Chapter - 4

CHAPTER - IV

CHARACTERISTICS OF THE K/T BOUNDARY AND THE K/T BOUNDARY IN GLOBAL CONTEXT

IV.1. INTRODUCTION:

Considering the complexities of the various issues directly or indirectly involved in the problem dealt by the author, it is now felt that it would be worthwhile to review some of the outstanding works on the K/T boundary sequences in other parts of the world and understand their characteristics in general and especially in the context of the Indian Subcontinent.

IV.2. CHARACTERISTICS OF THE CRETACEOUS-TERTIARY BOUNDARY: GENERALITIES:

The Cretaceous-Tertiary transition sections can be grouped in to the following two groups on the basis of associated rocks and their characters:-

A: Marine sedimentary sections.

b: Continental / terrestrial sedimentary sections.

The Cretaceous period forms very important part in the evolution and geological history of the earth, and many important changes have occurred during the period and transition of Cretaceous-Palaeocene. Some of the important ones are mentioned below:

IV.2.1. Physical Changes:

IV.2.1.1. Break-up of the Gondwana Land and Migration of the Indian Subcontinent:

(a) The final break-up of Indian subcontinent from Madagascar, Africa, Antarctica, Australia and its north and northeastward journey crossing the equator at very fast rate (app. 21 cm/year, Negi et al 1995). (b) The redistribution / modification in the pattern of land and sea (palaeogeographic changes). (c) World wide scenario of rapid volcanism and out pouring of flood basalts on global scale. (d) Wide spread tectonic and epierogenic and eustatic changes, wild fires, climatic fluctuations and many such changes.

IV.2.1.2. Meteoric / Cometary Showers:

Wide spread meteoric / cometary showers at different places world over (Fig-3a, 3b). These meteoritic and cometary impacts generated wide spread disastrous effects on the atmospheric and ecological system world over; and also had similar effects on the contemporary biota as suggested by Alvarez et. al. (1980), Bohor B.F. et. al. (1984), Gilmour et. al. (1980), Officer and Drake (1983, 1985), Rusell (1979), Silver and Schultz (1982), Wolbach et. al. (1985) and many other workers.

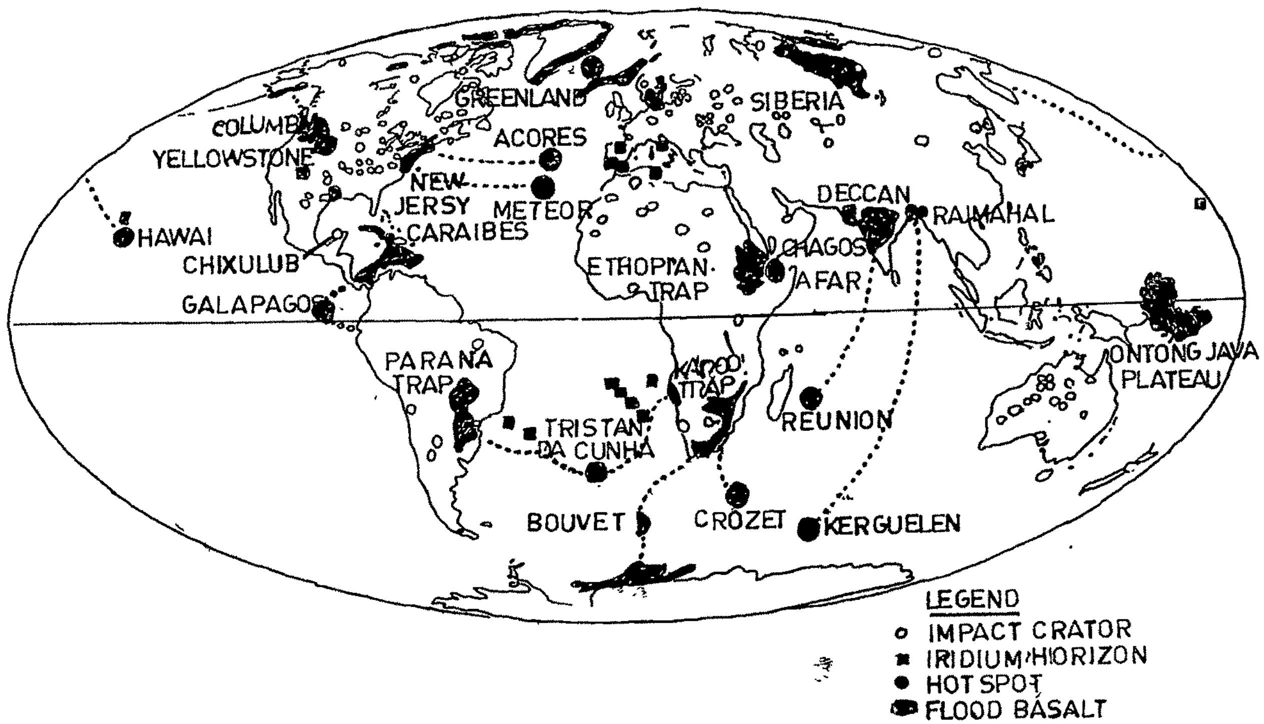

Fig. 3A. Map of world showing important K/T sections, meteorite falls and Iridium anomalies after Wolbach et al, 1985

Fig

Fig
33 A

IV.2.1.3. Wild Fires:

It is also believed that there were world wide fires connected to the extra terrestrial factors like meteorites and cometary materials (Wolbach et. al. 1985).

IV.2.2. Climatic Changes:

During the Cretaceous period, wide spread (atmospheric) climatic fluctuations have been recorded from different sedimentary sections in many parts of the world. These changes had very pronounced effects on the contemporary life. Such changes of climate and their effects on the ecological systems have received a wide attention of researchers and various working groups in different parts of the world. In this respect, detail studies have been carried out by Axelford (1981), Bernd (1973), Barner and Washington (1982), Cretoz and Chamber (1984), Epetheny (1978), Hallam (1984b, 1984c, 1985), Perrish (1982), Pal (1971), Savin (1977), Smiley (1967), Twidell and Hutton (1986), Wolf (1978), and many others. They have tried to establish relationship of climate and biotic changes. These changes include sharp and rapid fluctuations in the temperatures, rate of precipitations, subsequent global warming in the later part of Cretaceous, wide spread atmospheric pollution resulting form world wide volcanism and meteoric showers, acid rains, dust clouds and subsequent cooling followed by uniform warming of the ecosystem. Ghevariya et. al. (1983) have for the first time carried out the studies of the geological history of rocks and palaeoclimatic changes from Mesozoic record of Western India.

IV.2.3. Biotic Changes:

As a consequence upon physical and atmospheric changes, there was a wide spread effect on the biota which is best represented in various contemporary stratigraphic rock records in various parts of the world. Different workers have carried out studies on various aspects of such changes. The drastic changes include faunal, floral record patterns, relative abundance in the stratigraphic record and/or decrease (turn overs) and diversification/ appearance of new forms with advent of time or as a consequence of catastrophic changes (Sheenan et. al., 1996). The Cretaceous-Tertiary boundary sections are widely and systematically studied in different parts of world either in marine sedimentary or in continental (fluvial, lacustrine) regimes. The important places, where the Cretaceous-Tertiary sequences are recorded include localities (Fig-2) from North America, Canada, Spain, Italy, New Iceland, France, Russia, Africa, India, Australia and Turkey. Important Indian sections include Anjar (Ghevariya, 1985, 1995; and Bhandari et. al., 1995, 1996), Um Shohryngkey ruied section of Meghalaya (Bhandari et. al., 1987), Takli (Rana, 1984; and Bhandari et. al., 1988a) and some well (sub-crop) in the Krishna-Godavari basin and Kaveri basin on east coast offshore well (Raju et. al., 1991) and from Kutch offshore well. The succession of Kutch offshore well section (K-1) is comparable to uppermost part of the K/T sequence from Kaveri offshore basin. The major part of the K-1 well section comprises limestone and is dated as 66.5 m.y. on the basis of keeled *globotruneana* fossils (Raju et.al., 1991). The Anjar K/T section is located within the third intertrappean volcanosedimentary sequence exposed at a distance of 5 km towards south of Anjar town. In Gujarat, the probable areas for other K/T sections include parts of Saurashtra near Chotila and Wankaner, parts of Kheda near Othwad, and between Sevalia and Kalol. The trappean and volcanosedimentary sections in these areas offer good probable sites. The land dwelling reptiles - *dinosaurs* - were totally wiped out. In marine sections, *ammonites, belemnites, brachiopods* were reduced or became extinct. Nearly 70% of the formerly existing plant species became extinct, and new forms of plants - *angiosperms* - became dominant. Gradual appearance and dominance of mammals was marked.

IV.2.4. Mineralogical Changes:

The recognition of world wide catastrophic events from various K/T boundary sections have indicated presence of shock mineral grains such as shocked quartz, zircon, chromites (Bohor et. al., 1984; Bohor, 1990; Bostnick and Kyte, 1996). Presence of spherules and microtektites, which include sanidine spherules (Smit and Klaver, 1981), and spherules of potassium felspars, glauconite, pyrite etc. (Montanari et. al., 1983; Smit and Kyte, 1984; Brooks et. al., 1986), glasses with shapes resembling to those of microtektites have also been found from Beloc section near Haiti (Hilderbrand et. al., 1991; King and Boynton, 1991, 1993), which have been dated to be of 65.01± 0.03 Ma (Izett et. al., 1991). The meteoritic spinels are (2 to 10 microns in size) rich in nickel, and have been found at some K/T boundary site sections, where irridium anomaly is observed (Robin et. al., 1992). These spinels are indicative of bolide impacts.

The presence of nanometer size diamonds in geological section of K/T boundary sites and presence of certain group of amino-acids favour impact origin (Carlise, 1992, 1995). Ir/nanometer size diamond ratio similar to C_2 type chondrite, carbon isotope ratio unlike terrestrial origin further supplemented by fifty one amino-acids out of which 18 are found in carbonaceous chondrites and based on C and N isotope ratios in diamonds. Hilmour et. al. (1992) suggest an impact or plasma origin for these diamonds. Presence of carbon soot has been recorded in the K/T boundary sections, which provide a worldwide forest fires (Wolbach, et. al., 1985, 1988; Iwany and Salawitch, 1993). These tremendous amount of dust, ash and smokes could have formed a thick cover of clouds and drastically recorded reduced or minimised penetration of solar light.

IV.2.5. Stratigraphical and Sedimentological Changes:

The normal marine or continental sections at various places in the world in the Cretaceous-Tertiary boundary transitions show siliciclastic and/or sand calcareous spherulitic oolitic layers (Bohor, 1990; Smit et. al., 1996), excessive ejecta rich ash and sands containing blanket deposits with high impact generated minerals like shocked quartz and glass (Ocampo and others, 1996). In the sections at times there are sudden changes of lithological units and clay fraction/mud fraction with smectite, atapolgite and kaolinitic minerals and spherules are recorded (Bohor, 1990; Bohor et. al., 1987; Adatte, 1996; Stinnesbeck and Keller, 1996). Sections with multi-erosional and bioturbation events and alternate events of deposition as well as alternate episodes of terrigenous influx and hemipelagic sedimentation (Oliva and Keller, 1996) and at times catastrophic events are also recorded in form of volcaniclastics or ejecta dominated stratigraphy with distribution of mineral species typical of such events as discussed earlier. Such event stratigraphic sections have been studied at many places (Courtillot et. al., 1996; Hofman et. al., 1997; Swisher et. al., 1992; Fett et. al., 1991; Bohor et.al., 1993; Krogh et.al., 1993; Kamo and Krogh, 1995). Geological successions with sharp fluctuations of sea level changes and catastrophic events - tsunami - flesh flood etc. are found at many places (Haq et.al., 1987; Hallam, 1992; Holser and Magaritz, 1992; Schmitz et.al., 1992; Olsson et.al., 1996).

IV.2.6. Geochemical and Isotope Changes:

The geochemical and isotope implications of various factors and processes which operated during the K/T events at various places, are reflected in the chemical profiles of various elements across the K/T sections. Irridium anomaly have widely been reported from many sections as mentioned earlier. These anomalies of irridium, Cr, Ni, Au, Ag, and other elements may be one event or multiple events (Graup and Spettel, 1989; Bhandari et.al. 1995). In certain sections presence of amino-acids (amino isobutyric acid) probably of extraterrestrial origin below and above the KTB but not at KTB (Zhao and Bada, 1989). It has been suggested that these amino-acids are derived from cometary sources (Zonne and Grinspoon, 1970). At times a sharp decrease in $\delta^{13}C$ at and above the K/T boundary attributed to planktonic extinction, indicative of strange love ocean, followed by planktonic boom (Hollander et. al., 1993). The expressions in $\delta^{18}O$ values indicating changes in sea water tempeture of several degree before and after the K/T event (Sarkar et. al., 1992). A slow cold wave is followed by a sudden warm epoch. Martin and mac Dougall (1991) have found an increase in strontium isotope ratio ($^{87}Sr/^{86}Sr$), which they attributed to enhanced weathering due to impact induced acid rain. However, Nelson et.al. (1991), suggest an increase in ratio prior to KTB also. Gendener et.al. (1992), found an enrichment in N and S isotopic ratio ($^{15}N/^{14}N, ^{34}S^{32}S$), which is attributed to interaction of acid rain with organic matter in case of N ; and an anoxic event in case of S as noticed by Kajiwera and Kaiho (1992). Heymann et.al. (1996) detected Fullerencs (C_{60}, C_{70}) at various KTB sites with estimated mean global C^{60} concentration at the KTB to be 1.4 mg/cm2. Luck and Tucekian (1983) found that the $^{186}Os/^{187}Os$ ratio to be n1 in case of K/T clay, which was similar to the value in meteorites or the earth's mantle, whereas the crustal values for this ratio is n10. Kyte (1996), has found a 2.5 mm fragment separated from the K/T clay horizon of a mid Pacific core, which shows high concentration of Fe, Cr, Ir, characteristic of chondrites and is suspected to be the fragment of bollide responsible for K/T impact. Schraytz et.al. (1996) have detected almost pure micron size iridium nuggets from Chicxulub impact melt.

Besides above changes, a severe temperature fluctuation, a slow cold wave (-6°c) followed by a severe heat pulse (+10°c). The cold wave is believed to be due to blanketing

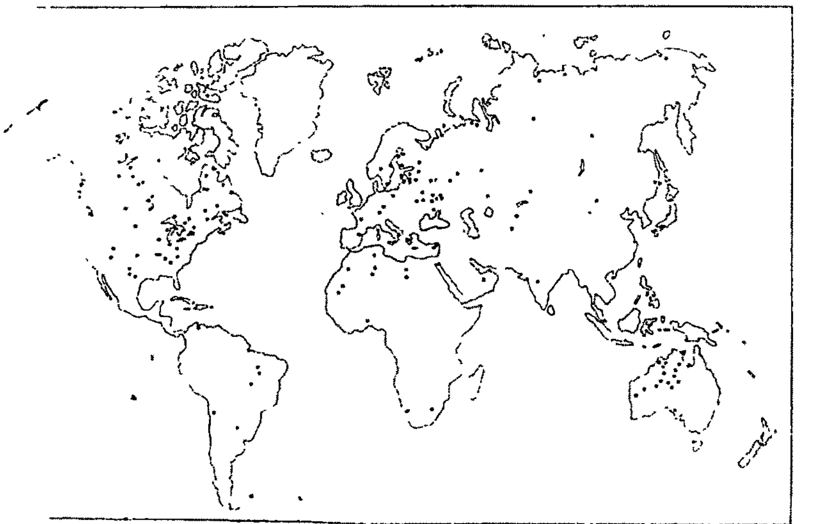

Fig. 3 Map of world showing important meteorite/high velocity falls.

of sunlight by soot, dust and sulphuric acid aerosols and the heat wave is due to green house effect resulting from release of large amounts of CO_2 as a consequence of impact on carbonate rocks (O'Kerfe and Ahrens, 1989). Based on analysis of palaeosol carbonates, it has been found that CO_2 concentration of the atmosphere at the time of KTB was about 800-1200 ppm (Gosh et.al., 1995; Bemer, 1992).

IV.2.7. Palaeomagnetic Changes:

The palaeomagnetic measurements carried out at different places in the world indicates that the K/T transition was marked in the reversal magnetic chron, and that these are very frequent short magnetic chron changes (reversals). The palaeomagnetic measurements of Anjar section by the author with the help of flue gate magnetometer suggest N-RNR sequence, and a polarity reversal after flow A. The studies carried on collaboration with PRL establishes N-R chron the first three flows being Normal, whereas the fourth flow showing a strong reversed magnetic polarity. Hofmann et.al. (1997) have also recorded the same palaeomagnetic polarity events. The polarity reversal event and the geochronological dating of flow sequence suggest a chron 29R-31N; which encompasses the Cretaceous-Tertiary boundary event in other places in world.

IV.3. GEOCHRONOLOGICAL CHARACTERISTICS AND EVIDENCES:

The geochronological dating of the Cretaceous-Tertiary boundary transition sections have been done at different places by many workers. It is widely believed and accepted that the K/T transition took place at 65.5 m.a. from present. A recent attitude is increasingly to further reduced this age to 65.0 m.a. The palaeontological scale indicates 66.5 m.a. age for the boundary transition. Thus, there is an overlapping of a common period of 66.5 to 65.5 m.a. in palaeomagnetic scale and geochronological time scale, but increasingly agreed trend is restrict boundary transition at 65.5 m.a. Thus, it would be seen that the palaeontological boundary show some lagging/overlapping by 1 m year. The palaeomagnetic and geochemical evidences have helped in minimising broad spreading events. The recent trend is to conclusively decide the K/T boundary transition dates from geochronological evidences, which are further aided by palaeontological, mineralogical, geochemical, palaeomagnetic, sedimentological and stratigraphical evidences.

The K/T boundary is thus associated with one or many sets of imprints of the above discussed changes. Different sets of signatures of each set of changes are briefly summarised in Table- :

IV.3.1. Palaeontological Signatures:

The palaeontological evidences of K/T boundary are varied and comprise of faunal and floral evidences in marine as well as terrestrial environments. Extensive work has been carried out by different working groups in different parts of the world. The marine sections show mass mortality of mega fossils (*ammonites, belemnites, brachiopods - rhynchonellids, terebratulids* - and microfauna like *foraminifera* from various sections.

Table: Major observations at Cretaceous-Tertiary Boundary (modified after Shukla and Bhandari, 1997):

Biological Signatures

1. *Global extinction of a large number of marine and land species* (Sepkoski, 1992): About 50% of general and ~15% of families are believed to have become extinct. In severity, the K/T extinction is only next to P/T extinction. The extinction is gradual, step-wise or sudden is still debated.
2. *Extinction is believed to be selective.* Studies of Kaiho (1994) shows difference between extinction of planktonic and benthic foraminifera. It has been suggested that extinction was mainly confined to tropics and had some latitudinal dependence (Keller, 1994).
3. *Near disappearance of pollen and plants.* At the base of the KTB *Micula murus* zone has been identified. Complete extinction of *dinosaurs.*

Geological Signatures

1. *Deccan flood basalts, timing and duration* Available $^{40}Ar/^{39}Ar$ ages of these basalt flows range between 63 Ma to 68 Ma (large scale ($10^6 km^3$) flood volcanism in central and western India). It has been suggested that bulk of the basalts erupted within a short interval of time of less than 1 Ma around KTB (Courtillot *et al.*, 1996) However, Venkatesan *et al.*, (1993) pointed out that major peak of Deccan eruptions predated KTB by more than 1 Ma and its duration was not less than 3 Ma
2. *Chicxulub Crater.* (a) Chicxulub crater (diameter ~200 km) in the Yucatan peninsula has been identified as the crater formed at the KTB (Sharpton *et al.*, 1996). (b) The age of melt crater rocks at 64.98±0 05 Ma (Swisher *et al.*, 1992) is the same as the age of tektites from Haitian KTB site (Izett, *et al.*, 1991). (c) Apart from the 65 Ma resetting age, the zircons from various K/T sites (Colorado, Beloc and Sakatchewan) also give ages of ~64.5 Ma similar to the age of Chicxulub platform, indicating that it is the only large impact crater at KTB (Bohor *et al.*, 1993; Krogh *et al.*, 1993; Kamo and Krogh, 1995). (d) The geometry of the crater and the ejecta indicates that the bolide hit from southeast direction at a low angle (20° to 30°) and the ejecta was thrown in a northwesterly direction.
3. *Sea-level changes·* Sea level changes causing regression and transgression are believed to be the main factor in causing extinctions at KTB (Hallam, 1992). A sharp drop of 100 m prior to KTB and an equally rapid rise thereafter have been observed for various sections (Haq *et al*, 1987; Holser and Magaritz *et al.*, 1992; Schmitz *et al.*, 1992). It has been argued that these fluctuations would affect even the terrestrial reptiles because of lowering of water table (Berrera, 1994).

Chemical and Isotopic Signatures

1. Global occurrence of enhanced level of iridium with orders of magnitude higher concentration above the background. In some sections, the Ir peak is superimposed on a broad hump whereas a few sections show multiple Ir peaks (Graup and Spettle, 1989; Bhandari *et al*, 1995).
2. Presence of amino acids (-amino isobutyric acid), probably of extraterrestrial origin below and above the KTB but not at KTB (Zhao and Bada, 1989). It has been suggested that these amino acids are derived from cometary source (Zahne and Grinspoon, 1970).
3. A sharp decrease in $\delta^{13}C$ at and above the K/T boundary (Hsu and McKenzie, 1990) attributed to planktonic extinction, indicative of strangelove ocean, followed by planktonic boom (Hollander *et al.*, 1993)
4. Excursions in $\delta^{18}O$ values indicating changes in sea water temperature of several degrees before and after the K/T event (Sarkar *et al.*, 1992) A slow cold wave is followed by a sudden warm epoch
5. An increase in strontium isotopic ratio ($^{87}Sr/^{86}Sr$) attributed to enhanced weathering due to impact induced acid rain (Martin and macDougall, 1991). However, Nelson *et al*, (1991) suggest an increase in this ratio prior to KTB also.
6. Enrichment in N and S isotopic ratios ($^{15}N/^{14}N$, $^{34}S/^{32}S$) attributed to interaction of acid rain with organic matter in case of N (Gardener et al., 1992) and an anoxic event in case of S (Kajiwara and Kaiho, 1992).
7. Fullerence (C_{60}, C_{70}) have been detected at various KTB sites with estimated mean global C_{60} concentration at the KTB to be 1.4ng/cm^2 (Heymann et al., 1996).
8. $^{187}Os/^{186}Os$ ratio is found to be ~ 1 in the K/T clay, similar to the value in meterites or the Earth's mantle whereas the crustal value for this ratio is ~ 10 (Luck and Tureklan, 1983).
9. A 2.5 mm fragment separated from the K/T clay horizon of a mid-pacific coast shows high concentration of Fe, Cu and Ti, characteristic of chondrites and is suspected to be the fragment of the bolide responsible for K/T impact (Kyte, 1996). Schuraytz et al., (1996) have detected almost pure micron size iridium nuggets from Chicxulub impact melt.

Mineralogical and Other Features

1. Presence of shocked mineral grains such as shocked quartz, zircons and chromites (Bohor et al., 1984; Bohor, 1990; Bostwick and Kyte, 1996) This is a stronge evidence in favour of impact hypothesis.
2. Spherules and microtectites have been reported from K/T sites. These include sanidine spherules (Smit and Klaver, 1981) and others having composition of potassium felspar, glauconite, pyrite, etc. (Montanari et al., 1983, Smit and Kyte, 1984; Brooks et al, 1985). Glasses with shapes resembling those of microtectites have been found from Beloc section near Haiti (Hildebrand et al., 1991; Kring and Boynton, 1991, 1993) which have been dated to be 65.01±0 08 Ma (Izett et al., 1991; Ocampo et al., 1996; Smit et al., 1996; Bohor et al., 1996).
3. Discovery of nannometer sized diamonds favour impact hypothesis (Carlise, 1992, 1995). The authors found Ir to nannometer size diamond ratio to be similar as observed in case of C2 type chondrites and further noticed that carbon isotopic ratio did not favour a terrestrial origin. The horizon containing the diamonds had 51 amino acids out of which 18 are found in carbonaceous chondrites only. Based on C and N isotopic ratio in diamonds, Gilmour et al, (1992) suggest an impact or plasma origin for these diamonds.
4. Miteoritic spinels usually 2-10 microns, rich in nickel have been found at the KTB showing a prominent peak where the iridium enhancement is observed (Robin et al, 1992). These are believed to be produced in the atmosphere during the entry of the bollide.
5. Presence of soot in the boundary clay provides an evidence of large scale forest fires (Wolbach et al, 1985, 1990; Ivany and Salawitch, 1993), which could have contributed to the loss of sun light.

Environmental Signatures

1. A severe temperature fluctuation, a slow cold wave (-6°c) followed by a severe heat pulse (+10°c). The cold wave is believed to be due to blancating of sun light by soot, dust and sulphuric acid aerosols and the heat wave is due to green house effect resulting from release of large amounts of carbon dioxide as a consequence of impact on carbonate rocks (O'Keele and Aluens, 1989). Based on analysis of palaeosol carbonate, it has been found that CO_2 concentration of the atmosphere at the time of KTB was about 800-1200 ppm (Gosh et al., 1995; Bemer, 1992; Barrera, 1994; Barrera and Keller, 1994)

J. Smit (1982, 1988, 1990), M. Feist and F. Colombo (1988), Brooks et.al. (1986), Bohor Bruce et.al. (1987) and many workers observed that the older Upper Cretaceous forms do not continue after the boundary event. However, in some cases, earlier dominance is reduced.

The *globigerinids* (e.g. *trancoma*) were reduced and new forms *globigerinid euglubids* greatly increased and dominated.

In floral records the transition event was marked by the abundance of *fern spike* and *sphgnum moss* layer at the boundary. Bohr et. al. (1984, 1987), J. Medus et.al. (1988) recorded such events in Spanish K/T sections. At times, the boundary events are marked by dominance of *angiosperm* flora and post event dominance of *fern spike* layer (Nichols and Flemino, 1990; Arunkumar, 1992; and Lerbekmo et.al., 1987). In some sections in West Canada *angiosperm pollens* dominate in place of *fern spike* layers in West Canadian sections. Abundance of *charophyte* flora are also recorded above boundary layer (Fiest and Columbo, 1988).

The *molluscan* assemblage of diverse nature dominated by suspension features up to the K/T boundary contact were replaced by very low diversity assemblage of predominantly deposit feeders and carnivores in early Palaeocene in certain sections in Eastern Texas (Hensen et.al., 1987). The planktonic *foraminifera,* calcareous nannofossils, suspension feeders, *bivalves* suffered highest mortality, while benthic *foraminifera*, carnivores and deposit feeding *gastropods* and *bivalves* were comparatively less affected.

Alligator and chelonian fauna are also associated with the boundary sections (below boundary) in Basque country (Astibia. H., et.al., 1987).

The continental sections also record similar pattern in the dominance continuance and mortality of old groups and emergence of new groups/forms. Many form of *ostracods, sponges, chamophytes, dinoflaggellates (dynocysts)* show changes through time. Major changes are recorded in floral compositions. About 70% of the existing species were exterminated / declined with emergence and dominance of *angiosperms*, deciduous vegetation and *dicotyledons*.

The land vertebrates were most severely off by these changes. These include complete extinction of dinosaurs and significant reduction in the reptilian forms, at the same time, some reptiles, mammals, emerged as dominant groups. Microvertebrates dominated in the initial phases. These include rodents (Niall et.al., 1992).

Attempts have been made at many places in the world to link or correlate the faunal, floral switch overs to other evidences in order to arrive at some possible explanations to the factors responsible for such changes and propose some model / scenario, which played a dominant role as interplay of various factors offering the palaeobiological, palaeoecological and palaeoenvironmental set up that existed at the transition period before and after such changes.

IV.3.2. <u>Stratigraphical and Sedimentological Signatures</u>:

In many boundary sections in the world, it has been observed that, finely laminated sequence of argillites, ash, clay rich in atapolgite / smectite (Bohr, et.al., 1987) and abundant carbon soot and oxidised organic matter (OM) dominate (Bohr, et.al., 1984; Smit, 1990).

Laminated sequences contain brown or red layers, which have been found to be rich in irridium concentration. At times marl layers and evaporite minerals dominate. The clay/ shale/ash layers contain *sponge spicules* spherules (sanidine), felspar clasts, kaolinite or 'goyazite' (Bohr, et.al., 1987) and tiny needles of various composition within such ash / clayey or siliceous layers Such layers are considered the result of activity of microorganisms or due to accumulation of mineral concentrations. In some places, golden yellowish coloured spike layers / grains were also recorded.

The overall characters of boundary sections of marine origin are calcareous and argillaceous, at times chemically precipitated chert, micrites containing *forums, bivalves* and *brachiopods*. The continental sections comprise palaeo-soils, clays, shales, chert, limestones, quartz/chert, dominant ash, red layers (limonites), volcaniclastics, felspar clasts, tuffs, porcellanites. Few sections with varved layers with sharp contortions, storm surge accumulations are also recorded at some places in Texas (Hensen, et.al., 1987; Niali, et.al., 1992).

IV.3.3. <u>Geoenvironmental Signatures</u>:

The $\delta^{13}C$ values of K/T sections in middle and low latitudes are marked by sudden and pronounced decrease for near surface water carbonate and reduction in the surface to bottom $\delta^{13}C$ gradient, indicating a severe drop in the surface water productivity in the ocean of tropical and subtropical region (Barrera and Keller, 1994). The stable isotope data of carbon, oxygen, and strontium from Maestrichtian planktonic and benthic *foraminifera* from southern high latitudes ocean sites reveal major changes in climate and ocean water chemistry during the early to late Maestrichtian transition, some 4 to 6 m.y. prior to the Cretaceous-Tertiary (K/T) boundary. The ^{18}O results suggest accelerated cooling resulting in lowest marine temperatures of the Late Cretaceous. The Late Maestrichtian rise in the sea water $^{87}Sr/^{86}Sr$ ratio begins at the time of this change and suggest increased rates of continental weathering and / or run off. The $\delta^{13}C$ values show a negative shift ~0.5% followed by ~1.00%. The $\delta^{13}C$ fluctuations may reflect change in deep water chemistry with cooling, variation in reduced carbon storage in coastal areas caused by eustatic sea level fluctuations and increased surface water productivity (Barrera, 1994).

IV.3.4. <u>Geochemical Signatures</u>:

The boundary sections show abnormally anomalous values of certain challophile and lithophile elements. The siderophile, rare earths and volatile elements also show sharp deviations and enhancements / reductions along the depth profiles in the sedimentary sections with K/T transitions. These deviations (peaks) coincides with the material evidences. Such observations on Ir, Os and Ir/Os ratios in majority of the K/T boundary sections have indicated anomalous values in both marine and continental sections. In case of continental sections, the values of the ratios and individual elements appear on the higher sides than the contemporary marine sections (Lerbekmo, et.al., 1987; Hensen, et.al., 1987; Brooks, et.al., 1986; Alvarez, et.al., 1980, 1981, 1990; Bhandari, et.al., 1987, 1994, 1995, 1996).

IV.4. SOME OUTSTANDING WORKS ON K/T BOUNDARY:

M. Feist and F. Colombo (1988) studied the Cretaceous sections from Tramp and Coll de Nargo area, Lerida Province and the Figols Vallicebre area, Barcelona. They demarcated the boundary below the limestone overlying the red beds of Tramp Formation on the bands of Charophytes.

J. Smit (1982) studied marine sections from Biarritz Zwamya hubio, Italy, El Kef, Sturers Kilint, Reichenhall, Latteneshire in Western Europe. He found a common distinct marl layer, which shows a sharp change in the distribution of *Planktonic Foraminifera.* Except one species of *Planktonic Foraminifera* (*Gnembelitria cretacea* Cushman) all previous forms were exterminated in the higher part of the section.

Palynological criteria was used for separating Mastrichtian and Lower Palaeocene strata in mid-continent North America by Stânley (1965), Hall (1969), Ortz (1969), Shead (1969), Srivastava (1970), Tschudy (1971) and (1973) and Sweet (1978). They recognised phytogeographic provinces based on their studies.

Medus J. et al (1988), on the basis of *Miierisprite succussulus* Tschudy (1976) Parazolla Hall (1969) from Vallcebre limestone of Fontllonga of eastern Spanish Pyrenees demarcated probable Danian sequence.

Nichols and Fleming (1990) identified the Cretaceous / Tertiary boundary in continental rocks of region from New Mexico to Alberta in western North America on the coincidence of a palynological extinction horizon and irridium abundance anomaly. They also found that the abrupt extinction is consistent with impact hypothesis and is inconsistent with progressive change of palaeoclimate. They recognised these two criteria viz. (1) the anomalous concentration of Iridium, and (2) presence of palynological extinction horizon as essential for recognition of K/T boundary.

The K/T boundary can also be distinguished by presence of "fern spore" abundance anomaly called the "Fern Spike Layer" or Sphagnum moss, Nichols et al (1985). They also found that the KTB localities can also be characterised by presence of certain set of shock metamorphosed minerals, which have origin as impact debris (also found by Boher et al, 1984).

IV.4.1. Marine K/T sections:

It is, however, important to note that the stratigraphy of several complete marine sections show a number of characteristics briefly mentioned as below:

1. There is an abrupt extinction of planktonic forums followed by -
2. a thin lamina with high concentration of siderophite elements considered as direct fall out level of impact element.
3. This lamina is followed by a 1 to 30 cm thick clay or marl layer (which represents normal back ground supply of hemipelagic clay).
4. A gradual return to calcareous sedimentation with the appearance of the first Palaeocene species. Smit (1982) also found similar events and biostratigraphy in the Gredero section in SW Spain, and in the K/T section in N Tunisia.

IV.4.2. <u>Continental K/T Sections</u>:

First discovery of an Irridium anomaly in terrestrial sediment was dependant upon RH Tschudy's recognition of a floral break in a core hole from Raton basin, New Maxico (Orth et al, 1981). Subsequent studies in the mid-continent area of the United States conclusively demonstrated the coincidence of palynofloral extinction event and a geochemical anomaly (Pillmore and others, 1974; Smit and Van der Kans, 1974; Nichols and Fleming, 1988; Bohors and Others, 1987).

Subsequent studies by Jazykiewicz and Sweet (1988) and by Sweet (1988), Sweet et al (1989) demarcated K/T boundary positions at various places in Western Canada and parts of United States, on the basis of palynological evidences and irridium anomalies.

Bohor Bruce F. et al (1987) and Bohor et al (1984) recorded root from forest fires, and shock quartz in certain sections. Bohor Bruce F. et al (1987) found high Ir, Cr, Pt, Au and Ag values in a kaolinitic layer. Spherule layer containing (film) goyazite, which are found after the replacement of original spherules. Those kaolinitic claystone layer contains abundant fern spore. The spherule layer is overlain by smectitic (clay) mud layer which contains shock metamorphosed quartz grains besides smectite mineral, high concentration of Ir, Pt, Ag, Au and relatively less *fern* spores and more abundant *angiosperms* pollens. The boundary at Dogle Creek, Wyoming is marked above the spherule layer of W. Gonole on pollen and Ir anomaly.

Lerbekmo John, F., Sweet Arther, R., Louis Robert M. st (1987) found abundance of *angiosperm* pollen-spores in the horizon above the Ir layer. This is in contrast to the mid-continental K/T sections from America and Morgan Creek locality from where fern spikes were common.

Henson et al (1987) while studying the sedimentological and extinction pattern across the Cretaceous-Tertiary boundary interval in East Texas United States found high irridium anomalies in the Brazos river Cretaceous section. They noticed an abrupt decline in the diversity and abundance of planktonic *foraminifera, mollusca* and calcareous *nannofossils* in conjunction with an increase in iridium levels. *Molluscan* assemblages are diverse and are dominated by suspension feeders up to K/T contact, but are replaced by a very low diversity assemblage of predominantly deposit feeders, and carnivores in early Palaeocene.

The species of microfauna and microflora species that lived or fed in the water column suffered the highest mortality, while benthic, dominantly deposit or carnivorous taxa (benthic *foraminifers*, carnivorous and deposit feeding *gasteropods* and *bivalves* were less affected.

Raju D.S N., et al (1995) also recorded K/T transition section from off shore Godavari delta. The *foraminifera* in the subcrop well section show reduction and disappearance of certain planktonic *forams* and appearances of some forms.

Arun Kumar (1992) while studying the palynological changes in sediment across K/T boundary sections in Texas, United States, found conspicuous changes in the composition of *palynomorphs* and found that they are more due to environmental changes than the evolutionary changes. He found certain *fern* pollen-spores in abundance in section.

Robert R. Brooks et al (1986) recorded first continental section at Woodside Creek and at three other sites in New Zealand, high irridium anomalies.

Bhandari et al (1987, 1994) while studying the Um shohryngkow river section in south Meghalaya recorded the high irridium anomaly. They also found that *M. Murus* and *Naphrolithus frequensus* extinction zones coincide with the anomalous irridium layer. The depth profiles of select siderophile and chalcophile elements show peaks in coincidence with irridium anomaly in Meghalaya section.

Presence of volcanic ash, tuff, limestone, marl, limonitic layer with irridium anomaly and at times siliceous cherts, felspar clasts (sanidine), spherules, globules, tektites, and other metamorphosed minerals are also common in addition to the other palynological and faunal evidences.

Larger land dwelling reptiles (dinosaurs) suffered a sudden, sharp and abrupt decline in abundance & diversity in majority of the places where continental or mixed sections of Cretaceous-Tertiary transition are exposed. They totally vanished at the K/T transition event. In North America, however, the reports of few *dinosaurian* fossils (teeth and small skeletal parts are recorded from Morison Formation. These fossils are thought to have been reworked from the Maestrichtian horizon and redeposited in the nearby erosion valley channels involving very little transportation.

The above discussions make it clear that the K\T boundary section at different places show certain characters, majority of which may be found either at one place or in a few sections or differently at differently at different section. These changes are recorded in the sedimentation records (either marine or continental sections differently) at different places. These changes and characters can be summarised under different heads as:- physical, physiographical, atmospheric, cosmic, sedimentational, palaeoclimatic, biotic (palaeontological), geochemical, mineralogical, palaeomagnetic and geochronological.

The majority of the Cretaceous-Tertiary boundary sections of marine as well as continental origin indicate certain sets of stratigraphical, sedimentological, geochemical, mineralogical, diagenetic, palaeontological, palaeomagnetic, geochronological characters (signatures), dynamics and events, which are unique. These changes and their imprints, the characters are studied in great details in almost all such sections all over the world in order to unravel certain mysterious happenings.
