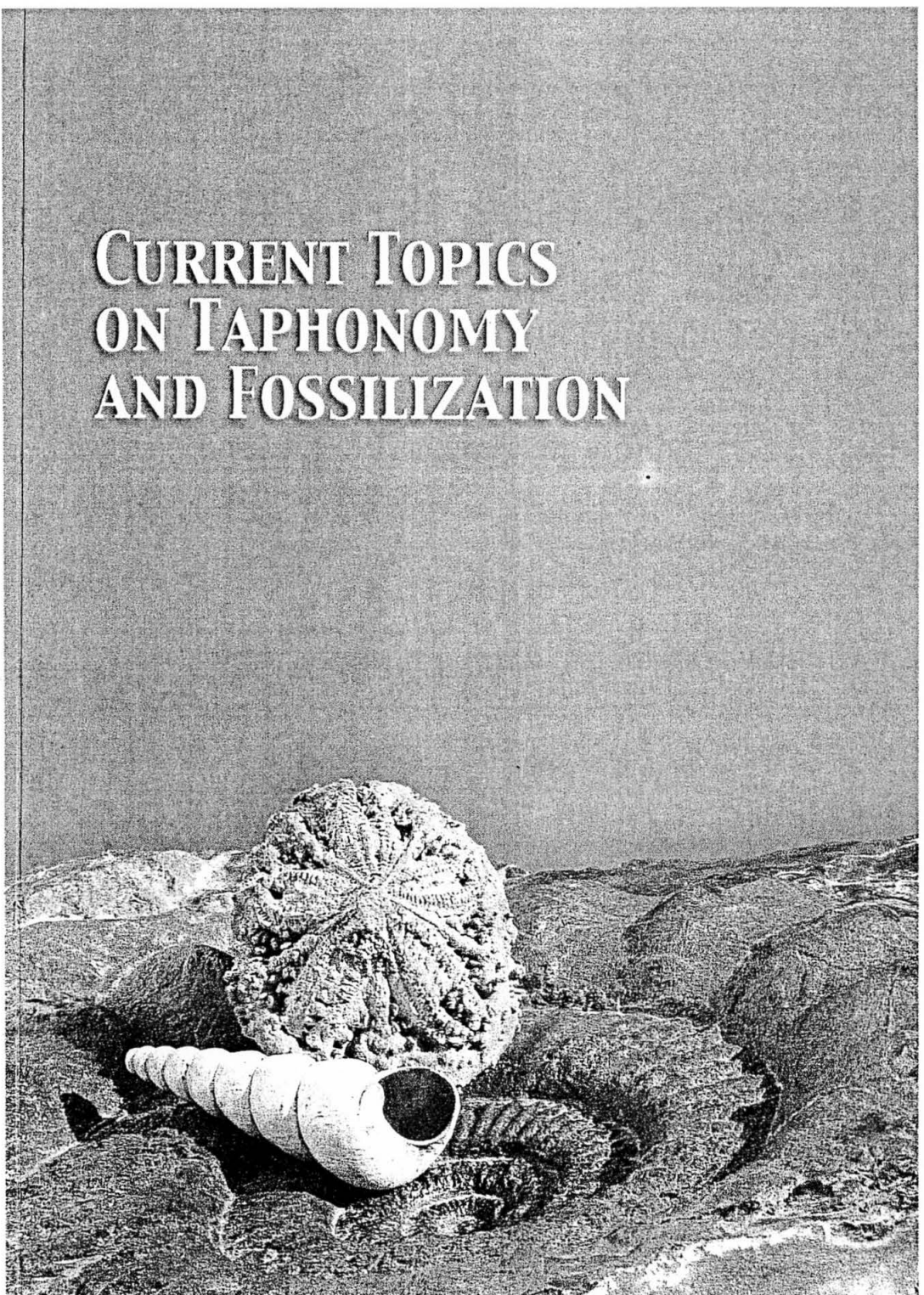

Taphonomy in analysis of the pattern of extinction at the Cretaceous/Tertiary boundary

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INTRODUCTION

The fossil record is incomplete, biased and shows stratigraphical disorder. However, these features do not reduce the usefulness of the paleontological data for identifying and interpreting the successive extinction events (Fernández López, 2000). The ongoing accuracy that is needed to interpret the extinction events in detail may generate taphonomical and methodological problems, making the interpretation of the event difficult and engendering controversy (Molina, 1994, 1995). The best example that can be considered is the strong controversy about the pattern of extinction at the Cretaceous/Tertiary boundary (K/T). The micropaleontological record is one of the most useful tools to establish the extinction pattern across the K/T boundary, especially in pelagic sediments, where a high resolution sampling can be performed.

The K/T boundary extinction event is one of the five major mass extinction that occurred in Earth's history. In a general way the extinction pattern seems to be quite clear and the cause well documented (Smit, 1993). The impact of a large meteorite over 10 km in diameter landing in the Yucatan peninsula, seems to be the cause of the sudden extinction of dinosaurs, ammonoids, belemnoids, rudists and most species of marine planktic microorganisms (foraminifers and coccolitophorids). It has been estimated that this mass extinction involved more than 70% of the species living 65 million years ago.

This extinction event is the most recent mass extinction, and contains the best preserved fossil record, especially in deep-sea sediments. This allows high resolution studies based on continuous sampling every few centimeters. Based on this

methodology, the coincidence between the level containing the impact evidence and the planktic microorganisms mass extinction has been tentatively established. Nevertheless, due to taphonomical and methodological problems, a strong controversy between planktic foraminiferal specialists that interpret a catastrophic mass extinction, lead by Smit (1979, 1982, 1993), and those that interpret the mass extinction as a gradual phenomenon, lead by Keller (1994, 1996), has arisen. In order to solve the controversy between impact and multiple causes followers, some taphonomic aspects are analysed in this paper that may clarify the pattern of extinction across the K/T boundary.

CONTINUITY OF THE RECORD

The interpretation of the pattern of extinction as catastrophic or gradual mainly depends on the continuity of the stratigraphic record and the sampling intensity. Furthermore it depends on other methodological problems related to sampling, such as sample size, Signor-Lipps effect, etc. Consequently, the ongoing samplings to study the K/T transition should be very detailed, of high resolution and almost continuous, which should allow the correct interpretation of the extinction pattern. Apart from that, the continuity or discontinuity of the stratigraphic record is an important problem that may affect the interpretation. A hiatus or a strong condensation may generate a coincidence of the last appearance data of taxa recorded below the hiatus, although the species did not disappeared simultaneously, giving a false catastrophic mass extinction pattern.

On the other hand, the bad quality of the fossil record may also difficult the interpretation. One of the worst preserved fossil records is that of the dinosaurs, although this is an emblematic group of the K/T boundary extinction event. Obviously, the big size of dinosaurs fossils do not allow high resolution sampling at centimetre scale and it is almost impossible to establish the precise coincidence with the level containing the impact evidence. Furthermore, the outcrops are very scarce in terrestrial environments and very few fossils are preserved, because the Signor-Lipps effect is very strong and shows a false gradual mass extinction pattern. On the contrary, one of the groups with best preserved fossil records is that of planktic foraminifera: they are very abundant in most samples of pelagic marine sediments (Molina, 1990, 1996), and its small size allows high resolution samplings at centimetre scale. Nevertheless, in very deep marine environments planktic foraminifera may be affected by dissolution (Thunell & Honjo, 1981; Malmgren, 1987). Anyway, these are the microfossils that best allow to interpret the extinction pattern and to check whether there is a precise coincidence between the impact level and the extinction pattern, allowing to establish the cause and effect relation.

The continuity of the stratigraphic record is essential for the interpretation of the pattern of extinction. The coincidence between the clay layer containing the impact evidence (iridium) and the catastrophic mass extinction of planktic foraminifera was

first recognised in Gubbio (Italy). Nevertheless, when this section was later compared with other K/T boundary sections, such as Caravaca and El Kef, it turned out to be a condensed section (see Smit, 1993). In general, this kind of condensations, or small hiatuses, are frequent in deep sea sections due to dissolution and in shelf sections due to erosion. Nevertheless, bathyal and abyssal sections are often more continuous and sometimes are very expanded (MacLeod & Keller, 1991). The most continuous sections known are situated in Tunisia (Aïn Settara, El Kef, Elles) and Spain (Agost, Caravaca, Zumaya). Nevertheless, the most expanded ones are located around the Yucatan peninsula, concretely in Mexico (Bochil, El Mimbral, El Mulato, El Peñon, La Ceiba, La Lajilla, Coxquihui), Cuba (Peñalver, Cacarajicara), Haiti (Beloc) and USA (Brazos River), where the layer containing the impact evidence is usually thicker than one meter.

REELABORATION

Reelaboration is one of the most important taphonomic processes that may lead to misinterpretations of the extinction pattern. This process is particularly relevant at the K/T boundary, due to the close temporal and spatial proximity of the samples. Traditionally the paleontologists have recognized the reelaborated fossils by their different preservation and the long chronological gap (Bignot, 1986). Nevertheless, the proximity of the samples minimise enormously the validity of these criteria in the K/T transition. Only in some sections such as Zumaya this criteria can be used thanks to the different degree of preservation and colour. Reelaborated specimens of Globotruncanids and complex heterohelicids were identified in the basal Tertiary grey marls of Zumaya, due to their typical Maastrichtian red colour, which is different from the basal Paleocene white colour (Arz *et al.*, 1999). Reelaboration processes affecting benthic foraminifera were also identified in K/T sediments from the Gulf of Mexico: shallow water benthic foraminifers (e.g. large lenticulinids) were found together with typical deep bathyal assemblages (Alegret *et al.*, 2001). The explanation to this mixture is directly related to the K/T boundary impact event: the impact triggered the destabilisation of the continental margin around the Gulf of Mexico, thus generating large mass fluxes (including shallow benthic foraminifers and other shelf sediments) from the platform toward the slope. Shallow benthic foraminifera were thus resedimented together with deep assemblages.

A technique based on the C and O isotope analyses of the microfossil tests may be used to determine whether the species found in the basal Tertiary are survivors or reelaborated. A similar isotopic signal to that of the Cretaceous indicates that the Cretaceous specimens are reelaborated, but if the signal is similar to that of the Tertiary, the species are considered as survivors. This technique was used for the first time by Hsü *et al.* (1982) to study K/T boundary foraminifera and calcareous nannoplankton; it was later applied to planktic foraminifera by Barrera & Keller (1990), which lead Keller (1994, 1996) and MacLeod & Keller (1994) to conclude

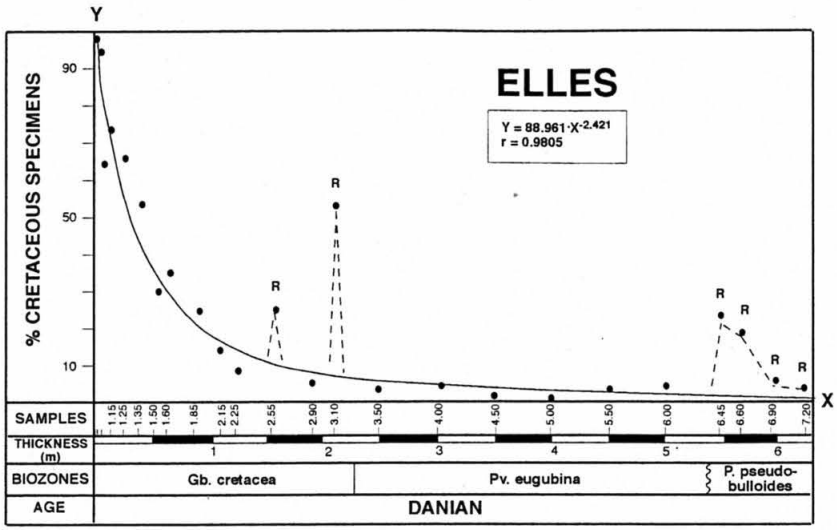

Figure 1.- Progressive decline in abundance of the Cretaceous specimens in the lower Danian at Elles section (Tunisia).

that most of the species present in the basal Tertiary were survivors. Nevertheless, using similar isotope analyses, Kaiho & Lamolda (1999) concluded that most of these species were reelaborated.

The quantitative study of the assemblages can also be used as criteria to know whether the Cretaceous specimens in the basal Paleocene are accumulated-autochthonous or reelaborated. Arz *et al.* (2000) observed that the relative abundance of the Cretaceous specimens decrease suddenly but progressively since the K/T boundary, following a decreasing curb called ARECS. The ARECS curb is clearly observed at the Elles section, Tunisia (Figure 1). Its decrease might be due to the progressive decline in abundance of the Cretaceous survivors, but more probably to a decrease of the relative abundance of Cretaceous reelaborated specimens.

Figure 2 shows the relative abundance of the supposed Cretaceous survivors counted in the terminal Maastrichtian at the El Kef section, and its relative abundance in the basal Paleocene discounting the Tertiary species. Both percentages are very similar, except for large Cretaceous species, suggesting that the specimens found in Tertiary sediments are Cretaceous reelaborated species. Only the Cretaceous species *Guembelitria cretacea* and *G. trifolia* increase their percentages after the boundary, clearly indicating that they are survivors to the K/T event.

In order to solve the problem related to the reelaboration, it is necessary to consider all the techniques and also observe whether the Cretaceous species found in the basal Tertiary are always the same or not in the different sections throughout the

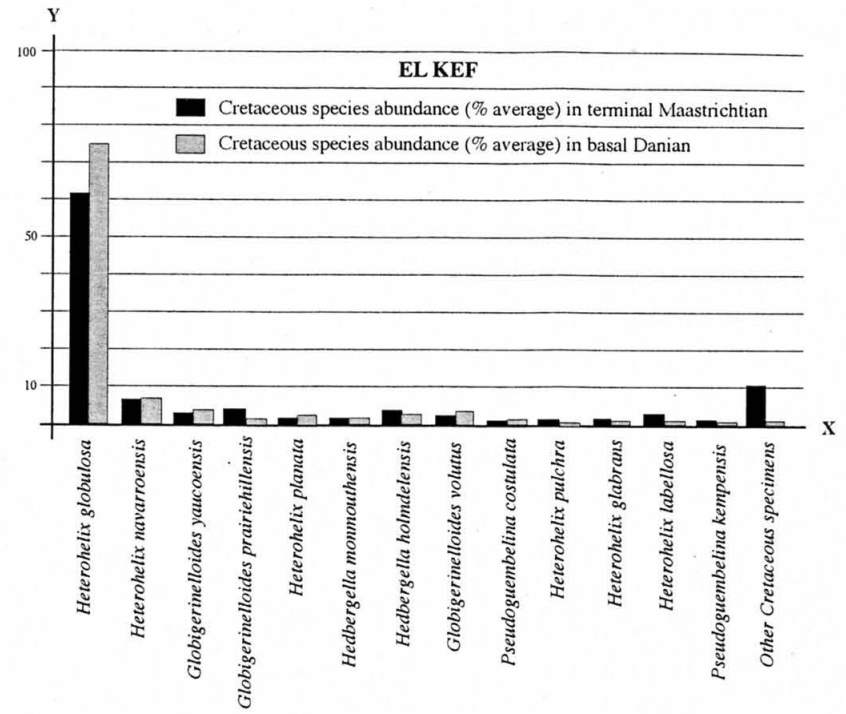

Figure 2.- Relative abundance of the supposed Cretaceous survivors at El Kef section across Maastrichtian vs. Danian, discounting the Tertiary species.

world. Keller (1994, 1996) and MacLeod & Keller (1994), apparently based on this statement, still maintain that most of the species are survivors. Nevertheless, Smit (1982, 1993), Arz *et al.* (1999, 2000) and Arenillas *et al.* (2000), after studying the same sections, reached the conclusion that only two species of the genus *Guembelitria* (and probably, some few others such as *Heterohelix globulosa, Hedbergella holmdelensis* and *H. monmouthensis*) were clearly survivors. Consequently, about 90% of the species of planktic foraminifera became extinct simultaneously at the K/T boundary and the patterns of catastrophic mass extinction precisely coincide with the meteorite impact evidence.

SUMMARY

Taphonomic reelaboration is a very important factor affecting our interpretation of extinction patterns in the event at the Cretaceous/Tertiary boundary. Effects of reelaboration can affect microfossils derived from narrowly spaced samples. Other

taphonomic and methodological problems arising in micropalaeontologic studies are also considered. However, different techniques help us to resolve these problems and allow us to corroborate that planktic foraminifera show a catastrophic extinction pattern coinciding with the evidence of a meteor impact.

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