Chapter - 8

CHAPTER VIII

INFRATRAPPEAN - INTERTRAPPEAN SEDIMENTARIES AND THEIR SEDIMENTARY, BIOGENIC AND VOLCANOGENIC STRUCTURES

The Infratrappean sedimentary sequence comprise the following :

1. The calcareous sandstone and intercalated units of the Katrol formation.

2. The sandstones, shales, clays and ironstone and intercalated sequence of the Bhuj formation.

VIII.1. KATROL FORMATION:

The rocks of Katrol formation are exposed in the northwestern parts of the area, around north of Tharauda, Ratanpur, Ningal and west of Pakhera villages. The sequence comprises calcareous sandstone, shales, siltstone at the top of the sedimentary units of Katrol formation (Fig. 10) and the overlying intercalated sequence of siltstone and shales. This sequence contains rich assemblages of trace fossils with the underlying calcareous sandstone unit containing well preserved footprints and foot tracks of dinosaurs, that are described in detail in Chapter IX.

The trace fossil assemblage reveal beach barrier and shore face environmental features of the palaeo-coast.

VIII.2. BHUJ FORMATION:

It generally comprise an intercalated sequence of siltstone/shale and sandstone (Transitional sequence, Fig-9 and 10) in the basal part. The Bhuj formation comprises of alternately repeating burrowed ferruginous sandstones, ironstones, shales, clay, siltstone and friable sandstone. The shales and clay and sandstone and ironstones contain plant fossils of upper Gondwana affinity and form the basal/Lower Member of the Bhuj Formation.

The ironstones, burrowed sandstones, and siltstone sequence forms rhythmically alternating sequence which can be grouped into the cyclothems.

The lower member is overlain by an assemblage of ferruginous and glauconitic sandstone, siltstone, glauconitic sandy clays, loose sand, limestone and marl intercalations in the extreme northwest part of Kutch (Ukra) area. This assemblage contain *ammonites, belemnites, brachiopods, corals* and a variety of marine forms. This assemblage is termed as the Ukra beds.

The Ukra beds in the northwestern Kutch and the rocks of Lower Members elsewhere are overlain by dominantly fluvial sandstones, shales, siltstones, ironstones and rhythmically alternating bioturbated sequence with ironstones, carbonaceous fossiliferous shales and white felspathic sandstone and kaolinitic clay form the Upper Member (Fig-9 and 10). The

rocks of the Upper Member has yielded well preserved *dinosaurian* fossils at Fatehgarh, Pakhera and Dayapar, and the clay and sandstone contain rich assemblage of plant fossils of Upper Gondwana affinity.

VIII.3. INTERTRAPPEAN SEDIMENTARY BEDS/MESOZOICS:

At Anjar, the section comprises of Mesozoic sandstone and part of Bhuj Formation in basal part and volcanosedimentary sequence (Fig-2). The volcanosedimentary sequence comprises lava flows and the intervening Intertrappean sedimentary beds. The sedimentary beds comprise tuffaceous volcaniclastic and calcareous sandstones, brown, grey and black fossiliferous shales, marl, nodular and cherty fossiliferous limestone.

The basal Intertrappean bed comprises white, felspathic, compact and friable tuffaceous sandstones, variegated sandy clay, ash bed and bentonitic clay. Better sections are exposed in the canal cutting section in the Anjar tank (Ganga Talao) and at a place south of Shinugra.

The second Intertrappean bed comprise sandstones, gypseous clays, shales, marls, nodular and cherty limestone and black cotton soil with boulders of basalts. Thin partings of gypsum are common. The sandstone has developed concretionary nature near top part due to the calcareous nature and selective and differential weathering of quartz grains. At places the grains form clustering. The top part of sandstone has become compact due to baking effect. The sandstone contains ferruginous rounded concretions and contains burrows (*Ophiomorpha*). The sandy clay horizon, near west of Viri village contains certain rounded and conical calcareous structures with internal fibrous structures, which could be some organic structure, sideritic and calcareous concretions and petrified wood.

The black, carbonaceous lenses of shale contains invertebrate fossils mostly bivalves, gasteropods, and plant material. Yellowish marl intercalations are common with thin cherty partings. These marly intercalations contain very small black coloured (about 2 cm long) tiny fossil plant structures (moss). The sandstone unit contains *dinosaurian* bones, which are mingled with volcanic (lava) material, and sandstone shows impregnation of lava material.

The shales, banded chert and laminated and stratified sandy limestone are common in the third and fifth Intertrappean beds. Finely laminated, extremely light in weight, whitish, yellowish ash lenses and thin laminae are common in the second and third Intertrappean bed. The dinosaurian fossils from second and third Intertrappean beds have totally different look. Those from the second Intertrappean bed are dark, dirty white to greyish with highly granular and spongy appearance on weathered surface. Whereas, those from third Intertrappean bed are slightly pinkish white, highly fragile and crumple after exposure and dehydration.

The Intertrappean sequence at Anjar and at other places generally occurs in the lower part of the volcanics. The upper part of the trappean lava flows are generally composite in

nature comprising of quick alternations of porphyritic and fine grained units with very few red bole beds. The composite flow comprise more than one, at times four to five such alternations. Looking to these general characters, the volcanosedimentary sequence of Kutch was classified under the Anjar Formation with type section at Anjar and other supporting sections at different places (Fig-2).

VIII.4. INTERTRAPPEANS AROUND ANJAR:

VIII.4.1. First Intertrappean Bed:

The basal Intertrappean bed is exposed in stream/canal cutting near Anjar town water tank and also in the area south of Shinugra village. Two Intertrappean beds are exposed with intervening lava flows along the canal section. The basal Intertrappean bed is about 0.6 to 0.7 m thick and comprise slightly indurated, white, felspathic sandstone and overlies the exposed basal flow. The sandstone shows current bedding and contains pebbles of trap and sand pebbles along stratification as well as along current laminae.

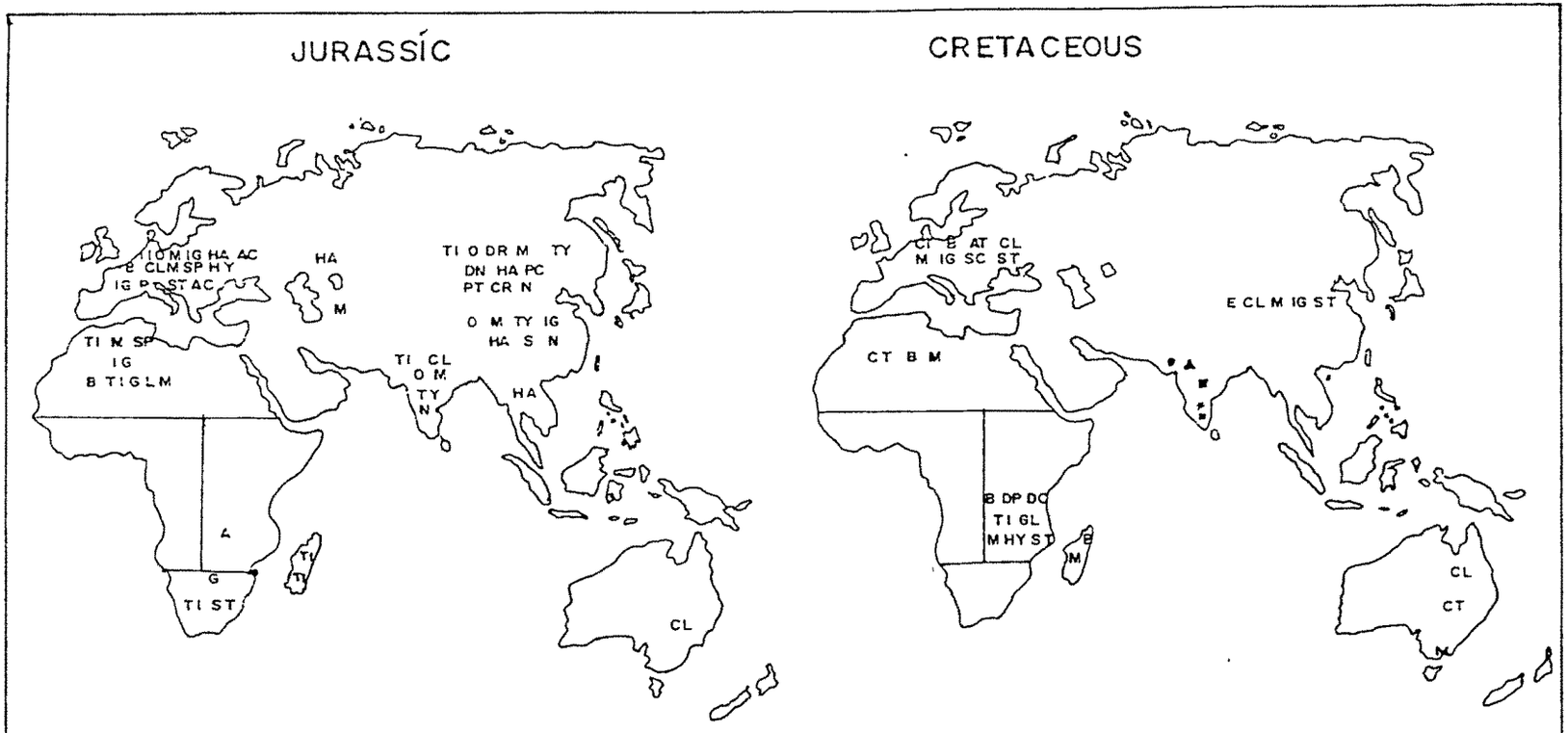
Another Intertrappean bed is exposed further upstream in the same nallah. It consists of 1.2 m thick sequence of red, yellow, and greenish, sticky sandy clay. The sandy clay contain clay gals and pebbles of white and yellow current bedded tuffaceous sandstones with volcaniclastic material. The bed is overlain by a basalt flow. It has not yielded fossils. This Intertrappean bed and lava flows were grouped together as basal flow as it was not possible to trace the lateral extension in the inhabited area and the section is seen in the canal cutting only.

VIII.4.2. Second Intertrappean Bed:

The second Intertrappean beds is exposed along the south and southwest of Viri village as a continuous east west trending outcrop along the basal part of the basaltic ridge, this Intertrappean bed is traceable for a larger distance. This Intertrappean bed consists of yellowish concretionary calcareous and tuffaceous sandstone, volcaniclastics, feldspar clasts, ash, shale and thin lenses of porcellanites and chert. This bed is fossiliferous, and has yielded petrified fossil wood, algal remains invertebrates and dinosaurian fossils. This Intertrappean bed can be approached after a cross-country distance of about 2 Km towards southwest of Viri village. Walking along strike ridge of basalt (flow 2) immediately south of Viri village may easily lead to the outcrop in absence of any land mark. This bed has aggregate thickness of about 8.0 m based on the outcrop width. Average dips and summing up of different sections with their relative positions within the same Intertrappean bed.

VIII.4.3. Third Intertrappean Bed:

The third Intertrappean bed is exposed continuously for a distance of about 3 Km at the base of a east-west trending ridge (.90 point) further west wards, it is discontinuous and patchy in nature intermittently merging with red bole bed along the strike. The main dinosaurian pit is located towards eastern end of this Intertrappean bed. This Intertrappean comprises black mud, black clay (soil) with calcareous concretions, while cherty and brown



L E G E N D

A Ankylosaur AC Acanthopholididae AD Antrodemus AN Antarctosaurus▲ AL Allosaurus●▲■
AT Atlantosauridae B Brachiosauridae▲ BA Barosaurus BP Baraposaurus■ BR Brontosaurus▲
CL Coeluridae● CR Ceratopidae▲ CT Cetiosaurinae DC Dicraeosaurinae D P Diplocinae
DN Deinocheiridae DR Dromaeosauridae E Euhelopodinae HA Hadrosauridae HY Hypsilophodontidae
I G Iguanodontidae● KT Kotosaurus KN Kentrosaurus KG Kargnasaurus L Laplatosaurus●
M Megalosauridae●▲■ MJ Manjugasaurus▲■ N Nodosauridae O Ornithomimidae▲✕■ PC Pachy-
-cephalosauridae PT Protoceratopidae PS Psittacosauridae SC Scelidosauridae ST Stegosauridae✱
S P Spinosauridae TI Titanosauridae●▲■ TY Tyrannosauridae✱

GEOGRAPHIC DISTRIBUTION OF JURASSIC & CRETACEOUS DINOSAURS OF ASIA & AFRICA

Fig. 17. Geographic distribution of Jurassic and Cretaceous dinosaur in Asia and Africa

fossiliferous shales, ash and volcaniclastics with intervening chertified fossil wood of monocot as well as invertebrates (physa, lymnea, palludina) charophytes. The white grey fossiliferous shales yielded insitu articulated dinosaurian fossils. This Intertrappean bed shows variation. The estimated thickness based on outcrop width and average dips of composite sections was about 9.0 m. Separate pitting at (.)90 point has exposed about 5.80 to 6.0 m section. Sunil Bajpai (1990) has measured 8.30 m thickness at about 250 to 300 m northwest of the main locality of dinosaurian fossils. The pit sections are not correlated on the basis of common horizon. The pit sections have indicated that this Intertrappean comprises cyclically repeating alternations of fossiliferous back clay/mud, shales, marls, and limestones. This Intertrappean beds show highly variable lithology due to facies change when traced along strike either to east or to west (fig. 17A). It contains rich assemblage of vertebrate, invertebrates and plant fossils. Recent work by other workers have revealed a number of additional floral aspects.

VIII.4.4. Fourth Intertrappean Bed:

The fourth Intertrappean bed is lensoid and discontinuous in nature. It is composed of about 1.0 m thick red bole and lensoid bodies of reddish sandy clay.

VIII.4.4.1. Red bole bed:

This red bole bed is sandwiched between fifth and sixth flow and is exposed towards south of .90 point.

VIII.4.5. Fifth Intertrappean Bed:

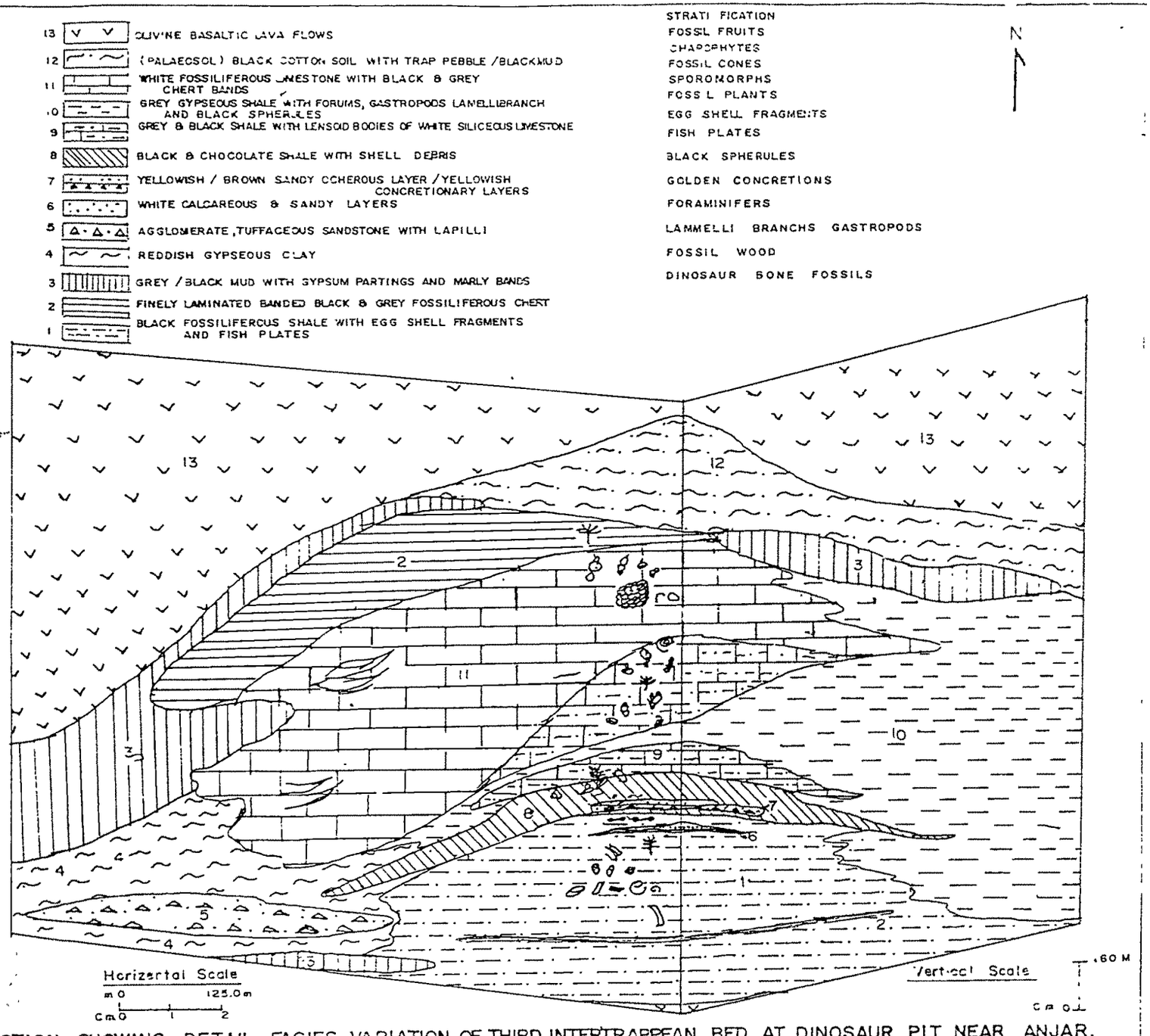
This Intertrappean bed is sandwiched between sixth and seventh flows between Devalia and Shinaya and towards north and northwest of Shinaya village. It is composed of about 1 to 1.5 cm thick section of thin microlaminated limestone, marl, thinly laminated chert, micro cross rippled laminated and stratified sandy limestone with intervening lenses of volcanoclastics. This changes to reddish sandy clay further eastwards and to friable stratified fossiliferous sandstone towards further east and northeast of Shinaya village.

The laminated and stratified limestone and sandy limestone and marl occasionally contain a few quartz and sericite, chlorite flakes arranged parallel to the layers. Siderite and limonite coated grains are also seen in the micro section. The sandy limestone and marl contains micro gastropods and other bivalves and microsections size plant material (Plate-XVII/2).

VIII.5. LAVA FLOWS:

The lava flows of the Kutch area are dealt here in a concised, comprehensive manner to incorporate petrography, petrochemistry, mode of eruption, chemical characters and signatures of different flows of different sections and are described below:

Composite sections of lava flows and the Intertrappean beds are not exposed in a single continuous stream section. Corresponding basal flows and the Intertrappean sequence



SECTION SHOWING DETAIL FACIES VARIATION OF THIRD INTERTRAPPEAN BED AT DINOSAUR PIT NEAR ANJAR.

Fig. 17A Detail facies map of third inter-trappean bed along east-

can be best seen in the cross country traverses from (1) Anjar tank to west for a distance of about 1.5 Km. The basal section is exposed in the canal cutting west of tank. This Intertrappean and the lava flows can not be differentiated and demarcated separately around tank due to thickly populated township. (2) From Shinugra Road (about 750 m south of village) to near Devalia village, where five successive lava flows and five younger corresponding Intertrappean beds are exposed. The first, second, third flows can be seen and traced about 0.5 to 2 Km east of this of traverse line and further eastwards in the strike continuity. The higher flows and the Intertrappean can be located east of Devalia and around Shinaya village. The volcano sedimentary sequence around Anjar may be about 190 m thick. The thickness of lava flows is computed on the basis of average dips and out crop width. These thickness can be verified in some stream sections near Mindiala, Shinaya and along Sang river sections. A careful observation along the above traverse lines may also help in judging the thickness of volcano sedimentaries. A composite section of volcano-sedimentary unit is given vide table III. Similar volcano sedimentary sequences are recorded west of Anjar area; the important sections which includes Khedoi, Chandia and Baladia. The individual lava flows of Anjar area show different textural and compositional characters. The chemical and normative composition also shows difference in case of individual flows.

The Intertrappean sequence at Anjar contain ash layers within first, second and third layers. The lithological criteria like black shales, feldspar clasts, iridium/osmium rich layers, oxidised organic matter, wide spread fire etc. indicate a strong possibility for K/T boundary. The magnetostratigraphic measurement also indicate NRN sequence which indicate a reversal of polarity between third and fourth lava flows at Anjar. The chronostratigraphy indicates 68.7 Ma to 61.4 Ma years for basal and youngest flows in Anjar section. Third and fourth lava flows indicate 65 and 64 respectively. Thus, the third Intertrappean with layers containing high iridium - 1.5 ng/g - which is about 20 times more than back ground values, appear to be the most possible candidate for K/T boundary.

Ref.

VIII.6. DAYAPAR AREA:

In the Dayapar area, the sequence is similar to that in Anjar. The exposed section comprises basal Mesozoic sequence. The volcanosedimentaries can be recorded in the form of lava flows and the interstratified sedimentary beds.

VIII.6.1. Mesozoic:

Basal Mesozoic comprises alternating sequence of green glauconitic sandstones, shales and sandy clays. The basal part of Dayapar section comprises black carbonaceous fossiliferous shales, feldspathic sandstones with ferruginous and marly intercalations. The sandstone at times is highly burrowed, structures being filled with yellowish ferruginous matter. Burrow structures are mainly vertical, at times inclined forming post depositional burrows. At times yellowish and marly thick bend are seen along the bedding surfaces in the above sequence. At times, the sequence in the basal part show irregular deposition on palaeoslopes indicating trend of the underlying Mesozoic sequence. Upper part of the

Ref.

Mesozoic (Bhuj Formation) is overlapped by various younger units revealing brief events of erosion and redeposition as channel fillings. The basal part of Mesozoic shows increasing proportion of black carbonaceous shale intercalations as compared to the intertrappeans.

VIII.6.2. Volcanosedimentary Sequence at Dayapar:

The volcanosedimentary sequence at Dayapar comprises five lava flows and the intervening four Intertrappean beds.

VIII.6.2.1. Intertrappean Beds:

The Dayapar section exposes (Fig-2) Intertrappean beds comprising greenish, glauconitic, sandy and sticky clays, sandstones, fossiliferous shales, marl, limestone, siltstone and red bole. The complete section of Intertrappean beds and lava flows can be seen in a general cross country traverse from northwest of Dayapar to south towards Biliari to Julrai and Daulatpar to Shamjiwaro in the south. The first Intertrappean comprises of sandy clays with invertebrate fossils. The second Intertrappean bed comprises sequence of glauconitic sandy and sticky clays with marly intercalations. The fossiliferous limestone, marl and tuffaceous sandstone and the shales dominate in the basal part. This is overlain by purple, grey and reddish sandy burrowed clays. The reddish and the purple sandy clays with marly bands contain dinosaurian and other reptile bone fossils and other invertebrate fossils, some of which include *Physa, Palludina* and some ostracodes. Vertebrates include dinosaurian limb bones, chelonia and skeletal parts of other lizards. Plant fossils includes algal remains, charophytes, fossil wood and some dicot and monocot leaf impressions. The third Intertrappean bed consist of a sequence of sandy clays, sand and sandstones which grades to red bole beds. Fourth Intertrappean comprises a sequence of loose, friable sandstones, sands, grey and green clays, shales and green ochreous bands. They contain various invertebrate fossils. Red bed comprise of thin ochreous bands and red clays. The Intertrappean bed at Dayapar and Ashaladi contain ash nodules and thin layer of marly intercalations.

VIII.6.2.2. Lava Flows:

At Dayapar five flows with intervening Intertrappean beds are recorded. The flows are demarcated on the basis of physical, mineralogical criteria, presence/absence of pipe amygdals, vesicular zones, geodes and Intertrappean red bole beds. The volcanosedimentary sequence of Dayapar, Daulatpar and Matanomadh are traceable over a considerable distance along the strike.

Of the volcanosedimentary section at Dayapar, the basal part of the section is fossiliferous and comparable to the Anjar section so far as the lithological composition and fossil content of the volcanosedimentary units are concerned. The fossil content of the basal three Intertrappean comprise charophyte, ostracodes, gasteropods and lamellibranchs, and dinosaurian chilonia. The basal part of the section may possibly contain a K/T section, hence the sampling of the basal section was done for various purposes.

The magnetostratigraphic studies of the section was carried out with the help of fluxgate field magnetometer. The Dayapar section shows NRN sequence (Fig-32). Chronostratigraphic measurements are not carried out.

VIII.7. MATANOMADH SECTION:

At Matanomadh area, the sequence of seven lava flows with five Intertrappean beds and a red bole bed with intervening lava flows are exposed. Volcanosedimentary units have deposition similar to the Mesozoic sedimentary beds in the basal part of the sequence. This sequence can be continuously demarcated in the area between Dayapar to Matanomadh, Ghuneri, and Haripar areas.

VIII.7.1. Intertrappean Beds:

The Intertrappean comprise red and greenish sandy clays, bentonitic and sub-bentonitic clays with white calcareous nodules, gypseous veins and fossils (mainly shell and casts of ostracodes, lamellibranchs) and thin beds of sandstones, black carbonaceous and fossiliferous shale and basal trap pebble conglomerate.

The first Intertrappean bed comprises about 2 m thick sequence of sandstone, clays and fossiliferous carbonaceous shales. The carbonaceous shale contains impressions of dicot leaves and assemblage of invertebrate and fossil wood. This bed is sandwiched between lava flows F1 (about 15 m thick) and flow F2 (25 m thick). The second Intertrappean bed is about 6.5 m thick and comprise an alternating sequence of reddish friable and ferruginous volcaniclastic burrowed sandstone, green glauconitic clays with white kaolinitic and ash nodules. The burrowed sandstone and clays contains rhizomes and fragments of petrified wood. This unit forms a gentle break in slope on the steep faces of hillocks and is traceable in the area between Matanomadh, Ghadani, Haripar and Ravapar. The second Intertrappean bed is sandwiched between flow F2 at base and flow F3 (15 m thick) at the top. The third Intertrappean bed is 4.0 m thick and consists of a sequence of variegated friable sandy and glauconitic clays, sticky and sub-bentonitic clays and loose sands. This Intertrappean is sandwiched between flow F3 and flow F4 (35 m). The red bole comprises ochreous layer and red kankery nodules (about 0.3 m to 0.5 m thickness). The first three Intertrappean beds are promising for the study of the possible K/T transition in this area.

The basal Intertrappeans and the lava flows are about 60 m thick near northwest of Matanomadh village and become thicker towards east and northwards (Fig-3). Near Ghadani Walka-Haripar area and east of Matanomadh, it shows a sequence of five Intertrappean beds and red bole and seven flows with a thickness of about 190 m.

VIII.7.2. Lava Flows:

In the Matanomadh area, there are seven flows of variable thickness. The lava flows are olivine bearing basaltic to doleritic in composition. The lava flows were recognised on the basis of various criteria like amygdal and vesicular top surface, presence of pipe amygdals and Intertrappean sedimentary beds, bentonitised, weathered and zeolitised

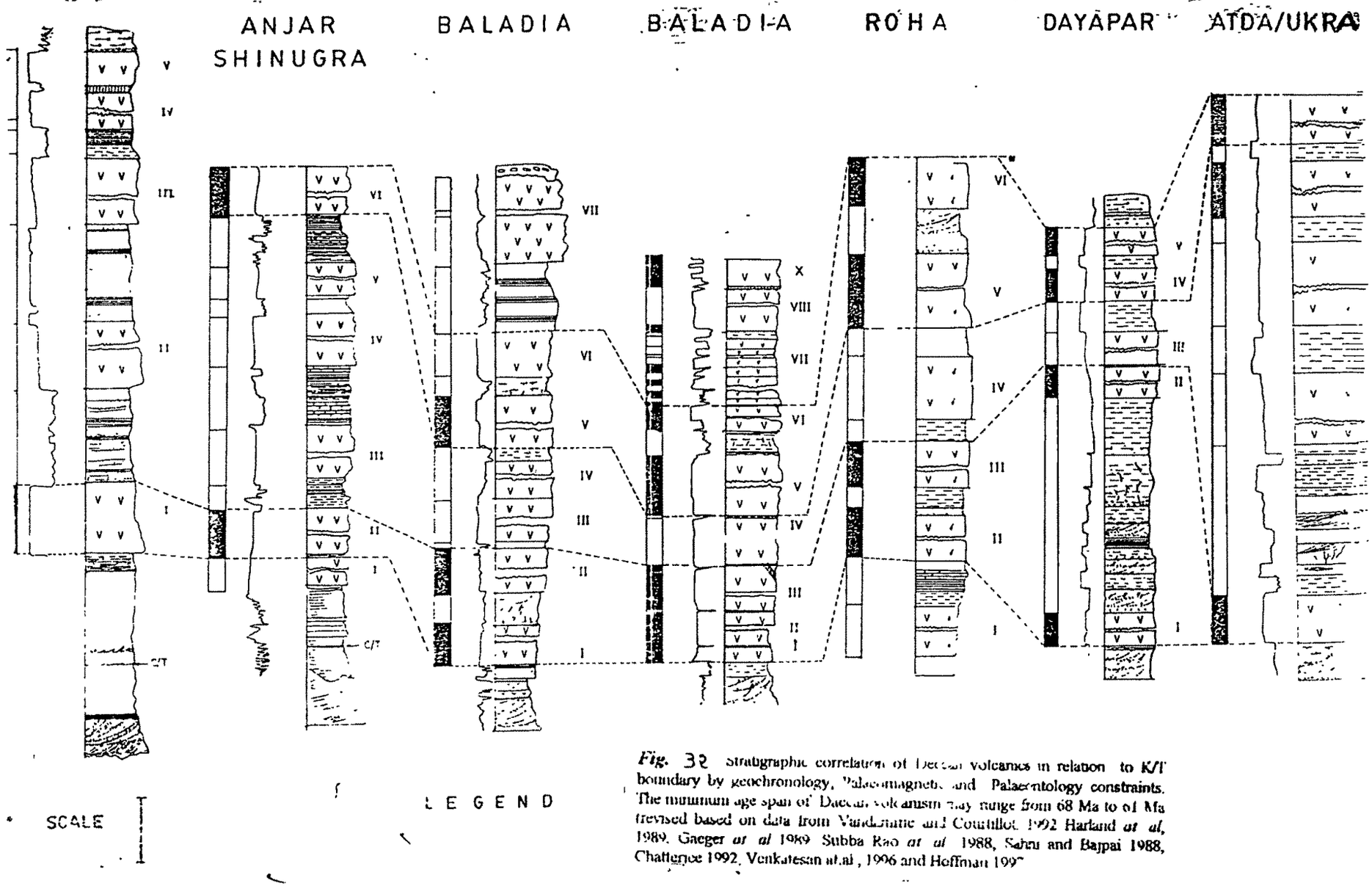


Fig. 32 Stratigraphic correlation of Deccan volcanics in relation to K/T boundary by geochronology, Palaeomagnetism and Palaeontology constraints. The minimum age span of Deccan volcanism may range from 68 Ma to 61 Ma (revised based on data from Vandamme and Courtillot 1992 Harland *et al*, 1989, Gaeger *et al* 1989 Subba Rao *et al* 1988, Sahni and Bajpai 1988, Chatterjee 1992, Venkatesan et.al , 1996 and Hoffman 1997

surfaces, red bole beds etc., which at times on weathering develops covering cavernous appearance, on which the Intertrappean sedimentary beds are seen. Pillow lava structure is also seen at two places in nallah cuttings near Bhima talav.

VIII.8. UKRA:

In the Ukra area, the felspathic sandstone member of Bhuj Formation is overlain by interstratified volcanosedimentary Formation comprising lava flows and the Intertrappean beds. The Intertrappean volcanoclastics comprise a sequence of felspathic and yellow coarse, gritty current bedded sandstone, trap pebble conglomerate containing shells of lamellibranchs. Three Intertrappean beds along with three lava flows are recognised in the Ukra-Atda area.

VIII.8.1. Intertrappean Beds:

The Intertrappean beds are exposed in the Ukra hill and the hills located towards south of it. The first two Intertrappean beds are composed of trap pebble conglomerates, white volcaniclastic sandstone, loose sand and clays. The first Intertrappean is about 2.0 m thick and comprises trap pebble conglomerate, loose sand, red and glauconitic clays. The trap conglomerate contains pebbles of vesicular and amygdaloidal basalts of varied composition, shape, size and nature. These pebbles include porphyritic, glomeroporphyritic, tectilitic basalts with sub-rounded, oval and oblong shapes. Some of them show flow structure and consist of plagioclase felspar, augite, magnetite and volcanic glass as main constituents. Other pebbles include ferruginous and friable sandstones, ochreous shale. Trap pebbles are chief constituents forming more than 95% of the clasts. Matrix is mainly gritty, sub-angular to angular quartz and clay. The basal Intertrappean is 2.0 m thick, whereas, the upper one (second Int.) is about 6.5 m thick, with basal trap pebble conglomerate bed with intervening basaltic flow. The second Intertrappean bed contains sandy clay and red clay towards top. The third Intertrappean is about 1 to 1.5 m thick and comprises greenish white sand, sandstone and calcareous sandy nodules and sandy clays. This is overlain by a coarse, porphyritic, basaltic flow about 7.0 m in thickness. Similar set up of Intertrappean and volcanics is also found in the Pranpar-Umarsar area.

VIII.9. MATANOMADH FORMATION (SUPRATRAPPEAN ROCKS):

The Supratrappean rocks unconformably overlies the volcanic rocks in all the areas. In Anjar area, they are exposed as narrow, linear out crop trending NW-SE and NE-SW directions in eastern and northwestern parts of area. The constituent rocks are purple and violet coloured altered ash, saprolite, kaolinite, bentonite, laterite and at times bauxite with variable thickness.

VIII.10. ANTARJAL FORMATION:

The Supratrappean rocks of Matanomadh Formation are unconformably overlain by rocks of Pliocene age. These rocks at times, show overlapping relationship with the lava flows in the southern and eastern parts of the area. The rocks comprise basal lateritised

kankers and conglomerates, calcareous fossiliferous sandstone, siltstone and clays. The siltstone and sandstone contain clay gals and larger fossil invertebrates, vertebrate bones and petrified fossil wood logs. The mottled clay and sandstone contain avian egg shells at many localities. The aggregate thickness of the section in a nallah near southeast of Antarjal near Adipur town shows about 40 m of thickness. Based on the location of the section near Antarjal, the name 'Antarjal Formation' is proposed for this sequence.

VIII.11. MILIOLITIC LIMESTONE:

Miliolitic limestone occur as small isolated blanket over Mesozoics, lava flows and the younger rocks. The Miliolitic limestone comprise of basal trap pebble, polymictic bouldery conglomerate, loose sand, friable sandy limestone, silty clays. The limestone and silt/sand show current bedded nature and stratification. The stratification and palaeocurrent laminae are parallel to sub-parallel to the palaeoslopes of the underlying rocks. Miliolite is found on the higher reaches of the nallahs and rivers.

VIII.12. SEDIMENTARY, BIOGENIC AND VOLCANOGENIC STRUCTURES:

The volcanosedimentary sequence in the Anjar, Dayapar and Ukra area show various primary and tectonically generated structures. The primary structures include various sedimentary structures, volcanogenic and volcanosedimentary structures, biogenic structures, which include several important structures, grouped under various categories.

The secondary structures include the tectonically induced structures like the folds, faults and other deformation generated structures. A brief account of various structures is given below:-

VIII.12.1. Sedimentary Structures:

VIII.12.1.1. Bedding:

The bedding surface is regular (in thinly bedded shale, siltstone and sandstones), in rocks of upper part of Bhuj Formation as well as in the Intertrappean sediments (Plate-X/ 1, 2). The limestone and marl show thinly bedded nature in third Intertrappean bed (Plate-VI, VII, VIII, IX, X, 1 and 3). At times, the stratification is seen in the limestone.

VIII.12.1.2. Current Bedding and Climbing Ripple Lamination:

The sandstone of Upper Member of Bhuj Formation, and the sandstone units of the second Intertrappean bed trap pebble conglomerate, and the lensoid sandy Ukra limestone units of the upper part of the third Intertrappean bed show current bedded nature. Climbing ripple laminations are common in the sandstone, trap pebble conglomerate and limestone. The trap pebble conglomerate of first and second Intertrappean beds in the Ukra hills show exceptionally large (more than 1.5 m long) current laminae with regular arrangements of graded trap pebbles along the laminae.

VIII.12.1.3. Lamination:

The grey and black shales, chert, ash, siltstone, limestone and porcellanite ash and mud show extremely thin, finely laminated nature. The ash, limestone, shale and chert show cylindrically repeating grey, white, pink, to brown bands, in which the set of darker coloured laminae alternately repeat with lighter colour laminated bands. Each colour band comprise 5 to 7 laminations in basal part, 10 to 17 laminations in the middle part and 18 to 53 microlaminations in cycle in the upper part of the ash bed (average thickness of the laminae is more in the basal part of the ash sequence, where as the laminations are comparatively thinner in the upper part of the sequence). The colour variations in the laminated units are more in the basal part. The variation comprising of white, yellow, brown, chocolate coloured in the basal part, chocolate and dull white coloured in the middle part, and greenish to whitish in the upper part. Each cycle of laminae start with a darker colour at base and successively become lighter in colour at top. The next laminae comprises either whitish brown to yellowish red in the basal part. Such brown and whitish to yellowish red laminae show cyclically repeating alternations. The laminated ash bed near Shinugra village shows a typical cyclothem sequence of 2.5 m thick ash bed (Fig-3) with rhythmic alternations. The ash bed comprises tuff and altered volcanic clasts, felspars, altered pill's hairs and ash globules (Plate-XVI/1).

The laminated ash comprises of cyclic alternations of purple coloured laminated ash, yellowish tuff, red layers, calcareous bands and gypseous partings. The basal layer contains spherules and white felspar clasts.

VIII.12.1.4. Wavy Bedding:

The third and fifth Intertrappean beds of Anjar section show wavy and lenticular (flaser) bedding in the siltstone/shale intercalations and in the marl, gypsum and mudstone intercalated sequence (Plate-VI, VII, VIII, IX, X).

VIII.12.1.5. Channel Structures and Microfans:

The channel structures of small dimensions, are seen within the shale/mudstone sequence. The individual channel width varies from 0.50 m to about 1.0 m and channel depth is about 0.5 to 0.80 m. The microfans comprising of siltstone/mud and brown shales are seen in the third Intertrappean as well as in the fifth Intertrappean bed in Anjar section and in the Dayapar, Ukra and Matanomadh sections. Besides this load casts and polygonal cracks/mud cracks and desiccation cracks (sun cracks), rain drops impressions are recorded in Anjar, Dayapar and Bhachau areas.

VIII.12.1.6. Graded Bedding:

The sandstone units of the Upper Member of Bhuj Formation and the Trap pebble conglomerate units of the Intertrappean beds near Ukra hills and Atda, show graded bedded nature. The Trap pebbles in the conglomerate are sorted according to size. Comparatively larger boulders and cobbles are found in the basal part. Pebbles and smaller fractions are

seen in the upper part of the graded unit. There are four to five such repetitions with conglomerate and finally it is overlain by sandy clay, and siltstone. The sandstone of Bhuj Formation and intertrappeans at Dayapar and Matanomadh also show such a graded bedded nature.

VIII.12.2. Volcanogenic and Volcanic structures:

Various volcanogenic and volcanic structures observed in the area are grouped under:

Pillow lava, Ropy lava, Climbing ripple laminations, Flow Fronts, Lava conduits, flow stratification, flow breccia, stretched amygdules, pipe amygdules, pyroclastic surge cones, volcanic cones, Feeder fissures, Flow channels, Ring dykes, and columnar joints.

VIII.12.2.1. Pillow lava:

The pillow lava structure is observed in the Anjar and in the Matanomadh area. The pillow lava structure comprises oblong to oval shapes to kidney shaped structures with convex side upwards and concave side at base and staked in the horizontal row of two to three at the base of fourth Intertrappean in Anjar in a road cutting about 3 km south of Viri village on Viri-Devalia road. The pillows measure about 60-80 cm long and 20 cm, in diameter and taper at either ends with a tendency to assume cylindrical shape due to load of the overlying basalt. In another section in the Chandroda river cutting south of the bridge the pillow lava structure is exposed in the river bed and on the western bank.

In the Matanomadh section, the pillow lava structure is observed in the basal part of the basaltic flow, F4 near south of bridge near on the eastern bank of the river.

VIII.12.2.2. Ropy lava structures/Climbing ripple lamination:

The ropy lava structure is observed at many places in the Anjar area. Better sections of structures are exposed near 1.5 km southeast of Bhuvad and near Makhian villages. The lava assumes twisted cord like form and shows microripple laminations on the twisted surface.

VIII.12.2.3. Flow Fronts:

Lava flow fronts are exposed in a section along the Chandroda river, south of the bridge and at a locality towards southeast at a distance of 1.5 km of Bhuvad. The flow fronts are normal and show gentle rolls. In the Chandra river section, the flow fronts show steeper to sub-vertical slope and form troughs and multiple channels, due to preexisting lava topography and palaeolava slope.

VIII.12.2.4. Flow Conduits:

Flow conduits/tunnels are exposed in Chandroda river section towards eastern bank. The lava tunnel is about 20 cm in diameter and has developed aureole of about 45 cm diameter with successive lighter coloured rims surrounding the conduit due to the heat of the flowage of hot lava material.

VIII.12.2.5. Flow Stratification/Surge Deposits and Breccia:

The pyroclastic flows and surge cone deposits (Plate-XIII/1) breccia flows and porphyritic olivine bearing basaltic flow (F2) in Anjar area show flow stratification. The flow stratification in the surge pyroclastics and the breccia flow is seen due to the sorting and stratification of fragments parallel to flow bedding (Plate-XIII/3). In case of a porphyritic flow in Anjar area, the crystal settling in alternate layering of feldspars and mafics has generated the flow stratification.

VIII.12.2.6. Pipe amygdules, stretched amygdules:

Pipe amygdules are developed at the inter flow contacts and are at times about 25 m long and show slight bending in the direction of lava flowage. At times the amygdules are stretched in the direction of flow migration in the flow fronts. Lava blisters, lava bulbs are common in the composite flows which form the upper part of the Deccan trap sequence of Kutch.

VIII.12.2.7. Pyroclastic surge cones/Volcanic cones:

The pyroclastic surge cones are seen as accretions / slope deposits surrounding the cones and fissures forming accumulations of bombs, lapilli and pyroclastic in the Anjar area and in the Baladia, Matanomadh areas. These deposits at times form huge accumulations along the slopes. Pyroclastics and flow breccia are associated with the fissures in the Anjar area forming continuous structure for a distance over entire strike length.

Small volcanic cones are seen associated with the feeder dykes and fissures and these volcanoes form a continuous chain structure over entire strike length. These volcanics tap the feeders from shallow depth and formed source of lava for the overlying flows.

VIII.12.2.8. Feeder dykes/Feeder fissures:

The feeder fissures and feeder dykes occur as sets of parallel east-west trending dykes forming zones with en-echelon patterns in the area between Anjar and Punadi. The main feeder dyke trends parallel to the third flow between Anjar and Kera. It forms a composite multiple dyke and is associated with a chain of small volcanic cones and numerous dyke-lets of various shapes which cut across the flow breccia and pyroclastics and merge with the higher flows. The multiple dyke is associated with the pyroclastics and flow breccia along the southern margin (Fig.1a).

Certain dykes merging from the volcanic cones trend in NE-SW/NW-SE and feed three basal flows in the area east of Baladia (Fig-4A).

VIII.12.2.9. Flow Channels:

The flow channels and multiple channel shift structures are recorded in the area south of Chandroda and southeast of Kera. The lava channels are recorded over eroded surface of the earlier formed flows. The channel depth varies from few cm to about 1.5 m, and

channel width varies from 1 m to about 2 m. Migrating channels are commonly associated with the cones/fissure and spread in the down slope of the palaeo-surface provided by earlier rocks.

VIII.12.2.10. Ring Dykes:

Ring dykes are commonly associated with the volcanic cones in the area east of Makhian and near Mathado villages. The ring dyke is corded in form of a narrow, quaquaversally outward (25°-30°) structure within the younger flows. One such prominent structure was recorded near Makhian villages. It measures about 1.0 km in width and 500-700 m in shorter axis. The dyke shows a burning effect on either margin on the country rock (Fig.4 A).

Numerous such dykes in the east of Makhian and Bhuvad are found.

VIII.12.2.11. Columnar Joints:

The basaltic/gabbroic dykes wherever they intruded the Bhuj Formation, it has developed the columnar joints within the sandstone. The basaltic magmatic material permeated within microsection and the reaction of basaltic magmatic matters with the sandstone has caused baking effect due to which the columnar joint structure is developed.

VIII.12.3. Biogenic Structures:

The biogenic structures include burrows and invertebrate tracks/trails. Vertebrate traces and tracks. The vertebrate tracks include dinosaurian foot prints and foot tracks, which are separately described under the fossils of different types in this thesis. The sandstone members of the second, third and fifth Intertrappean bed are at times highly burrowed. The ferruginous sandstone of Bhuj Formation is highly burrowed and forms important marker zones. The burrows and worm structures include syndepositional, post depositional and pre-lithification.

VIII.13. DEFORMATIONAL STRUCTURES:

The Mesozoic and volcanic sedimentary sequence show deformational structures. These structures include folds, faults, feeder dykes and dykes.

VIII.13.1. Folds and Domes:

The Mesozoic rocks form ENE-WSW to East-West trending domal anticlinal and synformal structures in the area north of Chandia, Tharauda, Mathada, east of Khedoi near Shinugra and Anjar areas. The rocks of Katrol Formation are exposed at the centre of the dome in the area north of and near Tharauda. The rocks show quaquaversal dips 10° - 12° near Tharauda, and near Anjar town (10°-25°) due south, west and steeper due north (at 25°). Near Saindpura-Ratnal area the Deccan lava flows and the overlying Tertiary rocks form a northeasterly gently plunging syncline. The Deccan trap lava flows are forming local domal structures at a locality near northwest of Fatehpur, where the plug like body form a dome with a quaquaveral dips of 10°. Another such asymmetrical domal anticlinal

structure is seen near Mathada village. The Mesozoic (sandstone of Bhuj Formation) sandstones and Deccan lava flows are involved in domal anticlinal structure.

The southern and the southwestern limb show dips of about 15°, where as the northeastern limb show dips of about 5° (Fig. 4A).

The lava flows and the Mesozoic sandstone inliers show a gentle sharp southeasterly plunging anticlinal structure towards six km south of Anjar and north of Shinaya village. The corresponding complementary faulted partly preserved synclinal structure is exposed near south of Anjar town. The structure is sharp and is faulted on the eastern limb. The supratrappean (Matanomadh) and rocks of Antarjal formations.

A small narrow plunging anticlinal domal structure is seen exposed near Anjar town in the Ganga Talav and canal cutting. The structure is about 2 km long and 700 m wide at the eastern end. The lava flows and the sandstone inlier are involved in the folding. The basal flows show dips of about 10° due south on the southern limb, whereas the northern limb show dips of about 25° - 30° due north. The Mesozoic and the lava flows form numerous small (localised) domes and plug like bodies.

Numerous such small plugs and ring dyke complexes are recorded between Mathala, Makhian villages and towards southeast Chandia villages. Such structures are located in the vicinity of faults or feeder dykes. The plugs are surrounded by thin, sub-vertical, circular, basic and gabbroic dykes which also show quaquaversal dips, between Makhian, Bhuvad and Chandroda villages. The rocks of Bhuj Formation show small domal circular to oblong structural pattern towards south in the vicinity of Katrol faults. Such chain of domal structures of sandstone, shale, siltstone sequence of Katrol Formation are seen near southwest, southeast of Saiyadpura, north and northeast of Pakhera near Chubdak villages.

The eastern limb of easterly plunge main domal anticlinal structure near 2.0 km north of Anjar town is faulted at the apical core and at the southern limb. The Katrol formation rocks near Ningal form the core of the anticline. The northern limb of this plunging anticline is faulted omitted between Saiyadpura and north of Chubdak villages. The northern limb is steeper and dips at 35°-60° due north.

Similarly in the Dayapar, Ukra-Atda area also the domal anticlines, synclines, faults are existing (Fig-7).

VIII.14. FEEDER AND INTRUSIVE DYKES:

VIII.14.1. Intrusives:

The Mesozoic rocks are intruded by basic dykes of doleritic, basaltic and gabbroic compositions. These dykes have two prominent trends as north-south and northwest-southeast. The northwest-southeast trend appears to be the older as the north-south set of dykes cut across them. Certain north-south trending dykes cut the sandstone (Upper Member of Bhuj Formation) as well as the lava flows also as in case of one dyke near

Chandia. Such dykes feed the basal flows at several places. At times, these dykes emerge from plugs located within the older sediments and they cut across basal flows and merge with basaltic lava flows indicating them to be the feeder dykes for the basal group of flows. At times such dykes, induce thermal effect on the friable sandstone of Bhuj Formation and develop columnar joints in the sandstone, in the immediate contact some of the dyke due to the diffusion of magmatic material in the intergranular space of the host rocks.

A subsidiary younger set of northeast-southwesterly trending dykes cut across both earlier sets and appear to be youngest in the sequence. Such intrusive dykes continue for a maximum distance of 7 to 10 km and show a maximum width of about 3 m. The feldspars and magmatic material in the dykes show reaction with the quartz of host rocks and form reaction rims.

VIII.14.2. <u>Feeder Dykes</u>:

The multiple sub-vertical to vertical dykes associated with the pyroclastics and breccia flows and a chain of volcanic cones all along the strike of the dykes form a system of feeder dykes. They are recorded in the areas south of Anjar, Viri, Shinugra, Khedoi, Chandia, Jambudi, Baladia and Kera. The oldest set of the feeder fissures are exposed in the basal, peripheral area of the basaltic flows. These are described elsewhere.

A parallel to sub-parallel system of such en echelon dykes, are recorded in the southern and parts of areas between Mindiala, Anjar, Chandroda Bhaleti, Khedoi, Facharia, Mathada, Chandia, and further west. These dykes are also associated with the pyroclastics, breccia and chain of small cones, from which the dyke-lets emerge and feed/merge with the higher flows (detail description is given elsewhere).

They should have been described in more detail II.
