Cretaceous – Tertiary Mass Extinction

Meteoritic Versus Volcanic Causes

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The bolide impact theory for mass extinctions at the Cretaceous-tertiary (K–T) boundary was a revolutionary concept. This theory was contested by short duration global volcanism as a possible alternative cause for the K–T extinction. Though there is a converging evidence for an extra-terrestrial impact coinciding with the terminal Cretaceous, the causative link between the impact and the K–T mass extinction is debatable. Thus, while the impact theory is re-emerging, available evidence is still insufficient to rule out either of the two hypotheses.

Introduction

It is now widely believed that life on earth began very early in its geological history, probably about 4000 My (million years) ago (Mojzsis and others, 1996). Since then it underwent several evolutionary branchings to the complex diversity as we see today. Nevertheless, it was not a smooth voyage for life all along, the evolution was punctuated by geologically instantaneous events of mass mortality. New species emerged at the expense of their predecessors following each extinction event and life went on evolving ever more vibrantly. In the geologic record of rock strata, such mass extinction events are identifiable based on sudden absence and reduction in diversity of fossil assemblage across stratigraphic boundaries. Among several episodes of mass extinction in geologic history, the one which occurred at the close of the Cretaceous period, about 65 My ago, was very significant as it wiped out almost 70% of life forms that inhabited the planet at that time. This event is also believed to have caused the disappearance of the giant reptiles called dinosaurs.

The Cretaceous–tertiary (K–T) boundary sections studied the world over by Alvarez and coworkers in 1980 ascribe the *Terminal Cretaceous Crisis* to an asteroid impact. This hypothesis was however challenged by Officer and Drake (1983, 1985) with volcanism as an alternative cause for extinction. More than 75 K–T sites have since been described from all over the world both onshore and offshore. The 'EL Kef' K–T boundary site in Tunisia is considered the most complete K–T boundary section known to date.

Smit and Romein in 1985 proposed a standard K–T boundary sequence of lithology and biostratigraphy.

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The Evidence for External Cause

The K–T boundary is marked by a few centimetres thick dark grey to black boundary clay enriched in iridium and several other chalcophile elements and is believed to represent the global fallout of the impact dust. Quite often the boundary clay contains compressed microspherules of sanidine and haematite, thought to be microtektites or high temperature droplets formed by the impact. Besides, shocked deformation features have been observed in quartz and feldspars in the boundary layer and are taken as supportive evidence for the impact origin of the boundary clay. Other evidence of impact has also been advanced recently. These include presence of amino acids of probable extraterrestrial origin, microdiamonds, meteoric spinels, and fullerenes (C_{60}, C_{70}) in many K–T sites.

Iridium Anomaly

In 1978, Walter and Louis Alvarez and coworkers of the University of California detected an unusually high concentration of Ir in the boundary clay separating the Cretaceous formations from the overlying tertiary formations at Gubbio, Italy. Iridium, one of the elements in the platinum group of metals, occurs in extremely low quantities in crustal rocks, but in significantly

Table 1.

Site	Ir peak (ppb)
Stevens Klint, Germany	87
Caravaca, Spain	44
Woods Creek, New Zealand	28
DSDP site 465A, Pacific	15
Average crust	0.025
Average C1 chondrite	380

higher quantities in chondritic meteorites. This observation led these investigators and Ganapathy (1980) to propose a 'meteorite impact theory' to account for the Ir anomaly at the K-T boundary. The blanket of dust cloud that rose into the upper atmosphere following the catastrophic impact is considered to have induced far-reaching climatic consequences that ultimately culminated in mass extinction. The Ir anomaly reported by the above researchers was subsequently identified in many K-T sites all over the world (*Table 1*) both on land and deep sea sections. In India too Ir-rich boundary clays are reported by Bhandari and his group from two localities, viz., the Um Sohryngkew section near Cherrapunji in Meghalaya and in the intertrappean beds at Anjar, Kutch in Gujarat.

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Detailed geochemical studies of the K-T boundary clay indicate anomalous concentrations not only of siderophile elements like Ir and Os but also chalcophiles like Cr, Co, Ni, As, Se and Sb. The table above lists the four most Ir-rich boundary clays in the world and compares them with average Ir abundances in the earth's crust and carbonaceous chondrites.

Although elements like Ir enriched in the boundary clay are apparently meteoritic, others like As and Sb are clearly terrestrial. The boundary clays are invariably rich in organic carbon and pyrite and were deposited under strongly reducing conditions. Studies of Birger Schmitz indicate that the enrichment of these metals is due to precipitation by chemical processes. He concludes that geological boundaries (such as the K–T boundary) are defined by lithological facies change and pore fluids migrating across such boundaries shed their metals, particularly on encountering reducing conditions. The author cites the metal-enriched lower-upper Permian 'Noble Shale' of Poland as an example of this kind of metal deposition in boundary clays. The ultimate source of the metals, however, remains an enigma.

Many meteorite craters exist on the earth, as for instance the Arizona crater in the USA, the Lonar crater in India and the Acraman crater in Australia, some with Ir anomalies too. Grieve (1991) has listed over a hundred impact craters of various ages on the earth. The impact which Shoemaker Levy 9 made on Jupiter in July, 1994 was observed 'live' by astronomers. While meteorite impacts are not well-known events in the history of the earth and the planets, strong support for the impact theory comes from the identification of the giant ($\sim$200 km diameter) Chicxulub crater at Yucatan peninsula in Mexico. This crater has been dated by Swisher and coworkers in 1992 as 64.98 ± 0.05 My. Schuraytz and coworkers (1996) detected micron-size iridium nuggets from Chicxulub impact melt. Several cores retrieved from Yucatan peninsula also provided tangible proof for the impact event. These evidences confirm that Chicxulub represents an extraterrestrial impact event coincident with the late Cretaceous period of mass extinction. Besides, Kyte (1996) isolated a 2–5 mm fragment from the K–T clay in a Pacific core, rich in Cr, Fe and Ir, akin to chondrites, which is suspected to be a fragment of the K–T impact bolide.

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It is interesting to mention here that S Chatterjee of Texas Technical University and D K Rudra of Indian Statistical Institute have recently postulated the occurrence of a giant crater ($600 \times 450 \times 12$ km) of K–T age, one half of which is identified near Bombay High and the other half at the Amirante arc near Seychelles, the bifurcation of the crater being due to spreading across the Carlsberg ridge. The crater has appropriately been named as 'Shiva Crater' and like the Chicxulub crater, is filled by tertiary sediments constituting a potential petroleum field.

Carbon Soot at the K–T Boundary

Of considerable interest supporting the bolide impact theory is the measurement of carbon soot in the K-T boundary clay in classical sites in Denmark, New Zealand and Spain by Edward Anders in 1988 and Wendy Wolbach in 1993. The boundary clay is 10^2 to 10^4 times enriched in elemental carbon (soot) and the amount of soot at the boundary clay is estimated to be equivalent to 10% of the present day biomass carbon. These authors speculate that such a huge mass of carbon could come from global fires triggered by an impact which must have burnt 90% of the Cretaceous forests.

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Venkatesan and Dahl (1989) provided organic geochemical evidence in support of a global fire at the boundary. According to these authors the bulk of the airborne polycyclic aromatic hydrocarbons (PAH) generated by pyrosynthesis during the fire is adsorbed to the surface of particulate carbon soot and so the carbon-enriched boundary clays must also contain elevated concentrations of PAH. Measurements in the boundary clay from Woodside Creek, Stevens Klint and Gubbio by these researchers, indeed, have indicated enhanced levels of PAH reflecting a pyrolytic origin for the PAH. That the bulk of the K–T carbon was biomass carbon is confirmed by the ~25% depletion of ^{13}C in the soot consistent with comparable levels of ^{13}C depletion in modern C_3 plants.

The global fire that produced voluminous soot is believed to have aggravated the environmental stress of an impact. Soot absorbs solar radiation more efficiently leading to prolonged darkness and cold. Further, poisons such as NO, NO_2, CO and organic pyrotoxins emitted during the fire would also have affected species survival very adversely. The detection of PAH retene in some boundary clays by Anders is considered significant as retene is diagnostic of conifer combustion.

Faunal Turnover across the K–T Boundary

The close of the Cretaceous period was marked by the disappearance of marine reptiles, flying reptiles, dinosaurs, ammonites, scleractinian corals, bivalves, gastropods and echinoderms. Besides, coccolithophorids, planktonic foraminifera and belemnites almost completely disappeared, though not instantaneously. Extinction was particularly severe among calcareous planktonic organisms, tropical reef invertebrates and large-sized plankton became extinct over a very short time of 10,000 years, while other extinctions were prolonged. The ammonites, for instance, had been in decline from the Campanian through the end Maastrichtian. The most significant extinction was within the Maastrichtian, a few million years before the end of the Cretaceous period.

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A striking feature of the K–T faunal turnover is that the faunal changes were not instantaneous. High resolution studies at El Kef clearly show that all species did not become extinct simultaneously, but the extinction is spread over 32 cm of sediment with major extinctions beginning 25 cm below the boundary. The planktonic foraminiferal diversity declined by 78% across the K–T at El Kef while the benthic species declined by only 37%. Further, most faunal changes were sequential, the large and more specialised forms disappearing earlier than primitive and generalised species. The selective nature of species extinction was long known in theory and was first demonstrated across the K–T boundary at El Kef by Gerta Kellar in 1988, confirming that even in a paroxysmically changing environment the theory of selectivity in species extinction holds good.

Volcanic Causes

Many palaeontological observations, however, go against an extraterrestrial cause for the Cretaceous biotic crisis. Any impact of extraterrestrial origin should have instantaneous effect on terrestrial life, but evidences show that much of the faunal and floral crises precede the K–T boundary by a few hundred

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thousand years and continue into the tertiary for much longer time. The extinction itself was selective with relatively large-sized and specialised forms disappearing earlier than general and less ornate forms.

Further, many groups like flying reptiles, fresh water vertebrates, snakes and many land plants were little affected. In addition, Ir has been detected recently in volcanic gases in Kilauea and Hawaiian eruptions and also in volcanic ash beds preserved in Antarctic blue ice. High resolution studies of the K–T boundary suggest that Ir anomaly does not occur as a single spike, but as multiple spikes stretched over several hundred thousand years succeeding the K–T boundary. The boundary clay itself is not ubiquitous at all K–T sections. Moreover, shocked minerals, considered to constitute conclusive evidence of impact, are also identified from magmatic and volcanic associations such as the Thoba and Long Valley explosions. The microspherules in the boundary clay are now considered to be authigenic minerals unrelated to impact.

Officer and coworkers in 1987, postulated that the cause of Ir anomaly across the K–T boundary is intrinsic to the earth, having been derived from volcanic sources; their contention is based on the detection of Ir in mantle-derived gas of volcanic exhalations. This alternative necessitates a terminal Cretaceous volcanic activity of global nature. The eruption of the Deccan Trap basalt (DT) represents the largest single continental flood basalt episode in the last 200 My. Bulk of the DT outpourings have occurred during the K–T interval. Argon isotopic dating of the DT by Courtillot and others in 1988 have reduced the length of this interval to 5 My between 65 My and 60 My with bulk of the lavas having emplaced in about 6,00,000 years of this interval. Geologically speaking this is an instantaneous event. The DT presently occupies nearly half a million square kilometres of Central and Western India with a maximum thickness of 1.5 km but must have been three times more extensive during the

Cretaceous times, indicating the colossal volume of the DT extrusion. Short-duration global volcanic activity of this kind would have expelled carbon dioxide, sulphur atmosphere reducing the thickness of the protective ozone layer and inducing perturbations in ocean and atmospheric chemistry. The acid rain caused by the Cretaceous volcanic activity is estimated to be 14 times greater than the fossil-fuel-based acid rain that poured over Europe and the United States in 1976, estimated at 120 million tonnes.

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Besides the DT, explosive volcanic ash beds broadly coinciding with the close of the Cretaceous have been detected in DSDP and ODP (Ocean Drilling Programme) cores in Walvis Ridge, Kerguelen plateau, Maud Rise and Haiti in southern high latitudes. The end of Cretaceous was also characterised by emplacement of carbonatite and kimberlite swarms all over the world; these are known to be sources of huge volumes of gaseous emanations, particularly carbon dioxide. All these volcanic episodes at the end of the Cretaceous period could have contributed stupendous volumes of gaseous components which are sufficient to overload the ocean with carbonate and bicarbonate ions making the ocean water more acidic, detrimental to a wide spectrum of carbonate-secreting organisms of the ocean. The temperature fluctuations resulting from this atmospheric overloading would have caused a greenhouse effect leading to a terrestrial biotic crisis. Hydrochloric acid aerosols injected into the stratosphere have detrimental effects on ozone layer thickness. Measurements in Krakatoa and Agung eruptions indicate ozone reduction of 8%; in comparison the K–T volcanism would have reduced the ozone layer thickness by 110 times. The effect of the resulting enhanced UV radiation would have been fatal on the population of diurnal communities like the dinosaurs.

It may be mentioned here that Venkatesan and Pande, based on geochronological data for the DT of Western Ghats, argued in 1993 that the main pulse of the DT extrusion pre-dates the K–T event by at least a million years. These authors in 1996 reported ^{40}Ar / ^{39}Ar isotope ages for the Anjar traps of Kutch where Ir-rich intertrappean beds were identified earlier by Bhandari and group in 1995. According to these age data, the Anjar traps are indistinguishable from the K–T boundary age. Further, the presence of Ir-bearing intertrappean beds sandwiched between two DT flows and the occurrence of several flows below the intertrappean here support the earlier contention of these authors that the initiation of the DT volcanism preceded the K–T boundary event. This negates any causal link between Deccan volcanism and the Cretaceous mass extinction.

Oxygen and carbon isotope measurements on planktonic foraminiferal tests across the K–T indicate tremendous perturbations in the terminal Cretaceous ocean: productivity was very low, large bottom water masses were deficient in oxygen and surface water was very cold. These perturbations are best explainable in terms of widespread volcanism induced by fast spreading lithospheric plates.

No discussion on K–T extinction is complete without a reference to dinosaur extinction. Dinosaurs which roamed the earth for 165 My in the Mesozoic era (225 My-65 My) had come to the verge of extinction many times in the Mesozoic but everytime these giant reptiles were able to rebound and establish themselves. The dinosaurs witnessed their golden age in the Jurassic period (190 My-135 My ago); thanks to the film maker Steven Spielberg for restoring this period through his 'Jurassic Park' enabling us to 'witness' the fury of these incredible creatures which were almost wiped out by an event that closed the Jurassic. Surprisingly new genera of dinosaurs evolved following this mystery. Unfortunately the Cretaceous extinction did not leave behind any of their survivors. Being large and specialised animals they were more vulnerable, unable to survive the climatic extremities of the late Cretaceous, aggravated by the enhanced UV radiation, and like many other large mammals,

Suggested Reading

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left the world without leaving any successor to their clan. Recent statistical studies by Hurlburt and Archibald in 1995 demonstrate that the dinosaurs did not vanish suddenly but underwent a gradual decline and their last survivors were dated to be of early tertiary age. This finding also goes against an impact theory for the dinosaur extinction.

Evidences appear to converge towards an extra-terrestrial impact event at the close of the cretaceous period, though the extent to which it was responsible for the extinction is disputable.

From the foregoing review it follows that available evidences are inconclusive to support fully either of the two postulations for the K–T extinction. While the impact theory is fascinating, palaeontological and geochemical evidences are insufficient to consider it as the sole agent of the terminal Cretaceous annihilation. Nevertheless, evidences appear to converge towards an extra-terrestrial impact event at the close of the Cretaceous period, though the extent to which it was responsible for the extinction is disputable. Short-duration global volcanism is capable of bringing about the kind of climatic and biotic crisis witnessed at the K–T transition. But the theory is severely handicapped because worldwide volcanic episodes synchronising with the terminal Cretaceous catastrophe are few.

Despite the shortcomings, the impact theory appears to be on the come back trail if the recent discovery by Kenneth G Miller is any indication. Miller of Rutgers University disclosed in a meeting of the American Geophysical Union a few months ago the discovery of a two-inch thick layer of glass beads in New Jersey, USA. The glass bead layer was retrieved from the bottom of a 2000 feet deep bore hole drilled just north of Atlantic City. The site was at the sea floor 65 My ago and the author attributes the glass beads to impact melting when an asteroid hit what is now the Yucatan peninsula in Mexico.

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> But I have seen the science I worshipped and the airplane I loved destroying the civilization I expected them to serve.
>
> *Charles A Lindbergh Jr.*