CRETACEOUS-TERTIARY BOUNDARY EVENTS: MASS EXTINCTIONS, IRIDIUM ENRICHMENT AND DECCAN VOLCANISM

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ABSTRACT

Cretaceous-Tertiary boundary events include radical changes in the structure and evolution of over 80% of both land and marine organisms, possibly as a result of a catastrophic event, signatured by anomalously high values of iridium, an element common in cosmic bodies and now also known in volcanic emanations. Currently, two hypotheses explain mass extinctions on the basis of either extra-terrestrial impact or internal [Deccan Trap] volcanism. Mass extinction appears to be a gradual, taxonomically selective process affecting both continental and marine organisms. This paper examines the role of Deccan volcanism as a possible source for the Cretaceous-Tertiary boundary events by delimiting the timing and duration of the activity based on recent palaeontological data from the Deccan peninsula in conjunction with palaeomagnetic and radiometric dating.

INTRODUCTION

THE transition period from the Cretaceous to the Tertiary demarcating the erathemic boundary (KTB) was one of the most eventful in earth's history. This temporal span saw radical changes in the structure and evolution of both marine and land organisms with the disappearance of several well-established and successful groups such as the dinosaurs and ammonites. Other events towards the end of the Cretaceous may have served to enhance the process of mass extinction. These include a major regressive cycle, global lowering of temperature, increased sea-floor spreading and last but not least, a catastrophic activity (either of extra-terrestrial (ET) or of earthly origin) as signatured by anomalously high values of iridium. The causes for large-scale biotic extinctions at the KTB have been debated at length and are essential in our understanding of the physical and biotic processes that have led to the periodic extinction of organisms throughout the geological histroy. Recently, three major observations have been made which have fuelled the controversy further; In 1980, the presence of Ir, a rare element of the earth was noted[1] and its occurrence was ascribed to an ET impact. In 1983, the presence of Ir enrichment in air-borne particles from the Kilauea volcano was recorded[2] and in 1983 and 1985, the Deccan Traps (DT) were suggested[3,4] as a possible source for the KTB iridium. Recently, the duration of the eruption of DT has been constrained[5].

Though the general scenarios of the ET and DT catastrophic events are the same, a circum-global (volcanic) dust cloud resulting in the lowering of temperatures, destruction of the existing ecosystem and subsequent mass extinctions, there are several basic differences between the hypotheses advocating an ET source and those favouring an internal cause. The former is considered to be a monocausal phenomenon, nearly instantaneous in its devastation while the latter is considered to be more gradual and selective in its effects. The present report attempts to examine the biotic turnover at the KTB in terms of the current hypotheses postulated for mass extinction and lays special emphasis on the recent data constraining the span of the DT activity. As biotic processes are directly influenced by abiotic (physical) forces, a comprehensive understanding of the KTB events necessarily demands a multidisciplinary approach by earth scientists, astrophysicists and biologists. This theme is central of IGCP Project 216 under whose involvement, the preliminary work concerning the Indian sections was carried out[6].

MASS EXTINCTION

A firm basis for recognizing the reasons for mass extinctions and their selective nature, requires an analysis of biological, stratigraphic and palaeoecological aspects not only for those groups that suffered mass mortality but also of those few survivors and other organisms who benefited from such earthly crises. Mass extinctions have been defined[7] as the loss of 50% or more of ecologically and genetically diverse taxa within a narrow geological range representing 4 m.y. or less. By this yardstick, the KTB mass extinctions were most pronounced, as over 80% of the species became extinct worldwide within a 2.5 m.y. span. As a result of intensive research on the extinction processes during the last few years, there has been a proliferation of data on the subject[8] though a general consensus has not been achieved. At present, there is some agreement amongst several palaeontologists that the KTB extinction was gradual, selective taxonomically, periodic but not necessarily with a fixed cyclicity, environmentally non-discriminatory in the sense that both marine and continental organisms were affected, but that depth, latitudinal position and similar spatial variables may have acted as determinants.

The major groups of organisms that ultimately suffered extinction at the end of the Cretaceous were already on the decline 2 to 10 m.y. before the end of the KTB. A recent study[7], based on High Resolution Event Stratigraphy (HIRES), entailing analysis of sedimentary cycles representing the time span of 10^3 or less, has shown that reef-forming taxa including rudistids, several molluscs, deep-water echinoids, diverse ammonites and inoceramids underwent a "step-wise" reduction in their taxonomic diversity towards the end of the Maastrichtian. A similar gradual decline has been documented for large land organisms represented by the dinosaurs[9,10]. It has been pointed out that fluctuations in dinosaur taxonomic diversity were not unusual during their long history[11], the marked difference being that the disappearing genera were not replaced at the same rate as originating taxa. The dinosaurs were ultimately replaced by competition from immigrant mammals during the last few hundred thousand years of the Maastrichtian. The possibility of the occurrence of non-reworked dinosaurs above a possible Ir anomaly at the base of the lowest Z Coal in the Fort Peck Reservoir area (Montana) has been considered[9], implying thereby a Palaeocene age for their last appearance.

All organisms in both marine and continental enviroments were not equally affected by factors causing extinction. Of the 20% species that survived, a few actually benefited from the crises and became dominant and more diversified in the Tertiary as, for example, foraminifera, mammalia and angiosperms. Larger animals weighing more than 25 kg, such as dinosaurs and ammonites did not survive; smaller animals on the other hand particularly those that were ecological generalists, were less prone to decline. Representatives of the latter group include several freshwater forms (molluscs, ostracodes and charophytes) and diverse vertebrates e.g. fishes, frogs, turtles, lizards, snakes, crocodiles and placental mammals. This selectiveness suggests that fluvial environments were relatively more tolerant of the changes across the KTB. However, continental faunas and floras represented by dinosaurs, marsupial mammals and the *Aquilapollenites* province were devastated. A similar selectivity has also been noted for marine biotas; marine organisms with calcareous skeletons were widely succeptible to change as exemplified by foraminifera and coccolithophorids. Shallow-water formainifers show major extinction as compared to deep-water benthic forms. Dinoflagellates, which are more tolerant of carbonate-level fluctuation survived unchanged across the KTB. The differential success of shallow-water marine macroinvertebrates is marked by the extinction of several taxa including those associated in reef communities[7], but on the other hand, a bryozoan and crinoid community sensitive to salinity and anoxic conditions, thrived unchanged in Denmark across the KTB[12].

In consonance with the ET impact theory, various extinction events throughout geological history have been considered to be cyclical with a periodicity of about 26 m.y.[13] corresponding to the paths of intersection of the earth and ET bodies. Opinions are divided[14] as to the interpretation of cyclical extinction data though there is no denying that several major extinctions have been delineated during geological history i.e. Silurian/Devonian; Permian/Triassic; Cenomanian/Turonian; Cretaceous/Tertiary; Eocene/Oligocene, etc. At present, ET impact involvement on cyclicity of extinctions has yet to be properly documented.

IRIDIUM ENRICHMENT AT THE KTB

Close stratigraphic sampling across the KTB at Gubbio, Italy led to the recognition of a boundary clay level with anomalously high Ir content[1]. Since then, Ir anomalies at the KTB have been demarcated on a worldwide basis in 75 sites extending from Denmark to New Zealand and the number of such documentations increases every year. In India, an Ir high at the Um Sohryngkew river section at Meghalaya has been demarcated[15]. Ir abundances vary among sites by at least two orders of magnitude ranging from 3 to 340×10^{-9}g Ir/cm^2. The distribution of Ir is discontinuous as not all KTB transitional sequences are known to possess enhanced Ir. Furthermore, wherever found, Ir distribution indicates that it was environmentally non-discriminatory as it is found in both marine and non-marine environments[16]. This suggests that the causative factor was globally distributed but that at any one site, Ir content may have been differentially lost as a result of non-deposition, sedimentological and erosional processes. Ir concentrations are usually found in a clay which has been subjected recently to intense geochemical study to gain insight into its composition. In Denmark, the boundary clay (Fish Clay) is smectite-rich, while at the Italian sections it is enriched in kaolinite. In the Caucasian area, the clay is predominantly palygorskite[17]. This clay therefore appears to be heterogeneous in composition.

Ir concentration does not appear everywhere to be confined to a single "spike" but occurs over a measurable span ranging from about 10 to 100 k.y. or possibly even longer. It has been conjectured that in some sites which show anomalously high background levels of Ir, the distribution results from the effects of smearing from bioturbation. Ir background levels are consequently higher within 2 m of the faunistically defined KTB. In some sections of North America (Texas and Alabama) as well as those in Haiti, there are reports of multiple Ir enrichment events. This fact is significant as the data show that the enrichment mechanism was not instantaneous but spanned a time interval at least 0.1 m.y. in duration.

DECCAN VOLCANISM

The possibility of the Deccan volcanics providing the necessary source of iridium enrichment at the KTB has been raised following the record of Ir emanation from deep-mantle shield volcanoes in Hawaii[2,18] and the reiteration of an earlier hypothesis that this activity spanned a geologically short period of time near the KTB[5,6]. As such, there is a greater need for studying the Deccan volcanic activity not only for its geochemical signature but also for constraining the time of eruption. The latter aspect necessarily demands inputs from biostratigraphic controls as well as from palaeomagnetic and radiometric dating.

At present, most of the information on Ir emission is from recent volcanic eruptions of the Kilauea volcanoes of Hawaii[18], considered to be deep-seated mantle in structure as are the Deccan trap eruptions. However, very little is known about the specific locations of the fissuring or cratering through which the Deccan lavas were extruded and hence a detailed comparison is not possible. Further, it is difficult at present to precisely correlate the amount of expected Ir emission from the presumed magnitude of Deccan volcanism because all parameters of Ir emanation and mechanism of DT emplacement are not thoroughly understood. Recent estimates[18] suggest that the observed Ir values at the KTB are comparable with amounts that may have been released by DT volcanism and are based on a K/T flux rate of Ir at 63×10^{-9}g Ir cm^{-2} and a Kilauea flux rate of 31g Ir d^{-1}.

The timing and duration of the DT therefore are of special significance and the magnitude of the controversy can be gauged by the diversity in the opinions expressed during the last 7 years. One viewpoint[19] maintains that the dispersion in K/Ar values obtained indicate a range from the Turonian to the Oligocene. Another hypothesis[5,6] based on several measurements along with palaeomagnetic studies[20] suggests a duration of less than 1 m.y. On the other hand, a recent proposal[21] supports a fairly long duration for the DT (about 25 m.y.) but considers that the activity was confined to the Cretaceous.

Recent work done at the Vertebrate Palaeontological Laboratory of Panjab University indicates that the conclusions supporting a short span for DT activity[5,6] are best supported by the palaeontological data for freshwater assemblages and by evidence from petroleum exploratory drilling at Narasapur[22] (Rajmahendri) and in the Bombay offshore[23]. In southern peninsular outcrops in the Tiruchirapalli area as well, tuffaceous beds near the KTB have been reported[24].

A recent paper[25] presented at the First International IGCP Project 245 Symposium on the non-marine Cretaceous at Urumqi, China suggests that the palaeontological data support a Maastrichtian age (latest Cretaceous) for both the Lameta Formation as exemplified by the well-known Jabalpur Cantonment sections and the Takli Formation, commonly recognized as the Nagpur intertrappeans. These inferences are based on the following observations; Dinosaurian elements are present in both the infra and intertrappeans[26–29]. Furthermore, the dinosaurian assemblage of the Lameta is now considered to be Maastrichtian (rather than Turonian[30]) because the assemblages of dinosaurs to which comparisons were originally made in South America and Madagascar are now firmly dated as post-Turonian. Microfossil assemblages from the Lameta of the Bara Simla Hill section and those from the Takli and equivalent intertrappeans of Maharashtra and Andhra Pradesh are identical, with most of the species of ostracodes, charophytes and microvertebrates being specifically indistinguishable[26,27,31]. In fact, the charophytes are similar specifically to taxa known from the undifferentiated latest Cretaceous-earliest Palaeocene from other parts of the world[32,33]. *Nemegtichara*, a characteristic Maastrichtian taxa from the Cretaceous-Palaeocene sequence of the Nemegt Basin of Mongolia has recently been identified in the intertrappeans outcropping west of Hyderabad[33]. Other typical Maastrichtian taxa from the Lameta include the myliobatoid *Igdabatis*, recorded earlier from the Maastrichtian of Niger[5]. Recent finds of mammals from the Hyderabad intertrappeans again indicate a latest Cretaceous grade of evolution for these palaeoryctoids[34].

The palaeomagnetic data strongly support a short duration for the Deccan trap eruptions[5,6,20] because most studies have indicated that in all the sections investigated there are no more than three reversals and even in the thick sections sampled (about 1000 m as in the Western Ghats), there is usually only a single reversal. This is significant as there was considerable reversal of polarity near the KTB corresponding to the time interval indicated by the fossil evidence. An opposing viewpoint[21] which has also recognized a few reversals, has assumed their sections to correspond to a 25 m.y. interval in the Cretaceous represented by the Gubbio long normal, Gubbio A and Gubbio B magnetic anomalies.

K/Ar dating of the basalts has not proved to be very precise as several of the dates obtained are thought to be consistent underestimates as a result of argon loss and the weathered nature of some of the samples[19]. A few more reliable 40 Ar/39 Ar ages determined recently[35,37] fall roughly within ± 5 m.y. of the globally established KTB interval corresponding to about 67 m.y.

In view of the current controversy, it is necessary to analyse the relative merits of the two main hypotheses (ET and DT) relating to the major K/T events. The ET hypothesis after a shaky start survived initial scepticism to become a leading viewpoint for mass extinctions[38]. Recent opposition in the form of the DT (internal) hypothesis has become sharper[3–5,17]. Essentially, both hypotheses favour the existence of a circum-global dust cloud, either of ET or of volcanic origin with the concomitant release of pollutants, the blocking off the sun's heat and the piercing of the ozone layer. While both hypotheses do not explain all the observable phenomena in a satisfactory manner, the DT hypothesis appears to be more conformable with a gradual, environment-induced catastrophic KTB event. There are, however, several features which are better explained by one hypothesis rather than by the other: shocked quartz caused by impact cratering has been cited as a point favouring the ET hypothesis as these structures have been located at the KTB from several sites and are usually associated with impacts[38]. Recently, however, impacts have been recognised in DSDP sites associated with the explosive-type Toba volcanics in the Indian ocean[17]. The presence of shocked quartz is yet to be fully explained by both hypotheses: if the ET impact took place on continental areas, there should be some record left of the crater which is yet to be located; on the other hand, if the ET impact occurred in the oceans, one would not expect the presence of shocked glass circum-globally. Similarly, the DT volcanics are not considered to be explosive, hence the Toba volcanic model does not fit very well. Certainly, this is an area of research where more work is needed to be carried out. Other features such as microspherules, soot and Ir occurrence can be reasonably explained by both hypotheses. As there are historically documented models for volcanic induced mass mortality as for example the Laki and Krakatoa eruption, the DT hypothesis can rationally account for a scenario in which certain organisms of the Late Cretaceous may have faced extinction as a result of the vast quantities of noxious gases and acid belched out into the atomosphere: H_2SO_4 (17×10^{12} tons) and HCL (27×10^{12} tons) as estimated[17]. CO_2 flux

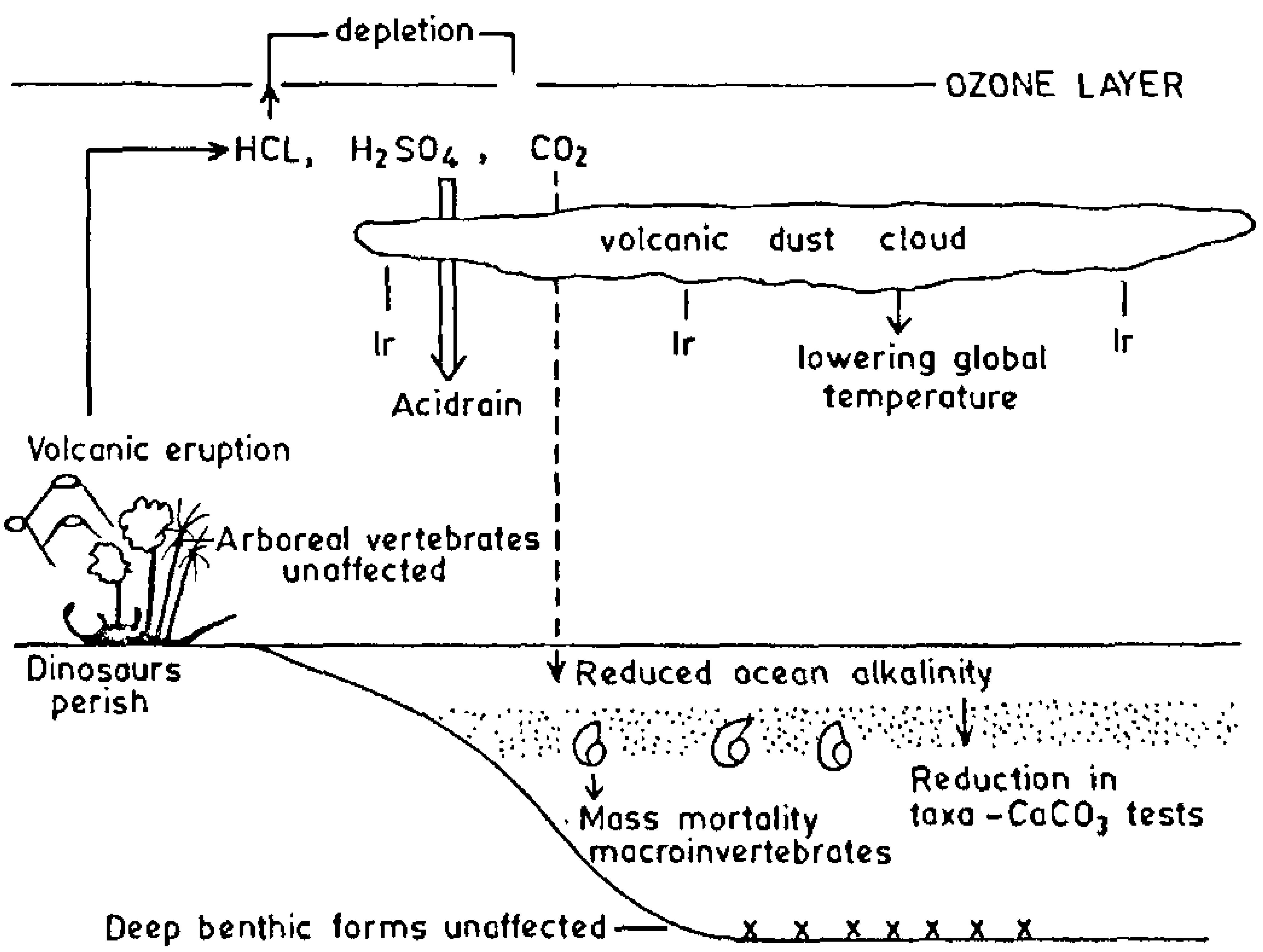

Figure 1. Scenario for Cretaceous-Tertiary boundary events including those of mass extinctions based on Deccan volcanic activity hypothesis.

rates would be of the order of 0.9×10^{15}g yr^{-1}, and would tend to reduce ocean alkalinity resulting in the observed reduction and modification of the calcareous skeletonized marine organisms[17]. Similarly, the depletion of the ozone layer as a result of HCL aerosol discharge into the atmosphere would tend to affect the larger animals such as the dinosaurs which would be left unprotected to UV radiation in their natural continental environments (figure 1).

In conclusion, extensive and intensive work on the KTB sequences worldwide has provided us with a better understanding of the probable causes leading to the complex problem of mass extinction. To obtain a comprehensive idea of the causative factors of the KTB events, inputs are needed from several disciplines of the earth and physical sciences, especially from geochemical studies. In India, more rigorous investigations need to be carried out on the Deccan volcanism before a final appraisal car be made of the relative merits of the ET and the DT hypotheses.

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SCIENCE NEWS

A CHILD SURVIVAL SUMMIT SUCCEEDS

The global eradication of polio, the reduction of measles deaths by 95%, the virtual elimination of neonatal tetanus, a 70% drop in diarrhoea deaths and a 25% fall in the case-fatality rate from acute respiratory infection in children under the age of five, and a 50% reduction in maternal mortality rates — these were the 12-year goals proposed at a three-day child survival summit.

"EPI is saving the lives of more than a million children in the developing world every year from measles, neonatal tetanus and whooping cough, and saving close to 2,00,000 children from paralysis by polio. As recently as 10 years ago, fewer than 5% of the developing world's children were immunized against measles or had a third dose of either polio or DPT (diphtheria, pertussis or whooping cough, tetanus) vaccines. Today, more than half of the world's infants in developing countries have been immunized", Dr Henderson reported.

"Much more progress has been made than was considered possible in 1980 when the Diarrhoeal Diseases Control programme got under way", said Dr Merson. "In 1986 approximately 750000 deaths from diarrhoea were avoided. This number can perhaps be doubled next year to 1.5 million and doubled again to 3 million by 1995".

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NEWS

DOUBLE-VISION SPACE RADARS

Scientists of Kharkov (the Ukraine) have created a double-vision radar for scanning the Earth. It was tested on artificial satellites.

The new radars produce photographs that clearly show the processes in the upper layers of the atmosphere and over land and seas of the Earth. The photographs show optical view of clouds and mist, with black spots of plains, mountains and water bodies in between. The new radar, looking through clouds and mist, produces a perfect picture of about 500 km of the Earth's surface.

For the first time in world practice, two pictures are taken simultaneously and printed out on a single sheet. Computers match the two pictures geographically.

The new equipment can predict river floods, find subterranean water in arid zones, monitor grain ripening on vast territories, locate fish schools and best pastures. Ships moving along the Northern Sea route will receive information on ice-free spots.

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