

# How the Deccan Volcanism and the Chicxulub Asteroid Impact Resulted in the Biological Crisis Ending the Mesozoic Era

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## Author's contribution

*The sole author designed, analyzed and interpreted and prepared the manuscript.*

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## ABSTRACT

The direct causes for the end-Cretaceous biological crisis are still enigmatic despite of the numerous studies carried out at the Chicxulub asteroid impact site and in the Indian late Cretaceous Deccan volcanic province. None of the discussed physical and chemical devastating factors explained the selective extinction-survival pattern. The present study analyzes the vulnerability of faunal and floral groups to a sudden ecological disaster as the result of the incidental co-occurrence of the asteroid impact during Deccan volcanism. Their combined ejecta must have shaded the sunlight, ceasing photosynthesis for about 2-3 years and lowering the temperature on earth, which must have been crucial for cold-blooded reptiles. The darkening would have blurred seasonality, drastically reducing floral blooming, fruition and organism reproduction, all of which resulted in the collapse of the marine and terrestrial food-chain and prey-predator relationships. Apart from death by starvation, the main killing was carried out by the organisms themselves through a Darwinian struggle for life leading to a selective elimination of the temporarily vulnerable taxa. Those which succeeded to escape adapted to refuge sites and survived. The

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disappearance of most of the Cretaceous carnivore reptiles enabled the survivors to fearlessly explore the Tertiary world and acclimatize to previously inaccessible habitats, which continuously shaped with the ongoing changes in the ecological and biological settings. This dynamic development of the Tertiary ecosystems accelerated the evolutionary tempos leading to rapid speciation. Despite being direct descendants of Cretaceous survivors they were given a new taxonomic identity and their precursors were considered wiped-out, intensifying the apparent end-Cretaceous 'mass extinction'.

*Keywords: End-cretaceous biological crisis; Deccan Province volcanism; asteroid impact; atmosphere darkening; food-chain collapse; natural selection.*

## 1. INTRODUCTION

The different faunal and floral taxonomic composition between the latest Cretaceous and the Early Tertiary marked the biostratigraphic boundary between the Mesozoic and Cenozoic eras. The statistically calculated extinction of nearly 50% of Cretaceous marine genera is one of a few periodic extinction events during the Phanerozoic [1]. The possible catastrophic nature of this end-Cretaceous event was expressed by the nearly simultaneous disappearance of the most common and characteristic Upper Cretaceous faunal groups such as the diverse planktonic foraminifera, many calcareous nannoplankton species, rudist bivalves, nerineid gastropods, ammonites and belemnites, marine mosasaur and plesiosaur reptiles, as well as terrestrial non-avian dinosaurs and pterosaurs [2]. Most of these organisms were highly successful and widely distributed over the Late Cretaceous world. Therefore, their apparent abrupt elimination puzzled paleontologists and animated the imagination of the public. Among the latest Cretaceous hazardous phenomena thought to have affected the global ecosystems was the impact of an extraterrestrial body, based on a rise in iridium content in end-Cretaceous sediments. The impact ejecta of a large asteroid might have darkened the atmosphere, ceasing photosynthesis and leading to the collapse of the food-chain [3]. The huge crater about 180 km in diameter discovered at Chicxulub on the Yucatan Peninsula substantiated the asteroid hypothesis [4]. Previous studies raised doubts regarding the devastating effect of the asteroid impact because the amount of ejected fine components calculated was too-small [5], and because none of the associated physical and chemical factors could have controlled the worldwide selective extinctions [6]. Alternatively the intensive volcanic activity of the Deccan Traps in west-central India [7,8] and its resulting ecological perturbations were advocated [9]. However, all

these catastrophic scenarios were rejected by the survival of organisms highly vulnerable to the killing factors suggested such as frogs and salamanders surviving the alleged acid rain [10]. The lack of concentrations at the Cretaceous-Tertiary boundary (KTb) of vertebrate and invertebrate skeletons putatively killed instantaneously makes the catastrophe scenario questionable [11]. The concise evaluation of the accumulated multidisciplinary data carried out by 41 authors supports the asteroid impact scenario as the trigger for the end-Cretaceous mass extinction, although the direct control of the impact on the biological crisis was not specified [12]. The present reevaluation of the accumulated information focuses on the response of individual taxa to the ecological perturbations that the Deccan volcanism and/or the asteroid impact might have inflicted on life on earth because none of their suggested physical and chemical hazardous factors could have resulted in the puzzling extinction-survival pattern.

## 2. POSSIBLE CAUSES FOR THE END-CRETACEOUS BIOLOGICAL CRISIS

### 2.1 Upper Cretaceous Ecosystems

During the Late Cretaceous the continental plates shifted further apart and widened the Atlantic seaway, intensifying global circulation across the meridian Tethys Ocean [13]. The prevailing warm climate, extensive oceans and wide continental shelves were associated with a rise in nutrient content in the Tethys, where phosphorites accumulated in increasing quantities since the Coniacian up to the Early Eocene [14]. These optimal ecological conditions enhanced the diversification and the abundance of the marine phytoplankton, calcareous coccolithophorids and planktonic foraminifera with the diversified keeled Globotruncanidae, all of which became the primary marine food source and increased the Late Cretaceous marine

productivity of larger invertebrates and vertebrates as well. However, the disappearance in the Maastrichtian of taxonomically unrelated genera or families having a common mode of life or physiological disadvantages suggests the involvement of an anomalous factor shaking the ecosystems and leading to over-predation of vulnerable taxa up to their total elimination. The Late Cretaceous crowded biosphere might have lost its food-chain balance as the result of ecological perturbations increasing the predatory pressure on organisms providing easy prey. The early growth stage of the inoceramid bivalves was attached to a substrate on the bottom of rather deep marine environments. With growth the shell reclined on the sea bottom exposed to predators such as the shark *Ptychodus* [15]. The fragile prismatic shell fragments when bitten rarely preserving the shape of the biting teeth. Inoceramid prisms may reflect predation on these large sessile bivalves, which probably lead to inoceramid demise already in the middle Maastrichtian [16], whereas their related small *Tenuipteria* survived to the end of the Cretaceous [17]. During the latest Cretaceous irregularly coiled (heteromorphs) nostoceratid ammonites disappeared before the KTB [16]. These nekto-benthic, slow-moving ammonoids constituted easy prey compared to the better swimming planispiral and orthocone (Baculitidae) species, which ranged close to the KTB [16,18], some of which probably survived the impact event (Ir-anomaly) for a short time (New Jersey, USA) [19]. The latest Cretaceous-earliest Danian (?) ammonite *Hoploscaphites constrictus johnjagti* Machalski differs from the typical *H. constrictus* by pronounced ribbing and tuberculation on the body chamber, which probably developed against predation pressure by shell crushing vertebrates [20].

## 2.2 The Ecological Effect of the Deccan Volcanic Activity

Carbon and oxygen isotope analyses and paleoecological studies on latest Cretaceous foraminifera detected fluctuations in seawater temperature and hence in the marine ecosystems [21,22]. The abrupt warming by 3°-4°C of the deep ocean seawater (analyzed on benthic species) close to the end-Cretaceous upper CF2 and basal CF1 foraminifera biozones (Fig. 1) was related to the 'greenhouse' warming effect as the result of the sunlight screening ejecta of the contemporaneous beginning of the Deccan eruptions of Phase 2 [9,23]. Planktonic species richness dropped by 50% and dwarfed

species increased by up to 60% together with an increasing abundance of low-oxygen tolerant, small heterohellicids (foraminifera) and the disaster opportunist genus *Guembelitra* [9,24]. Coccolithophorids likewise show dwarfing in some species and an increase in abundance of the disaster opportunist *Micula decussata* [23]. The global warming was followed by cooling to former temperatures and a reduction in the abundance of dwarfed microorganisms to the previous setting [9], questioning the rise in temperature as the main ecological hazard to the marine plankton, and the Deccan volcanism as the direct cause for the end-Cretaceous 'mass-extinction'.

An experimental extraction of symbiotic zooxanthellae from live *Globigerinoides sacculifer* (Brady) for 72 hours resulted in early gametogenesis and smaller test sizes when compared to untreated specimens [25]. Individuals kept in continuous darkness in untreated seawater underwent early gametogenesis, had short survival times and small test sizes. After reinfection by zooxanthellae these treated *G. sacculifer* resumed their normal life cycle and test size. Accordingly, the increase in abundance of dwarfed and low-oxygen tolerating species during the Deccan volcanic eruptions might have resulted from the sunlight screening ejecta temporarily interrupting photosynthesis rather than from global warming [9].

Basalt flows of Phase 2 along the eastern extension of the Deccan Traps in northeast India (Krishna-Godavari Basin) are interbedded with marine pelagic sediments of the latest Cretaceous (CF1 Zone) and overlain by Early Tertiary (PIa Zone) sediments [26], straddling the biostratigraphic KTB and ranging throughout the earliest Paleocene P0 Zone (Fig. 1). More to the northeast (Um Sohryngkew) the pelagic Cretaceous-Tertiary transition sequence does not comprise volcanics and seems to be complete. An Ir-anomaly was detected at the biostratigraphic KTB in between the CF1 and P0 zones, across which the  $\delta^{13}\text{C}$  record decreases [26,27].

This single iridium anomaly in the Deccan volcanic province, which operated in three phases some 2.5 million years [29], attests to its extraterrestrial origin [3] attributed to the Chicxulub asteroid, which in India and in other regions coincides with the biostratigraphic KTB [12].

The calculated 10 k.y. total duration of lava emissions [29] shortens Phase 2 to below the estimated period of its 'greenhouse' warming effect [9]. Actually, the emission of poisonous gases and sunlight screening ejecta were suggested to cause the end-Cretaceous ecological perturbations [9] rather than the basalt floods suggesting that volcanoclasts and aerosols were emitted into the atmosphere without lava flows, affecting the atmosphere for longer periods than represented by the basalts.

### 2.3 The Chicxulub Asteroid Impact

The global distribution of the iridium anomaly at the KTB is associated in places with shocked quartz, rock-melt spherules and micro-diamonds within a thin clay layer [4,12] suggesting a geologically short impact event. Studies around the Chicxulub region revealed sequences of a complex sedimentary composition several meters thick. They begin with a layer of rock-melt impact spherules followed by up to 10 m of pelagic marl containing latest Maastrichtian foraminifera (CF1 Zone) of a rather constant species composition regarded as being gradually deposited, and hence implying that the impact had no biological affect for about 300 (or 150) k.y. up to the KTB, where a small Ir-anomaly was detected [30,31]. Spherules appear in various concentrations throughout the sequence concentrating into upward fining layers, associated with quartz sand and silt, benthic foraminifera, clasts of reworked origin and marly limestone layers. These sediments were intensively burrowed by *Chondrites*, *Zoophycus*, *Ophiomorpha* and *Thalassinoides* in places, being interpreted as of long periods of sedimentation and colonization by infaunal communities after the deposition of the basal impact spherule layer and prior to the Ir-anomaly at the KTB at the top of the sequence [30]. Any exhumed infaunal organism will immediately burrow into the stabilized sediment, challenging the above estimated duration of sediment accumulation. Sedimentological criteria attesting to the high-energy conditions created by the impact event should not be confused with normal depositional processes over long periods [4]. The granulometry of the ejected particles settling through the atmosphere and thereafter through the water column must be considered [4], whereby the fine fraction with the iridium settled last to the sea bottom. Geochemical analyses of sediments close below and above the KTB in the

impact region revealed volcanic components [30], which can be related to the Deccan volcanism.

### 2.4 The Combined Effect of the Deccan Volcanism and Asteroid Impact

The latest Maastrichtian 'greenhouse' warming effect was possibly caused by the Deccan ejecta temporarily deteriorating the marine ecosystems. However, these recovered before the KTB [9], and thus the Deccan volcanism alone could not have resulted in the end-Cretaceous biological crisis. The extension of Phase 2 into the earliest Paleocene (P0 Zone) across the biostratigraphic KTB and the associated single Ir-anomaly detected in northeast India [26,27] indicate that the Chicxulub asteroid impact occurred during the late stage of Phase 2, which might have been intensified by the impact shock-waves. The continuous rise of hot volcanoclasts and gases during several years carried the ejecta of the impact explosion to high atmospheric levels, slowing the gravitational settling down of all ejected particles. These shaded the sunlight and darkened the atmosphere probably for 2-3 years, in contrast to a darkening effect up to one year of a single major eruption. The abrupt elimination of most of the marine plankton with photosynthesizing endosymbionts marks the biostratigraphic KTB in Cretaceous-Tertiary pelagic continuous successions. It occurs within the rise in iridium content (Ir-anomaly) contributed by the asteroid impact [3]. Accordingly the impact must have been involved in the cessation of photosynthesis, which on land is attested to by a fungal layer 0.4-cm-thick detected at the base of iridium enriched coal 1-cm-thick at the KTB in a terrestrial sequence in New Zealand (Greymouth Coalfield). "This fungiferous interval implies wholesale dieback of photosynthetic vegetation at the K-T boundary in this region" ...and "would have lasted a few years at most, because the recovery of ferns initiates within the maximum iridium anomaly layer" [32]. This 'fern spore spike' (fern spore dominance) [33] at the KTB (Ir-anomaly) was previously detected in the Western Interior of the United States [34], indicating the wide distribution of this floral marker and of a global floral crisis. This geologically instantaneous biological crisis ending the Mesozoic Era is therefore directly related to the Chicxulub asteroid impact during the Deccan volcanism.

### 3. CONTROL OF THE END-CRETACEOUS EXTINCTION-SURVIVAL PATTERN

The total cessation of photosynthesis and hence primary production drastically reduced the biogenic fixation of <sup>12</sup>C, whereas the disintegration of the dead organic components increased the <sup>12</sup>C in the atmosphere and ambient water, resulting in a sharp decrease of δ<sup>13</sup>C values at and across the KTB [35]. Severe food shortage in the marine environments increased predation, which rapidly intensified the selective devouring of the vulnerable organisms. The terrestrial food chain was affected after several months of near darkness during which deciduous trees shed their leaves and annual plants hardly developed. The blurred seasonal differentiation suppressed animal mating and reproduction, plant blooming and fruit bearing. It triggered an aggressive struggle for life under the dim day light leading to intensive predation of vulnerable

species and the consumption of plants [36], all of which further intensified famine and the demand for nourishment. The biologically-initiated end-Cretaceous killing process is corroborated by the lack of bone-beds and skeleton concentrations at the KTB boundary, which would be expected from an abrupt death by some physical or chemical factors [11]. The biological killing process crushes skeletons, devours organisms and plants almost without leaving any relics to fossilize, thus selectively eliminating the vulnerable taxa and edible plants. It was most effective during the 2-3 years of no photosynthetic activity and accomplished a few years later while photosynthesizing organisms and plant gradually appeared [32]. Some Cretaceous individual survivors may have only become extinct in post-impact earliest Tertiary times, as suggested by ammonites in Lower Danian sediments, unless proven reworked [37].

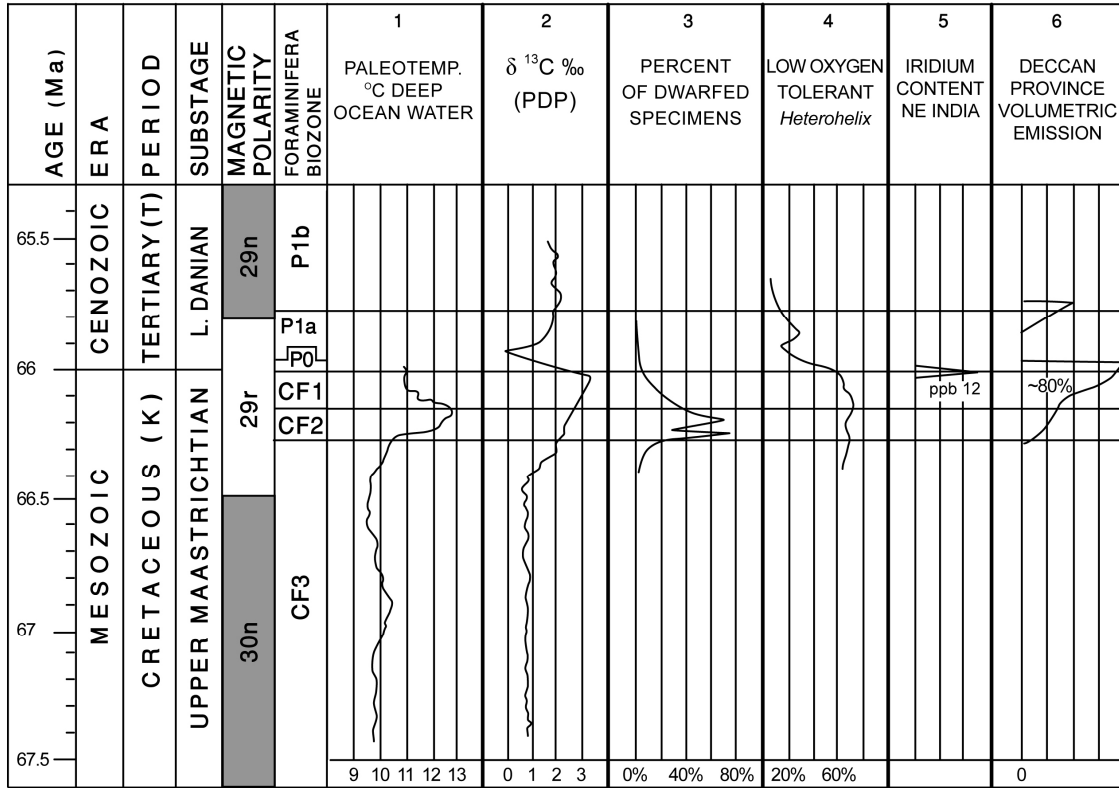


Fig. 1. Trends of changing physical, chemical and biological factors across the KTB. Time scale according to the International Chronostratigraphic Chart 2014. Magnetic polarity, planktonic foraminifera biozones and columns 1-5 emended from [9,24,26,27]. Column 6 is based on [28]

## 4. EXAMPLES OF TEMPORARY VULNERABILITY TO PREDATION

### 4.1 Reptiles

The extinction of some of the most successful large Late Cretaceous organisms such as the non-avian dinosaurs, pterosaurs, marine reptiles (e.g., mosasaurs, plesiosaurs), ammonites, belemnites, and rudist bivalves suggests that these diverse vertebrates and invertebrates could not cope with the severe reduction in food sources and the resulting predatory pressure. The non-avian dinosaurs were oviparous reptiles laying 1-7 (or more) eggs in nests, most of which were situated on rather flattened open ground at seashores [38], on tidal flats [39], beside fluvial-lacustrine-estuarine environments [40], and on sandy aeolian dune fields [41], where the dinosaurs could watch for any endangering intruders coming from large distances. This precaution was needed to protect the relatively large eggs and the hatchlings during rather long parental care [41], which could be snatched from the nest or consumed on site after the distraction of the parents. The exposed flat landscape enabled the cold-blooded reptiles to absorb the warmth of the early morning solar radiation, which was vital for their daily activity. However, this strategy turned inefficient during the 2-3 years of near darkness and considerable drop in temperature, whereby the activity and ability of the non-avian, probably cold-blooded dinosaur to withstand predators was drastically reduced. Sun screening resulted in a temporary lack of seasonal differentiation, ceased mating and reproduction for about two years. The disadvantage of the non-avian dinosaur's frequent mode of nesting on open ground is evident by the survival of other oviparous reptiles such as crocodiles, turtles and the amphibian frogs and salamanders, which laid their eggs hidden in coastal sands, among plants on wetland, or in the water, whereby the hatchlings successfully survived into the Cenozoic Era. The scarcity of dinosaur relics close below the KTB initiated the debate on whether their extinction before the Cenozoic was step-wise as the result of gradual deterioration of the terrestrial ecosystems, or instantaneous as part of the end-Cretaceous extinction of other faunal and floral groups. The lack of bone beds at the KTB (Ir-anomaly) can be explained by the biological intensive predation and consumption of any edible component, hardly leaving any identifiable fossil. A large fragment from the left femur of the sauropod dinosaur *Alamosaurus sanjuanensis*

which weathered out from a ferruginous sandstone bed above the KTB in the San Juan Basin (New Mexico) yielded U-Pb date of 64.8+/-0.9 Ma [42], which its apparent Paleocene age is uncertain.

Pterosaurs were oviparous flying reptiles which lived and nested on open ground, mainly on beaches where they could run for take-off and for landing. Their resting posture made standing up to defend themselves very awkward [43]. Pterosaurs used to catch fish by flying over the sea, which the darkness or dim light considerably inhibited. Starvation eliminated the young while the weakened adults were killed by predators.

### 4.2 Marine Organisms

The collapse of marine primary production and hence the food chain resulted in intensive predation among marine organisms and the elimination of those that could not withdraw into refuge sites. The reptilian mosasaurs and plesiosaurs were among the huge organisms requiring large quantities of food. The severe food-shortage during the 2-3 years of no primary production weakened them against more agile and aggressive predators, resulting in their total elimination. Ammonoids were consumed by other ammonoids, by belemnoids [44], by marine reptiles (mosasaur bites) [45], and probably by large fish and sharks. The ammonoid exoskeleton limited the expansion of the mantle cavity and hence the intensity of the jet stream whereby ammonoid movement must have been in pulses like in extant nautilids. Therefore the ammonoids situated in their fragile conch provided easy prey to many marine predators, especially during the latest Cretaceous increased predation pressure. The world-wide distributed nostoceratid heteromorphs disappeared in the upper Lower Maastrichtian [16], probably because of their slow movement. The streamlined heteromorph scaphitids and orthocone baculitids ranged close to the KTB [16,18], or apparently survived into the lowermost Danian [37]. Octopods were suggested to be ammonoids in which the conch (ammonite) degenerated in Jurassic times. Thereby they obtained remarkable jet power and maneuverability and developed additional abilities to mislead and escape from predators whereby they survived the end-Cretaceous biological crisis [46].

Late Cretaceous nautiloids were attacked by mosasaurs [47] and other marine creatures.

These slow moving cephalopods might have escaped the temporary increase of predatory pressure by diving into deeper and darker water where the predators were less active. Extant nautiloids comprise two pairs of gills and a physiological adaptation to low-oxygen content, differing from the single pair of gills in all other cephalopods. The arm-tentacle structure and the primitive eye in extant nautiloids completely differ from those of other living cephalopods and may have evolved during adaptation to deep and dark marine environments during the latest Cretaceous and the Early Cenozoic.

A trophic control apparently directed the aulacocerid and belemnoid evolutionary trends [44]. The latest Cretaceous belemnite *Groenlandibelus* occurs with and without the rostrum, which balanced the skeletal fragments accumulating in the crop at the anterior part of the body before being regurgitated. The disappearance of the rostrum indicates a considerable reduction in the skeletal fraction of the available prey, which seems related to the decrease in latest Cretaceous ammonite abundance [44]. *Groenlandibelus* has mixed belemnoid-sepiid–spirulid characteristics and may have been the ancestor of Cenozoic coleoid taxa.

Rudists were significant constituents of Upper Albian-Cenomanian-Turonian carbonate platforms, whose geographical extent decreased thereafter, though rudist diversity increased in the Campanian and decreased during the Maastrichtian [48] with a few species ranging close to the KTB [18,49]. No fossil rudist bioherm was buried under sediments comprising impact-melt spherules or enriched with iridium. The decrease in rudist diversity and distribution during the Late Maastrichtian may have resulted from the increase in predatory pressure. These bivalves were dominant constituents of reef-like settings recalling extant hermatypic corals, and mixed with them under suitable conditions (Jamaica; [50]). However, in many Upper Cretaceous carbonate platforms corals were scarce, being killed by incidental cover by sediments which rudists could overcome. The reproductive strategy of hermatypic corals in the Australian Great Barrier Reef may explain the decrease in rudistid abundance and distribution during the latest Cretaceous predatory pressure. One hundred and five scleractinian coral species were observed to spawn almost synchronously on a few nights of the year in late spring [51], attracting fish [52] and probably other organisms

feeding on the gametes and the free swimming planula stage. Despite the observed intensive predation on coral spawns, the synchronous release of a large quantity of gametes may have increased the survival ratio enough to maintain the coral species population. Rudist bioherms were dominated by one or a few species, which probably spawned during certain annual seasons and might have attracted predators because of the general food shortage. Thereby most of the succeeding generations were considerably reduced up to total elimination of the rudists at these sites.

## 5. EARLY TERTIARY BIOLOGICAL RECOVERY

The severe food shortage and predatory stress as the result of the 2-3 years of no photosynthetic activity forced the organisms to look for alternative food sources, to escape the predators and hide in shelters. Thereby large populations split into smaller ones thus inhabiting numerous refuge sites, where they had to adapt to new ecological settings and establish new biological relationships. Soon after the 2-3 years of atmosphere darkening the marine phytoplankton recovered, probably due to the high content of dissolved iron from decomposed volcanic dust [53]. The terrestrial flora recovered much slower, probably because of climatic instability under further Deccan volcanism and the possible loss of floral habitats as the result of intensive soil erosion when trees shed their leaves and annual plants temporarily disappeared. The collapse of the global biological system was too severe to be able to restore itself in a short time despite the rapid renewal of photosynthesis. The disappearance of most of the food-chain top predators (e.g., non-avian dinosaurs, pterosaurs and large marine reptiles) required the restructuring of prey-predator relationships, first in the shelters and later in the open habitats. The adaptation of the survivors to the dynamically changing physical, chemical and biological settings in the many isolated refuge sites considerably accelerated natural selection and species radiation in each inhabited ecosystem in contrast to the assumed “sustained radiation into vacant ecospace” [2]. Unfortunately these evolutionary ‘factories’ of species remained undiscovered, leaving a gap in the fossil record. After the stabilization of the extensive ecosystems the descendants of Cretaceous survivors tried to acclimatize there, and left their fossil record there, some as unchanged Cretaceous species, but the majority

attained new shapes during intensive natural selection and were distinguished as new species.

The occurrence of the new Early Tertiary marine species close above the KTB Ir-anomaly and impact rock-melt spherules disregards their long evolution during thousands of years. The narrow sedimentary interval representing this period in the open marine environments probably results from the slow recovery of calcareous microfossils mainly of the planktonic foraminifera.

The Early Paleocene (Danian P0 and P1a zones) planktonic assemblage comprising *Globigerina hillebrandti* known from Upper Maastrichtian deposits was assigned to the genus *Hedbergella* [54]. This small (0.13 mm) trochospiral survivor resembles several species of the P0 and P1a zones [9], whose 'primitive' Early Tertiary forms recall in shape and dimension the Hungarian Early Jurassic *Globuligerina geczyi* Görög [55], which is one of the world's earliest planktonic foraminiferid. Keeled forms (*Rotalipora*) appeared in the Late Albian after an evolution of 80-90 Ma [56], considerably diversifying during the Late Cretaceous. The early Tertiary keeled planktonic foraminifera (*Morozovella angulata*) appeared in the Late Paleocene (Thanetian, 59.2 Ma) about 6 million years after the recovery of the ocean ecosystems. The relatively rapid introduction of the Tertiary keel structure suggests that the surviving Late Cretaceous 'primitive' globigerinids preserved the genetic information for the secretion of keels and other morphologies under suitable conditions.

## 6. SUMMARY AND CONCLUSION

The single Ir-anomaly detected at the biostratigraphic KTB close to the Deccan volcanic province [9,26,27] corroborates its extraterrestrial origin [3], and hence the involvement of the latest Cretaceous Chicxulub asteroid impact with the KTB biological crisis. Neither the Deccan volcanism nor the impact of the large Chicxulub asteroid could have caused the end-Cretaceous 'mass extinction' in the selective extinction-survival pattern. Only the combined ejecta of the incidental asteroid impact during the Deccan volcanic emissions of Phase 2 might have together considerably darkened the atmosphere for 2-3 years, ceasing marine and terrestrial photosynthesis, and hence primary production. The associated drop in temperature must have been fatal to cold-blooded reptiles whereby dinosaurs and pterosaurs became vulnerable to predation. Apart from the devastating effect on photosynthetic organisms

and plants, all other selective eliminations were carried out by the organisms themselves while struggling for life under severe food-shortage, devouring every vulnerable creature and all available plants. The survivors in numerous isolated refuge sites had to cope with unfamiliar ecosystems and the dynamically changing climate during the Deccan volcanic activity and the restructuring of the ecosystems. The frequent ecological changes accelerated natural selection and speciation among most of the Cretaceous survivors, leaving their evolutionary record in yet undetected refuge sites. Following the stabilization of the world's extensive ecosystems, the unchanged Cretaceous survivors and their different-looking evolutionary descendants migrated into the open environments from where most of the Cretaceous carnivores disappeared. There the acclimatized species increased their populations and distribution, many appearing in the Early Tertiary fossil record as new species. However, all the Tertiary taxa are evolutionary descendants of Cretaceous ancestors, diminishing the apparent mass extinction to a severe case of natural selection carried out by the organisms themselves. The technical-statistical evaluation of the fossil record resulted in the erroneous conclusion about a catastrophic mass-extinction event. The Cretaceous-Tertiary turnover was actually a severe case of Darwin's theory of natural selection [57].

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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