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The K/T mass extinction, Chicxulub and the impact-kill effect

by GERTA KELLER*, LIANGQUAN LI*, WOLFGANG STINNESBECK** and ED VICENZI***

Key words. – K/T boundary, Mass extinction, Yucatán, Selectivity, Multi-event scenario.

Abstract. – The Chicxulub structure on Yucatán is now commonly believed to have been formed by the Cretaceous/Tertiary (K/T) boundary bolide impact that caused the catastrophic extinction of organisms from dinosaurs to microplankton. However, the mass extinction began well before the K/T boundary and the kill-effect that may be directly attributed to a K/T impact is relatively small (only planktonic foraminifera and nannoplankton affected), highly selective (only tropical-subtropical species extinct) and restricted to low latitudes. Moreover, key evidence cited in support of Chicxulub as K/T impact crater is still controversial (e.g., impact origin of glass), or contradictory : the so-called "impact-generated megatsunami deposits" in northeastern Mexico contain burrowing horizons that indicate deposition occurred over an extended period of time. This database suggests a multi-event scenario that includes a pre-K/T event (impact or volcanism) that formed the spherule deposits in northeastern Mexico and a K/T event (Ir anomaly, mass extinction) with both events coinciding with climatic and sea level fluctuations during the last 200-300 kyr of the Maastrichtian.

L'extinction en masse de la limite Crétacé/Tertiaire, Chicxulub et l'effet de l'impact sur les extinctions

Mots clés. – Limite K/T, Extinction en masse, Yucatán, Sélectivité, Scénario multi-événementiel.

Résumé. – L'extinction massive de la limite K/T, supposée liée à un impact semble avoir débuté quelques 200-300 ka avant la limite. Un scénario mettant en jeu un événement prédatant la limite et un événement K/T est invoqué pour expliquer la sélectivité des extinctions.

VERSION FRANÇAISE ÉTENDUE

Il est maintenant communément admis que la structure de Chicxulub, située au Yucatán, Mexique, résulte de l'impact d'une météorite ayant frappé la surface de la terre, à la limite Crétacé-Tertiaire (K/T), causant ainsi la disparition instantanée de nombreux organismes, allant des dinosaures au microplancton. Cependant, l'extinction massive, supposée liée à l'impact, a débuté 200-300 ka avant la limite Crétacé-Tertiaire. Par ailleurs, les extinctions que l'on peut directement attribuer à l'impact sont assez réduites (seuls les foraminifères planctoniques et le nannoplancton sont affectés), très sélectives (seules les espèces tropicales à subtropicales disparaissent) et restreintes géographiquement aux basses latitudes. De plus, les preuves confirmant cette hypothèse restent controversées (origine et composition du verre des sphérules) ou contradictoires, puisque les dépôts clastiques proches de la limite K/T, qui auraient été générés de façon presque instantanée par un megatsumi suivant l'impact, contiennent des niveaux bioturbés indiquant une sédimentation couvrant une période de temps de plusieurs années, voire de milliers d'années. Ces données parlent donc plutôt en faveur d'un scénario multi-événementiel impliquant un événement prédatant la limite crétacée-tertiaire (impact ou volcanisme) ayant produit les dépôts de sphérules du nord-est du Mexique et un événement crétacé-tertiaire proprement dit (anomalie en iridium et extinction massive), tous deux coïncidant avec les importantes fluctuations climatiques et eustatiques enregistrées durant les 200-300 Ka du Maestrichtien.

INTRODUCTION

A popular scenario holds that at the Cretaceous/Tertiary (K/T) boundary, some 65 million years ago, a large bolide struck the Earth near Chicxulub on the Yucatán Peninsula, Mexico, and caused the sudden global extinction of organisms large and small from dinosaurs to microplankton. The proposed corollary kill mechanisms are manifold, ranging from acid rain and sulfur poisoning, to global cooling due to the formation of highly reflective sulfuric acid clouds, nuclear winter accompanied by the shutoff of photosynthesis, global warming due to a greenhouse effect (CO_2 release), global wildfires, destructive earthquakes and megatsunamis that caused havoc particularly along the Gulf of Mexico coast and the Caribbean Islands [Brett, 1992; Sigurdsson *et al.*, 1992; Smit *et al.*, 1992, 1996; Pope *et al.*, 1994; Ivanov *et al.*, 1996]. These corollary consequences of a large bolide impact are equally plausible consequences of major global volcanism. Only timing sets them apart. A bolide impact is a single instantaneous event, whereas major volcanism is a longterm event.

The Deccan Traps volcanism of India provides ample evidence for longterm volcanism at K/T boundary time beginning at least several hundred thousand years before and continuing several hundred thousand years after the K/T boundary [Courtillot *et al.*, 1988, 1996; Hansen *et al.*, 1996]. There is also ample evidence of a bolide impact at the K/T boundary in sections worldwide (e.g., iridium anomaly, shocked quartz). Chicxulub has been proposed as the K/T boundary impact crater, although this crater may not be of K/T boundary age [see Ward *et al.*, 1995].

How can we test whether an impact or volcanism, or a combination thereof, caused the end-Cretaceous mass extinctions ? In theory, this should be easy. Only a bolide im-

* Department of Geosciences, Princeton University, Princeton, NJ 08544, USA.
** Geological Institute University of Karlsruhe, 76131 Karlsruhe, Germany.
*** Materials Institute, Princeton University, Princeton, NJ 08544, USA.
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pact calls for an instantaneous catastrophic extinction that would leave a single major kill horizon in the stratigraphic record. All other hypotheses require an extended period for the buildup of lethal effects to organisms and therefore predict that the mass extinction should have occurred gradually and over an extended period of time. In practice, testing these hypotheses has not been easy. Neither impact nor volcanism-caused mass extinctions, or any other longterm causal factors, have been conclusively identified as the culprit for the end-Cretaceous mass extinction as the controversy in the literature amply testifies. Nevertheless, the only way to test these hypotheses and their corollaries is to examine the fossil and sediment records and evaluate the resulting database. Because of space limitations, this report examines only the main hypothesis that a bolide impact is the sole cause for the K/T boundary mass extinction and that Chicxulub is the impact structure.

IS CHICXULUB THE K/T BOUNDARY IMPACT CRATER?

It is almost sacrilegious in today's science climate to question whether Chicxulub is indeed the K/T impact crater. Virtually from the day of its discovery, this structure has been hailed as the longsought K/T boundary crater that proves that a bolide impact caused the end-Cretaceous mass extinction [Hildebrand *et al.*, 1991; Sharpton *et al.*, 1992, 1996]. While it is possible, or even likely, that this circular structure was caused by an impact, how strong is the evidence that places this event precisely at the K/T boundary?

The first piece of evidence for a K/T boundary age comes from two $^{40}Ar/^{39}Ar$ ages of 65.2 ± 0.4 Ma and 64.98 ± 0.05 Ma [Sharpton *et al.*, 1992; Swisher *et al.*, 1992] from a single andesite sample below the breccia in Yucatán Core C1 (sample N9). (Eight samples analyzed from three stratigraphic intervals in the andesite of another core (core Y6, samples N14, N17, N19) yielded variable ages between 58.2 to 65.4 Ma and were interpreted as the result of low temperature alteration.) The second piece of evidence comes from linking these two $^{40}Ar/^{39}Ar$ ages to similar ages (64.48 ± 0.23 Ma, Izett [1991]) obtained from Beloc, Haiti, and Mimbral in northeastern Mexico (mean age of 65.01 ± 0.08 Ma, Swisher *et al.* [1992]). The third piece of evidence is the apparent similarity in the chemical compositions of the andesitic glass in the Yucatán cores and glass spherules from Beloc and Mimbral [Smit *et al.*, 1992; Jehanno *et al.*, 1992; Stinnesbeck *et al.*, 1993; Koeberl *et al.*, 1994; Leroux *et al.*, 1995]. And the fourth evidence is the stratigraphic position of the glass spherules from Haiti and Mimbral near the K/T boundary. Based on these four pieces of evidence, we can thus assume with some fidelity that the glass bearing layers in all three localities represent the same event – an event that occurred within about 200 kyr of the K/T boundary.

Why then should we question whether Chicxulub is the longsought K/T boundary impact event? There are two major problems. The first is the assumption that the glass spherules from Mimbral and Beloc and the andesitic glass from the Chicxulub cores are produced by an impact at Chicxulub. This interpretation is still controversial. Impact glasses are formed from melting of target rocks. At Chicxulub, the target rocks consisted of > 1000 m of evaporites and limestones. However, the composition of the andesitic glass and glass spherules from Haiti and Mimbral are incompatible with any mixture involving evaporites as target rocks [Koeberl, 1993; Blum and Chamberlain, 1992]. Koeberl thus concluded that an impact origin for the andesite glass and Chicxulub breccia may be the wrong interpretation. Glass spherules from Haiti and Mexico have also been controversial. Izett [1991] originally interpreted the glass composition as compatible with an impact origin, and Koeberl [1992] concurred with this interpretation based on the low water content. In contrast, Jéhanno *et al.* [1992] and Lyons and Officer [1992] interpreted these glasses as of volcanic origin. More recently, Leroux *et al.* [1995] suggested that they could be either impact or volcanic, whereas new analyses of glass from Mimbral and Sierrita in northeastern Mexico are consistent with a volcanic origin [Vicenzi *et al.*, 1996]. Clearly, interpretations on the glass origin are not unanimous and additional work is needed to clarify the origin of the glass from Haiti and Mexico.

The second problem is stratigraphic. The breccia deposits of Chicxulub are poorly dated, though available evidence suggests that they may predate the K/T boundary [Ward *et al.,* 1995]. Until more conclusive stratigraphic data is obtained from new drilling of the Chicxulub crater, the age of the Chicxulub breccia must be inferred from circumstantial evidence from K/T deposits in northeastern Mexico. Breccia deposits of Guatemala, Cuba and Brazil and the siliciclastic and/or spherule-rich deposits of central and northeastern Mexico, Texas and Haiti, henceforth called event deposits, are all stratigraphically below the K/T boundary as this boundary is defined worldwide (e.g., iridium anomaly, Ni-rich spinels, the extinction of tropical-subtropical planktic foraminifera and the first appearance of Tertiary species) [Keller *et al.*, 1996; Lopez-Oliva and Keller, 1996; Stinnesbeck *et al.*, 1996, 1997] (fig. 1). In many of these localities, these event beds are overlain by a 10 cm to 50 cm thick layer of shales, marls or limestones representing normal sedimentation. This layer is overlain by a thin clay layer marked by the Ir anomaly and mass extinction of tropical planktic foraminifera that characterize the K/T boundary elsewhere. This raises the question whether the event bed is the K/T boundary event or whether it represents another earlier event.

Deposition of the event bed may have occurred sometime during the last 100-200 kyr of the Maastrichtian as indicated by the presence of the planktic foraminiferal index species *Plummerita hantkeninoides*. This species evolved in the lower part of magnetochron 29R, about 300 kyr before the K/T boundary, and disappeared at the K/T boundary [Pardo *et al.*, 1996]. Except for the Chicxulub cores, this species is present in all sections examined and first appears about 50 cm to 100 cm below the unconformity that marks the onset of breccia or siliciclastic deposition. Estimates of sediment missing at this unconformity in northeastern Mexico range from one to a few metres [Smit *et al.*, 1992; Keller *et al.*, 1994]. Thus, stratigraphically the presumed impact spherules at the base of the event bed may predate the K/T boundary by perhaps as much as 100-200 kyr. However, there are two competing ways of interpreting the complex stratigraphy of these event beds : (1) a single Chicxulub impact, or (2) a multi-event scenario (fig. 2).

In the Chicxulub impact scenario, as advocated by Smit *et al.* [1992, 1994, 1996]; Alvarez *et al.* [1992] for the northeastern Mexico siliciclastic deposits, we assume that deposition of the event beds are the result of the K/T bolide impact on Chicxulub. In this scenario, the spherule layer at the base of the event bed represents airborne fallout of impact melt glass and thus represents the K/T boundary event. This event is followed by coarse beds of sandstone deposited by impact-generated megatsunami waves. The overlying alternating beds of sand, shale and marl are interpreted as the back and forth wave action after the megatsunami waves passed, whereas the overlying 10 cm to 50 cm thick layers of shale, marl or limestone are interpreted as the final settling of fines out of the water column. Iridium settles last and marks the end of impact related sediment deposition (fig. 2). This scenario gains support from

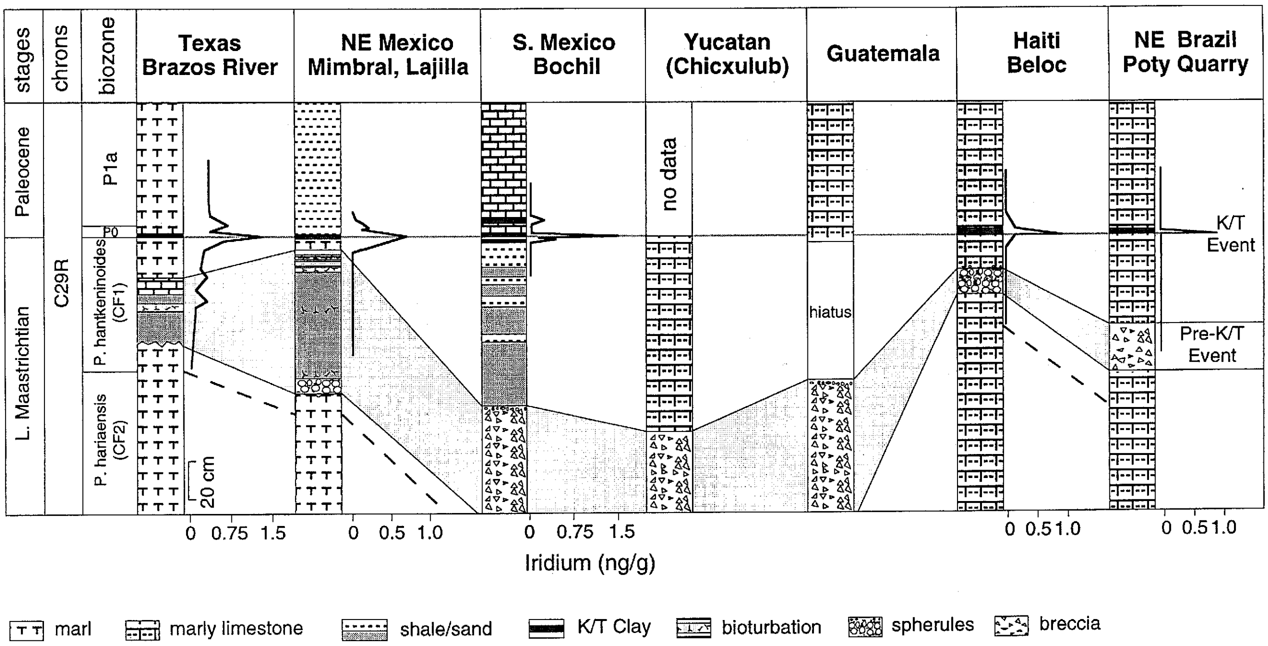

FIG. 1. – Stratigraphy of near-K/T boundary clastic deposits in sections from Texas to Brazil. Note that the K/T boundary clay layer with maximum iridium concentrations and the mass extinction of tropical and subtropical planktic foraminifera is a well-defined horizon above the siliciclastic deposits similar to the K/T boundary event in sections worldwide. The sediments between the K/T boundary and the siliciclastic deposits suggest a return to normal hemipelagic conditions near the end of the Maastrichtian. Note that proponents of the impact-generated megatsunami scenario place the K/T boundary at the base of the siliciclastic and breccia deposits based on the assumption that these deposits are a result of the K/T impact event and were deposited over a period of hours to days. (Figure modified after Keller and Stinnesbeck [1996]).

FIG. 1. – *Stratigraphie des dépôts clastiques près de la limite K/T de coupes réparties du Texas au Brésil. Il est à noter que la couche d'argile à maximum de concentration d'iridium de la limite K/T et que l'extinction en masse des foraminifères planctoniques tropicaux et sub tropicaux correspondent à un horizon bien défini situé au-dessus de dépôts siliciclastiques similaires dans les coupes mondiales de la limite K/T. Les sédiments situés entre la limite K/T et les dépôts siliciclastiques suggèrent un retour à des conditions hémipélagiques normales vers la fin du Maastrichtien. Les tenants du scénario du megatsunami généré par un impact placent la limite K/T à la base des dépôts siliciclastiques et bréchiques en se basant sur le fait que ces séries résultent de l'impact de la limite K/T et ont été déposées en quelques heures ou jours [modifié d'après Keller and Stinnesbeck, 1996].*

the proximity of localities with event beds to the Chicxulub crater and the megatsunami a large impact is likely to have generated.

But there are a number of problems with this interpretation. For example, if the glass spherule layer is of impact origin with the spherules transported through the air in a matter of minutes and settled to the ocean floor in a matter of hours to days, one would not expect them to be concentrated at the base of the event deposit, but rather at the top or mixed throughout. Also difficult to explain is the presence of two spherule layers separated by a sandy gluconite-rich limestone layer in many sections. Smit *et al.* [1994] explained this two-spherule layer occurrence as postdepositional deformation with the sandy limestone layer squeezed in between as soft sediments. The presence of this double spherule layer over hundreds of kilometres in northeastern and central Mexico (e.g., Mimbral, Mulato, Sierrita), however, suggests that it is most likely a primary depositional feature [Adatte *et al.*, 1996; Lamolda *et al.*, 1996; Stinnesbeck *et al.*, 1996; Lopez-Oliva and Keller, 1996].

Bioturbation within the event bed is a major problem for a scenario of rapid single event deposition. Smit *et al.* [1992] originally noted the abundantly bioturbated surface at the top of the event beds and suggested that they represent recolonization of the ocean floor after the megatsunami event. Subsequent investigations by other workers revealed several discrete bioturbated horizons (e.g., *Ophiomorpha, Chondrites, Zoophycos, Planolites, Thalassinoides*) also within the event bed [Ekdale and Stinnesbeck, 1994; Keller *et al.*, 1997] (fig. 2). These burrowed horizons indicate the repeated establishment of resident benthic communities on the sea floor over an extended time interval and hence conflict with an interpretation of rapid tsunami event deposition over a period of hours to days.

The alternative multi-event scenario views these event beds as a result of longterm and multi-event deposition taking into account the various stratigraphic data as previously advocated by Stinnesbeck *et al.* [1993, 1996] and Keller *et al.* [1997]. In this scenario, the event beds predate the K/T boundary event and may represent a second event (Chicxulub impact and/or major volcanic activity) that coincided with the sea level regression-transgression during the last 100-200 kyr of the Maastrichtian [Keller and Stinnesbeck, 1996]. The primary evidence for a second event are the two spherule layers separated by a sandy glauconitic limestone near the base of the event bed. These two layers suggest either two spherule producing events, or one event and later reworking and redeposition of the spherules into the second layer.

Several discrete horizons of bioturbation between the top of the spherule layers and the iridium anomaly at the K/T boundary suggest that sediment deposition occurred over an extended period of time. Above the spherule layers, the presence of truncated burrows infilled with spherules at the base of the sandstone suggests temporary recolonization of the ocean floor after spherule deposition (fig. 2). Subsequent erosion truncated the burrows and was followed by rapid deposition of sand probably during a low sea level. In the upper part of the event bed, the presence of two to three additional truncated burrowed horizons within the alternating sand, shale and marl layers suggest repeated co-

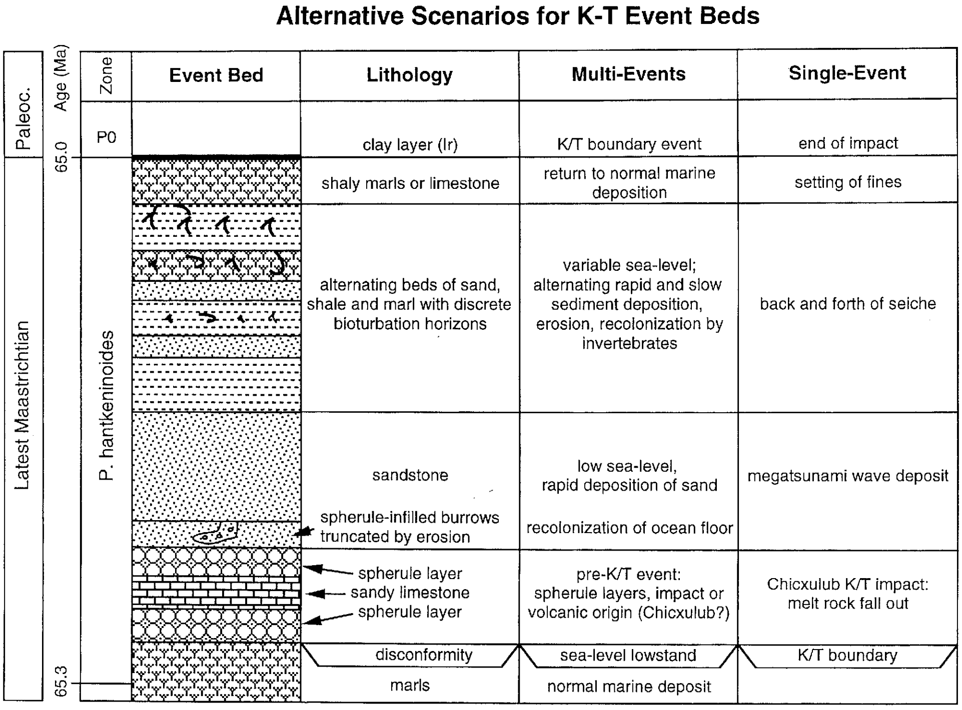

FIG. 2. – Summary of single event and multi-event scenarios proposed as interpretations of the siliciclastic event bed in K-T boundary transitions in northeastern Mexico. Note that the major difference between these two scenarios is that one is theory driven (Chicxulub impact caused melt glass fallout and megatsunami) whereas the other is data driven and strives to incorporate sedimentary features that are inconsistent with rapid single event deposition (e.g., the presence of two spherule layers at the base followed by bioturbation and erosion marks the establishment of a biotic community prior to deposition of the upper event bed; several discrete horizons of bioturbation within the event bed indicates repeated establishment of benthic communities over a period of weeks, months or years; the marl or limestone layer at the top precedes the iridium anomaly and planktic foraminiferal mass extinction). Implicit in the multi-event scenario is the possibility of a second major event (volcanic or impact), in addition to the K/T boundary event, during the last 100-200 kyr of the Maastrichtian. Summaries of single event scenario from Smit *et al.* [1992, 1994, 1996] and multi-event scenario from Stinnesbeck *et al.* [1993, 1996] and Keller *et al.* [1997].

FIG. 2. – *Résumé des scénarios mono ou pluri événementiels proposés pour interpréter les dépôts siliciclastiques de la transition K/T au nord du Mexique. La principale différence entre ces deux types de scénarios réside dans le fait que le premier est théorique (l'impact de Chicxulub a causé une retombée de verre fondu et un mégatsunami) tandis que le deuxième est pratique et intègre des données sédimentaires en désaccord avec un dépôt rapide et unique (par exemple, la présence de deux niveaux de sphérules à la base suivis de traces de bioturbation et d'érosion indique l'installation d'une communauté biotique avant le dépôt du banc supérieur ; plusieurs horizons discrets de bioturbation à l'intérieur des bancs indiquent l'établissement répété de communautés benthiques sur plusieurs semaines, mois ou années ; la couche marneuse ou calcaire sommitale précède l'anomalie en iridium et l'extinction en masse des foraminifères planctoniques. Le scénario multiévénementiel implique la possibilité d'un deuxième événement majeur (volcanisme ou impact) en plus de l'événement de la limite K/T, durant les derniers 200-300 ka du Maastrichtien. Résumés des scénarios monoévénementiels d'après Smit* et al. *[1992,1994, 1996] et pluriévénementiels d'après Stinnesbeck* et al. *[1993, 1996] et Keller* et al. *[1997].*

lonization of the ocean floor followed by erosion [Keller *et al.*, 1997]. This repeated pattern of bioturbation, erosion, and alternating (occasionally cross-bedded) sandstone layers, shales or marls suggests that sediment deposition was episodic and may have occurred over a relatively long time interval that is not consistent with rapid single event impact-tsunami deposition over a period of hours to days.

The shale, marl or limestone layer that overlies the event bed in various localities (fig. 1) may indicate the return to normal sedimentation during a rising sea level. Careful analysis of the foraminifera in this layer revealed a latest Maastrichtian assemblage similar to that in the marls below the event bed with no evidence of major reworking such as size sorting, broken specimens, or selective morphologically based bias that would suggest a reworked origin [Lopez-Oliva and Keller, 1996]. The iridium anomaly above this layer marks the extinction of tropical-subtropical planktic foraminifera, followed by the first appearance of Tertiary species, all of which mark the K/T boundary in low and middle latitudes worldwide. Thus in this multi-event scenario, the K/T boundary is placed at the iridium anomaly and foraminiferal K/T boundary markers just above the event bed. Implicit in this multi-event scenario is the possibility of a pre-K/T glass spherule producing event that may be either of volcanic or impact origin (Chicxulub?) and a second K/T boundary impact event that is represented worldwide by Ir anomalies and a biotic catastrophe.

The strength of the multi-event scenario is largely in the number of stratigraphic, lithologic and biotic observations it can explain, such as the stratigraphic sequence of spherule layers, multiple discrete horizons of bioturbation truncated by erosion, the presence of fully developed and apparently non-reworked foraminiferal assemblages at the top followed by the mass extinction and iridium anomaly. The major weakness is the necessity of invoking a second major catastrophic event, whether impact or volcanism, preceding the K/T boundary event. There is currently no evidence of a pre-K/T boundary event and no evidence of major volcanism at this time in central America. However, the age and stratigraphic position of the Chicxulub breccia is sufficiently uncertain to date that it could well be a pre-K/T event.

WHAT IS THE IMPACT KILL-EFFECT?

Which organismal extinctions can be directly attributed to a sudden catastrophe at the K/T boundary? In theory this question should be easy to answer by simply documenting the stratigraphic levels of species extinctions with respect to the impact horizon as represented by an iridium anomaly. Indeed, this has been done for K/T boundary sections worldwide over the past 15 years and has provided the necessary biological and environmental constraints to test the impact mass-kill hypothesis and its corollaries (acid rain, global freezing, greenhouse warming etc.). With such an excellent global database, why is there still a major controversy regarding the nature, tempo and causal factor(s) of the K/T boundary mass extinction?

The major reason is that fossil data for virtually all organismal groups do not unequivocally support the sudden catastrophic mass extinction predicted by the impact scenario [MacLeod *et al.*, 1997] (fig. 2). Many organismal groups show no mass extinction, or any other environmental effects, that can be attributed to an impact (e.g., dinoflagellates, pollen and spores, radiolaria, ostracodes) [Askin, 1988; Méon, 1990; Donze *et al.*, 1995; Hollis, 1996]. Some groups show diversity changes at the K/T boundary as well as before and after that are difficult to attribute to a single impact event (planktic foraminifera, calcareous nannoplankton) [Keller, 1996; Keller *et al.*, 1996; Gartner, 1996]. Some groups are extinct half a million, or as much as two million years, before the K/T boundary event (e.g., inoceramids, rudists and most ammonites) [MacLeod *et al.*, 1996; Johnson and Kauffman, 1996]. Other groups decline gradually during the Maastrichtian and are nearly extinct by the time of the K/T boundary (e.g., remaining ammonites) [Stinnesbeck, 1996]. In still other groups, a component survives the K/T boundary event and thrives well into the Danian (e.g., some planktic foraminifera, calcareous nannofossils and invertebrates [Keller *et al.*, 1996; Gartner, 1996; Brouwers and Deckker, 1996; Marincovich, 1996; Zinsmeister and Feldmann, 1996]. In addition to this overall selectivity in extinctions, there is a distinct latitudinal pattern to the K/T boundary mass extinction. In high latitudes, faunas and floras tended to survive the K/T boundary event, whereas in low latitudes they tended to succumb (fig. 2) [Keller *et al.*, 1993; Keller, 1993; 1996].

With this complex and varied pattern of extinction and survivorship, should anyone be surprised that there is no consensus on what caused the K/T boundary mass extinction? Figure 3 demonstrates why it is so difficult to make a case for a bolide impact as a global kill– mechanism. Not only is there no instantaneous global mass extinction, but even the organismal groups most severely affected by the K/T boundary event in low latitudes (planktic foraminifera) show selectivity in extinctions [Keller, 1993, 1996]. For example, extinctions affected only complex, large and ornate tropical-subtropical species which are intolerant of environmental changes. Virtually all of these disappeared at or before the K/T boundary. This group comprised about two thirds of the planktic foraminiferal assemblages in low latitudes, but none of these taxa were abundant in the latest Maastrichtian ocean. In terms of planktic foraminiferal biomass, as estimated by the percent of individuals in the total assemblages, this group amounted to only 15-20 %. In contrast, K/T event survivors are simple, small and unornamented species, tolerant of environmental changes and with a wide latitudinal distribution. This group dominated the late Maastrichtian (80 % of the assemblage) and declined in the Danian probably due to competition from the newly evolving Tertiary species that were better adapted to changing environmental conditions [Keller *et al.*, 1996]. A number of workers have argued that the impact-kill total for planktic foraminifera at the K/T boundary is nearly 100 % and that the gradual extinction and survivorship patterns are artifacts of sampling (e.g., Signor-Lipps effect). However, MacLeod [1996a, b] has shown that there is no statistical basis for this interpretation.

The complexity in the extinction pattern of planktic foraminifera, the group most adversely affected by the K/T boundary event, demonstrates why no simple answers can be found to the question of who got killed by the bolide impact. However, some estimates can be obtained for low latitudes. A maximum estimate for planktic foraminifera appears to be the two-thirds of the assemblage that consisted of tropical-subtropical species (fig. 3). Among nannofossils about half the assemblage is estimated to have been eliminated. Benthic foraminifera, the only other marine microfossil group adversely affected by the K/T boundary event, suffered few species extinctions, but many species temporarily disappeared. None of the other microfossil groups

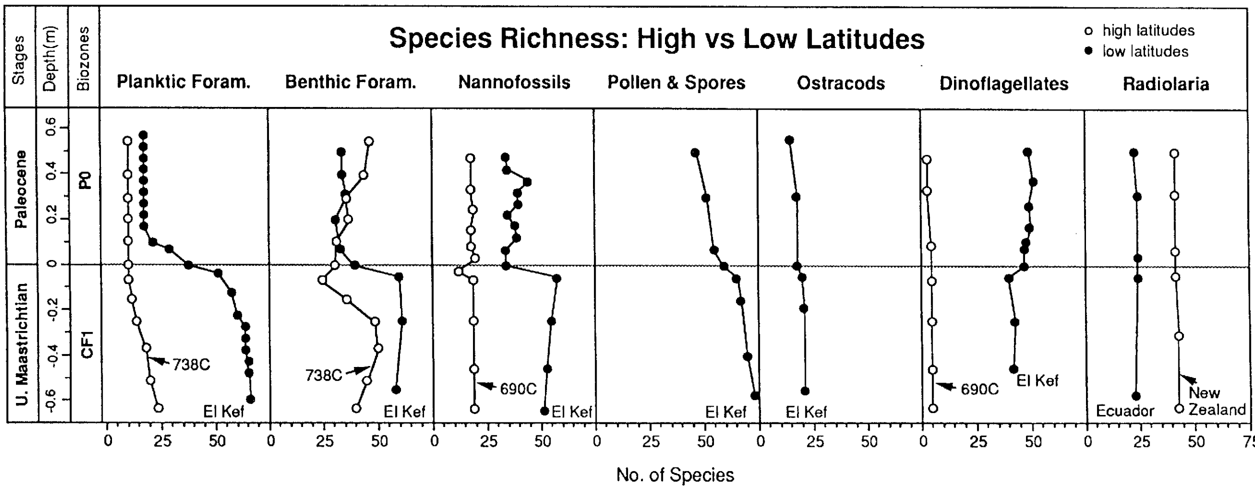

FIG. 3. – Species richness patterns across the K/T boundary in marine microfossils of high and low latitudes. Note that major changes are apparent only in planktic foraminifera and nannofossils and only in low latitudes. The benthic foraminiferal species decline is a temporary emigration of species, most of which reappear in the Danian. (Figure modified after Keller *et al.* [1996]).

FIG. 3. – *Richesse spécifique en microfossiles marins des hautes et basses latitudes de part et d'autre de la limite K/T. Les changements majeurs sont notables seulement pour les foraminifères planctoniques et les nannofossiles et seulement pour les basses latitudes. Le déclin de diversité des foraminifères benthiques s'explique par une émigration temporaire des espèces, la plupart réapparaissant dans le Danien [modifié d'après Keller* et al., *1996].*

show significant species extinctions in low latitudes. Moreover, high latitudes appear to have been safe havens for species, with no significant extinctions in any microfossil groups [Keller, 1993; Keller *et al.*, 1993]. This is a meager sum-total of marine extinctions due to a K/T boundary bolide impact.

CONCLUSIONS

The K/T boundary mass extinction is popularly believed to have caused the extinction of most organisms from dinosaurs to micro-organisms. But the fossil record indicates that there was no major global kill-effect at the impact horizon (e.g., iridium anomaly). In high latitudes, faunas and floras largely survived, though there are abundance changes in species populations. In low latitudes, only a meagre small percentage of the world's biota became extinct at the K/T boundary. Moreover, the extinctions were selective, affecting largely rare tropical taxa that are intolerant of environmental fluctuations. The actual mass extinction was a longterm affair in both high and low latutides, beginning well before the K/T boundary and continuing well into the early Tertiary.

We have raised some concerns with two popular assumptions : (1) that the glass spherules from Haiti and Mimbral and the andesitic glass from Chicxulub are of impact, rather than volcanic origin, (2) that they are of precisely the same age, and (3) that their similar geochemistry provides the critical evidence in support of Chicxulub as the K/T age impact crater. We believe that there is still insufficient data to support either of these assumptions. Moreover, the existing data and interpretations show that there is considerable uncertainty and many unresolved questions.

We have also raised some concerns with the generally accepted notion that Chicxulub is the K/T boundary impact structure and that siliciclastic and glass-bearing layers found in sections from Texas to Brazil are Chicxulub impact-generated air fallout (glass sperules) and megatsunami deposits. Our investigations indicate that these deposits contain multiple horizons of burrowing communities truncated by erosion and hence were deposited over an extended time period that exceeds hours or days. These deposits can therefore not be associated with a K/T boundary impact-generated megatsunami. Moreover, these deposits are stratigraphically well below, and hence predate, the K/T boundary. Designating Chicxulub as the K/T boundary impact crater is therefore premature.

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