Chapter - 14

CHAPTER-XIV

CONCLUSIONS

1. The rocks of Cretaceous/Tertiary age are very well exposed in the region of Kutch.

2. These rocks contain fossils of *dinosaurs* and their associated fauna and flora.

3. Many of such forms have shown world wide extinction at the end of the Cretaceous and beginning of the Tertiary time.

4. In order to understand such a problem in its global context, the author has extensively studied the Cretaceous/Tertiary exposures in Kutch and attempted a multi-disciplinary approach to investigate the same.

5. The *dinosaurian* history in Kutch has a very long record, starting from Upper Jurassic (Bathonian) in Patcham Island to about 65 m.y. from Anjar and other places like Matanomadh, Dayapar, Intertrappean beds of Maestrichtian/Danian transition. Important *dinosaurian* forms that dominated the scene include *sauropods*, like *Brontosaurus, Titanosaurus, Brachiosaurus, Barapasaurus, Manjungosaurus, Antarctosaurus, Branparopus; Ornithischian* forms like *Triceratops, Coelurus, Iguanodon* and *Thiropods* like *Megalosaurus, Hypsilophodontids, Camptosaurus, Allosaurus, Stegosaurus, Elephantopoides.*

6. The Mesozoic (Bathonian to Maestrichtian) *dinosaurs* mostly preferred the peneplained grounds, low lying flood plains, gently slopping grounds, for habitation and hatching.

7. The synthesis of the detail studies by the author which also forms his important contributions to the subject of K/T boundary and faunal extinctions in Kutch are summarised below:

8. Geological mapping on 1:50,000 scale was carried out in potential localities, wherever the Cretaceous/Tertiary transitional zones were likely to be exposed. Details of some of the potential sections are given below:

9. **Anjar Section:**

Anjar section covers strata from Upper Member of Bhuj and volcanosedimentary sequence covering seven lava flows and five intervening sedimentary beds, Intertrappean beds and the red bole bed. The Intertrappean beds comprise clays tuffaceous sandstone, red bole beds, chert, porcellanites, marls, limestones, grey shales, pyroclastic with feldspar clasts, gypseous shales and clays. The Intertrappean bed No.3 and 5 have evaporite dominating sequence which is replaced by chert. It shows a replacement parygnosis

(Anhydrite) gypsum-calcite-chert-quartzite with a regular arrangement of length slow and length fast chert and quartzite Anjar section shows a distinct biozonation with dominance of different faunal, floral groups. These zones were corroborated with geochemical, palaeomagnetic and lithostratigraphic details given importance vis-a-vis important changes in form of palaeoenvironments, ecology and climatic fluctuations. In the dinosaurian pit locality, the basal black shale, mottled marl the chocolate coloured shale sequence contain abundant fish scales, otoliths, ferns, cycades and profusely oxidised organic matter. The lamellibranchs and the sub-horizontal to inclined burrows are common within the section below the cherty limestone. The geekoid and dinosaurian egg shells are common in the basal section (below cherty limestone. The cherty limestone contains various planktonic forams and few benthic form. A detail study of micro sections have suggested that 'P' zone for the limestone horizon. The excavation carried out for the dinosaurian fossils at the pit locality has shown that the dinosaurian fossils occur below the cherty limestone and at the contact of black shale/chocolate coloured shale. The fern spore layer and cycade Megasporophylls are also found below limestone horizon. The avian mammalian angiosperms, spores Dinoflagellates, Azolla occur in upper part of the section and suggest a Tertiary affinity.

The multi-disciplinary studies of Anjar section has indicated the three multiple iridium anomalies Ir (in basal marl). Ir_2 in thin white layer in black shale and Ir_3 below the ash layer in brown chocolate coloured shale underlying cherty limestone. Dinosaurian fossils occur below the chocolate shale layer and above the black shale and Ir_2 layer. The iridium anomalies are 123 times higher than the back ground ratios. The Os/ Ir ratio is comparable to the continental sections of the world. The Ir, is a limonitic nodular concretionary continues all through the exposed pit section. This overlies a Kaolin rich thin ash layer sponge spicules chalcophile globules. This Ir layer defines the geochemical K/T boundary, layer in Anjar section.

The fifth Intertrappean bed contains chert shale clay and laminated fossiliferous limestone containing bryozoans algae, larger forams and abundant plant debris.

10. **Dayapar Section:**

The Dayapar section contains five Intertrappean beds, of which the basal two beds are fossiliferous. The second Intertrappean bed is exposed near north west of Dayapar and is richly fossiliferous and has yielded dinosaurian and other reptilian (tortoise-chelonian, lizards and crocodilean) avian bones and eggs, and varied group of plant fossils. These fossils (dinosaurs and charophytes) and field measurements of palaeomagnetic measurements indicate a close similarity to Anjar section

11. **Ukra Section:**

The Ukra section shows volcanosedimentary section comprising four flows and three Intertrappeans of trap pebble conglomerate gypseous clays, shales and sandy clays The flows show NRN-R polarity sequence in field measurements.

12. **Important Findings by the Author:**

Geochemical and palaeomagnetic studies:

The K/T boundary sections in Kutch are characterised by finely laminated ash layers, finely laminated grey and black shales with very high concentrations of Os/Ir ratio (= 1.2) and concentration varying between 750 to 1414 ng/g.. The other siderophiles (Ni, Fe,, Mn, show high concentration in the anomalous layer in conformity to Ir/Os of the chalcophiles and lithophiles (Ca. Ba, Na, Sb, Zn, Sc, Hf, Th, Se, Ag, Ac, As, Al, Mg and K) Ba, Sb, Zn, Se, Ag show abnormally high concentration in conformity to the siderophile elements of the REE the Ce, Yb, Lu show anomalous values. The volatiles Ta, Cs, Zr show anomalous values. The analysis of the samples was done at the PRL, Ahmedabad Laboratory. The concentration of the Ir/Os varies from 7 to 20 higher than the back ground values and the immediately overlying and underlying horizons in the Anjar-III Intertrappean bed.

The palaeomagnetic laboratory studies of the oriented drill cores sample of flows F1 to F7 have suggested that the basal three flows F1-F3 show a normal polarity chron, whereas the upper four flows F4-F7 show a reversed polarity chron. The intervening III Intertrappean bed at Anjar comprises of 7.5 cyclic repetitions of mud, shale, fine argillite and limestone/marl assemblage forming one major cycle several hard compact marly intercalation may resolve the polarity reversal and may help in further locating the initiation of the reverse polarity chron. The geochronological studies of the samples of flows F1-F7 have given some plateau ages and integrated Isochron ages which are very close to the KTB events.

It is implied from the geochemical studies that the Deccan Volcanism was initiated at 68.7 ± .8 ma (F1) and continued up to 61.0 ± 1.6 m.y. (F-VII) The geochronological dating has indicated age of F-III. Flow 65.3 ± .6 m.a. and F4 range at 65.1 ± 1.6 m.y. by $^{40}Ar/^{39}Ar$ method. The age of the III Intertrappean bed range from 65.3 ±0.6 m.a. to 65.1 ± 1.6 m.y. suggesting an age of about 0.2 m.y. for the depositional history of 6.5 metres and this average sedimentation rate of about 3.5 cm/1000 years. The three meteoritic strikes were after 30,000, 48,000 and 54,000 years after the eruption of the flow III. The last dinosaur outlived the 48,000 year event of 2nd meteoritic strike but died before the final flow. The K/T boundary layer is located above the dinosaur bone bed $_{(Ir)}$ layer). The ash layer is associated with fine globules of Iridium which indicate a air fall out of the aerosol after the big bang. The palaeontological indication of the boundary layer are fern spikes, cycade sporophyls, charophytes, dinosaurian bone fossils The overlying planktonic foraminifer zone contain Palaeotextularia, Globigerinid bulloids, G. eugbina, Nodosa uridae sp which demarcate zone P, indicating a palaeocene horizon (Danian P). The angiosperm spore elements of *Manucarpus Palamaepollenites, dinoflagellate scariosum, azolla* and *algae* from zones above cherty limestone suggest a Tertiary age for the above the cherty limestone Avian egg elements are also dominant in this zone The trace fossils *planolites*

show sub-horizontal to inclined burrow habits in the shales blow the boundary layer and are mainly suspension feelers, but after the boundary the show vertical habit and are confined within shale/mud starting from the base of cherty or gypseous layers. These are mostly vertical scavenging carnivore burrows. K/T boundary based on these trace burrows has been demarcated elsewhere in KTB sections also.

The mineralogical studies of the Intertrappean bed III has suggested fine grained multiple fractured shocked grains of quartz showing shock zoning colour pattern in micro section.

The sediment characters of the section above cherty limestone suggest a general dryness, high temperature and temperate to acid climate as suggested by the thin partings of gypsum and siliceous cherty intercalations. The marl lenses also show calcritised voidal openings with deposition of gypsum crystals in the voids and partings, suggesting a general starving conditions of lagoon for sedimentation.

In the second Intertrappean bed, the faunal and floral evidences suggest probable uppermost Cretaceous - Maestrichtian faunal elements (*Titanosaurid* and *hypsilophodontidae* elements and *ostracodes*, charophytes and mosses).

The third Intertrappean (at dinosaur pit locality, contains uppermost Maestrichtian faunal elements in the basal unit (lower 1.3 m) of the section. The floral element of Maestrichtian include cycadean megasporophylls, fern spikes, algae, and other gymnosperms spores and cones.

The section above the ash layer in the brown shale and the overlying cherty limestone is considered to be of basal Palaeocene (Danian in age) on the basis of fossils. The faunal elements indicating Tertiary age are avian, ostracodes, floral elements like *palmae* spores, gervenella-algae, azolla and many megafossil plants of angiosperm affinity show relative abundance.

The studies of Anjar and the Dayapar section has suggested that :

1. The lithostratigraphical succession of Bhuj and Katrol Form part of the upper Gondwana of Indian subcontinent and contain well preserved plant fossils.

2. The lower part and upper part of Bhuj Formation contain few centrally erupted plugs and plug deposits. These plugs and the dykes of various phases of eruption with trap pebble conglomerates form the early phases of the trappean eruptive activity.

3. The history of the dinosaurian fossils in Kutch started in upper Jurassic in Bathonian times and continued with intermittent evidences till end of Maestrichtian and outlived in the basal Tertiary and possibly form the youngest dinosaur record of dinosaur from Indian subcontinent.

4 The stratigraphic parameters and the sedimentological, mineralogical, geochemical, geochronological and palaeomagnetic characters of the section at Anjar and Dayapar

suggest existence of the K/T boundary within the III Intertrappean bed at Anjar and the II Intertrappean bed at Dayapar areas. The presence of globules, felspar clasts, Iridium rich spherules, highly oxidised organic matter substantiate this fact.

5. The micropalaeontological evidences of spore-*pollens*, mega fossils of plants and vertebrates also suggest existence of boundary.

6. The dinosaurian fossil record of insitu occurrence do not occur above the iridium anomaly I3 (last layer).

7. The faunal and floral evidences of second Intertrappean bed at Anjar suggest that a probable uppermost Cretaceous Maestrichtian age.

8. The third Intertrappean bed at Anjar contains uppermost Maestrichtian elements in the basal unit (lower 1.3 m. of section). The Maestrichtian elements include cycadean *megasporophyles*, fern spikes, algae, fish scales, otoliths, gymnosperm cones and spores.

9. The section above the ash layer in the brown shale and the overlying cherty limestone is considered to be of basal Palaeocene (Danian in age) on the basis of fossils. The faunal elements indicating Tertiary age are avian, ostracodes, floral elements like palmae spores, gervenella-algae, azolla and megafossil plants of angiosperm affinity show relative abundance.

The rate of sedimentation of 4.5-5.0 m / 1000 years:

The rate of sedimentation of 4.5 - 5 cm per 1000 years suggests three distinct geochemically anomalous layers in the Anjar IT-3 suggest three separate events of meteorite strike within a duration of about 54,000 years after the eruption of Deccan Trap flow III. The first event occurred after 30,000 years, the second followed at 48,000 the last followed at 54,000 after the formation of third flow. The meteoritic strikes did not initiate Deccan Volcanism.

10. The Deccan trap volcanism predates meteoritic events and was initiated around 69 m.a. before and continued up to 61.0 ± 1.6 m.y. with a duration of about 7 to 8 m.y. Dinosaurs continued to live in volcanically active terrain for about 3 to 4 m.y. with an unfavourable degrading ecological set up.

11 The Deccan eruption was through central as well as fissure eruption in subaqueous environments within plate boundary or plate margins. The fissure eruption dominated the scenes.

12. The basal flows were alkaline in nature . Eruption took place intermittently with breaks of quiet period which supported sedimentation in the small lakes, pools and lagoons, which supported life.

13 The basal flows are simple alkaline rich in Anjar, Bhachau with high TiO_2, alkali, P_2O_5 and MgO and suggest a continues differentiation process from same source. Spilitisation and reaction rim around pyroxene and olivine are common in Dayapar.

14. The later part of the flow are tholeiitic in nature. There must have been later contamination in magma in Dayapar area which has given rise to reaction rims.

15. In the fifth Intertrappean bed, the angiosperm dominate. The forms on comparison suggest *miliolida* and some larger forums. The fossil assemblage suggest Upper Palaeocene to Lower Eocene age. There was repeated and frequent subaerial exposures, which led to the extensive mottling and calcretisation under temperate condition in alternations with longer humid periods in lower and upper part of the sequence. The temperate dry spells were longer in the middle part. In the upper parts, the conditions were largely humid, with alternations of short dryer spells of temperate conditions.

16. The higher flows in Anjar, Bhachau sections indicate a reversal of trend in major oxides indicating a possible mixing of the magma at some stage in the renewed cycle of eruption. The basal flows are different at all the places and overlie the different units of Bhuj Formation.

17. The Deccan Trap eruption predates the K/T boundary, but it played important role in the climatic variations, in the environmental set up and ecological set ups which ultimately lead to severe and frequent short term but very effective and deadly fluctuations, deviating from normal climatic patterns, poisoning of basin waters through acid rains and lowering of temperatures etc., due to heavy intermittent discharge of gases, ash, thick dust cloud blankets, lowering of solar radiation, minimising photosynthesis, and depleting available oxygen by numerous closely spaced eruptive cycles in almost all parts of the globe, in a simultaneous way.

18. The Deccan Trap eruption is correlatable with the drifting of Indian plate at various geological times as representative remnants of earlier manifestations of Deccan Trap and synchronous eruptions are progressively recorded by syn-sedimentation controls in the Upper Jurassic, Lower and Middle Cretaceous horizons at various places in stratigraphic sections in western India and in parts of the Gondwana land - elsewhere.

19. There were cyclically marine incursion (brackish incursion) in the third Intertrappean bed, after the boundary event and meteroritic fall. There was general dryness and semi arid to temperate torrid type of climate in the middle part with general starvation for sedimentation during drier periods. The ephemeral streams and gullies draining the trappean flows into the shallow lake/pond (covering about 2 km + 1.6 to 1.8 km). The pond was divided into numerous subenvironments of playas, low lying channels, bars, and fans. Algal mats covered the pond surface. The floor was covered by mud calcareous ooze and channels were occupied by black mud.

20. The upper age of the Gondwana flora *Ptilophyllum*, *Araucarites* and related form need to be revised as there is a progressive change in forms with advent of time

21. The Foot prints and foot traces suggest different types of herbivores, *sauaropods*, *ornithopods*, and *theropod* dinosaurs. They preferred mainly the low lying flat sandy

shores/lake margins as their habitats. They mostly consumed C3 and C4 type of fibrous herbs, dry plants shrubs and consumed water from the ponds/lakes.

22. They preferred wet, sandy sediments as hatching grounds and laid eggs in small depression. Their eggs were incubated by solar heat.

23. They had colonial habits and moved in herds and visited same hatching sites again over one year. They moved in structured herds and protected juveniles and sub-adults while in moving in herds as they kept the tiny-tots in the centre of herds.

24. The Dayapar volcanics are tholeiitic in basal part and alkaline in the upper part and possibly indicate separate cycles of eruption/differentiation.

25. As a sequence of volcanism and meteoritic strikes the tremendous degradation of the ecosystem due to sudden cooling, subsequent heating followed by uniformly very high temperate conditions, gas, dust, radiations, acid rains, and masking of cosmic radiation for a considerable time disrupted the food chain of plants and lead to the extinction of existing flora which also mounted pressure on the ailing herbivore dinosaurs ultimately creating tremendous stress on them.

26. The imbalance in the hormonal secretions caused pathological conditions in the eggs (multilayered unhatched eggs) and uniformly high temperature also caused unisexual fertilisation of egg causing either only males or females, which up set the population dynamics leading to their extinction.

27. The excessive heating of the environments and radiations of the strike caused pathological conditions in the skin and bones which also lead to their extinction. These caused their failure to the adaptability to the environment at changes which lead to their exterminations.

28. These studies by the author are unique in their kind in India, and have not been conducted so far at other places. The multi-disciplinary approach has generated many data which form a part of the problem. The present studies have clearly suggested factors responsible for the mass extermination of some forms by speeding up the dominance of unfavourable factors for further continuance of giant reptiles which were highly evolved and underwent diversifications and developed specialised physiology based and environmental need based body forms and body functions. The present studies have helped to record many new discoveries from different parts and have contributed to the much sought after informations from Indian side to the enhancement of the world scenario at the crucial Cretaceous-Tertiary transitional period in the geologic history of the earth