

THE CRETACEOUS-TERTIARY (KT) BOUNDARY



*The Cretaceous-Tertiary boundary in Zumaya (Guipúzcoa).
The Cretaceous is on the right and the Tertiary on the left.*

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According to the latest versions of the International Stratigraphic Scale, the proper name for the KT boundary is Cretaceous/Paleogene boundary (K/Pg). The period equivalent in rank to the Cretaceous is the Paleogene, whereas the term Tertiary is now considered unofficial. The stratotype of the K/Pg boundary was defined in the El Kef section (Tunisia), approved by the International Commission on Stratigraphy in 1990, and recently revised and officially defined by Molina *et al.* (2006).

The K/Pg boundary also marks the limit between the Mesozoic and Cenozoic Eras, between the Upper Cretaceous and Paleocene Epochs, as well as between the Maastrichtian and Danian Stages. It coincides with one of the five mass extinctions in Earth's history, which affected many groups of organisms, both marine and continental, including the popular dinosaurs. This extinction event is very useful to correlate the K/Pg boundary, which was specifically established at the base of the dark clay in the El Kef section. It is a yellowish red thin bed with relevant evidence for a meteorite impact. The impact extinction event is well recorded all over the world, also including several Spanish sections, particularly Agost, Caravaca and Zumaia.

The relevance of the stratigraphic sections or beds successions where the K/Pg boundary is recorded in the Iberian Peninsula and North of Africa (Figure 1) lies on the fact that it is in these sections where the causes and effects of the great end-Cretaceous biological crisis can better be observed and studied. This crisis affected three quarters of the continental and marine species, causing the extinction of groups as unrelated as dinosaurs, ammonites, belemnites and rudists, while other groups such as planktonic foraminifera were severely affected.

Due to their excellent location, good accessibility, sedimentary continuity, and fossil abundance, some Spanish sections are especially significant for the study of the K/Pg boundary and are considered sites of geological interest (García-Cortés, 2000, 2001; Meléndez and Molina, 2006), especially those of Caravaca and Agost (Betic Mountain Ranges), Zumaia (Basque-Cantabrian Mountain Range) and Fontllonga (Pyrenees) (Figure 2).

The interpretation of the causes which led to the great mass extinction event has troubled scientists since the XIX century. Initially, the proposed hypothesis assumed the extinction of dinosaurs as a result of the competition with mammals or of the evolution of plants with flowers, poisonous for the dinosaurs. In addition, plate tectonics and the inferred continental drift brought a new paleogeographic vision, with the consequent eustatic changes which allegedly were the cause of the great extinction at the end of the Cretaceous. Many hypotheses have been proposed in this direction, some of them rather preposterous, such as the flower poisoning. However, during the last decade, two of them have received great acceptance: a huge meteorite impact and an intensive volcanism.

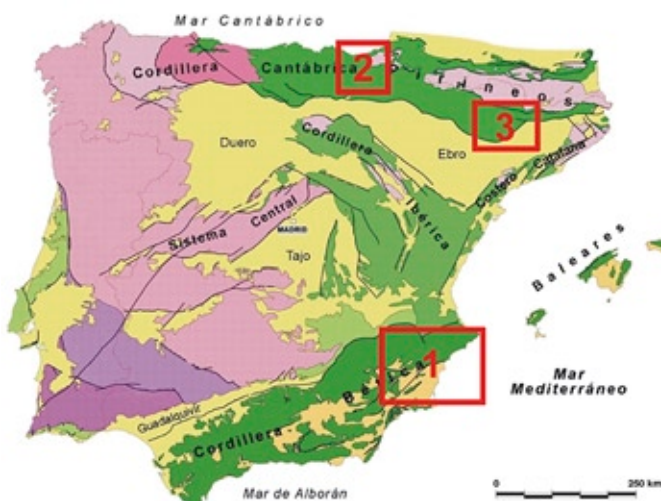
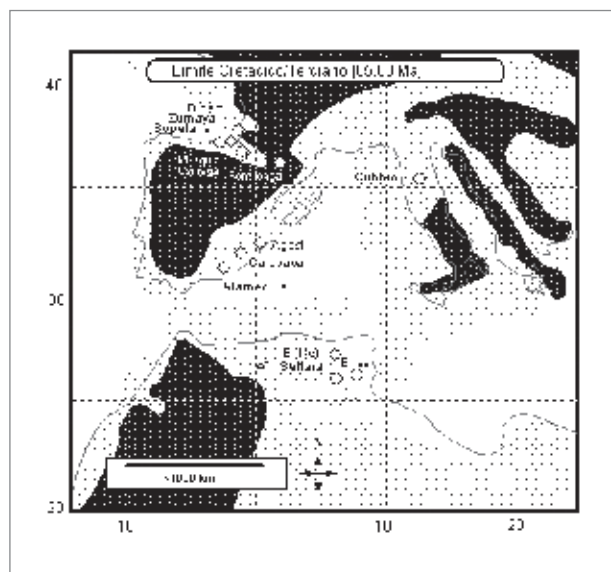


Figure 1, above. *Location of the sections mentioned in the text, within the paleogeography of the K/Pg transition.*

Figure 2, below. *Location of the geosites:*

- 1) Caravaca and Agost
- 2) Zumaia
- 3) Fontllonga

Intensive volcanism in the Decan plateau is very unlikely to be the triggering cause. Its maximum intensity was 1 million years before the mass extinction event, so the events did not coincide. The extinction pattern should have been gradual, but it turns out to be sudden and simultaneous, as revealed by planktonic nanofossil and microfossil groups. Furthermore, volcanism does not provide an acceptable mechanism capable of affecting so many groups and environments at different latitudes.

The discovery of an abnormal excess of iridium, a common element in meteorites, in the K/Pg boundary of the Gubbio section (Italy) by Álvarez *et al.* (1980), and simultaneously in the Caravaca section

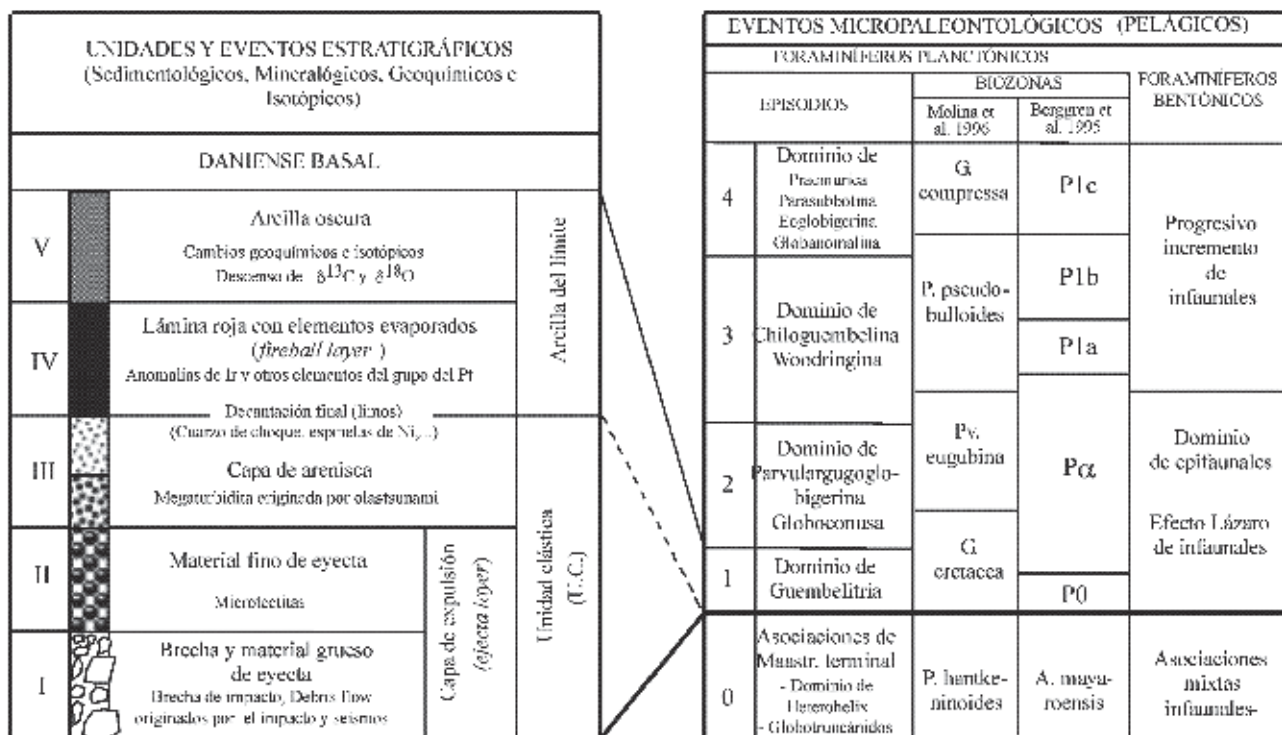


Figure 3. Correlation of units, events and episodes of the K/Pg transition (according to Arenillas et al., 2000a).

(Spain) by Smit and Hertogen (1980), allowed the documentation of a hypothesis timidly suggested some decades before. Since 1980, other researchers have found several evidences for an impact at the same level, such as microtectites caused by melting of the impacted rocks, nickel spinels formed by the high temperatures reached when the meteorite entered the atmosphere, as well as shocked-quartz grains caused by the enormous pressure generated by the impact. These and other impact evidences were ejected into the atmosphere during the impact, and have been found in different parts of the world, leading to the development of the impact theory for the K/Pg boundary with the documentation of the fall of a big meteorite. The impact on the Earth's surface would have generated enormous clouds of dust and gases, making photosynthesis very difficult and causing a great catastrophe with more or less fatal consequences for most living creatures.

The location in the Gulf of Mexico of the Chicxulub crater, north of the Yucatán Peninsula, with an approximate diameter of 200 km and dated 65.5 million years old, supports the impact theory with solid arguments, while helping to understand the processes that took place and their sedimentary record. All this evidence, together with the sudden mass extinction pattern, allows to establish a cause-effect relationship between the impact of a great meteorite and the mass extinction, since the bed containing the impact evidences coincides exactly with the level where the mass extinction occurs (Arz et al., 2000a; Arenillas et al., 2006).

The sedimentary record of the event is different depending on the distance from the impact area.

The K/Pg boundary sediments in the Mexican Gulf (Mexico, USA, Cuba, Haiti, Guatemala, etc.) would be directly linked to the impact processes, with rocks such as breccias, coarse material ejected by the impact, fine sediments with microtectites, and a layer of sediments corresponding to the turbidity currents originated by the big tsunami waves (Soria et al., 2001; Alegre et al., 2005). The deposition of all the particles suspended in the atmosphere and seas would result in a stratigraphic level showing the impact evidences. The proximal deposits, with metrical thickness, have been correlated to centimeter or millimeter levels found in distal areas, away from the impact, containing an abnormal excess of iridium as well as other impact evidences (shocked quartz, microtectites, nickel spinels, etc.). Immediately above this level, a layer of dark clay some centimeters thick was deposited where great geochemical changes have been detected: a decrease in the isotopic contents of $\delta^{13}C$ and $\delta^{18}O$, and an increase in the contents of total organic carbon, indicating an important rise of the calcite compensation level due to the sudden decline of productivity in planktonic marine environments.

The event responsible for all these evidences caused the biggest and most catastrophic mass extinction in the evolutionary history of planktonic foraminifera (Smit, 1993; Arenillas et al., 2000b; Arz et al., 2000b; Molina et al., 2005), as well as a drastic modification of benthic foraminifera associations (Alegre et al., 1999). From previous data and those gathered by Arenillas et al. (2000a) in several locations of the Mexican Gulf, Spain, Italy and North Africa, it is possible to set up a sequence of recognizable marine pro-

cesses at a global scale, separating individual stages related to the associations of planktonic and benthic foraminifera (Figure 3), where it is possible to recognize two main units: Clastic Unit and Boundary Clay, divided into 5 subunits.

The identification of the aforementioned units and of foraminifera evolutionary episodes depends on the sedimentary continuity of each section, as well as on its location with respect to the impact point. Subunit I is found at sections near the crater, subunit III extends to the Gulf of Mexico domain, while subunits IV and V show a global distribution of the final deposition and include the iridium anomaly, nickel spinels, shocked quartz and other evidences of very fine grain size. Subunit II or microtectite level, also displays a global distribution, although only small microtectites appear in some stratigraphic sections away from the Mexican Gulf within subunit IV (red bed). Distal sections away from the point of impact and on this side of the Atlantic do not record all the units corresponding to the proximal impact area. However, they do show the clay boundary layer and the red-yellowish level at its base, with the mineralogical and geochemical evidence of the impact (iridium excess, microtectites and nickel spinels).

In the sections of Agost, Caravaca and Zumaia, the K/Pg boundary is found in sediments from deep marine basins. Thanks to their continuous record and good conservation, it has been possible to establish the catastrophic mass extinction pattern for planktonic foraminifera (Figure 4). Furthermore, in Zumaia it has been possible to verify how ammonite extinction did not happen before the event, but coincides with the K/Pg boundary. Due to the scarcity of fossils and the higher discontinuity of the record, it is harder to identify the mass extinction event in shallow platform sediments, and especially in continental sediments. However, identifying the boundary in continental sediments is paramount to establish the cause effect relationship between the meteorite impact and the mass extinction of land plants and animals.

The section of Caravaca (Murcia) is in the external domain of the Betic Mountain Ranges and displays a continuous marine succession from the Upper Cretaceous to the Middle Eocene. The sedimentary sequence (Figure 5) is mainly made up of hemipelagic marls and marly limestones, with interbedded limestones and calciturbidites. It shows a centimetre level of dark grey clay separating the Maastrichtian (Cretaceous) from the Danian (Paleogene), and contains mineralogical and geochemical evidences, as well as evidence for foraminifera mass extinction. At the base of the centimeter level there is a red-yellowish millimetre layer (Figure 6) hosting the impact evidences of a great meteorite.

The section of Caravaca is one of the most complete sections worldwide to define the K/Pg boundary. It has great heritage value and Barranco del Gredero, the creek where it is located, was recommended for



Figure 5, above. *Maastrichtian marls and K/Pg boundary (located on the ravine to the left) at Barranco del Gredero (Caravaca).*

Figure 6, below. *Detail of the impact red-yellowish lamina of the K/Pg boundary (between the two coins) at Barranco del Gredero (Caravaca).*

protection (Molina, 2004). Most of its importance is because this trench helped Smit and Hertogen (1980) to establish the meteorite impact theory as the most probable cause for the mass extinction in the K/Pg boundary, published one month before the Álvarez's team published their results on the Gubbio section (Italy). The scientific priority of the discovery was given to Álvarez's team, as they had presented their proposal in a scientific meeting in 1979, although Walter Álvarez later recognized Jan Smit as co-author of this theory.

In the province of Alicante, also in the Betic Mountain Ranges, there are several sections, Agost, Finestrat and Relleu, being Agost the most interesting and better studied of them, probably equal or better than that in Caravaca. The K/Pg boundary layer in Agost



Figure 7, above left. *K/Pg boundary at the base of the dark clay, beneath Lower Danian marly-limestones at Agost.*

Figure 8, above right. *K/Pg boundary between Maastrichtian marly limestones to the right and Danian limestones, at Zumaia.*

Figure 9, left. *Detail of the K/Pg boundary with diagenetic calcite in the impact level and clay from the boundary behind the scale, in Zumaia.*

is around 10 cm thick, rich in dark grey clay (Figure 7) with a limonitic lamina at the base, around 2 mm thick and red-yellowish in colour, containing the impact evidence. The mass extinction of planktonic foraminifera coincides with the level with the impact evidence, affecting mainly the groups which lived in intermediate and deep waters, as well as the tropical genii (Figure 4).

In the central sector of the Betic Mountain Ranges, around the town of Alamedilla (Granada), several sections allow the study of the K/Pg transition. Unlike Caravaca and Agost, in these sections the Upper Cretaceous, Paleocene and Lower Eocene are represented by red bed facies. The existence of a small interruption or stratigraphic gap affecting at least two planktonic foraminifera biozones from the K/Pg boundary has been highlighted. Here, the boundary may be represented by an argillaceous level present at some sites and absent at some others for tectonic reasons.

In the Pyrenees and the Basque-Cantabrian Basin, the Sopelana section is found (Lamolda *et al.*, 1983), but the most studied classical section is Zumaia (Gipuzcoa), located northwest of the town, and specifically at the cliff of Aitzgorri Point (Figure 8). This section is very well exposed and was the other candidate when the section of El Kef was chosen to define the K/Pg bound-

ary. A stratigraphic series with deep marine facies crops out in the Zumaia cliffs, consisting of brown and grey marls with fine sandstone interbeds (uppermost Maastrichtian, Upper Cretaceous), upon which a centimeter layer of dark clay appears (K/Pg boundary). The rest of the section on top of it (Danian, Paleocene) consists of limestones and marls.

The K/Pg boundary layer is represented by 10 cm of dark grey clay, showing in its base a lamina of diagenetic calcite of about 1-2 cm (Figure 9). Coinciding with the K/Pg boundary level containing the already known impact evidences, the extinction of most of the planktonic foraminifera species has been verified with an extinction pattern fitting the mass extinction model compatible with the meteorite impact theory (Arz *et al.*, 1999).

In Spain, there are continental or very shallow marine environment sections (Garum facies) displaying the K/Pg transition in the localities of Arghuis, Campo, Benabarre and Aren, in Huesca (Pyrenees of Aragón), and in Coll de Nargó, Isona and Fontllonga in Lerida (Pyrenees of Cataluña). The best studied section is the one near Fontllonga, south of the Sierra del Montsec (Ager Basin), where the Tremp Formation crops out containing fossil footprints and remains of dinosaurs and other land organisms. The K/Pg boundary was located through paleomagnetism, identifying it in a

sandstone body with abundant dinosaur footprints, which highlights the existence of living dinosaurs just before the K/Pg boundary (López Martínez *et al.*, 1998). Although the iridium anomaly or other direct traces from the impact have not been found here, a strong decrease of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotopes has been recorded, which makes it possible to relate this anomaly to a global event of change in the ecosystems.

In short, the aforementioned Spanish sections display an excellent record of the K/Pg transition, and have made it possible to study the event in detail, and to find out the causes leading to the mass extinction. These sections make up some of the most interesting sites in our geological heritage and demand proper protection.

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