REVISTA ESPAÑOLA DE PALEONTOLOGÍA, **n.º Extraordinario,** 127-140. 1988.
**Palaeontology and Evolution: Extinction Events**

# THE BASQUE COASTAL SECTIONS OF THE K/T BOUNDARY - A KEY TO UNDERSTANDING "MASS EXTINCTION" IN THE FOSSIL RECORD

*Jost WIEDMANN*

Geol.-paläont. Institut, Universität,
Sigwartstr.10, D-7400 Tübingen. F.R.G.

## ABSTRACT

Investigations at the K/T boundary section at Zumaya, northern Spain, underline the importance of this section in (1) establishing a Maastrichtian ammonite zonation and (2) in understanding "mass extinctions" in the fossil record. "Mass extinction" at the K/T boundary can be restricted to two groups of oceanic surface plankton, i.e. foraminifera and calcareous nannofloras. Ammonites and inoceramids exhibit a gradual decline through the late Cretaceous, as probably also do the Temperate belemnites and the bulk of involved vertebrates. Most of these groups disappear a long time before the boundary.

Compared with the available environmental factors, the course of ammonite diversity through time perfectly parallels the course of global sea level changes. Times of high extinction rates (e.g. the era and system boundaries) coincide with times of maximum regressions, while the subsequent evolutionary radiations match with the new sea level rise. There is no need for any cosmic catastrophy to explain the decline of most invertebrate and vertebrate groups.

Coeval with the short-time extinction of oceanic surface plankton at the boundary itself, the following environmental and depositional changes were observed: minor (positive as well as negative) changes in temperature, boundary clay sedimentation, enrichment of iridium and noble metals, occurrence of sanidium spheres and shocked quartz, and changes in carbon and strontium isotopes. All these events were used to support the Alvarez hypothesis of a cosmic impact at the boundary. But they are much easier explained by increasing explosive volvanicity which, on the other hand, might correlate also with the time-equivalent magnetic reversals.

There is also neither need nor proof for a stepwise extinction as a consequence of a series of comet showers.

While most of the earlier Mesozoic major faunal breaks can likewise be related with marine regressions, the K/T boundary extinctions as a whole were caused by a complex scenario: the late Cretaceous changes in sea level as well as the increase of volcanic activity towards the boundary.

**Keywords: "Mass extinctions", biological evolution, sea level changes, volcanic activity, K/T boundary.**

https://doi.org/10.7203/sjp.25167

## RESUMEN

Las investigaciones en el límite Cretácico-Terciario (K/T) de la sección de Zumaya, norte de España, subrayan la importancia de esta sección en 1) el establecimiento de una zonación de ammonites maastrichtienses y 2) por el entendimiento de las "extinciones en masa" en el registro fósil. Las "extinciones en masa" en el límite K/T pueden restringirse a dos grupos del plancton oceánico de superficie, p. ej., foraminíferos y nanoflora calcárea. Los ammonites e inocerámidos muestran un declive gradual durante el Cretácico superior, como de igual manera lo hacen los belemnites de las zonas templadas y el conjunto de los vertebrados de esas edades. La mayoría de esos grupos desaparecieron mucho tiempo antes del límite K/T.

Comparado con los factores ambientales conocidos, el curso de la diversidad de los ammonites en el tiempo paraleliza el de los cambios globales del nivel del mar. Los momentos de altos índices de extinción (p. ej. los límites entre eras o sistemas) coinciden con los de máximas regresiones, mientras que las subsecuentes radiaciones adaptativas se ajustan a las nuevas elevaciones del nivel del mar. No hay necesidad de ninguna catástrofe cósmica para explicar el declive de la mayoría de los grupos de invertebrados y vertebrados.

Se han observado, coetáneamente con los cortos períodos de extinción del plancton marino en el mismo límite, los siguientes cambios ambientales y deposicionales: pequeños cambios (positivos y negativos) en la temperatura, sedimentación arcillosa en el límite K/T, enriquecimiento en iridio y metales nobles, presencia de esferas de sanidina y cuarzo diaclasado y cambios en los isótopos del carbono y estroncio. Todos estos acontecimientos se han utilizado a favor de la hipótesis de Álvarez acerca de un impacto cósmico en el límite K/T. Pero se explican más fácilmente por el incremento del volcanismo explosivo, el cual, por otra parte, puede correlacionarse con los cambios coetáneos de la polaridad magnética.

Tampoco hay necesidad, ni pruebas, de una extinción por etapas como consecuencia de una lluvia de cometas.

Mientras que la mayoría de las crisis faunísticas del Mesozoico inferior pueden relacionarse con regresiones marinas, la del límite K/T en su conjunto tuvo lugar en un escenario complejo: los cambios del nivel el mar en el Cretácico superior y el incremento del volcanismo hacia propio límite.

**Palabras clave: "Extinción en masa", evolución biológica, cambio en el nivel del mar, actividad volcánica, límite K/T.**

## INTRODUCTION

Just as with all "critical" stratigraphic boundaries (Precambrian/Cambrian, Silurian/Devonian, Frasnian/Famennian, Permian/Triassic, and even Triassic/Jurassic), the initial problem, likewise raised at the K/T boundary, is the scarcity of undisturbed and valuable marine transitional sections. The available sections in Europe and NW Africa (Fig. 1) are really not overwhelming in number. Of course, this has something to do with the problem involved.

The next problem becomes immediately obvious: Most of these sections are inappropriate for the present purpose, i.e. to understand mass extinctions, due to highly pelagic or turbiditic sedimentation, reduced thicknesses or condensation, hardgrounds, pebble beds and reworking at the boundary level, and/or absence or scarcity of megafossils.

(A) The Maastrichtian of the famous Gubbio section, Umbrian Appennines, is highly pelagic and, in some portions of the section, turbiditic. This also applies to the K/T boundary in the Lattengebirge, Northern Calcareous Alps. Nearly the same can be said of the Caravaca section in southern Spain, and the DSDP-ODP K/T boundary sites (e.g. Sites 356, 524, 577) from the Atlantic and Pacific oceans. They can only be used as reference sections for "mass extinction" or, more precisely, for the turnover in calcareous oceanic surface plankton (foraminifera, calcareous nannoflora) which is, indeed, coeval with the K/T boundary itself, as generally accepted [1].

(B) There are, however, a few possibly important sections in adjacent areas from which macro-invertebrate records are available. Yet, these are rather rare and generally restricted to the Lower Maastrichtian: In the Tunisian El Kef section only one ammonite of Lower Maastrichtian age is known (Salaj & Wiedmann, in press), and also in the Moroccan Agadir section Maastrichtian ammonites are extremely rare and again confined to the lower substage (Wiedmann *et al.* 1978, 1982). The Maastrichtian of the Carinthian Krappfeld Gosau Beds is again rich in pseudokossmaticeratids of the lower substage, but is probably incomplete towards the top. This is presumably much the same for the recently redescribed Quiriquina Beds in Central Chile (Stinnesbeck, 1985).

(C) In the North Temperature epicontinental Maastrichtian-Danian type sections (Maastricht, Stevns Klint, Nye Kløv) or at the Vistula River near Kazimierz, macro-invertebrates (ammonites, belemnites) are present throughout the Maastrichtian succession. It is remarkable, however,

---

[1] E. Vogt (1979) still continues to favour the inclusion of the Danian in the topmost Cretaceous due to the obvious relationships of Danian bryozoans with the Maastrichtian ones.

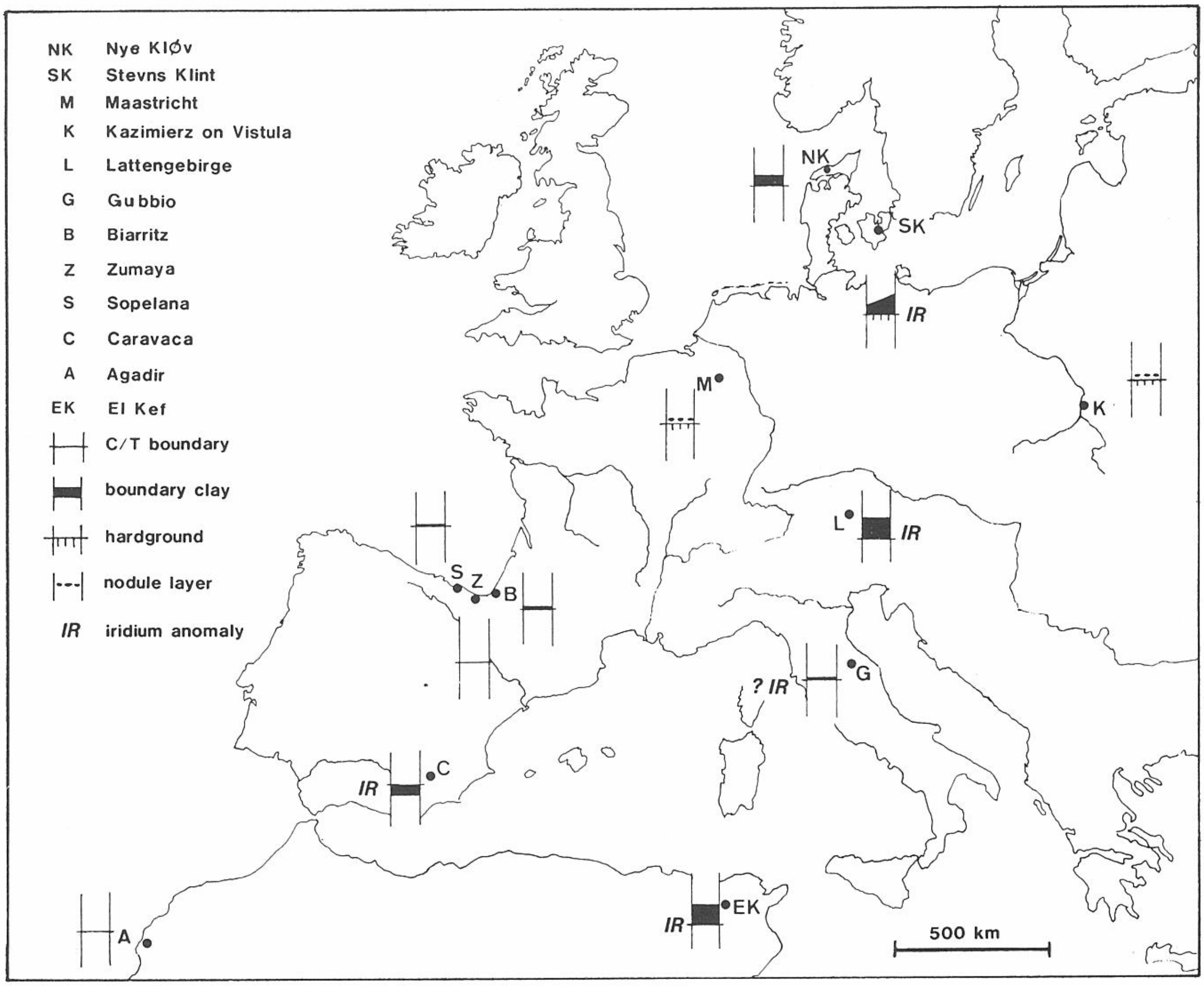

**Figure 1.** Sites of European and northwest African K/T boundary sections, the presence of "boundary clays", iridium anomaly, hardgrounds and reworking (from Wiedmann, 1986).

that reduced sedimentation, condensation, hardgrounds, reworking, burrowing, and phosphatic pebble beds are widespread in all these sections, and generally concentrated at the boundary. If we admit synchroneity of the iridium and the $\delta$ $^{13}$C signals, the extinction of planktonic groups is found to be diachronous in the Danish sections (Hansen *et al.*, 1986b).

(D) The recently published Maastrichtian section of Seymour Island, Antarctica (Macellari, 1986), is of extreme interest according to its ammonite diversity and density. In turn, this occurrence is still difficult to be interpreted because of a high percentage of endemic species.

(E) From this brief review it is evident that the sections around the Gulf of Biscay are of great importance. These are Biarritz, Sopelana (Viscaya Province) and Zumaya (Guipúzcoa Province). In all three sections the Maastrichtian-Paleocene transition is complete and non-turbiditic.

In the Biarritz section (Perch-Nielsen, 1979), however, macro-invertebrates have not been investigated so far.

The K/T boundary of Sopelana is likewise perfectly exposed at a cliff outcrop, but is unfortunately tectonized near the boundary level. These tectonics were the reason for previous records of "Tertiary" inoceramids (Kopp, 1959) as was later corrected by Bijvank (1967). Microfauna and nannoflora were recently described by Lamolda *et al.* (1983).

In consequence, the K/T boundary succession of Zumaya is the most valuable one of these sections.

## THE ZUMAYA SECTION

This section is described in detail in the field guide of the Leioa Conference which is published simultaneously. For detailed information, the reader is referred to this publication or to Wiedmann (1986, 1988a), respectively.

At the shoreline W and N of Zumaya, a continuous section is exposed ranging from Lower Campanian to Eocene. The Zumaya Syncline (Engeser *et* *al.*, 1984) is a parautochthonous structure becoming attached to the Iberian plate margin from a northerly position with respect to the Iberian Plate. Campanian through Eocene sedimentation is dominated by turbiditic input which ceases during the Middle Maastrichtian and is nearly absent in the Upper Maastrichtian. The advantages of the Zumaya boundary section can be summarized as follows.

(A) Continuity in the sedimentary record across the boundary; this boundary is placed within the upper portion of the upper purple marls (levels 12, 13, Fig. 2).

(B) Absence of tectonics in the transitional layers except for a thin Harnisch layer associated with the boundary level.

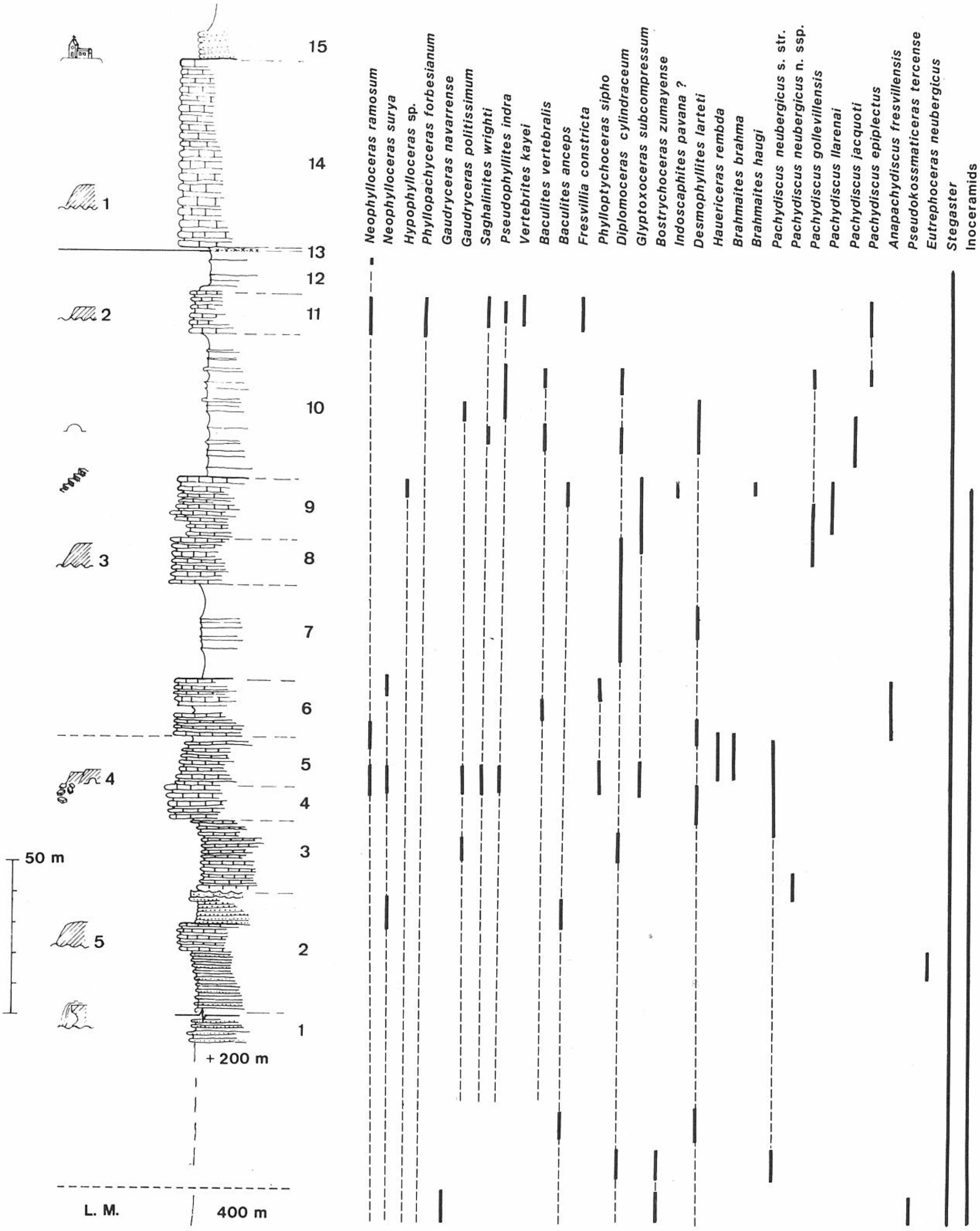

**Figure 2.** K/T boundary section at Zumaya, Guipúzcoa province, and macro-invertebrate ranges (from Wiedmann, 1988a). Symbols on the left for better orientation.

(C) Relatively high sedimentation rates allowing high biostratigraphical resolution. A total Maastrichtian thickness of roughly 800 m corresponds with an average sedimentation rate of 100 m/MA.

(D) Predominance of pelagic deposits and nearly complete absence of turbiditic sedimentation in the boundary layers. Very thin, rhythmic gray layers are composed of coprolites, show strong burrowing, and occasionally the turbiditic layer can be recognized.

(E) Deposition of these sediments was definitely above CCD and presumably also above aragonite solution.

(F) Presence or even relative abundance of mega– and microfossils throughout the section.

(G) Perfect exposures.

No "boundary clay" can be observed as in many other K/T boundary sections, but the boundary layer at Zumaya is, in turn, pyritic and therefore easy to recognize.

For the present purpose, the macro-invertebrates, mainly ammonites, of the Maastrichtian were investigated, thereby allowing the determination of a Maastrichtian ammonite sequence based on stratigraphic evidence. Moreover, the stratigraphic column can easily be correlated with equivalent zones of planktonic foraminifera (Table 1) first recognized by Herm (1965).

| | | | |
|---|---|---|---|
| **MAASTRICHTIAN** | **UPPER** | **Zone of Abathomphalus mayaroensis** | — |
| | | | ***Pachydiscus epiplectus*** |
| | | | ***Pachydiscus jacquoti*** |
| | | | ***Pachydiscus llarenai*** |
| | | | ***Pachydiscus gollevillensis*** |
| | | | ***Anapachydiscus fresvillensis*** |
| | **MIDDLE** | **Zone of Pachydiscus neubergicus**<br>= **Zone of Rugotruncana gansseri** | |
| | **LOWER** | **Zone of Pseudokossmaticeras tercense**<br>= **Zone of Globotruncana falsostuarti** | |

**Table 1.** Attempt to a Maastrichtian ammonite and foraminifera zonation based on the Zumaya section (from Wiedmann, 1988a).

This ammonite succession is certainly interesting, because of the presence of *Pachydiscus neubergicus* (Hauer) in the Middle Maastrichtian together with the occurrence of *Rugotruncana gansseri* (Bolli). *Pachydiscus neubergicus* was considered as an index species of the Lower Maastrichtian for a long time. Then, first Birkelund (1979) and subsequently Blaszkiewicz (1980) recognized its stratigraphic worth to define the Lower/Upper Maastrichtian transition. These observations from Denmark and Poland are fully confirmed and facilitate the separation of a Middle Maastrichtian (Wiedmann, 1988a).

Lower Maastrichtian, however, can be defined in the Zumaya section as well as in El Kef (Salaj & Wiedmann, in press) and the Krappfeld Gosau (Thiedig & Wiedmann, 1976) by *Pseudokossmaticeras* spp. being associated with *Globotruncana falsostuarti* Sigal at Zumaya.

Problems are related with the definition of the Upper Maastrichtian. At Zumaya the following ammonite sequence can be observed in stratigraphic order:

*Pachydiscus epiplectus* (Redtenbacher) upsection
*Pachydiscus jacquoti* Seunes
*Pachydiscus llarenai* Wiedmann ↑
*Pachydiscus gollevillensis* (D'Orbigny)
*Anapachydiscus fresvillensis* (Seunes).

This sequence parallels the occurrence of *Abathomphalus mayaroensis* (Bolli). Since this ammonite sequence is still unique, it cannot yet be generalized. Moreover, the definition of the late Cretaceous pachydiscids is very ambiguous, and the revision is still pending (Kennedy, in prep).

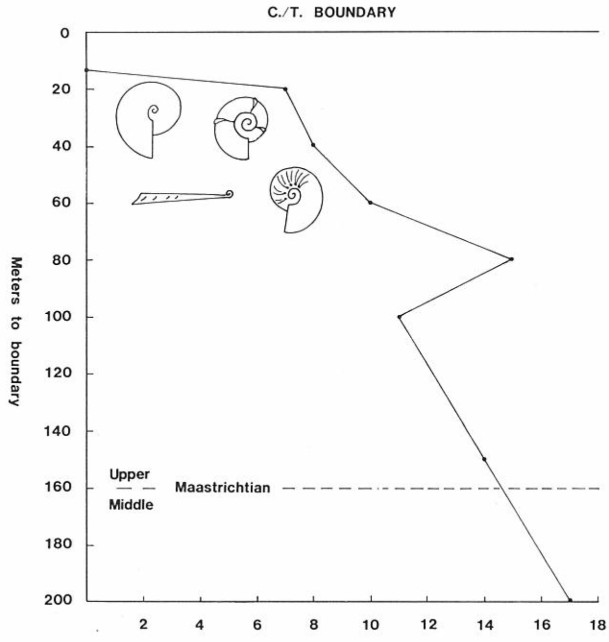

**Figure 3.** Quantitative ammonite distribution and decline in the Maastrichtian of Zumaya (from Wiedmann, 1988a).

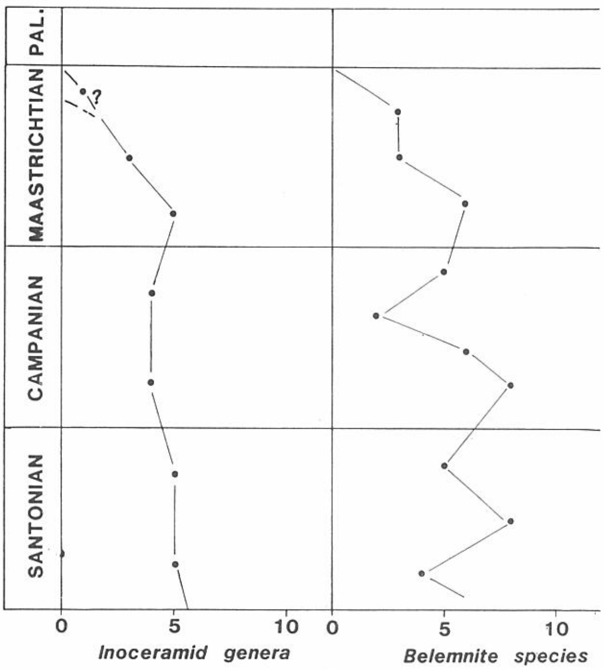

**Figure 4.** Inoceramid and belemnitid decline through the late Cretaceous (data from Dhondt, 1983 and Christensen, 1976).

## THE AMMONITE DECLINE

More interesting are, however, the general observations on ammonite decline:

(A) Ammonite diversity decreases during the Maastrichtian to a considerable extent. Considering the 17 ammonite species present in the upper part of the Middle Maastrichtian, only 10 species persist into the middle Upper Maastrichtian. Finally, only 7 species can be recognized just before ammonite disappearance (Fig. 2). In consequence, ammonite "extinction" was a continuous decline which can be observed throughout the Maastrichtian and the entire Upper Cretaceous (Figs. 3, 6).

(B) At Zumaya, the last ammonite-bearing level was found 12,5 m below the boundary; only one specimen of *Neophylloceras ramosum* (Meek) has been discovered above this level, e.g. 0,50 m below the boundary. Whether this is a local feature of the Zumaya section or can be generalized cannot be ascertained for the time being. Further investigations in adjacent sections are needed. In any case, calculations based on the sedimentation rate show that the maximum decline of ammonites occurred about 130.000 years before the Iridium Event.

(C) No relationship can be established between ammonite heteromorphy and ammonite decline; this confirms previous observations (Wiedmann, 1969). Only one heteromorphic species is among the last seven species. The Ammonitina are represented by only one pachydiscid species, as well, while phylloceratids and lytoceratids seem to dominate. This prevalence of deep-water stocks is comparable with observations on other Mesozoic system boundaries (Wiedmann, 1973b).

(D) There is a noticeable decrease in size of ammonites within the uppermost 60 m of the Upper Maastrichtian. Larger specimens are still present, but becomes less numerous. Due to the poor preservation of these small forms it is hard, though, to decide whether these forms are juveniles, inner whorls or true dwarfed specimens.

Birkelund (1979) described the last ammonites of the topmost Maastrichtian chalk (hardground facies) of Stevns Klint, presenting exclusively small specimens (op. cit., text-fig. 3) and considering them to be juveniles. Ammonitella stages were said to occur in great abundance. It is worth remembering that fragmentary baculitids were still observed in the Danian *Cerithium* Limestone of Stevns Klint, but are considered to be reworked (op. cit., p. 57). Similar observations were made at Kazimierz-on-Vistula.

(E) Comparable observations concerning a gradual decline before the end of the Cretaceous can be obtained from the inoceramids of the Zumaya section, if the random genus *Tenuipteria* is excluded. True inoceramids disappear at the Zumaya section in the upper portion of level 9 (Fig. 2).

Data on late Cretaceous inoceramids from A. Dhondt (1983) confirm the observations of a gradual decline before the end of the Cretaceous (Fig. 4).

(F) Prevalence of heteromorphic species, mainly *Hoploscaphites* and *Baculites* at Stevns Klint is due to climatic segregation. The North Temperate genus *Hoploscaphites* has not yet been found in the Basco-Cantabrian late Cretaceous and *Baculites* is rare. The total absence of belemnites in the Upper Cretaceous of the Basco-Cantabrian Chains is likewise related with its inclusion in the Subtropic Realm. But using belemnite data from Christensen (1976), also this group seems to decline gradually in diversity, at least in the European late Cretaceous (Fig. 4).

(G) The turnover in calcareous nannoplankton and planktonic foraminifera, however, is restricted to the boundary level (Herm, 1965; v. Hillebrandt, 1965; Kapellos, 1974; Percival & Fischer, 1977; Lamolda, this vol.). The fact that *Abathomphalus mayaroensis* (Bolli) ranges high up in the Zumaya section and that the Zone of Micula prinsii is much reduced (Lamolda, this vol.) at Zumaya, still needs explanation.

(H) No vertebrate data are available from northern Spain. Intensified efforts of vertebrate paleontologist made obvious, though, that "mass extinction" of marine and terrestric vertebrates, especially dinosaurs, was also by no means as spectacular as generally believed (Russell, 1967; McGowan, 1973, 1978; Archibald & Clemens, 1982; Clemens, 1982; Schopf, 1982; Carpenter & Breithaupt, 1986; Sloan *et al.*, 1987). As a matter of fact, the decline was as gradual as for ammonites, and many groups (dinosaurs, pterosaurians, ichthyosaurians, plesiosaurians, and possibly also the late Cretaceous mosasaurians) even disappeared before the end of the Cretaceous. In a very stimulating review on K/T boundary problems Jaeger (1986) pointed to the fact, that the numerical decline of terrestric dinosaurs contrasts with the coeval increase of continental environments -especially in the Western Interior Cretaceous. Collecting failure can, therefore, be excluded from having contributed to the extinction pattern.

Naturally, we have to admit that correlation between continental and marine K/T boundary beds still needs to be ascertained. This is likewise important for the interpretation of the turnover in angiosperms. The drastic change recognized in the North Temperate *Aquilapollenites* Province presumably took place near or at the K/T boundary (Clemens *et al.*, 1981; Hickey, 1981), but it is restricted to North America and northeastern Asia. The synchronous increase of angiosperm diversity towards the paleo-equator is, however, not in accordance with the presumed global impact.

The drastic and short-term replacement of pollens by spores at the boundary itself, however, is widespread (L. W. Alvarez, 1987; Pillmore & Flores, 1987; Fig. 5), and can therefore be related with the boundary event.

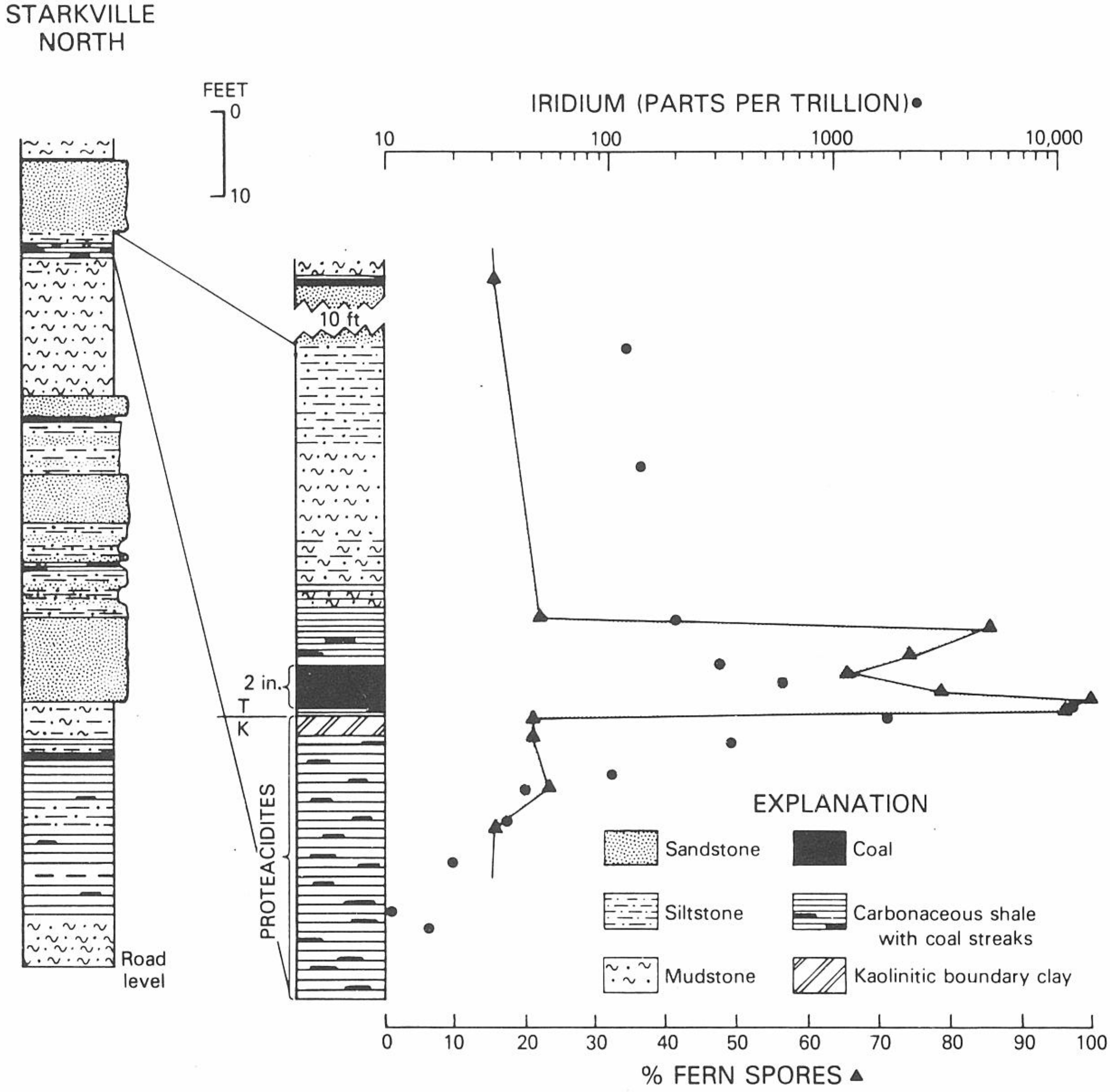

**Figure 5.** Correlation of iridium and fern spores peaks at the K/T boundary at Starkville North, Colorado (from Pillmore & Flores, 1987).

## MASS EXTINCTION AT THE K/T BOUNDARY?

From our actual knowledge, this question can clearly be denied. Extinction of many important Cretaceous or even Mesozoic faunistic groups, such as ammonites, belemnites, inoceramids, and the mentioned reptiles was not a sudden collapse, but a long-term decline. Most of these important groups became extinct before the end of the Cretaceous. No correlation with the "Iridum Event" may be constructed.

"Mass extinction" or better the turnover at the K/T boundary can thereby be restricted drastically to the groups of oceanic surface plankton (foraminifera, calcareous nannoplankton) from which it is known for a long time (Hofker, 1960; Bramlette & Martini, 1964; Herm, 1965).

Short-term substitution of angiosperm pollens by spores is a synchronous event and can be added to the boundary "extinction". If stratigraphic correlation is correct, the turnover in the northern *Aquilapollenites* floras may as well complete the extinction pattern at the K/T boundary which is, thus, by no means spectacular.

In full agreement with Birkelund & Hakansson (1982), these observations cannot be explained by one single boundary event; a complex scenario of late Cretaceous environments must have governed the differing late Cretaceous extinctions.

## THE DRIVING FORCES

What are, however, the driving forces of continuous decline as well as of instantaneous extinction towards and at the end of the Cretaceous?

(A1) As to start with the K/T boundary event, it might be interesting to look for organisms flourishing at the time of "mass extinction". Again, Birkelund & Hakansson (1982) recorded peaks in density and diversity of both bryozoans and some specialized crinoids (*Bourgueticrinus*) from the boundary beds of Jylland, Denmark. Since both fossil groups are very sensitive to changes in salinity and oxic conditions, these two factors can now be ruled out from having contributed to the boundary event. This means, that neither the occasional existence of organic black shales at the boundary level (e.g. the Fish Clay at Stevns Klint, Denmark) can be taken into account, nor the possibility of an "Arctic Ocean injection" (Thierstein & Berger, 1978) can be accepted.

(A2) Detection of the iridium anomaly and related phenomena (concentrations of noble metals, sanidine spheres, depletion of REE) in the K/T boundary beds at Gubbio (Alvarez *et al.*, 1980) was a strong argument in favour of an extraterrestrial cause of the evolutionary catastrophy, thus initiating a highly controversial and stimulating discussion. The discovery of shocked quartz was another strong support for the impact theory.

In the meantime, however, we became aware that the iridium is not present in all K/T boundary sections; in some places (e.g. the Lattengebirge, Northern Calcareous Alps (Herm *et al.*, 1981) ) two iridium anomalies were observed. The iridium anomaly seems to correlate with the local existence of the "boundary clay" which is, for example, not present at Zumaya. It needs to be stressed that the "boundary clay" yields different ages: It is uppermost Maastrichtian in Caravaca (Smit & ten Kate, 1982), but lowermost Paleocene in most other sections. Observations at different Gosau localities (Lahodynsky, in press) seem to confirm a diachronous nature of the iridium anomaly.

The recent discovery of a series of iridium anomalies within the Cenomanian-Turonian black shales of Western Interior (Kauffman, this vol.) is an important hint to the possibility that the concentration of iridium and noble metals has much more to do with the presence of organic matter for precipitation (Schmitz, 1985) than with anything else. As a matter of fact precipitation might be supported by microbial activity (Schmitz *et al.*, in press). This would explain the strong iridium peaks found in the Danish Fish Clay and in those sections where "boundary clays" are present, generally formed under starved and reducing conditions. It is not necessary to mention that no drastic evolutionary catastrophies happened equivalent to the Cenomanian-Turonian iridium concentrations, except for the extinction of the genus *Rotalipora*.

Volcanic activity was widespread and concentrated at the end of the Cretaceous (Officer *et al.*, 1987), and can be used as a natural source for iridium and noble metal enrichment. Compared with normal eruptions, aerosol eruptions at Kilauea, Hawaii, have shown an enormous increase of iridium presumably coming from a deep-seated source within the mantle (Zoller *et al.*, 1983; Olmez *et al.*, 1986).

The microspherules, described by Smit & Klaver (1981) from the boundary clay at Caravaca are composed of sanidine and other minerals and range from 100 to 1000 μm. They were interpreted to be altered microtektites and are meanwhile known from a variety of other K/T boundary sections. But in reality, they have a stratigraphic range from the mid-Cretaceous to the Paleocene (Naslund *et al.*, 1986) and they might be the mineral infill of prasinophyceans (Hansen *et al.*, 1986a).

One of the strongest arguments favouring the Alvarez hypothesis is the existence of shocked quartz with a multiple set of laminae detected in the boundary clay at a great number of localities all over the world (Bohor *et al.*, 1987). Even diamond has recently be described from the boundary clay of southern Israel (Rosenfeld *et al.*, 1987). These phenomena cannot be expected from volcanic rocks, but the high pressure required could occur in the country rocks which surround sites of highly explosive volcanicity (Rice, 1987; Hallam, 1987). These theoretical considerations, however, still need to be approved. As Hallam (1987, p. 1238) pointed out, the acceptance of shocked quartz as generated from a cosmic impact, requires not only an impact site on the continents, but moreover a crater size of 150 to 200 km in diameter.

The drastic and short-term negative excursion of the carbon isotope ratio in planktonic foraminifera and calcareous nannoplankton from deep-sea cores can be related with a reduction in the $\delta^{13}C$ gradient between surface and deep ocean waters. It is, indeed, as predictable from the extinction of calcareous surface plankton as is the formation of "boundary clay(s)" and the relative abundance of benthonic foraminifera (Herm, 1965).

The existence of a peak in the $^{87}Sr/^{86}Sr$ ratio of seawater (Elderfield, 1986) at the end of the Cretaceous is considered to be a response to the global sea level fall at that time (Wiedmann, 1969; Sliter, 1976; Kauffman, 1979; Hallam, 1987).

(A3) No drastic climatic change can be observed at the K/T boundary. What can be observed are two short-time minor peaks in $\delta^{18}O$ values at this boundary (Smit & ten Kate, 1982). If the interpretation of oxygen isotope data is correct, these two peaks can be and were related with the presumed impact: Cooling just before the boundary level would immediately follow the impact and correspond to the global covering by clouds of dust or water smoke, and the warming trend in the earliest Paleocene would document a subsequent glashouse effect. These phenomena are, however, much easier explained by the observed volcanic activity, ashfall and exhalation, probably culminating at the end of the Cretaceous. Darkening due to a long-term and global ash cloud cover must have affected the oceanic surface plankton. Subsequent deposition of the smectitic "boundary clay" does not need to be explained as the product of impact melt either; it is the background sedimentation during the interval of mass mortality in oceanic surface plankton.

(A4) The argument of a food chain collapse has often been used to explain unusual extinction rates at the end of the Cretaceous. But due to intensified research on the different evolutionary lines involved, and due to increasing stratigraphic resolution we have realized that the oceanic planktonics are the latest to become extinct.

(A5) For historical reasons, Schindewolf's (1945) attempt should be cited in order to explain extinction and especially the decline of ammonites by endogenous evolutionary processes, the Typostrophic Theory. The description of the final evolutionary stage, the "Typolysis", as a period of phyletic exhaustion, degeneration and overspecialization, was clearly adopted from the Cretaceous heteromorphic ammonites. Considered as short-living, convergent final offshoots of different lineages at that time, they are today understood as an independent and very successful ammonite stock of its own, prospering through the entire Cretaceous. In many lineages they were even able to recoil to the normal ammonite spiral (Wiedmann, 1969). Together with the normally coiled ammonites, heteromorphs range up to the end of the Cretaceous (Birkelund, 1979; Wiedmann, 1986, 1988a), but they do not increase in number.

(A6) Another more or less automatic set of mass mortalities would result from adopting the 26 MA periodicity in extinctions propagated by Raup & Sepkoski (1984), Sepkoski & Raup (1986) and Sepkoski (1986). Based firstly on diversity studies of Mesozoic and Cenozoic marine organisms, statistics were refined later on in using generic data. About 10 extinction maxima were described by the authors between late Permian and Middle Miocene. Most of them are separated from one another by a period of 26 MA, and the most important of these peaks being the K/T boundary extinction.

In relating this peak with the Alvarez hypothesis, the 26 MA periodicity is also automatically transferred to the cosmic events either as an impact of a single meteorite or as shower of comets (Hut *et al.*, 1987).

These ideas did not receive too much support by astronomers, and were possibly marved by incorrect statistical methods (Noma & Glass, 1987). There is, moreover, no way in understanding why this periodicity should not be transferred to the Paleozoic (Sepkoski, 1986, text-fig. 5). Finally, some of the postulated extinction peaks (e.g. the Aptian one) just did not exist.

(A7) Several attempts were made to relate extinction events with changes in the geomagnetic field. Weakening of the magnetic field which is associated with magnetic reversals can, theoretically, lead to an increasing influx of cosmic radiation and increasing mutation rates. In fact, there is only a limited number of reversals placed at the Maastrichtian-Paleocene transition after a relatively long magnetic quiet zone. These changes are regarded as being not significant since periods of much higher reversal frequency are known, but without any evolutionary response.

An interesting model was, however, launched by Loper & McCartney (1986) relating these Maastrichtian reversals with the coeval increase in volcanism. It is based on the assumption of periodic instability of the thermal boundary layer at the mantle base. This layer increases by thermal input from the core, thus becoming dynamically unstable, and the migrating mantle plumes give rise to (explosive and/or non-explosive) volcanic activity. Heat extraction of the core leads to a steady increase of both energy supply and, consequently, magnetic reversals frequency due to the dynamo in the fluid outer core. On the other side the also time-equivalent epeirogenic processes can be explained in as much as mantle plumes might lead to continental uplift and hence to marine regressions which are, indeed, an important feature of the Maastrichtian-Paleocene transition. Subsequent decrease of volcanic activity would then coincide with a period of continental subsidence and marine transgression. This is not only a very stimulating model, but it is highly realistic since it reasonably explains a number of rare events coinciding at the K/T boundary.

Summarizing the state of art to explaining mass extinctions at the end of the Cretaceous, we have to admit that the highly controversial but likewise very sophisticated discussion is still continuing, and it would be unwise to propagate any final conclusion. It is, however, obvious that these instantaneous extinctions have to be restricted to a very limited number of organisms mainly attributed to the marine surface plankton.

All endogenous ("Typolysis") and exogenous biological factors (e.g. food chain collapse, competition) can be ruled out from having played a larger role. Changes in salinity and in oxygen content can likewise be eliminated from the great number of environmental factors. Other boundary events (changes in temperature, presence of one or several boundary clays, iridium concentration(s) and shocked quartz, and even the late Maastrichtian magnetic reversals and epeirogenic changes) might correlate with the increasing volcanic activity towards the end of the Cretaceous. If the Loper & McCartney model will improve, there will be no need of the Alvarez hypothesis anymore, even if it is highly estimated. The strongest argument against the cosmic catastrophy is the continuous decline of both the involved marine invertebrates and many vertebrate groups, often occurring a long time before the iridium became deposited. There is also no need to make it a "stepwise extinction" (Kauffman, 1986, this vol.) and to correlate these events with a set of comet showers.

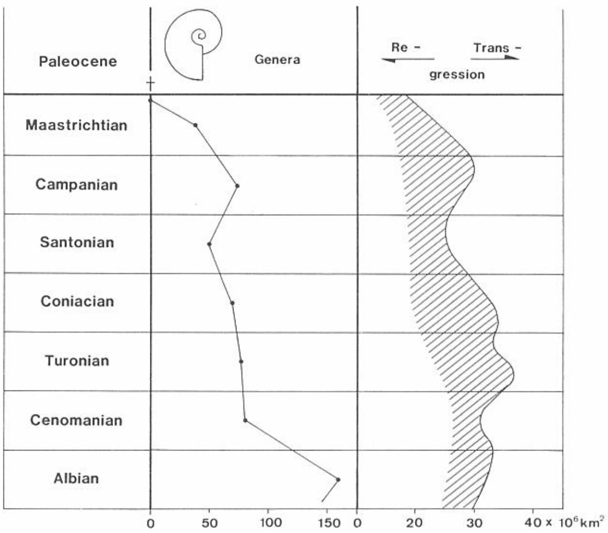

**Figure 6.** Ammonite decline and global sea level changes through the Upper Cretaceous (from Wiedmann, 1986).

(B) There is, however, one geological process available in order to explain these gradual extinctions: The epeirogenic changes in sea level were as fluctuating as was, for example, the course of ammonite diversity evolution. These fluctuations in sea level played, indeed, a ma-

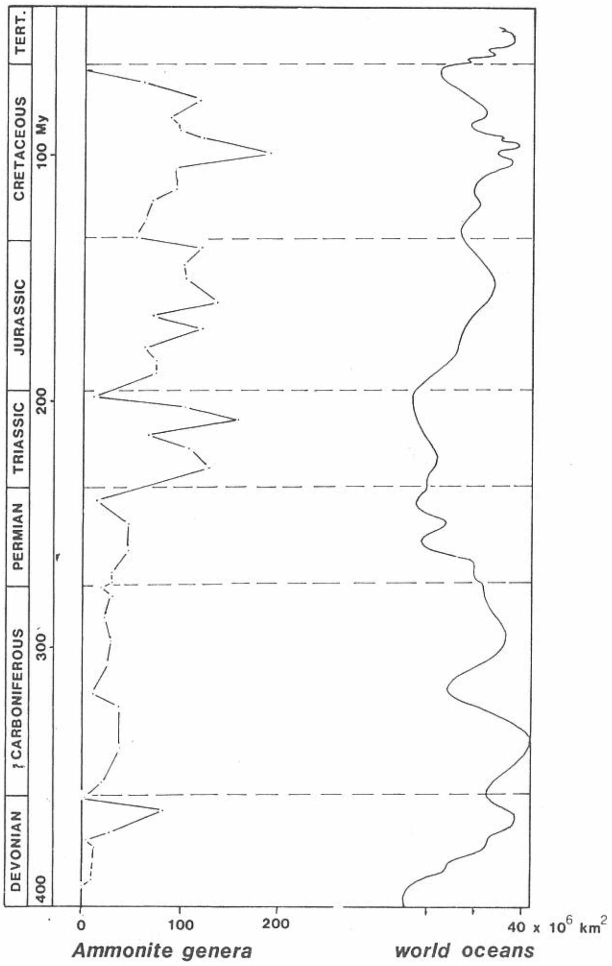

**Figure 7.** Ammonite diversity (from House, 1985) and global sea level changes (from Yanshin, 1973 and Sliter, 1976) through time.

jor role in the late Mesozoic (Ginsburg, 1965; Wiedmann, 1969), and it is really surprising how perfectly ammonite diversity matches the curve of global sea level changes (reconstructed from Yanshin, 1973 and Sliter, 1976) through the late Cretaceous (Fig. 6) and likewise through the Phanerozoic (Fig. 7). Nearly all peaks in ammonite diversity perfectly coincide with maximum transgressions, while decreasing diversity (= extinctions) coincide with major regressions (late Devonian, Permian-Triassic, Triassic-Jurassic, Jurassic-Cretaceous and Cretaceous-Tertiary boundaries). The coincidence of these two rare events (sea level change and ammonite diversity) through a time period of 350 MA is a strong argument supporting this correlation.

It is worth mentioning that Schindewolf presented in a little known talk given at Tübingen University (1950) an impressive diagram –partly based on Umbgrove (1942, 1947)– in which the course of organic evolution is shown to parallel that of sea level changes –without, however, paying particular attention to it (Fig. 8).

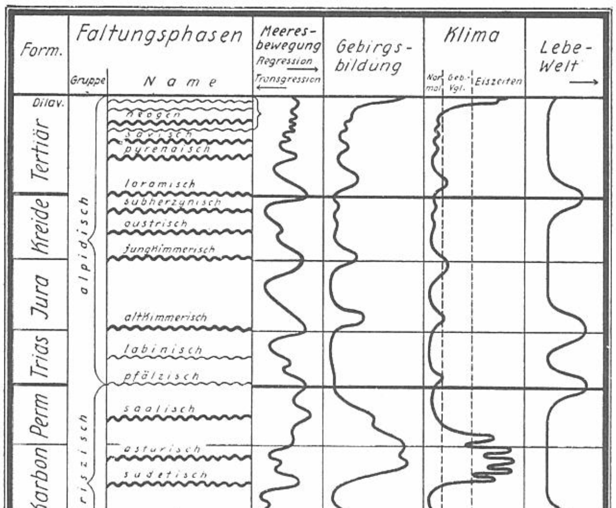

**Figure 8.** Schindewolf's (1950) diagram roughly comparing orogenies, sea level changes, climate, and organic evolution through time.

The fact, that global regressions can really be related with crises in organic evolution was convincingly demonstrated by Kummel & Teichert (1970). Reinvestigating the Permian-Triassic boundary beds of the Salt range and the Trans-Indus Ranges, not one continous marine section was found in the whole area across this boundary with its dramatic faunal break.

## COMPARISON WITH ELDER EXTINCTION EVENTS

It is very interesting that those favouring the Alvarez hypothesis rarely compared the K/T boundary with elder boundaries defined by similar faunal breaks. The reason is the absence of iridium at most of these boundaries.

Own investigations on ammonite evolution across the Mesozoic system boundaries (Wiedmann, 1968, 1970, 1973a, 1973b, 1973c, 1975) led to the conclusion that these boundaries can be compared with each other. The results may be summarized as follows:

(A) There is neither an abrupt and world-wide extinction nor a spontaneous replacement by new elements at these boundaries, as has generally been supposed. Instead, one can recognize the following distinct phases in the sequence of evolutionary events:

(A1) A continuous disappearance of the "antique" faunas.

(A2) A similarly continuous, gradual and largely synchronous appearance of (or substitution by) qualitatively distinguishable "modern" faunas in small populations, yet in various parallel lineages (mosaic evolution).

(A3) A quite revolutionary and quantitatively sudden diversification of the modern faunas, generally coinciding with the boundary or occurring above it with some delay.

(B) Extinction as well as early evolution are long-time procedures as is the final decline of the above mentioned marine invertebrates during the late Cretaceous. Correlation with one or even several cosmic impacts is rather difficult. These ideas would more likely match the generally instantaneous installation of modern faunas. Yet, this comparison has neither be done nor has it much in favour. It is a simple response to niche availability after the extinctions. Worldwide changes in the ecosystem limiting or promoting niche diversity are fully sufficient in order to explain the gradual extinction followed by the new adaptive radiation –or not, as is the case at the K/T boundary. The high degree of provincialism, endemism (Macellari, 1987; Wiedmann, 1988b) and specialization in the antique faunas, the constant survival of smooth oxycones regarded as inhabitants of deep-sea environments (even in the late Maastrichtian of Zumaya) support the idea that marine regressions and transgressions were the most effective environmental factors for ammonite life and evolution.

(C) This evolutionary pattern can, however, be camouflaged by restricted preservation, e.g. early diagenetic aragonite solution or/and low pyrite precipitation, as was observed in case of the late Triassic (Wiedmann, 1973c).

The idea of mass extinctions at the era and system boundaries must be seen today in a very differentiated way. There is no question at all that the Alvarez hypothesis initiated a very fruitful discussion on the interactions between geo- and biosphere, even if it, finally, may not withstand the increasing criticism.

But I would like to remember at this place, that not only the idea of mass extinctions at these boundaries originated in pictures given by Schindewolf (1954). He was also one of the first explaining the overall extinction by means of cosmic catastrophies (e.g. supernovae).

## ACKNOWLEDGEMENTS

The author appreciates linguistic advice by W. Schwentke. Field work was supported by Deutsche Forschungsgemeinschaft.

## BIBLIOGRAPHY

Alvarez, L.W. 1987. Mass extinctions caused by large bolide impacts. *Physics Today,* **1987**, 24-33.

Alvarez, L.W.; Alvarez, W.; Asaro, F. & Michel, H.V. 1980. Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science,* **208**, 1095-1108.

Archibald, J.D. & Clemens, W.A. 1982. Late Cretaceous extinctions. *Amer. Sci.,* **70**, 377-385.

Bijvank, G.J. 1967. Über das Vorkommen von Inoceramen im Tertiär und das Alter der Schichtenfolge in einem Küstenprofil bei Guecho (Vizcaya, Nord-Spanien). *Neues Jarhbuch Geologie und Paläontologie Mh.*, **1967**, 385-397.

Birkelund, T. 1979. The last Maastrichtian ammonites. In: Cretaceous-Tertiary Bondary Events (Eds. T. Birkelund & R.G. Bromley). *The Maastrichtian and Danian of Denmark, Symp. Copenhagen 1979.* **1**, 51-57.

Birkelund, T. & Hakansson, E. 1980. The terminal Cretaceous extinction in Boreal shelf seas — A multicausal event. *Geological Society of America, spec. Pap.,* **190**, 373-384.

Blaszkiewicz, A. 1980. Campanian and Maastrichtian ammonites of the Middle Vistula River Valley, Poland: A stratigraphic-paleontological study. *Prace Inst. geol.,* **92**, 63 pp.

Bohor, B.F.; Modreski, P.J. & Foord, E.F. 1987. Shocked quartz in the Cretaceous-Tertiary boundary clays: Evidence for a global distribution. *Science,* **236**, 705-709.

Bramlette, M.N. & Martini, E. 1964. The great change in calcareous nannoplankton fossils between the Maastrichtian and Danian. *Micropaleontology,* **10**, 291-322.

Carpenter, K. & Breithaupt, B. 1986. Latest Cretaceous occurrence of nodosaurid ankylosaurs (Dinosauria, Ornithischia) in western North America and the gradual extinction of the dinosaurs. *Journal Vertebrate Paleontology,* **6**, 251-257.

Christensen, W.K. 1976. Paleobiography of Late Cretaceous belemnites of Europe. *Paläont. Z.,* **50**, 113-129.

Clemens, W.A. 1982. Patterns of extinction and survival of the terrestrial biota during the Cretaceous/Tertiary transition. In: Geological implications of impacts of large asteroids and comets on the earth (Eds. L.T. Silver & P.H. Schultz). *Geological Society of America, spec. Pap.,* **190**, 407-413.

Clemens, W.A.; Archibald, J.D. & Hickey, L.J. 1981. Out with a wimper not a bang. *Paleobiology,* **7**, 293-298.

Dhondt, A.V. 1983. Campanian and Maastrichtian inoceramids: A review. *Zitteliana,* **10**, 689-701.

Elderfield, H. 1986. Strontium isotope stratigraphy. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **57**, 71-90.

Engeser, T.; Reitner, J.; Schwentke, W. & Wiedmann, J. 1984. Zur kretazisch-alttertiären Tektogenese des Basko-Kantabrischen Beckens (Nordspanien). *Z. dt. geol. Ges.,* **135**, 243-278.

Ginsburg, L. 1965. Les régressions marines et le problème du renouvellement des faunes au cours des temps géologiques. *Bulletin Societé géologique de France,* (7) **6** (1964), 13-22.

Hallam, A. 1987. End-Cretaceous mass extinction event: Argument for terrestrial causation. *Science,* **238**, 1237-1242.

Hansen, H.J.; Gwozdz, R.; Bromley, R.G.; Rasmussen, K.L.; Vogensen, E.W. & Pedersen, K.R. 1986a. Cretaceous-Tertiary boundary spherules from Denmark, New Zealand and Spain. *Bull. geol. Soc. Denmark,* **35**, 75-82.

Hansen, H.J.; Gwozdz, R.; Hansen, J.M.; Bromley, R.G. & Rasmussen, K.L. 1986 b. The diachronous C/T plankton extinction in the Danish basin. *Lecture Notes Earth Sci.,* **8**, 381-384.

Herm, D. 1965. Mikropaläontologisch-stratigraphische Untersuchungen im Kreideflysch zwischen Deva und Zumaya (Prov. Guipúzcoa, Nordspanien). *Z. dt. geol. Ges.,* **115**, 277-348.

Herm, D., Hillebrandt, A.V. & Perch-Nielsen, K. 1981. Die Kreide-Tertiär-Grenze im Lattengebirge (Nördliche Kalkalpen) in mikropaläontologischer Sicht. *Geologica bavarica,* **82**, 319-344.

Hickey, L.J. 1981. Land plant evidence compatible with gradual, not catastrophic, change at the end of the Cretaceous. *Nature,* **292**, 529-531.

Hillebrandt, A.v. 1965. Foraminiferen-Stratigraphie im Alttertiär von Zumaya (Provinz Guipúzcoa, NW-Spanien) und ein Vergleich mit anderen Tethys-Gebieten. *Abh. Bayer. Akad. Wiss., Math.-naturwiss. Kl., N.F.,* **123**, 62 pp.

Hofker, J. 1960. Le problème du Dano-Paléocène et le passage Crétacé-Tertiaire. *Révue Micropaléontologie,* **3**, 119-130.

House, M.R. 1985. The ammonoid time-scale and ammonoid evolution. In: The chronology of the geological record (Ed. E.J. Snelling). *Geol. Soc. Mem.,* **10**, 273-283.

Hut, P. et al., 1987. Comet showers as a cause of mass extinctions. *Nature,* **329**, 118-126.

Jaeger, H. 1986. Die Faunenwende Mesozoikum/Känozoikum - nüchtern betrachtet. *Z. geol. Wiss.,* **14**, 629-656.

Kapellos, C. 1974. Über das Nannoplankton im Alttertiär des Profils von Zumaya-Guetaria (Provinz Guipúzcoa, Nordspanien). *Eclogae geologicae Helvetiae,* **67**, 435-444.

Kauffman, E.G. 1979. Cretaceous. In: *Treatise on Inverte-*

*brate Paleontology* (Eds. R.A. Robison & C. Teichert). A. Univ. Kansas Press & Geol. Soc. Amer., Boulder, 418-487.

Kauffman, E.G. 1986. High-resolution event stratigraphy: Regional and global Cretaceous bio-events. In: Global Bio-events (Ed. O.H. Walliser). *Lecture Notes Earth Sci.* Springer, Berlin, **8**, 279-335.

Kopp, K.O. 1959. Inoceramen im Tertiär des Mittelmeerraumes. *N. Jb. Geol. Paläont. Mh.*, **1959**, 481-492.

Kummel, B. & Teichert, C. 1970. Stratigraphy and paleontology of the Permian-Triassic boundary beds, Salt Range and Trans-Indus Ranges, West Pakistan. In: Stratigraphic Boundary problems: Permian and Triassic of West Pakistan (Eds. B. Kummel & C. Teichert). *Dept. Geology, University of Kansas, spec. Publ.*, **4**, 1-110, Lawrence, Kansas.

Lahodynsky, R. In press. The K/T boundary and "yellow clay" layers in the Gosau Group, Northern Calcareous Alps, Austria.

Lamolda, M.A.; Orue-Etxebarria, X. & Proto-Decima, F. 1983. The Cretaceous-Tertiary boundary in Sopelana (Biscay, Basque Country). *Zitteliana*, **10**, 663-670.

Loper, D.E. & McCartney, K. 1986. Mantle plumes and the periodicity of magnetic field reversals. *Geophys. Res. Lett.*, **13**, 1525-1528.

Macellari, C.E. 1986. Late Campanian-Maastrichtian ammonite fauna from Seymour Island (Antarctic Peninsula). *Paleontological Society Mem.*, **18**, 1-55.

Macellari, C.E. 1987. Progressive endemism in the late Cretaceous ammonite family Kossmaticeratidae and the breakup of Gondwanaland. In: Gondwana Six: Stratigraphy, sedimentology, and paleontology (Ed. G.D. McKenzie). *Geophys. Monogr.*, **41**, 85-92.

McGowan, C. 1973. A note on the most recent ichthyosaur known; an isolated coracoid from the Upper Campanian of Saskatchewan (Reptilia, Ichthysauria). *Canadian Journal of Earth Sciences*, **10**, 1346-1349.

McGowan, C. 1978. An isolated ichthyosaur coracoid from the Maastrichtian of New Jersey. *Canadian Journal of Earth Sciences*, **15**, 169-171.

Naslund, H.R.; Officer, C.B. & Johnson, G.D. 1986. Microspherules in Upper Cretaceous and Lower Tertiary clay layers at Gubbio, Italy. *Geology*, **14**, 923-926.

Noma, E. & Glass, A.L. 1987. Mass extinction pattern: Result of chance. *Geological Magazine*, **124**, 319-322.

Officer, C.B.; Hallam, A.; Drake, C.L. & Devine, J.D. 1987. Late Cretaceous and paroxysmal Cretaceous-Tertiary extinctions. *Nature*, **326**, 143-149.

Olmez, I.; Finnegan, D.L. & Zoller, W.H. 1986. Iridium emissions from Kilauea volcano. *J. geophys. Res.*, **91**, 653-663.

Perch-Nielsen, K. 1979. Cretaceous nannofossils at the Cretaceous-Tertiary boundary in Tunisia. In: Cretaceous-Tertiary Boundary Events Symposium Copenhagen, 1979 (Eds. W.K. Christensen & T. Birkelund). *Proc. Univ. Copenhagen*, **2**, 238-243.

Percival, S.F. & Fischer, A.G. 1977. Changes in calcareous nannoplankton in the Cretaceous-Tertiary biotic crisis at Zumaya, Spain. *Evolutionary Theory*, **2**, 1-35.

Pillmore, Ch.L. & Flores, R.M. 1987. Stratigraphy and depositional environments of the Cretaceous-Tertiary boundary clay and associated rocks, Raton basin, New Mexico and Colorado. *Geological Society America, spec. Pap.*, **209**, 111-130.

Raup, D.M. & Sepkoski, J.J. jr. 1986. Periodic extinction of families and genera. *Science*, **231**, 833-836.

Rice, A. 1987. Shocked minerals at the K/T boundary: Explosive volcanism as a source. *Phys. Earth Planet. Int.*, **48**, 167-174.

Rosenfeld, A.; Honigstein, A.; Flexer, A.; Almogi-Lavin, A.; & Dvorachek, M. 1987. Extraterrestrial impact at the Cretaceous-Tertiary boundary in southern Israel. *Abstracts, Paleontology and Evolution: Extinction Events* (Eds. M.A. Lamolda & A. Cearreta), p. 267.

Russell, D.A. 1967. Systematics and morphology of American mosasaurs. *Bull. Yale Peabody Mus. Nat. Hist.*, **23**, 240 pp.

Salaj, J. & Wiedmann, J. In press. The Campanian-Maastrichtian boundary in the El Kef section, Tunisia.

Schindewolf, O.H. 1945. Darwinismus oder Typostrophismus? *Magyar biol. Kut. Munk.*, **16**, 104-177.

Schindewolf, O.H. 1950. Der Zeitfaktor in Geologie und Paläontologie. *Akad. Antrittsvorlesung*, Schweizerbart, Stuttgart, 114 pp.

Schindewolf, O.H. 1954. Über die möglichen Ursachen der groβen erdgeschichtlichen Faunenschnitte. *N. Jb. Geol. Paläont. Mh.*, **1954**, 457-465.

Schindewolf, O.H. 1956. Tektonische Triebkräfte der Lebensentwicklung? *Geol. Rundschau*, **45**, 1-16.

Schmitz, B. 1985. Metal precipitation in the Cretaceous-Tertiary boundary clay at Stevens Klint, Denmark. *Geochimica et cosmochimica Acta*, **49**, 2361-2370.

Schmitz, B.; Anderson, P. & Dahl, J. In press. Iridium, sulfur isotopes and rare earth elements in the Cretaceous-Tertiary boundary clay at Stevens Klint, Denmark.

Schopf, T.J.M. 1982. Extinction of the dinosaurs: A 1982 understanding. *Geological Society of America, spec. Pap.*, **190**, 415-422.

Sepkoski, J.J. jr. 1986. Global Bioevents and the question of periodicity. *Lecture Notes Earth Sciences*, **8**, 47-61.

Sepkoski, J.J. jr. & Raup, D.M. 1986. Periodicity in marine extinction events. *In: Dynamics of Extinction* (Ed. D.K. Elliott). Wiley, New York, 3-36.

Sliter, W.V. 1976. Cretaceous foraminifers from the southwestern Atlantic Ocean, Leg 36, Deep Sea Drilling Project. In: *Init. Rep. DSDP* (Eds. P.F. Barker; I.W. Dalziel *et al.*), **36**, 519-537, Washington D.C.

Sloan, R.E.; Rigby, J.K.; Van Valen, L. & Gabriel, D. 1986. Gradual dinosaur extinction and simultaneous ungulate radiation in the Hell Creek Formation. *Science*, **232**, 629-633.

Smit, J. & Klaver, G. 1981. Sanidine spherules at the Cretaceous-Tertiary boundary indicate a large impact event. *Nature*, **292**, 47-49.

Smit, J. & ten Kate, W.G.H.Z. 1982. Trace-element patterns at the Cretaceous-Tertiary boundary-Consequences of large impact. *Cretaceous Research*, **3**, 307-332.

Stinnesbeck, W. 1986. Zu den faunistischen und palökologischen Verhältnissen in der Quiriquina-Formation (Maastrichtian) Zentral-Chiles. *Palaeontographica* (A) **194**, 99-237.

Thiedig, F. & Wiedmann, J. 1976. Ammoniten und Alter der höheren Kreide (Gosau) des Krappfeldes in Kärnten (Österreich). *Mitt. geol. paläont. Inst. Univ. Hamburg*, **45**, 9-27.

Thierstein, H.R. & Berger, W.H. 1978. Injection events in ocean history. *Nature*, **276**, 461-466.

Umbgrove, J.H.F. 1942. *The Pulse of the earth.* 1st edit. M. Nijhoff, The Hague, 179 pp.

Umbgrove, J.H.F. 1947. *The Pulse of the earth.* 2nd edit., ibidem, 358 pp.

Ward, P. & Wiedmann, J. 1983. The Maastrichtian ammonite succession at Zumaya, Spain. *Abstracts, Symp. on Cretaceous stage boundaries.* Copenhagen 1983, 205-208.

Wiedmann, J. 1968. Das Problem stratigraphischer Grenzziehung und die Jura/Kreide-Grenze. *Eclogae geologicae Helvetiae,* **61**, 321-386.

Wiedmann, J. 1969. The heteromorphs and ammonoid extinction. *Biological Reviews,* **44**, 563-602.

Wiedmann, J. 1970. Über den Ursprung der Neoammonoideen - Das Problem einer Typogenese. *Eclogae geologicae Helvetiae,* **63**, 923-1020.

Wiedmann, J. 1973a. Ammonoid (r)evolution at the Permian-Triassic boundary. *Mem. canad. Soc. Petrol. Geol.,* **2**, 513-521.

Wiedmann, J. 1973b. Evolution or revolution of ammonoids at Mesozoic System boundaries. *Biological Reviews,* **48**, 159-194.

Wiedmann, J. 1973c. Ammoniten-Nuklei aus Schlämmproben der nordalpinen Obertrias–Ihre stammesgeschichtliche und stratigraphische Bedeutung. *Mitt. Ges. Geol. Bergbaustud.,* **21**, 521-616.

Wiedmann, J. 1975. The Jurassic-Cretaceous boundary as one of the Mesozoic System boundaries. *Mém. B. R. G. M.,* **86**, 358-362.

Wiedmann, J. 1981. In: Field Guide: Excursions to Coniacian-Maastrichtian of Basque-Cantabric Basin (Eds. A. Lamolda; J. Rodríguez-Lázaro & J. Wiedmann). *Publ. Geol. Univ. Autón. Barcelona.* Barcelona-Bellaterra, **14**, 53 pp.

Wiedmann, J. 1986. Macro-invertebrates and the Cretaceous-Tertiary boundary. *Lecture Notes Earth Sci.,* **8**, 397-409.

Wiedmann, J. 1988a. Ammonoid extinction and the "Cretaceous-Tertiary Boundary Event". *In: Cephalopods - Present and Past* (Eds. J. Wiedmann & J. Kullmann). Schweizerbart, Stuttgart, 117-140.

Wiedmann, J. 1988b. Plate tectonics, sea level changes, climate and the relationship with ammonite evolution, provincialism, and mode of life. *In: Cephalopods - Present and Past* (Eds. J. Wiedmann & J. Kullmann). Schweizerbart, Stuttgart, 737-765.

Wiedmann, J.; Butt, A. & Einsele, G. 1978. Vergleich von marokkanischen Kreide-Küstenaufschlüssen und Tiefseebohrungen (DSDP): Stratigraphie, Paläoenvironment und Subsidenz an einem passiven Kontinentalrand. *Geol. Rundschau,* **67**, 454-508.

Wiedmann, J.; Butt, A. & Einsele, G. 1982. Cretaceous stratigraphy, environment, and subsidence history at the Morrocan continental margin. *In: Geology of the NW African Continental Margin* (Eds. U.v. Rad *et al.*). Springer, Berlin, 366-395.

Wiedmann, J.; Reitner, J.; Engeser, T. & Schwentke, W. 1983. Plattentektonik, Fazies- und Subsidenzgeschichte des Basko-Kantabrischen Kontinentalrandes während Kreide und Alttertiär. *Zitteliana,* **10**, 207-244.

Voigt, E. 1979. Kritische Bemerkungen zur Diskussion über die Kreide/Tertiärgrenze. In: Cretaceous-Tertiary Boundary Events (Eds. W.K. Christensen & T. Birkelund). *Proceedings,* Univ. Copenhagen, **2**, 38-48.

Yanshin, A.L. 1973. On so-called world transgressions and regressions. *Bjul. moskovsk. obc. ispyt. prirody, n.s., otd. geol.,* **48**, (2), 9-44. [In Russ.].

Zoller, W.H.; Parrington, J.R. & Phelan Kotra, J.M. 1983. Iridium enrichment in airborne particles from Kilauea Volcano: January 1983. *Science,* **222**, 1118-1121.