Y1 and Y2 is a horizon with the large benthic orbitulinid foraminifer *Dicyclina schlumbergeri*? (Fig. 2). *Nummoloculina* (*N. heimi*?) also occurs in the lower part of this unit in cores Y1-38 and Y4-27 (Fig. 2). Nearer the platform margin (Y4), the upper part of this unit contains rudist limestone, but in other wells the rocks reflect more restricted depositional environments in the platform interior. Shallow-subtidal to intertidal dolomite makes up most of this section in Y5A, and anhydrite is interlayered with dolomite in the upper part of the unit in Y1, Y2, and T1. The fossil assemblage indicates an Albian-Cenomanian age for unit C.

Unit D is predominantly somewhat deeper-subtidal limestone and marl, containing horizons with abundant tiny, mainly trochospiral planktic foraminifers that were identified in samples Y1-24 and 27, Y2-17 and 18, Y4-20 and 21, and Y5A-17 (Fig. 2). We tentatively correlate this horizon and its conspicuous small-sized fauna with the Bonarelli event near the Cenomanian-Turonian boundary (Jarvis et al., 1988).

Unit E consists of shallow-platform limestones with intervals containing abundant small planktic foraminifers. The unit contains rudist-bearing limestones (Fig. 2), which were considered by López Ramos (1975) as Turonian in age, and a similar age is indicated by the presence of *Marginotruncana pseudolinneiana* and *Dicarinella imbricata* in samples Y1-25, Y2-18, Y4-17, and Y5A-14.

Unit F consists of dolomitized shallow-platform limestone with benthic foraminifers. Abundant textularid and miliolid foraminifers are at the top of unit F (Fig. 2). The presence of *Marginotruncana schneegansi* and *Globotruncana fornicata* in well Y5A-7 suggests a Santonian age for that part of this unit.

Unit G is a thick interval of breccia with abundant sand- to gravel-sized angular to subrounded fragments of dolostone, anhydrite, and lesser limestones that are suspended in a dolomicrite matrix. The poorly sorted fabric is similar to that of debris-flow deposits. López Ramos (1973) reported marl and limestone intercalations within the thick breccia from 1090 to 1270 m in well C1 (Figs. 1 and 2). In addition, Y4-4 and Y4-5 (Fig. 2) contain dolomite that may separate an upper breccia with rare or no planktic foraminifers from a lower breccia with abundant planktic foraminifers. Core Y2-7 is finely crystalline anhydrite, possibly also representing an undisturbed sedimentary layer within the breccia interval.

Clasts of carbonate rocks in these breccias are fragments of many different kinds of dolostone and limestone, which have different diagenetic histories. Anhydrite fragments typically make up 15%–20% of the breccia; much of the anhydrite is tiny angular cleavage splinters. Some breccia layers contain gray-green fragments of altered "glass." Other minor but significant constituents of the breccia are fragments of melt rock and basement rock noted by Schuraytz et al. (1994) in Y6-17 (1295.5–1299 m), Y6-19 (1377–1379.5 m), and C1-10 (1393–1394 m). In addition, Hildebrand et al. (1991, 1994) found shocked quartz from Y6-14 (1208–1211 m), and Sharpton et al. (1994) reported shock-deformed quartz and feldspar grains and melt inclusions in the dolomite-anhydrite breccia.

Planktic and benthic foraminifers are present in the breccia matrix and include *Abathomphalus mayaroensis*, *Globotruncanita conica*, *Rosita patelliformis*, *Pseudoguembelina palpebra*, *Racemiguembelina fructicosa*, and *Hedbergella monmouthensis*, which indicate a late Maastrichtian age for deposition of the breccia.

IMPLICATIONS FROM MESOZOIC STRATIGRAPHY OF NORTHERN YUCATAN

Any considerations of an end-of-Cretaceous impact in northwestern Yucatán should be done within the context and constraints of the Mesozoic stratigraphy of that area. The subsurface geology and biostratigraphy of northern Yucatán provide implications about the possible effects and timing of any such impact and the size of the structure that it could have produced.

Origin of Breccia

Sample descriptions from every well in northern Yucatán indicate that there is some sort of breccia or other anomalous deposits at or near the top of the Cretaceous strata. "Sandstone" in this part of the section (e.g., 1215–1250 m in well Y6 as described in Meyerhoff et al., 1994) should be considered anomalous, because this area was a broad carbonate platform during the Late Cretaceous, and there was no normal source for terrigenous sedimentation. Given the present sample control, it is not known whether these widespread breccias and "sandstones" are deposits of a single unit or of a zone of breccias. That there may have been more than one period of breccia deposition is suggested by core 7 (anhydrite) from well Y2, as well as cores 4 and 5 (dolomite) from Y4 (Fig. 2). These layers may represent undisturbed beds of sedimentary rock within the breccia interval. In addition, López Ramos (1973) reported limestone within the breccia interval in Y6. The small samples of cores Y4-4 and Y4-5, however, are highly fractured and may be pieces of particularly large breccia clasts rather than undisturbed layers.

Previous workers have considered several origins for the matrix-supported breccia: (1) penecontemporaneous disturbance or weathering, (2) collapse, (3) volcanism, (4) faulting, or (5) impact by a large extraterrestrial body such as an asteroid or comet.

The thickness and composition of the breccia argue against 1 and 2. Typical rip-up breccias and collapse breccias are far thinner than hundreds of metres. The tiny cleavage fragments of anhydrite indicate that the evaporite was anhydrite at the time of brecciation. Generally, bedded anhydrite such as this is the product of at least a few hundred metres of burial. These anhydrite clasts mixed with fragments of various types of dolomite and limestone show that this breccia was derived from excavation of older rocks, not from rip up of penecontemporaneous evaporites and carbonates. Collapse breccias form by dissolution of evaporites and carbonates, but in these breccias there is no evidence of dissolution of the constituents. Most of the anhydrite clasts appear to be mechanically fragmented, but not altered.

The fairly common occurrence of clasts resembling altered lapilli and "bentonitic breccia" (e.g., López Ramos, 1975; Meyerhoff et al., 1994) might indicate a volcanic source for the breccia. Even though laharic breccias in some tectonic settings may travel hundreds of kilometres from the source area and, after long periods of successive eruptions, attain thicknesses of a few hundred metres (Fisher and Schmincke, 1984), it is implausible that submarine volcanic activity within the Yucatán crustal block (an anomalous setting for volcanic activity) could generate lahars to equal the apparent thickness and distribution of the Upper Cretaceous breccia. In addition, the composition of the Yucatán breccia is unlike that of lahars or other volcano-related deposits. Most of the coarser nonigneous material is not derived from layers that were at or near the surface penecontemporaneous with deposition of the breccia. In addition, the mud matrix in the breccias in wells Y1, Y2, Y4, and Y5A is composed of carbonates, not clay minerals, as would be expected in lahars or other pyroclastic rocks.

Faulting could supply detritus for polymict breccias, but faulting along the margins of the Yucatán platform during the Late Cretaceous was mostly down to the basin (Vedder et al., 1971) and would not have supplied thick breccias to the interior of this carbonate-evaporite platform.

Detritus of older carbonate and evaporite rocks, along with altered fragments of melt rock and/or volcanic glass, quartz, feldspar, and other noncarbonate minerals in the carbonate-mud matrix of late Maastrichtian age, calls for an extraordinary origin for the breccia unit. As several workers have shown in the past few years, an impact origin is the most plausible assumption. If this breccia did result from an asteroid or comet collision, then great volumes of carbonate and evaporite rock excavated and fragmented by the impact remained unvaporized.

Extent of Chicxulub Structure

Good lithologic and biostratigraphic correlations of the sub-breccia units penetrated in wells Y1, Y2, Y4, and Y5A and the apparent geophysical log correlation with the Mesozoic strata below 1500 m in well T1 (Fig. 2) show that the Yucatan carbonate platform (beneath the breccia) was not substantially disturbed beyond about 100 km from the center of the presumed impact near well C1. The difficulty in correlating the Upper Cretaceous section in T1 indicates that this section probably is faulted. Such faulting may be consistent with collapsed flanks of a large impact basin about 300 km in diameter (as proposed by Sharpton et al., 1992); however, it also is consistent with the well crossing the Ticul fault or fault zone of late Cenozoic age.

Age of Strata Immediately Above Breccia

A precise age for the sediments directly overlying the breccia layers cannot be determined from most wells, on the basis of our investigation or from published data, with the possible exception of well C1. López Ramos (1973, p. 56) described 170 m (920–1090 m) of interbedded marls, shales, and limestones overlying 180 m (1090–1270 m depth) of limestone and bentonite breccia in this well. These intervals reportedly contain characteristic upper Maastrichtian planktic foraminifers, including *Globotruncana trinidadensis*, *G. rosetta*, *G. ventricosa*, *G. lapparenti*, *G. fornicata*, *Pseudoguembelina excolata*, *Heterohelix globocarinata*, *Pseudotextularia elegans*, *Planoglobulina carseyae*, and *Globigerinelloides volutus*. From this biostratigraphic evidence, the top of the Cretaceous in C1 is at 920 m or above, depending on the lag time involved in retrieving the drill cuttings. The top of the breccia unit could be as high as 938 m, the lowest depth to which presumably undisturbed marls and limestones can be correlated on electric log characteristics with equivalent beds in S1. This indicates that about 18 m of Maastrichtian marl overlies the breccia. A layer of Maastrichtian marl overlying the breccia unit or coeval siliciclastic rocks is consistent with the stratigraphy of this interval in sections in Mexico, Haiti, and Brazil (Jehanno et al., 1992; Keller et al., 1994; López-Oliva and Keller, 1996; Stinnesbeck and Keller, 1994; Leroux et al., 1995). We caution, therefore, that a scenario declaring Chicxulub as the site of the K-T-boundary impact crater is impossible to substantiate on the basis of present biostratigraphic control.

CONCLUSIONS

An improved stratigraphic context for interpreting the effects of a Chicxulub impact is provided by our integration of data from new biostratigraphic analyses of core samples with data from geophysical logs of the deep wells of the northern Yucatán peninsula. There is good biostratigraphic and log correlation of the subsurface Mesozoic section across the north-central Yucatán peninsula in Pemex wells Yucatán 1, 2, 4, and 5A. These wells show good log correlation with the middle Cretaceous interval in Pemex well Ticul 1, but tenuous correlation with the Upper Cretaceous section. This may be explained by faulting within the Upper Cretaceous strata, because the T1 well was drilled through the down-to-the-north Ticul fault or fault zone. There is insufficient structural data from these deep wells to evaluate proposed models of impact cratering (e.g., Sharpton et al., 1993).

Judging from the subsurface stratigraphy of the north-central Yucatán peninsula, the proposed site of impact probably was underlain by about 2500–3000 m of Mesozoic sedimentary rocks, consisting of ~35%–40% dolomite, 25%–30% limestone, 25%–30% anhydrite, and 3%–4% sandstone and shale.

Near the top of the Cretaceous interval across the entire northern Yucatán peninsula are unusual breccias containing clasts of dolomite, limestone, and anhydrite, as well as shocked quartz and feldspar, fragments of basement rock, and altered melt rock. The most likely origin for this breccia is an impact by an asteroid or comet with the northwestern Yucatán platform. Core-sample control in the wells we examined is too sparse to allow precise determination of the time of brecciation biostratigraphically. Better biostratigraphic age control is likely to come from new coring on the northern Yucatán peninsula (Marín and Sharpton, 1994) and from regional studies in northern and central Guatemala, where breccia deposits crop out (Hildebrand et al., 1993).

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REFERENCES CITED

Camargo, A., and Suárez, G., 1994, Structure and radial extent of the Chicxulub, Yucatan impact crater from multichannel seismic reflection data [abs.]: Eos (Transactions, American Geophysical Union), v. 75, no. 44 (supplement), p. 409.

Fisher, R. V., and Schmincke, H.-U., 1984, Pyroclastic rocks: Berlin, Springer-Verlag, 472 p.

Hildebrand, A. R., Penfield, G. T., Kring, D. A., Pilkington, M., Camargo-Zanoguera, A., Jacobson, S., 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.

Hildebrand, A. R., Bonis, S., Smit, J., and Attrep, M., 1993, Cretaceous/Tertiary boundary deposits in Guatemala: Evidence for impact waves and slumping on a platform scale?: Sociedad Mexicana de Paleontología, A. C., Congreso Nacional de Paleontología, IV, p. 133–138.

Hildebrand, A. R., and 16 others, 1996, The Chicxulub crater and its relation to the K-T boundary ejecta and impact-wave deposits, *in* Conference on new developments regarding the K-T event and other catastrophes in Earth history: Houston, Texas, Lunar and Planetary Institute Contribution no. 825, Abstracts, p. 49.

Jarvis, I., Carson, G. A., Cooper, M. K. E., Hart, M. B., Leary, P. N., Tocher, B. A., Horne, D., and Rosenfeld, A., 1988, Microfossil assemblages and the Cenomanian-Turonian (Late Cretaceous) oceanic anoxic event: Cretaceous Research, v. 9, p. 3–103.

Jehanno, C., Boclet, D., Froget, L., Lambert, B., Robin, E., Rocchia, R., and Turpin, L., 1992, The Cretaceous-Tertiary boundary at Beloc, Haiti: No evidence for an impact in the Caribbean area: Earth and Planetary Science Letters, v. 109, p. 229–241.

Keller, G., Stinnesbeck, W., Adatte, T., MacLeod, N., and Lowe, D. R., 1994, Field guide to Cretaceous-Tertiary boundary sections in northeastern Mexico: Houston, Texas, Lunar and Planetary Institute Contribution no. 827, 110 p.

Koeberl, C., Sharpton, V. L., Schuraytz, B. C., Shirey, S. B., Blum, J. D., and Marín, L. E., 1994, Evidence for a meteoritic component in impact melt rock from the Chicxulub structure: Geochimica et Cosmochimica Acta, v. 58, p. 1679–1684.

Leroux, H., Rocchia, R., Froget, L., Orue-Etxebarria, X., Doukhan, J., and Robin, E., 1995, The K/T boundary of Beloc (Haiti): Compared stratigraphic distribution of the boundary markers: Earth and Planetary Science Letters, v. 131, p. 255–268.

López-Oliva, J. G., and Keller, G., 1995, Age and stratigraphy of near-K/T boundary clastic deposits in NE Mexico, *in* Ryder, G., et al., eds., New developments regarding the K-T event and other global catastrophes in Earth history: Geological Society of America Special Paper (in press).

López Ramos, E., 1973, Estudio geológico de la Península de Yucatán: Asociación Mexicana de Geólogos Petroleros, Boletín, v. 25, p. 23–76.

López Ramos, E., 1975, Geologic summary of the Yucatán peninsula, *in* Nairn, A. E. M., and Stehli, F. G., eds., The ocean basins and margins, Volume 3, The Gulf of Mexico and the Caribbean: New York, Plenum Press, p. 257–282.

Marín, L. E., and Sharpton, V., 1994, Recent drilling and core recovery within the Chicxulub impact structure, northern Yucatán, Mexico [abs.]: Eos (Transactions, American Geophysical Union), v. 75, no. 44 (supplement), p. 408–409.

Marshall, R. H., 1974, Petrology of subsurface Mesozoic rocks of the Yucatan Platform, Mexico [M.S. thesis]: New Orleans, Louisiana, University of New Orleans, 97 p.

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.

Murray, G. E., and Weidie, A. E., 1962, Regional geologic summary of Yucatan Peninsula, *in* Field trip to peninsula of Yucatan: New Orleans, Louisiana, New Orleans Geological Society, 142 p.

Pilkington, M., and Hildebrand, A. R., 1994, Gravity and magnetic field modeling and structure of the Chicxulub crater, Mexico: Journal of Geophysical Research, v. 99, p. 13,147–13,162.

Pope, K. O., Baines, K. H., Ocampo, A. C., and Ivanov, B. A., 1994, Impact winter and the Cretaceous/Tertiary extinctions: Results of a Chicxulub asteroid impact model: Earth and Planetary Science Letters, v. 128, p. 719–725.

Schuraytz, B. C., Sharpton, V. L., and Marín, L. E., 1994, Petrology of impact-melt rocks at the Chicxulub multiring basin, Yucatán, Mexico: Geology, v. 22, p. 868–872.

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.

Sharpton, V. L., and nine others, 1993, Chicxulub multiring impact basin: Size and other characteristics derived from gravity analysis: Science, v. 261, p. 1564–1567.

Sharpton, V. L., Schuraytz, B. C., and Marín, L. E., 1994, Chicxulub ejecta deposits: Their importance for understanding the size and devastation of the KT impact event: Geological Society of America Abstracts with Programs, v. 26, no. 7, p. A334.

Sharpton, V. L., Marín, L. E., Carney, C., Lee, S., Ryder, G., Schuraytz, B. C., Sikora, P., and Spudis, P. D., 1996, A model of the Chicxulub impact basin based on evaluations of geophysical data, well logs, and drill core samples, *in* Ryder, G., et al., eds., New developments regarding the K-T event and other global catastrophes in Earth history: Geological Society of America Special Paper (in press).

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

Stinnesbeck, W., and Keller, G., 1994, Field guide to the Cretaceous-Tertiary boundary section at Poty, north of Recife, northeastern Brazil: Recife, Brazil, International Sedimentological Congress, 14th, Field Guide, p. 1–18.

Stinnesbeck, W., and 10 others, 1993, Deposition of channel deposits proximal to the Cretaceous/Tertiary boundary in northeast Mexico: Impact or gravity-flow deposits?: Geology, v. 21, p. 797–800.

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.

Vedder, J. G., and Cruise Scientific Staff, 1971, U.S. Geological Survey–DOE Leg 2: Geotimes, v. 16, no. 12, p. 10–12.

Weidie, A. E., 1985, Geology of the Yucatan Platform, Part I, *in* Ward, W. C., et al., eds., Geology and hydrology of the Yucatan and Quaternary geology of northeastern Yucatan Peninsula: New Orleans, Louisiana, New Orleans Geological Society, p. 1–19.

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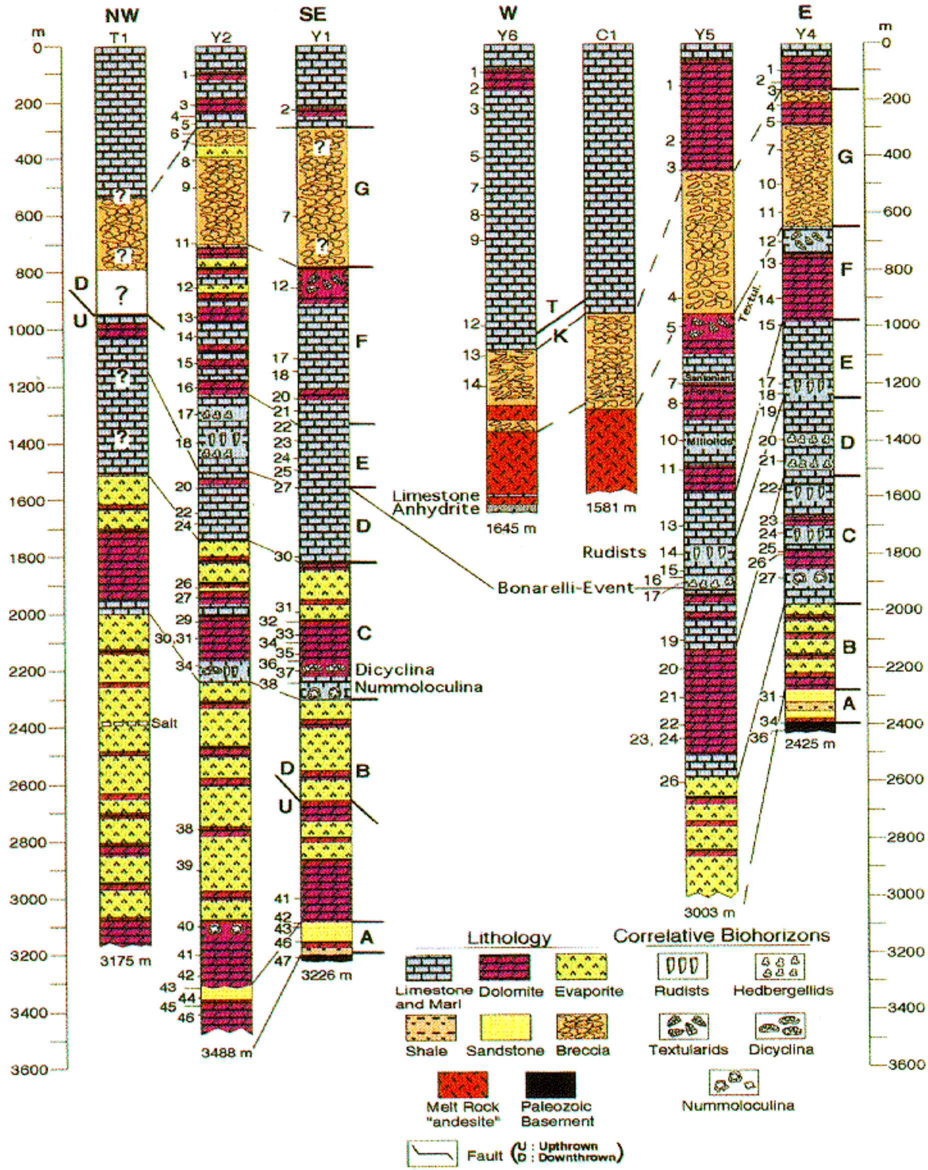

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1645 m
1581 m
3003 m
2425 m
Lithology
Limestone and Marl
Dolomite
Evaporite
Shale
Sandstone
Breccia
Melt Rock "andesite"
Paleozoic Basement
Correlative Biohorizons
Rudists
Hedbergellids
Textularids
Dicyclina
Nummoloculina
Fault (U : Upthrown D : Downthrown)