Chapter - 5

CHAPTER - V

THE AREA OF INVESTIGATION

As indicated earlier, the main area of study includes parts of Topographical maps 41I/4, and 41E/16 at Anjar falling between latitude N23°0' to 23°10' and East longitude 69°45' to 70°5' (Fig. 4). At Bhachau the area is restricted to a small part towards southeast, south and west of Bhachau. The area around Kera was covered for establishing the stratigraphical succession. The stretch from Matanomadh to Dayapar was covered partly in 41A/14 to establish stratigraphy and study of rock records. Detail work was also carried at Dayapar for study of the rock record and fossil contents and collection of multivariate data. The Ukra-Atda section believed to represent intrusive / feeder dyke (Biswas, 1971, 1974) was also studied in detail. This section shows repeated occurrence of trap pebble conglomerate horizons and other constituents as interstratified sedimentaries. All these detail studies were carried out on 1:50,000 topographical maps of Survey of India.

V.1. PHYSIOGRAPHY:

The Anjar and Dayapar sections being most potential for the K/T boundary, in depth studies were carried out by the author at these localities. These locations contain geological succession comprising upper most Mesozoic rocks (Katrol, Bhuj), Deccan lava flows and associated sedimentary intertrappean beds and are overlain by the supratrappeans and Tertiary rocks. Following physiographic divisions are recognised in these localities.

1. The northern high hills south of Katrol fault running in east-west direction.
2. Southernly gentle sloping plains of Mesozoic sediments in the western margin of the Anjar area. These southernly sloping plains of western margin are showing a gentler northernly slope north of Anjar town (41E/4 toposheet).
3. A series of parallel east-west striking low ridges, knolls and occasionally high hill of Deccan trap with intervening gentler southernly sloping grounds and plains.
4. A flat to gentler ground occupied by the Tertiary and Quaternary rocks.

V.1.1. The northern moderately high hills of Mesozoics:

The northen area in central Kutch is occupied by a east-west running strike ridge of moderate height, located towards south of Katrol fault. Mesozoic rocks, comprise rocks of Katrol and Bhuj Formations. Khatrod, Jandia and (.) 271 hill form the important hillocks in the area. Tharauda, Ratanpur, Pakhera, Ningal and Chubdak villages are located in these hillocks. The Kharod range forms water divide. The average elevation of this area is 120 m. The physiographic features in this belt are controlled by the lithology and structural features. Streams towards north of this divide flow towards north, ultimately draining to the Banni marshy land, and streams to the south of the divide zone flow towards south and ultimately drain to the Gulf of Kutch and the Arabian Sea. Prominant streams include Lerakh, Bhukhi, Sarkan, Sang.

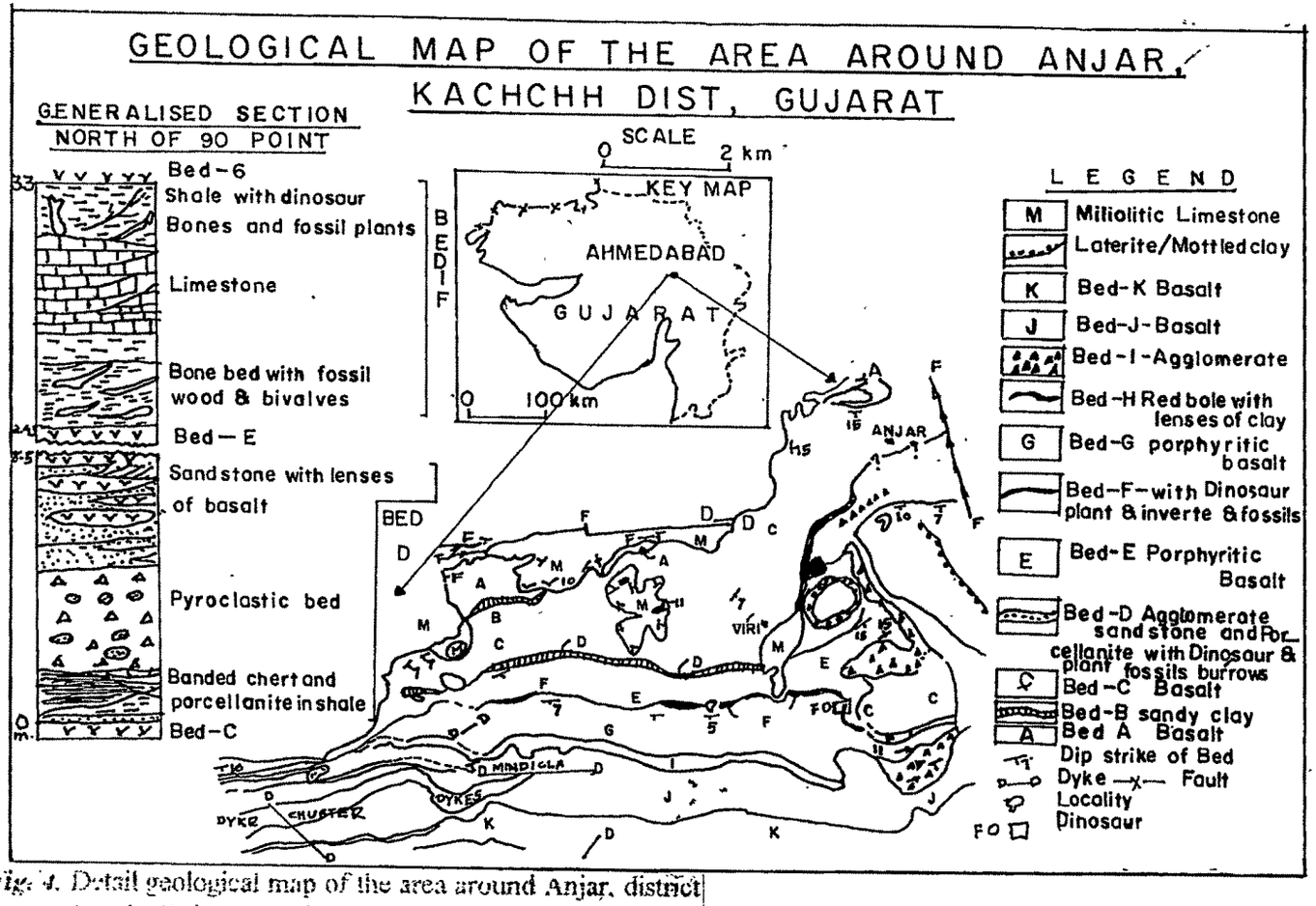

Fig. 4. Detail geological map of the area around Anjar, district Kutch, Gujarat

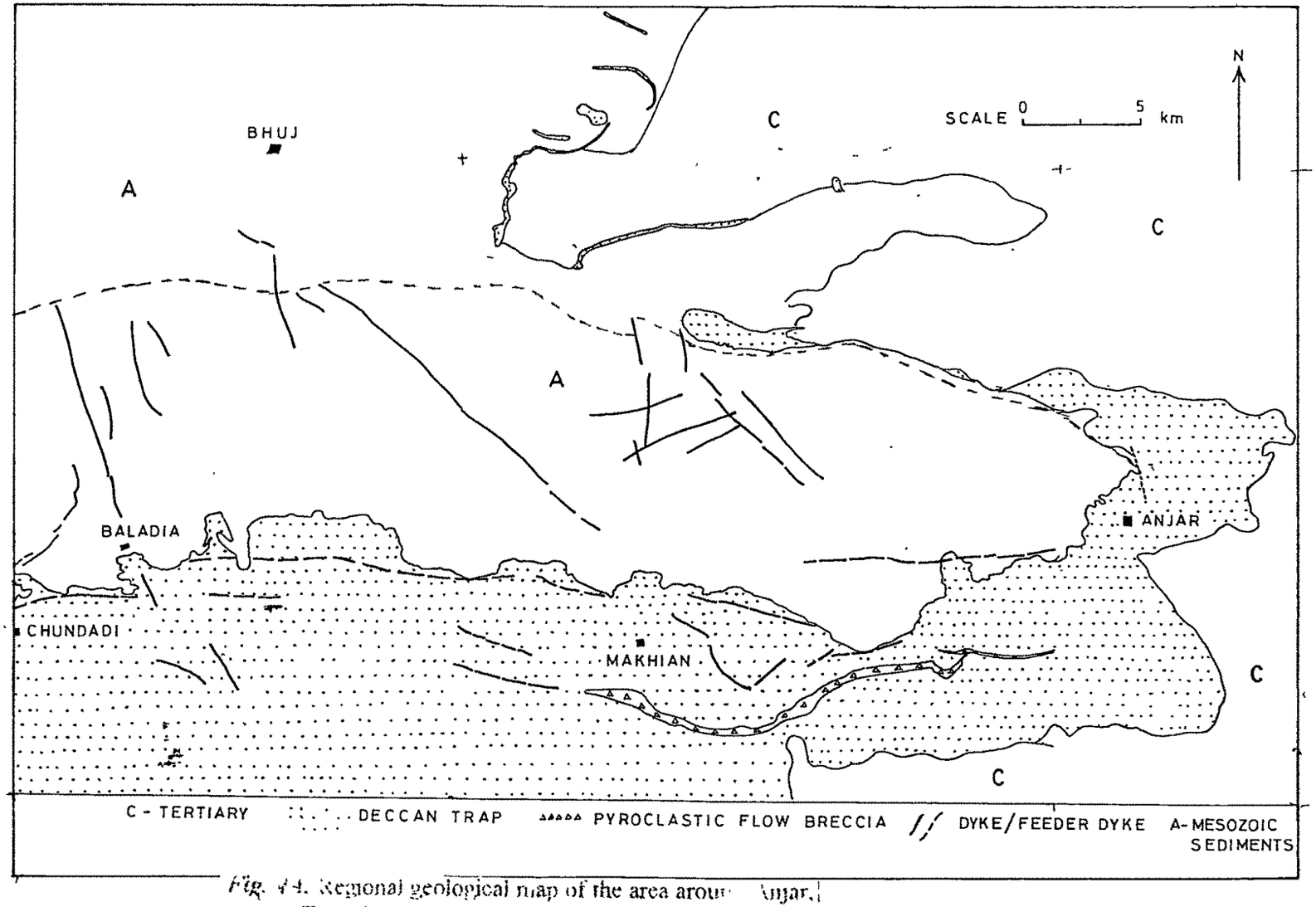

Fig. 44. Regional geological map of the area around Anjar, Toposheet 41E/16 and 41I/4.

V.1.2. Southerly sloping plains:

The southern part of the Mesozoic hills form a gently sloping plain country occupied by the rocks of Bhuj Formation and form sandy plains which are extensively cultivated. The important villages are Chandia, Loharia, Pantia, Wadva, Shinugra, Nangalpar, Dhabda, Kheda Mota and Kheda Nana, and Anjar, Khamra. The southerly slopping plain have one concave depression on the northeastern part of the area between Shinugra, Khamra, Khadri and Pantia villages. The general slope of these plains is towards east-southeast and northerly in the area north of Anjar, and finally to east towards northeast of Anjar town.

V.1.3. A series of east-west striking low ridges:

The area further south of (2) above is occupied by a series of east-west running parallel to subparallel low ridges and high grounds forming a broad tract with a general east-west trend. This tract is occupied by a series of moderately low strike ridges of Deccan lava flows, intertrappean sedimentaries, located at the foot zone (the basal gentler northernly slopping base of these low ridges), and few patches of the Cretaceous sandstone. The southern side of each ridge, forms a gentle flat ground with a gradient in the southern direction. The basal narrow fringe zone towards north of the hillocks show a northern slope till central inter ridge depression running either in the eastern or western direction is formed. These areas form cultivated areas in the Anjar, Shinaya, Devaliya, Kheda, Bhuvad, Wagura, Makhian, Mathada areas. At many places the break in slopes are occupied by intertrappean beds.

V.1.4. Flat gentle south and southeasternly sloping grounds:

The southern flank of the Deccan Trap hills and ridges form a south to southeasterly slopping ground, which is occupied by Laterite and other Tertiary rocks in the Shinaya, Devalia, Kumbhariya, Bhuvad, Fachariya area.

V.2. DRAINAGE:

The Letakh, Bhubhi, Sarkari and Sang form important streams in the area. The drainage is dendritic in the initial stages and become rectangular when two streams join. The drainage pattern of the area is controlled by structure and lithology. In the Deccan trap country, the drainage shows radial characters in certain cases, in Mathada-Makhian area, especially surrounding the moderate to high conical or circular bodies. At many places in the porous sandy country, the stream courses are lost and not traceable. The area to north and west of Anjar around Nagalpar, Nagal, Khamva, Pantia and Chandia, many streams coming out of the hilly tract and southern slopes of Mesozoic hills, loose their courses and are not traceable. Certain streams have meandering course when they pass through the shaly country.

The streams passing through the Mesozoic country have influent courses, while the streams show effluent courses in few instances, on cutting through the trappean country. The drainage and distribution of lithology has important effect on the water supply of the

area. The villages located in the Mesozoic (Katrol) rocks face some difficulty of drinking water since the ground water is saline and unpottable. The sandy plain and trough occupied by the Cretaceous rocks has perrenial source of underground water with potential aquifers. The gently sloping ground between moderate hills and low hills / ridges of Deccan Traps forms a potential, perrenial source of water in the study area and elsewhere in western parts around Kera, Matanomadh, Dayapar and Ukra areas. At Bhachau the sandy tract between trap hillocks and Tertiary / Quaternary plains, the water level shows variable depth, the average being around 30-35 m in the area covered by the Cretaceous (Bhuj Formation). The area covered by the Deccan lava flows also faces acute shortage of drinking water, and in almost all villages, the source of water supply lies in the northern parts (gently sloping plains covered by Cretaceous rocks). The water level is comparatively shallow (around +20 m depths).

The above physiographic and topographic units also occur at all the areas where important stratigraphic sections are studied.

V.3. GEOLOGY OF THE AREA:

In the areas of study, the geological succession varying in age from Upper Jurassic / Lower Cretaceous to Quaternary are found. These are represented by varied sandstones, siltstones, clays, conglomerates, lava flows and the intertrappean sedimentary beds of varying composition; and calcareous fossiliferous sandstones with a basal laterite layer (in case of Tertiary beds).

The general geological set up for the study area along with its salient features are given below:

In the area under investigations, the oldest rocks exposed are calcareous sandstone, siltstone and shales, belonging to the Katrol Formation, and are exposed in the area north of Wadva, Tharavda, Ratanpur, west and south of Pakhera and north of Khamra. The rocks of Katrol Formation are overlain by burrowed ferruginous sandstones, shales, siltstones, clays, rhythemically deposited ironstones and variegated friable sandstones belonging to Bhuj Formation. The rocks of Bhuj Formation are exposed in the east-west trending low lying tract between high hills of Katrol and Deccan lava flows, in the areas around Chandri, south of Tharauda, south of Ratanpar, Khamra, Pantea, Koharia, Chubdak, Khedoi, Shinugra, Nangalpar and north of Anjar. Certain inliers of rocks of Bhuj Formation are also found near Viri, south of Sinugra, Khedoi, and west of Mathado villeges. (in 41I/4 and 41E/16 toposheets). The rocks of Katrol and Bhuj Formation have yielded for the first time the well preserved foot prints and foot tracks of bipedal, tridactyl and quadrupedal dinosaurs from near Pakhera, Tharauda and Fatehgarh (Ghevariya, 1987; Ghevariya and Srikarni, 1988, 1990, 1994, 1996). The rocks of Bhuj Formation are overlain by an alternating sequence of lava flows and sedimentary intertrappean beds of volcaniclastic origin. The lava flows are olivine basalts in composition and show alkaline composition and spilitisation effect in Bhachau, Anjar and further west upto Baladia village. These

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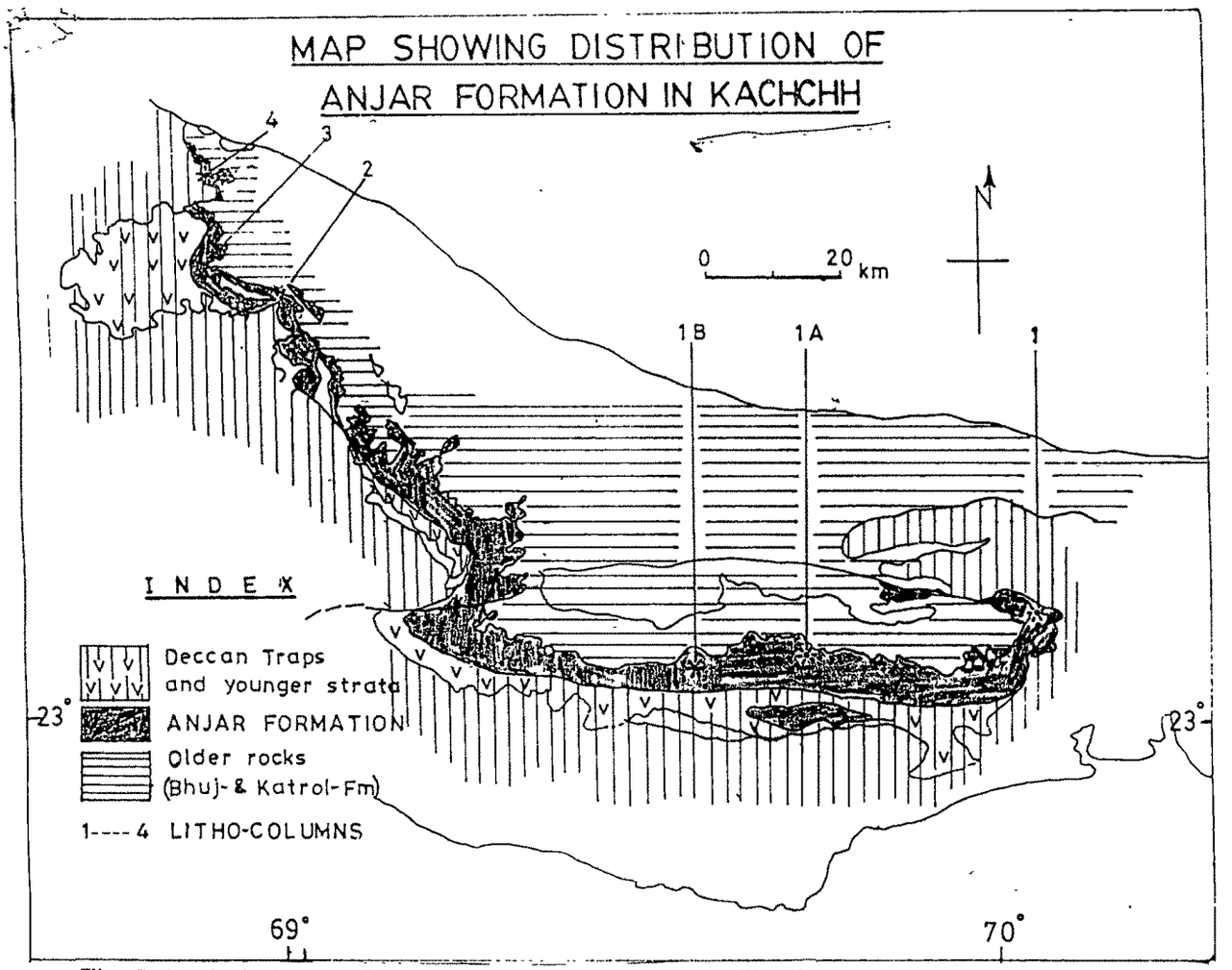


Fig. 5. Geological map of volcano sedimentary formation, Kutch, Gujarat.

rocks further show a sharp physiographic expression, in form of slightly raised ridges at Anjar, south of Shinugra, south of Chandia, Khedoi and Wadh villages. This volcano-sedimentary sequence has been proposed as Anjar Formation (Ghevariya and Srikarni, 1990; Fig-5), and have similar set up and physiographic expression at Bhachau (Fig-6), Kera (Fig-7), Matanomadh, Reha, Dayapar and Ukra localities. At all these places Flows are alternately interstratified with intertrappean beds of volcanoclastic sedimentary origin. At Anjar seven flows and five intertrappean beds, and one red bole bed are exposed. At Bhachau, five alkali basaltic flows with four intertrappean beds, at Kera twelve flows with four intertrappean beds, five flows and four intertrappean beds, at Reha, eight flows and six intertrappean beds at Matanomadh, eight flows and four intertrappean beds at Dayapar and four flows and three intertrappean beds at Ukra are exposed. At Ukra, the first three intertrappean beds have dominantly trap pebble comglomerate (about 90%) as the main constituent. The trap pebbles show varied composition and comprise of porphyritic, basaltic, fine grained doleritic and gabbroic subrounded, in nature. They show strong alignment along current laminae, and gradation in size in vertical sction.

The rocks of Anjar section are better exposed in the Bhachau, Anjar, Matanomadh and Dayapar regions where a clear characteristic composite section and individual constituents members can be demarcated.

The average thickness of the interstratified volcanoclastic unit, i.e. Anjar Formation varies from 93 to 293 m at different places, and comprise tuff, sandstones, shales, ash, reddish gypseous clays, marl, cherty limestone, conglomerate, mud, sandstones and sandy clays. Chert is dominant in Anjar and Roha sections, whereas limestone, marl, clays dominate at Anjar and Dayapar sections. The volcanoclastic sequence has yielded varied assemblage of vertebrate, invertebrate and plant fossils at Anjar, Bhachau, Dayapar, Roha and Matanomadh sections, important among which are dinosaurian fossils at Anjar and Dayapar.

The Deccan trap sequence is overlain by laterite horizons, comprising lateritised ash, basalt and saprolite, laterite, bauxite, kaoline and volcaniclastic tuffaceous sandstones, shales, clays with spheroidally weathered basalt and bentonite. A complete gradation from bauxite to laterite, saprolite, weathered basalt to unaltered parent rock is seen in many sections and profiles at Matanomadh, Dayapar and Roha(Fig. 8). A complete stratigraphic section from Deccan trap to laterite and Tertiary is studied at Bhachau, Anjar, Matanomadh and Dayapar areas. The laterite is overlain by rocks of different ages varying from Matanomadh-Madh Formation, to Eocene at Dayapar to Miocene-Pliocene at Bhauchau, and comprise of micaceous, tuffaceous ash, pebble conglomerate, gypseous shale, clays, marl and kaoline (Palaeocene-at Matanomadh and Dayapar), Gypseous shale, marl and sandstone with invertebrate and vertebrate fossils (Eocene at Dayapar and Ukra) and marl and sandstone with invertebrate fossils (at Bhauchau and Anjar-Miocene/Pliocene).

The rocks are found affected by various tectonic events, in different sections under study. Mesozoic rocks are thrownedinto domal anticlines, and synclines (Fig.5, 6 and 7) and these inherent structures and (later) post-trappian episodes and movements along the major faults have produced gentle domal and basinal structures in the trappean sediments. These and further movements along the faults have further affected the entire rock succession at Anjar, Dayapar and Bhauchau areas. The Deccan lava flows and associated intertrappean beds have formed broad east-west gentle anticlinal structures in Kera, Anjar and Bhachau areas. These structures are further complicated by various secondary structural episodes and intrusions. Though the volcano-sedimentary succession is comparatively thin as compared to other places in Maharashtra and Madhya Pradesh, these structural changes have helped to individually demarcate and trace the beds seperately.

V.4. CHARACTERISTIC OF THE INTERTRAPPEAN BEDS:

In the following paragraphs, the character of each of the stratigraphic unit studied is given separately in detail:

V.4.1. Anjar and Bhauchau Regions:

The lava flows and the interstratified sedimentaries are underlain by 1.5 to 2 m thick sequence (at Bhachau it is about 3.5 m) of laminated ash with red coloured bands. The ash is very light in weight, show cyclothems of finely laminated cycles of alternating white, reddish to brown coloured layers. Each cyclothem varies in thickness from 0.30 cm to about 2 cm and encompasses about 4 to 16 cycles; each of which contain 4 to 17 microlaminae in single cycle. The cycle starts at base with dark-brown and ends up the section with white laminae. The thickness of successive laminae decrease from base to top in each cycle, thickest being at base and thickness of each basal laminae of each individual cycle gradually decreases towards top in successive younger laminae from base to top. The overall thickness of the cycles and cyclothems also decrease from base to the top. The laminated ash sequence is overlain by largely well-stratified and laminated tuff and finally by the chilled fine grained basalt. The ash comprise of glass shards and minute thin grains of feldspars in the ground mass. The tuff contains feldspar clasts and grains in the ground mass and quartz grains. At times, the topmost units of the underlying gritty sandstones contains pockets and balls and lenses of laminated ash, tuff aligned along the larger current laminae indicating either active subaerial eruptions or weathering of such newly formed ash and tuff/lava flows in the vicinity, suggesting active eruptive phase of volcanism during sedimentation of Bhuj sediments before close of Creataceous, well before the onset of main Deccan eruptions in Kutch. These ash beds and red layers from Shinugra and Bhachau sections were analysed for Ir/Os content, but it was found that they do not contain anomalous values. Such basal ash sequences associated with Mesozoic horizons are found at Anjar, Bhachau, Baladia sections and similarly younger ash horizons are also found above trappean sequences at Ratnal, Chopadra, Matanomadh and Shamjiwaro (Fig. 7). The basal layer of the ash sequences contain thin layer rich in feldspar clasts, which are

totally altered white in colour and also contain white and purple coloured globes and spherules.

V.4.1.1. Upper age of Bhuj Formation:

The lava flows and intertrappeans rest on the Mesozoic sandstones with an erosional contact. An examination and correlation of different units of the underlying Mesozoic sandstones indicates that the basal part of the volcanoclastic overlap the Mesozoic sequence at various places and there is a discordance with the underlying sequence. The Mesozoic sequence at Anjar and Bhachau comprises friable, current bedded, felspathic sandstones, and siltstone, clays, shales, ironstones belonging to upper part of Bhuj Formation. The ironstones, siltstones and clays from basal part (500 - 1000 m) of upper Member and assemblage of siltstone and clays contain rich assemblage of upper Gondwana flora and some younger forms. The overall floristic composition of the horizon indicate Cretaceous age, i.e. younger than Albian. Therefore, it is quite likely that the upper age limit of the exposed younger horizon (i.e. the white felspatic sandstone and shales) may range upto Campanian. The white felspathic sandstone, about 100 m thick is associated with yellowish ferruginous bands. These ferruginous bands (about 80 to 100 m below top part) contain compressions and impressions of *calamites* and *equisetaceous* woody shoots and stems. The ill preserved, but identifiable impressions suggest presence of *ptilophyllum*, *araucarites*, *Ginkgo*, and other forms. These dominance of *dicotyledonous* leaves within the carbonaceous shaly units in the upper member in other sections like Bhachau, Matanomadh, Dayapar, Kanmer (eastern Kutch) areas. All these indicate need to raise old concept about upper age limit of Umia/Bhuj Formation. The analysis of different data indicate that the upper age limit of Bhuj Formation may be extended to Senonian to Campanian.

V.4.1.2. Basal contact and the first intertrappean:

The interstratified volcanosedimentary sequence - The Anjar Formation comprise seven lava flows and six interstratified sedimentary beds. The brief account of the volcanosedimentary is presented in order to study the characters and signatures of the boundary sections.

The first intertrapean bed is exposed in the Anjar village tank, and cutting about 1 km towards northwest of the tank and towards south of the Anjar-Mundra road, south of Shinugra road. It comprises 0.8 m to 1 m thick white, current bedded, indurated (at times friable also) felspathic sandstone, 0.5 m thick red and buff coloured sandy sticky clays, 0.30 m thick ash bed in the canal section. Whereas towards south of Shinugra village it comprises greenish grey to reddish tuffaceous and sandy clay. The urbanish settlement area around Anjar does not permit further lateral tracing of this unit. No major fossils were recorded from these sections.

V.4.1.3. Second Intertrappean bed:

The second intertrappean bed is about 8.5 m thick, contains burrowed current bedded sandstone with volcaniclastic matrix. The sandstone has calcareous concretions on the surface and contains lenses of siltstones in the upper part. Whereas it is tuffaceous in character in the lower part. The middle and the upper part contains yellow fossiliferous marl, black carbonaceous shales and clays, flowlets of porphyritic basalt, resembling the overlying (F3) flow in comparison in petrographic sections. The lower/basal volcaniclastic part of the bed contains agglomerate with bombs, lapelli, droplets of lava and clasts of white and honey yellow coloured felspars. The matrix comprises loose, ashy, green tuff granules and fragmented basalt, scoriaceous and pumiceous lava, compact quartzitic burrowed sandstone and sandy concretions of various shapes. The reddish sandy and clayey fraction dominates in further westward from Viri village. Siliceous and calcareous concretions and fragments of chertyfied and petrified fossil wood and worm burrows are common and occur as loose spread in the field, along the base of the low ridges and also as scree wash within streams emanating from these low ridges. The burrows comprise large *diplocraterion* living chamber. The loose spread also includes algal and stromatolitic limestone containing fossilised algal and moss like remains, rounded, cylindrical, oblong as well as small conical calcareous concretions of brownish colour with internal fibrous (in section when broken) structure, which could be after some - organic structure - invertebrate fossil cast or excreta material of some reptiles. Physa and bivalves are common within the rocks of lower and the middle units. The calcareous marly unit and top unit contains dinosaurian bones, and egg fossils (Plate-I/1 and XIX/2) fragments and clutches (Ghevariya, 1986, 1988).

The sandstone in the upper part of the top unit, contain interstratified lava flowlets, and large horizontal to subhorizontal burrows with cylindrical and tapering outline and rounded openings. These burrows show preferencial growth parallel to down current direction. The sediment composition and plant debris indicate that the lake in which the second intertrappean bed was deposited was moderately deep (hypolimnion), where a balance between oxygen produced and consumed existed. The littoral zone of such small lakes support development of algae and mosses. The marly yellow limestone may represent littoral zone of small a trappean lake.

Thus, it is clear from the above that second Intertrappean bed contains major felspar clasts, lapelli and pyroclastic, stromatolitic and algal remains, ash, porcellinites, spherules, concretions and suspension feeder invertebrates, dinosaurian fossils, and black shale facies. Some of these confirm to the characters of upper most Cretaceous and Cretaceous-Tertiary sections and to the sections deposited under the active volcanism. In the Anjar area, the active volcanism during intervening periods of the second and third intertrappean is indicated by plugs and vents.

Plate I/1 Dinosaurian bones and eggs from second Intertrappean bed at Anjar area.

Plate I/2 Isolated dinosaurian egg from second Intertrappean bed at Anjar.

V.4.1.4. Third Intertrappean bed:

The third flow (F3) in the Anjar area is overlying the second intertrappean bed, and this in turn is overlain by a 6 to 7 m thick sedimentary intertrappean bed - the third intertrappean bed and flow F4.

This intertrappean comprises well stratified argillaceous, siliceous and calcareous sediments alongwith minor amount of chemically precipitated sediments. The basal part of the section includes compact and hardened palaeosol containing black cotton soil, black mud with calcareous concretions and rhizomes and 15 to 20 cm thick black and gray chert with rich assemblage of fauna and flora. The middle part of the section consist of rock assemblage with black mud, well stratified, laminated black and grey shale, slightly compacted and hard in the lower part. The micro crossed ripple clay and shale units with lenses of silt, and tuffaceous sand. The silty and sandy layer above black mud and black shale, contain 1.0 cm thick layer of white marly nodular compact, concretionary sandy layer, which contains abnormally high Iridium and Osmium values (Ir_1). A very thin white siliceous layer, which at times splits in to two sublayers parallel to bedding surface. This contains high values of Ir/Os (Ir_2). This layer shows variation in thickness when traced laterally along strike on either sides, but persist in the entire exposed width of the section. The horizon of black shale with silty and sandy layer is overlain by grey and chocolate coloured laminated fossiliferous shale, which contains a thin reddish and ochreous sandy and limonitic nodular but more or less continuous layer (Ir_1) which shows anomalous values of Iridium, Osmium and other PGE elements. This is overlain by a thin brown yellow ash/ tuff layer of less than 0.5 cm thickness, below the limestone and chert layer. The ash/tuff layer also contain white clasts of altered felspar (sanidine spherules), and white globules. The overlying chery layer contains white banded silica and porcellanite band at base and top; which do not have lateral persistance. The cherty and porcellanite unit is overlain by a white and greyish coloured siliceous richly fossiliferous limestone with black and white coloured bands of chert. The limestone contains rich assemblage of *ostracoda, charophytes, forams* and other *gasteropods* and *lamellibranchs, physa, lymnae, palludina, cyprea* and many other forms are very common and abundant. The limestone and associated chert show lateral persistance over the entire length of the section at *Dinosaurian* fossil locality. This limestone is overlain by grey and black coloured shale, clay and marly limestone bands, with rhizome, and *physa* and other invertebrate, *avian* and *reptilian* egg shell fragments and vertebrate fossils. Abundant fossil wood fragments and fossil leaf impressions occur within the grey, red and brown chert bands, within the limestone/marls. The shale/ mud at times contains gypseous partings and lenses and numerous thin tuffaceous, cherty and porcellanous lenses. In the upper part of the section, the muddy lenses within marls alongwith cherty partings are common. The section shows prolific burrowing within the marly and muddy layer both above and below the cherty partings. The burrows are mostly vertical in position and are about 0.5 to 1.0 cm in diameter. Smaller burrows less than 0 5 cm in diameter and about 3 to 5 cm in length are more abundant in the higher part of the

section. The tuffaceous and porcellanous lensoid bodies at times are 10 to 15 cm thick. Three such intercalations are recorded in a exposed section at *Dinosaur* fossil locality (Plate-II/1 and 2).

The grey shale grades laterally into reddish sandy clay and fossiliferous gypseous shale on either sides. The partings of white, siliceous lenses and calcareous nodules, the tuffaceous and porcellanous partings along bedding surface. This horizon is also burrowed and contains similar partings of chert and white siliceous (porcellanite) matter. *Physa* and other invertebrates are grossly reduced in the upper part, and they are substituted by burrows and fossil plant remains. The top part of the section is dominantly clayey/muddy and contains insitu land deposited black cotton soil and clay with boulders of basalt. The black cotton soil represents palaeosoil horizon with rhizomes. Top clay in turn is overlain by olivine basaltic flow (F4).

The third intertrappean bed contains globules and spherules of various shapes, embedded within the calcareous and cherty layers. These resemble to some of the spherule layers described from many sections, in different parts of the world. The other important characters of the third intertrappean section include (a) the high Ir/Os and siderophile elements containing three separate layers (Fig-31a, b and c), (b) presence of *fern spikes* in the top part of basal black to grey shale, marl sequence unit, (c) occurrence of insitu dinosaurian fossils between the Ir rich layers (Ir_2 and Ir_1) just below the tuffaceous ash layer, (d) appearence and dominance of *foraminifera,* some of which are indicative of the Palaeocene/Lower Tertiary age, (e) relative dominance of the *angiosperm* fossils and spores-pollens in the higher part of the section above the *dinosaur* horizon. Besides this, other important changes (biotic changes) include the avian/other reptilian elements and egg shells in the upper part, the dominance of piscean and charophytes in the basal and upper part of basal horizon.

The palaeomagnetic measurements carried out in field and laboratory has suggested normal polarity event chron for the lower three flows (F1, F2, and F3) below the third intertrappean bed. The palaeomagnetic polarity chron for the upper four flows (i.e. F4, F5, F6, and F7) above the intertrappean bed - 3, show a Reversed magnetic polarity event. The geochronological dating of the underlying F3 and the overlying F4 flow have indicated ages of 65.3 ± 0.6 m.y. and 65.1 ± 1.6 m.y. indicating that of the event happened very close to the Cretaceous-Tertiary transition at Anjar. The micro-palaeontological studies of certain samples from the section of intertrappean bed no.3 have indicated presence of a datum line of the probable horizon in vicinity of the Ir layer (Ir_1). These include certain spores, pollens, dinoflagellates and algal fossils.

V.4.1.5. Fourth Intertrappean bed:

The third intertrappean bed is overlain by olivine bearing basaltic flow, which inturn is overlain by an intertrappean bed comprising 1.0 m thick lensoid reddish sandy clay grading in to red bole bed along the strike. This bed is generally unfossiliferous, but at a

Plate II/1 Excavation pit section showing anomalous layer of Iridium rich limonite (Ir).

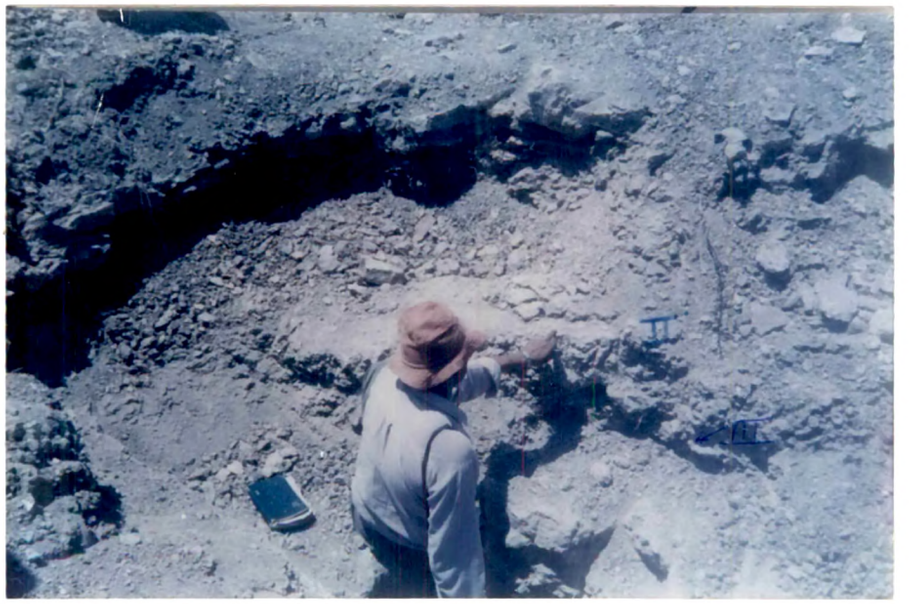


Plate II/2 Iridium rich layers II and III at same locality.

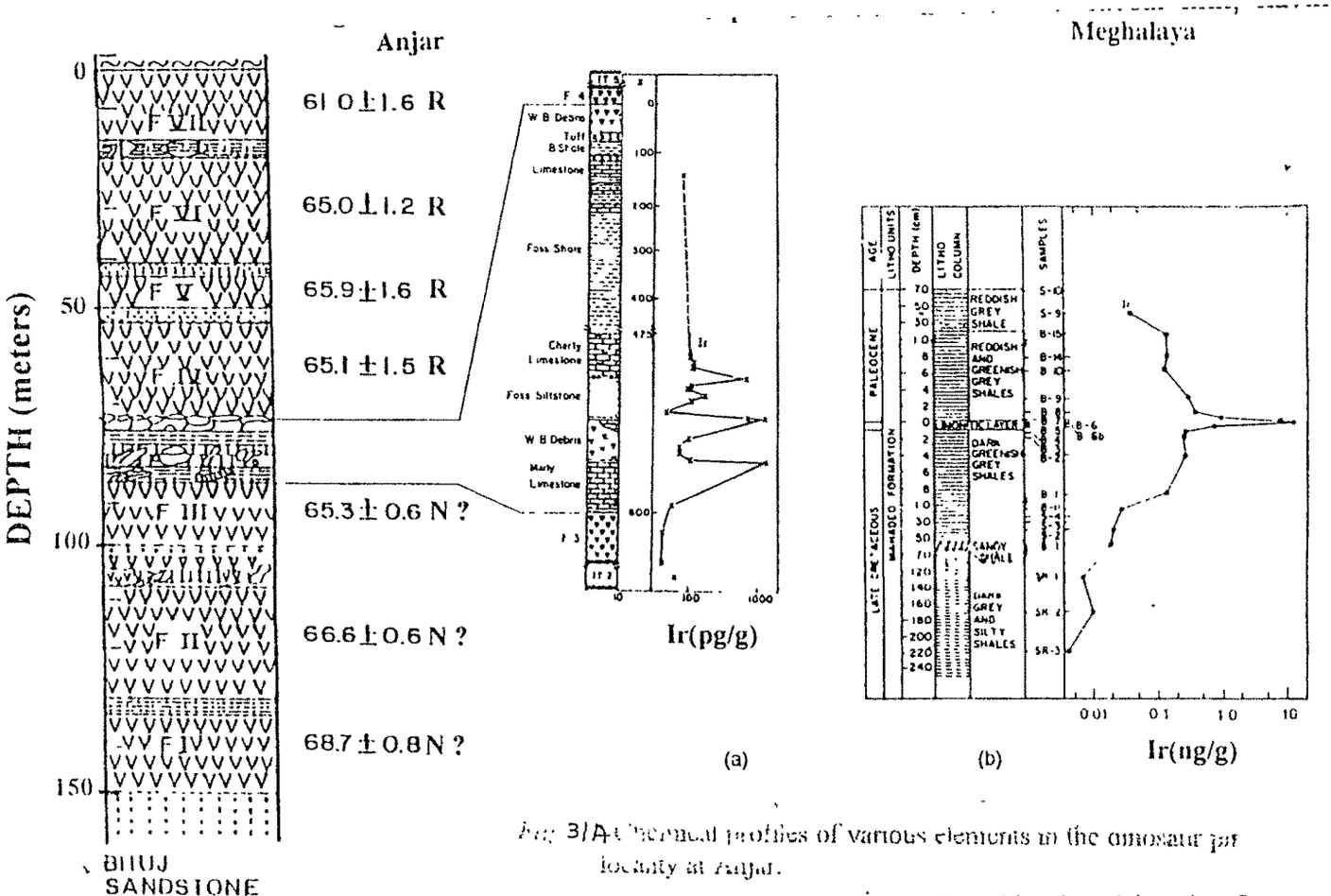
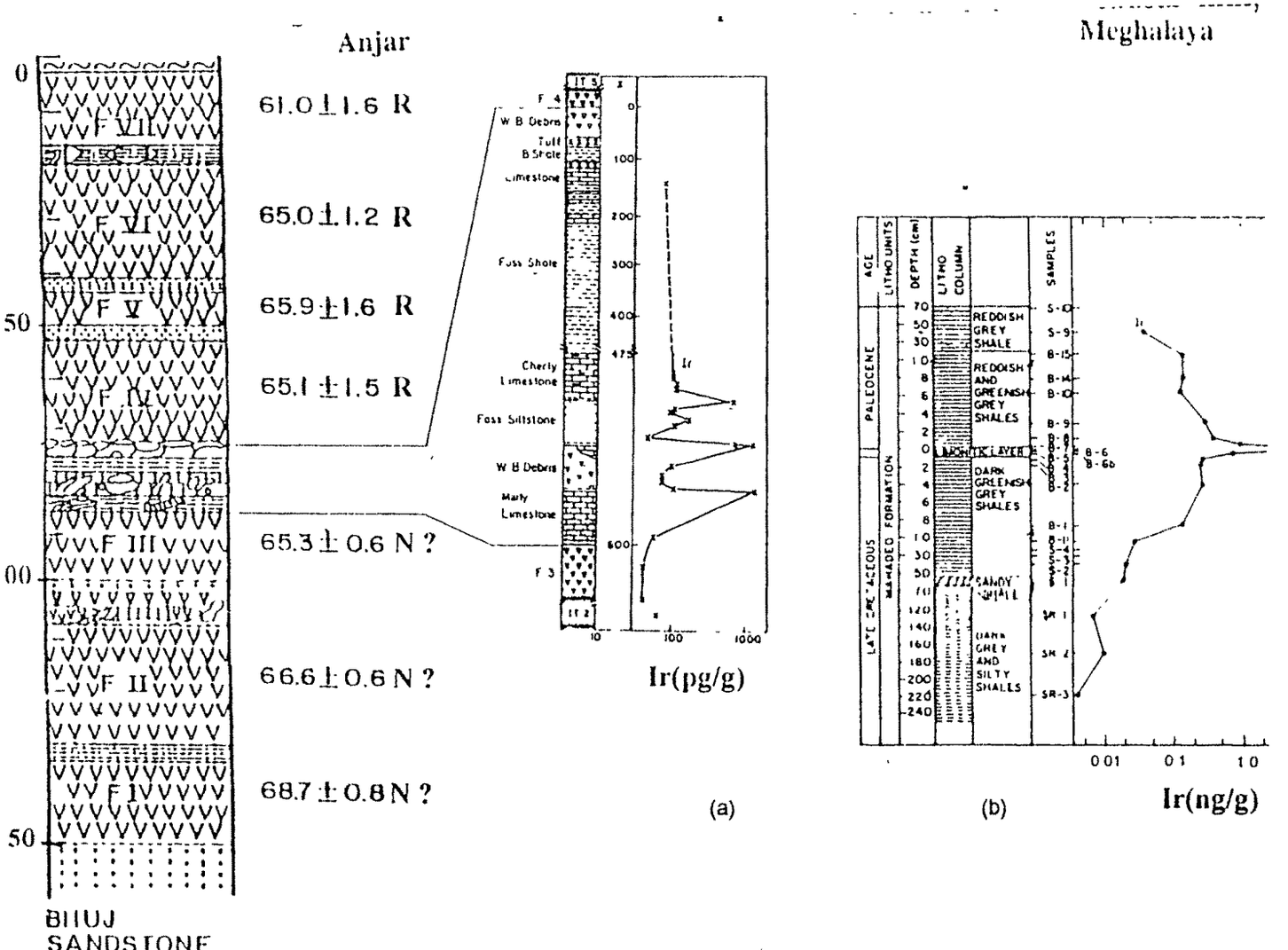


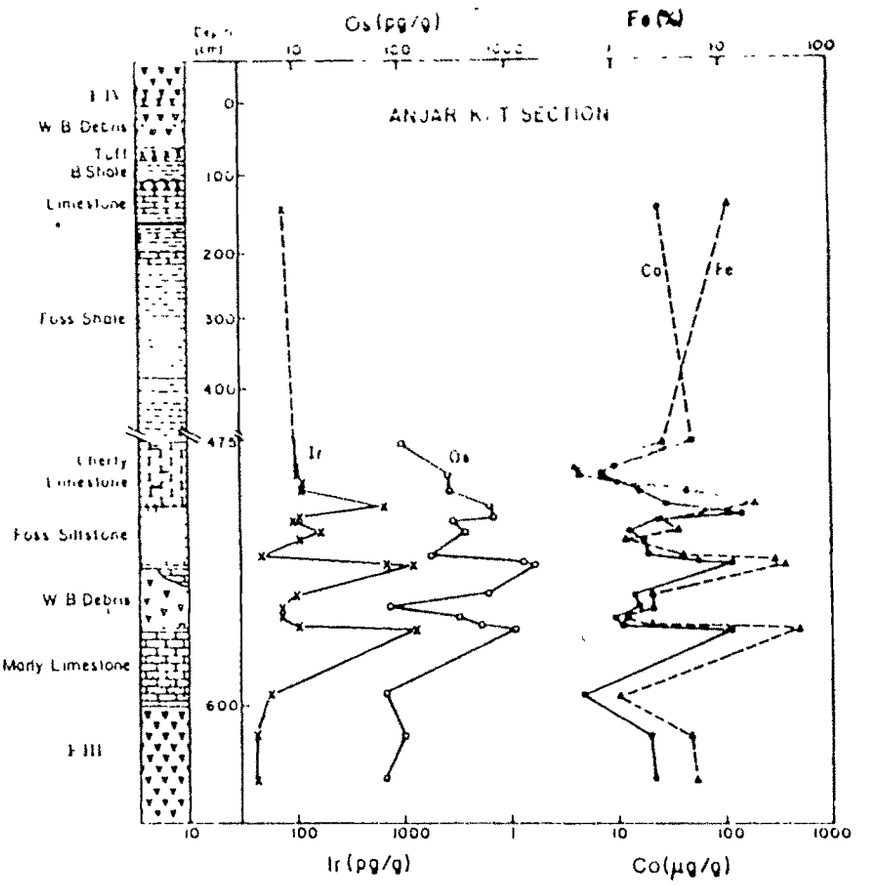
Fig. 3(A) Chemical profiles of various elements in the dinosaur bone locality at Anjar.

— Ir profiles observed in two Indian K/T sections. Anjar is a continental section from Kutch (a) and Um Sohryngkew River sect is a marine section from Meghalaya (b). The composite section of Anjar volcano-sedimentary sequence is shown on the left some sam locations are marked



ure 9 — Ir profiles observed in two Indian K/T sections. Anjar is a continental section from Kutch (a) and Um Sohryngkew R is a marine section from Meghalaya (b) The composite section of Anjar volcano-sedimentary sequence is shown on the left s locations are marked

Fig. 51. Chemical profiles of various elements in the dinosaur pit locality at Anjar.



Text-figure — Profiles of Ir, Os, Fe and Co in III intertrappean bed (pit BG1) **W. B.** is weathered basalt and **B.** is black.

Fig. 3. Chemical profiles of various elements in the dinosaur pit locality at Anjar

locality towards southwest, dinosaurian teeth was found from the reddish sandy clay. This bed is overlain by basaltic flow (F5).

V.4.1.6. Fifth Intertrappean bed:

This intertrappean bed is sandwiched between flows F6 and F7. It is composed of 1.0 to 1.5 m thick section of flaggy, microlaminated, limestone, calcareous sandstone, marl, thinly laminated chert, micro cross ripple laminated and stratified sandy limestone with intervening lenses of volcanoclastics. The dominantly calcareous section passes into reddish sandy clay further eastwards and to friable stratified fossiliferous sandstone towards further east and northeast of Shinaya village.

The limestone and the calcareous sandstone contain fossil algal and invertebrate fossils, and plant fossil debris.

The intertrappean beds 4, 5 and 6 are not so prominent as compared to the third intertrapean bed. In the Anjar section, the intertrappean bed no. 3 offers the most probable horizon for boundary transition.

V.4.2. Characteristics of the Dayapar Section:

In the Dayapar area, the stratigraphic sequence is similar to the Anjar area. The exposed section comprises basal Mesozoic, volcanosedimentaries and supratrappean sediments (Fig-7).

The Mesozoic sequence comprises alternations of green glauconitic sandstones, shales and sandy clays forminig upper part of Upper Member of Bhuj Formation. The basal part of the Dayapar section comprises black carbonaceous fossiliferous shales, felspathic sandstone with ferruginous and marly intercalations. The sandstone at times is highly burrowed. The burrow cavities are filled by yellowish argillaceous clays / silty ochreous matter. Burrow structures are mainly vertical and inclined, at times being subhorizontal also.

The Mesozoic sequence shows overlapping by various units of Bhuj sandstone and finally these are overlapped by various units of volcanosedimentary units, indicating brief events of erosion and redeposition. The volcanosedimentary sequence at Dayapar comprises six flows and five intertrappean beds of volcanoclastic sediments comprising variegated, tuffaceous sandstones, sandy clays, glauconitic sandy beds, gypseous clays, marly beds with prolific fossil assemblages of *charophytes, ostracoda, physa* and other related fossils and invertebrates. The reddish gypseous clay horizon in the basal part of the intertrappean sequence is extensively developed in the Dayapar and Matanomadh area. The basal reddish gypseous clay in the second intertrappean bed contain *dinosaurian* bone fossils and fragments of egg shells alongwith *chelonian, boidian* and other vertebrate fossils. The marly horizons associated with this contain microfossils and other floral assemblage indicative of upper most Cretaceous (Maestrichtian) age.

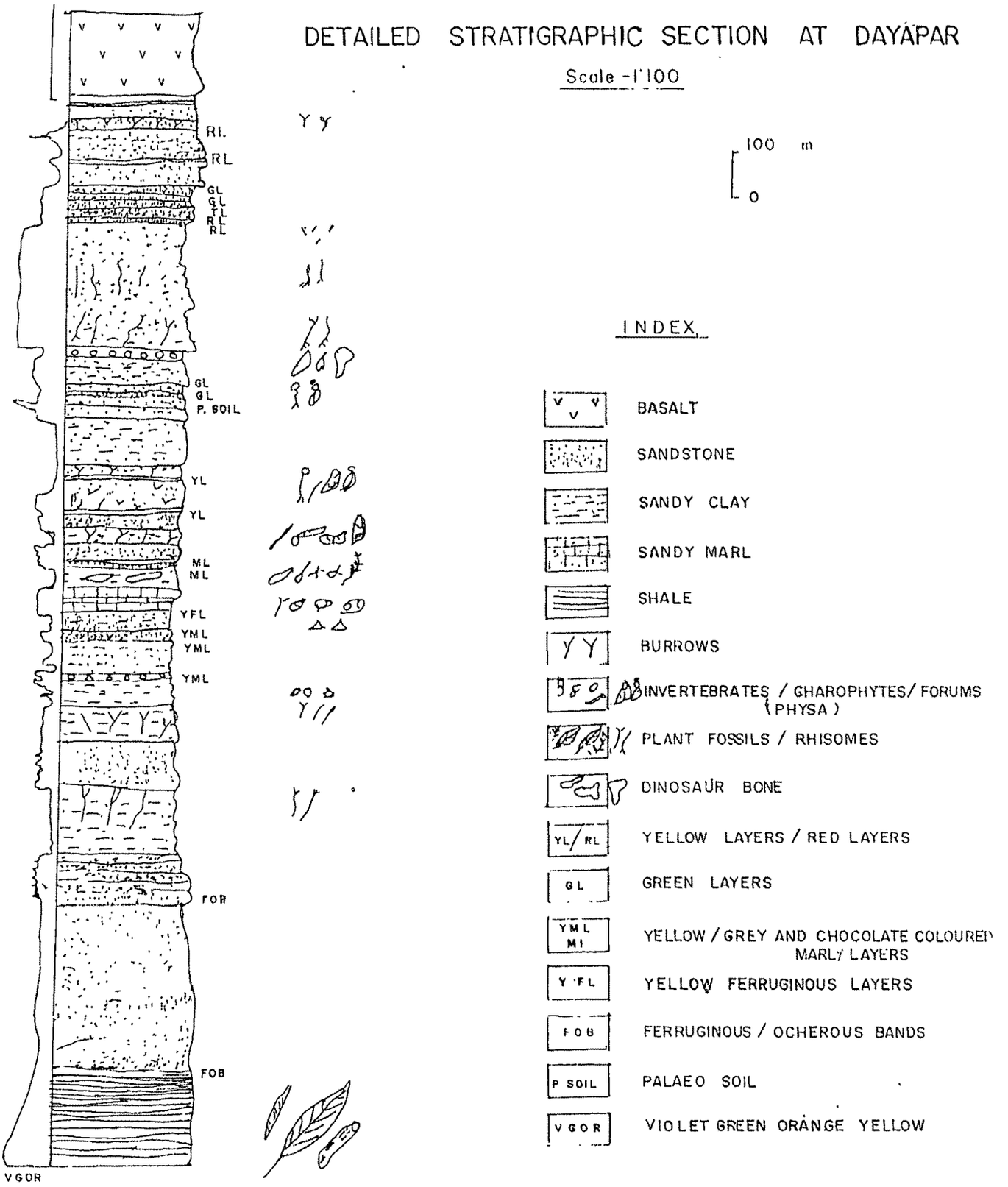


Fig. 8. Composite geological section of volcano sedimentary sequence at Dayapar.

The volcanosedimentary sequence of higher part, at Dayapar is similar to Anjar in characters. The sequence at Dayapar comprises six lava flows and four intertrappean beds comprising sandy clay, shale, ash beds and red bole beds. The first three intertrappean beds are studied in detail.

V.4.3. Other Sections:

The other locations where studies were extended for various purpose include the following:

V.4.3.1. Ukra Area, Matanomadh, Roha, Kera-Baladia Areas:

The general geological set up in these areas comprise Mesozoic as the base and volcanosedimentary sequences comprising lava flows of basaltic composition and intervening intertrappean beds comprising tuff clays, sand, tuffaceous sandstones, trap pebble conglomerates and ash beds with invertebrate and plant fossils (Fig-2). The lava flows in these areas are tholeiitic basaltic in composition. The intertrappean beds at Roha and Matanomadh contain plant fossils - dominantly *angiosperms* and *gymnosperms*, invertebrate. The Baladiya-Kera section has not yielded important fossils except plant fossils and invertebrate fossils from the marine bands from the Upper Member of Bhuj Formation. The Kera-Baladia section helps to connect the volcanosedimentary sections from eastern part of Kutch to the western sections.

The Ukra section forms the western most section of volcanosedimentary rocks of Kutch, with two prominant basal thick trap pebble conglomerate beds, and contains *bivalve* fauna. The higher intertrappean bed comprise greenish, greyish, white tuffaceous, compact sandstone, siltstone and sandy clay with volcaniclastic matrix.

V.4.3.2. Patcham Island: Chapri Bet Section:

The Chapri bet in Patcham island exposes, basal part of the Patcham Formation, and comprises a sequence of greyish to Khakhi coloured siltstone, shales intercalations in lower part of basal section, and yellowish siliceous coralline limestone, calcareous sandstone conglomerates and clays. The calcareous sandstone and coralline limestone conglomerate unit contains *dinosaurian* skeletal elements comprising vertebrae, femur bone, and bones of pelvic girdle, teeth and other reptilian bone fossils and fossil wood logs and insitu petrified trunks.

This unit is overlain by a sequence of variegated clays, sequence of siltstone, shale with marly bands passing into thick calcareous sandstone sequence forming middle unit of the Formation. The calcareous sandstone unit is overlain by an intercalated sequence of siltstone, marly bands, oolitic and sandy limestone bands of golden yellow colour and finely greyish black fossiliferous limestone, with occasional cherty bands and irregular partings. The golden oolite bands occur in several units which contain vertebrate and other fauna. The vertebrate assemblage includes *crocodilian*, *dinosaurian* and *fish* teeth. The calcareous and friable sandstone lenses within the Patcham Formation contains ill preseved

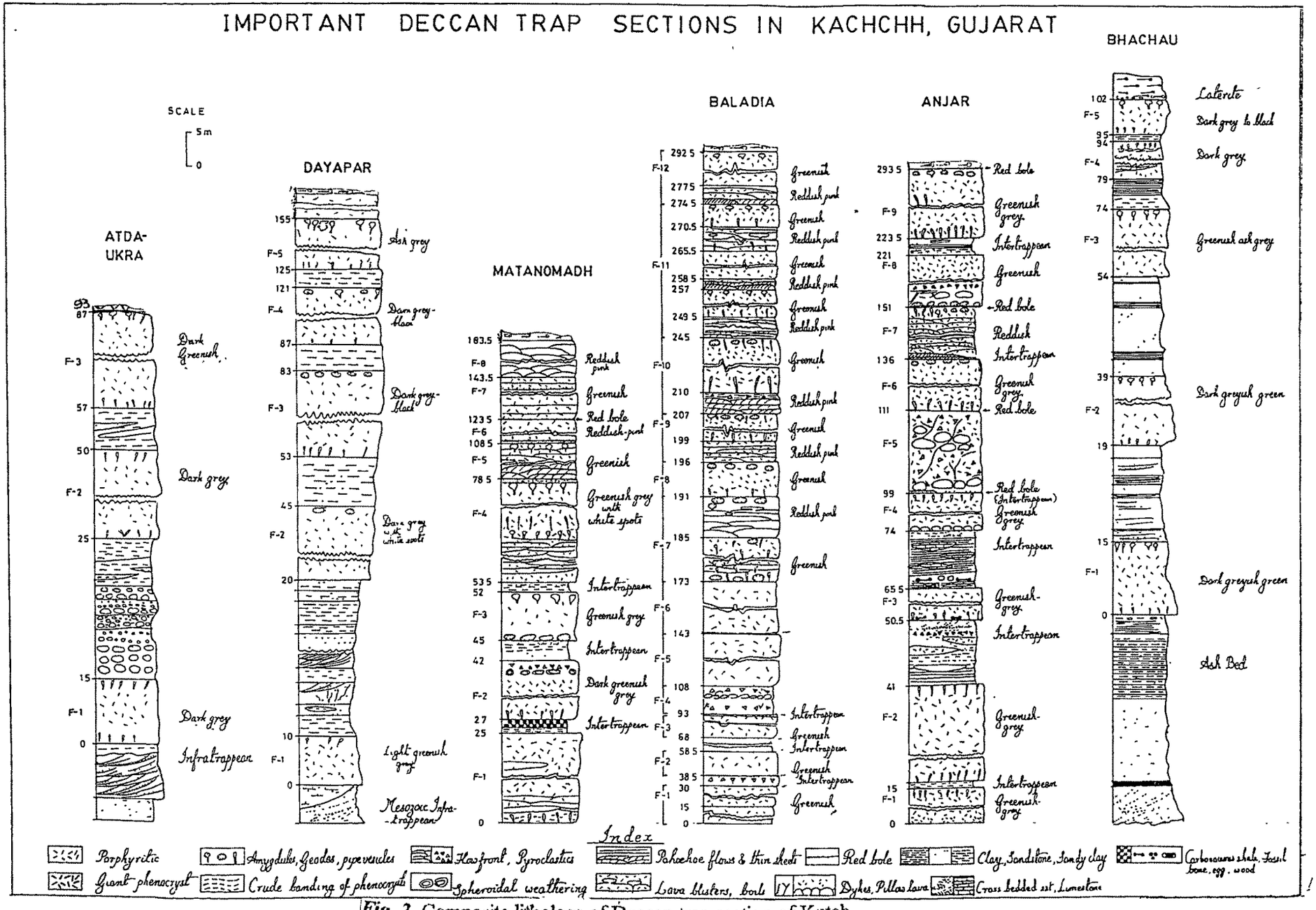
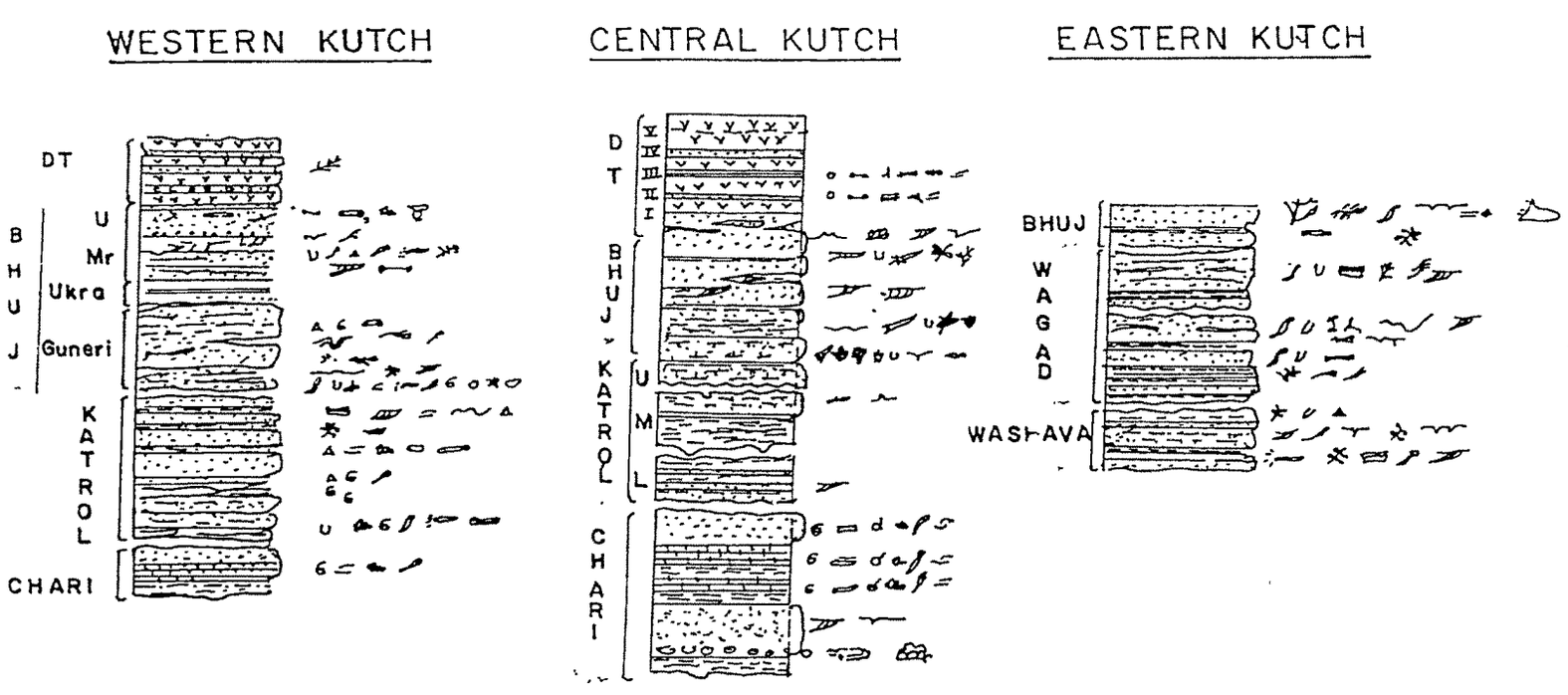


Fig. 2 Composite lithologs of Deccan trap section of Kutch, Gujarat.

COMPOSITE STRATIGRAPHY OF MESOZOIC OF KUTCH, GUJARAT



LEGEND TO LITHOLOGY

- Sand stone
- Shale
- Silts stone/sandy clay in Case of intertrappean beds
- Ferruginous sandstone
- Limestone/oolitic limestone
- Lava flows
- Calcareous sandstone
- Conglomerate/Trap pebble Conglomerate

Fm U,M,L,Mr Upper, Middle, Lower, Member Fm. Formation

INDEX TO STRUCTURES/BIOTA

- Horizontal burrows / inclined, irregular / vertical burrows
- Cones / Fruits of cycades
- Fossil plant leaves / fossil wood / Rhisomes
- Corals / Crinoid stem / crinoids / oscicle plates
- Ammonites / gastropods / Lamelli branches / Belemnites
- Brachiopods / Trigonia / Astrate
- Dinosaurian eggs / Bones / tooth / Foot prints
- Sedimentary / igigneous dykes
- Suncracks / Finely laminated shale / Loadcasts
- Ripple marks / Cross bedding (trough type)
- Channel structures / contorted cross bedding / algal algal bedding

Fig. 9. Composite Litho-stratigraphic section of Mesozoic rocks of Kutch.

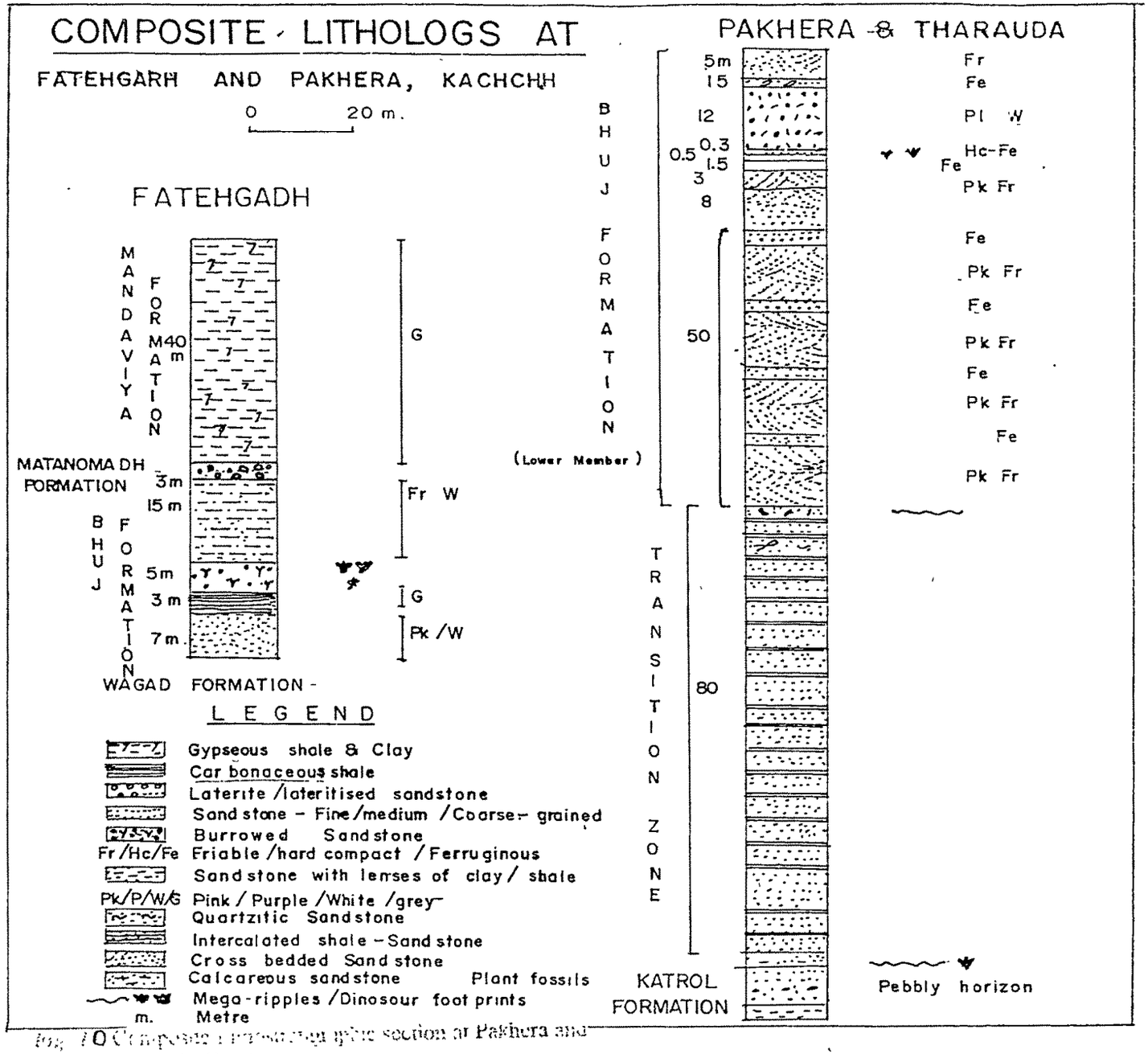


Fig. 10 Composite lithostratigraphic section at Pakhera and Fatehgarh, Kutch.

Gondwana plant fossils near Dhoravar and Rabviri villages.

The grey and pinkish white to khakhi fossiliferous coralline limestone of Patcham Formation is overlain by siltstone, shale with golden oolite limestone bands, which mark the begining of Chari series (Fig-9).

V.4.3.3. Tharauda, Pakhera Area: (Central Kutch, 41E/16)

In the Tharauda, Pakhera and Ratanpur area of central Kutch (toposheet 41E/16), the rock sequence belonging to the Katrol, lower part of Bhuj Formation and upper part of Bhuj Formation, viz. Lower and Upper Member respectively, are exposed (Fig-4A and Fig-10).

At Tharauda, the alternating and intercalated sequence of grey shales, siltstone, in middle part and calcareous sandstone with minor siltstone intercalations in the upper part belonging to 'Katrol Series' (Bhatt, 1996) are exposed. The upper part of Katrol series is overlain by 80 m thick alternating intercalated sequence of sandstone and micaceous thinly bedded shale and siltstone near south of (.) 271 point. This sequence is burrowed and varied in trace fossils. The entire sequence is grouped as the transitional zone, between the Katrol Formation and Lower Member of Bhuj Formation.

The Lower Member of Bhuj Formation conformably overlies the transitional sequence and comprises about 95 m thick variegated coloured, dominantly current bedded friable, ferruginus sandstone, at times becoming hard, ferruginised and compact. The top surface of the sandstone and siltstone contain a variety of trace fossils both of vertebrate and invertebrates. The important vertebrate trace fossils include foot prints and foot tracks of bipedal, tridactyl, quadruped dinosaurs (Plate-III/A/1, 2, 3 & 4). The Lower Member sequence at Pakhera is conformably overlain by rocks of Upper Member. The Upper Member of Bhuj Formation comprises sequence of friable, felspathic, current bedded sandstone, ferruginous sandstones with minor intercalations of siltstone and white clay. The ferruginous sandstone and siltstone contain Gondwana plant fossils near Wadli, Chandi and Pantia villages (Fig-4A) from the basal part of the Upper Member of Bhuj Formation. The upper part of the Upper Member of Bhuj Formation comprises a thick sequence of alternating repetitive cyclothems of friable felspathic sandstone burrowed ironstones, siltstones and clays and ash balls and lenses. The arenaceous units dominate in the sections and top unit becomes pebbly in nature and contain plant fossils near Shinugra.

The sandstone of the Upper Member is overlain by a thick unit of finely laminated cyclically alternating units of ash bed near Shinugra (Fig-2).

V.4.3.4. Fatehgarh:

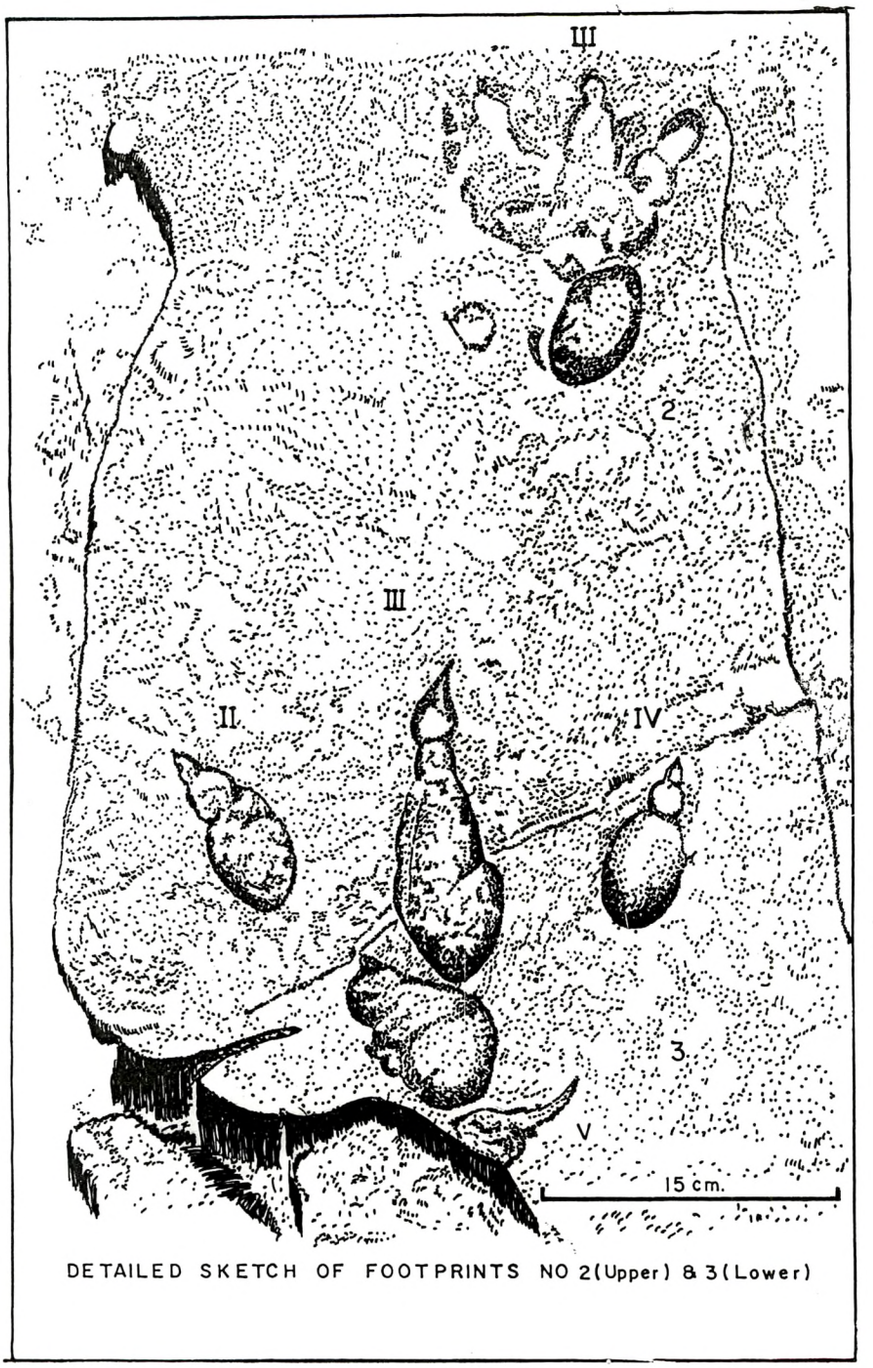
At Fatehgarh, located in the northern part of Wagad area (Fig-11), a 30 m thick sequence comprising pink, white, friable as well as compact quartzitic sandstone and shale/siltstone and white friable sandstones and kaoline belonging to the Upper Member of Bhuj Formation is exposed. The sandstone is intruded by a basic basaltic dyke of Deccan Trap (Fig-11).

Plate III/A/1 Bipedal, Tridactyl Ornithischian dinosaurian foot prints, Tharauda, near Anjar, Kutch.

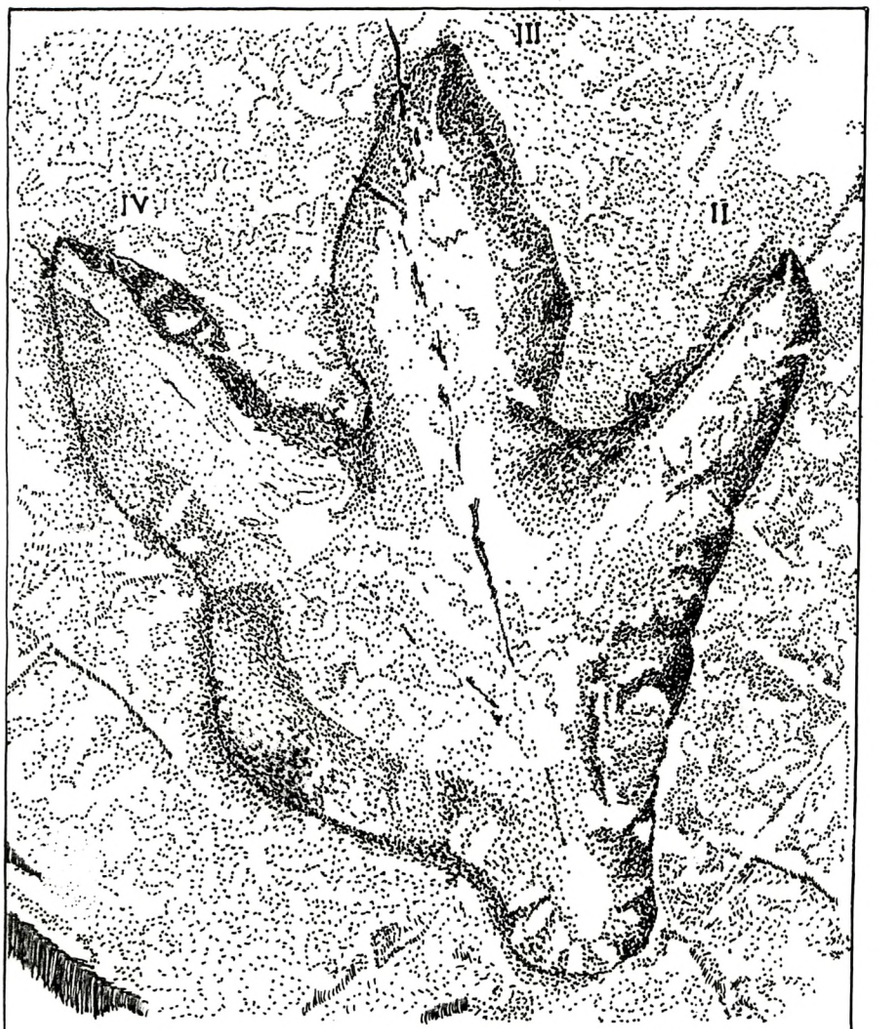
Plate III/A/2 Plaster cast of the bipedal Ornithischian tridactyl foot print.

Plate III/A/3 Bipedal, Tridactyl theropod dinosaur foot print.

Plate III/A/4 Plaster cast of bipedal theropod dinosaur from same locality, at Tharauda.



DETAILED SKETCH OF FOOTPRINTS NO 2(Upper) & 3(Lower)



DETAILED SKETCH OF FOOTPRINT No. 9

PRESENT DAY AVIAN TRACKS
(not to scale)

MEASUREMENT OF STRIDE AND LENGTH OF FOOTPRINT (l) OF THE ANIMAL FOR ESTIMATION OF SPEED AND HIP-HEIGHT (h = 4 X l)

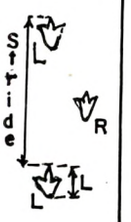


Plate IV/3 Plaster cast of Quadrupedal sauropod foot print at Fatehgarh.

Plate IV/1 Quadrupedal sauropod foot print, Fatehgarh.

Plate IV/4 Quadrupedal sauropod foot prints at Fatehgarh.

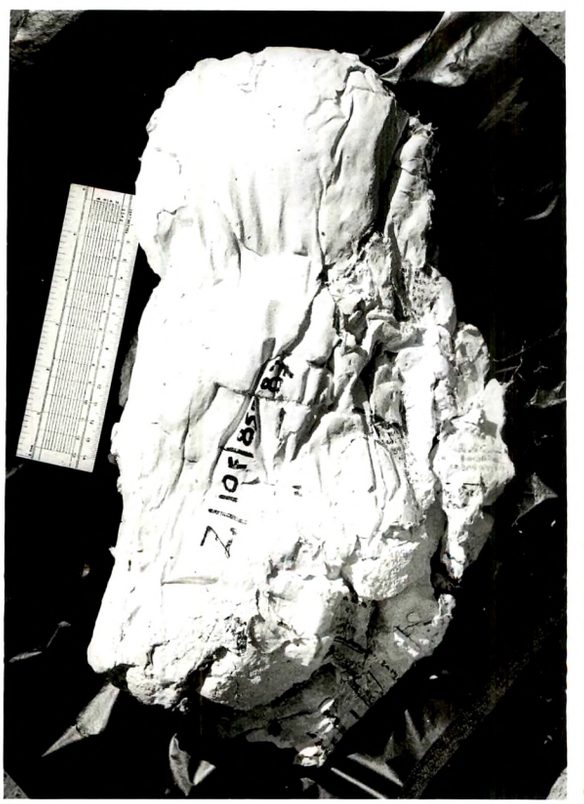


Plate IV/2 Plaster cast of Quadrupedal sauropod dinosaur foot print, Fatehgarh.

Plate V/1 Sauropod dinosaur foot print, Fatehgarh.

Plate V/2 Plaster casts of sauropod dinosaurs, Fatehgarh.

MAP SHOWING LOCALITIES OF RECENT DINOSAUR FOSSIL FINDS IN GUJARAT. FIGURE-13

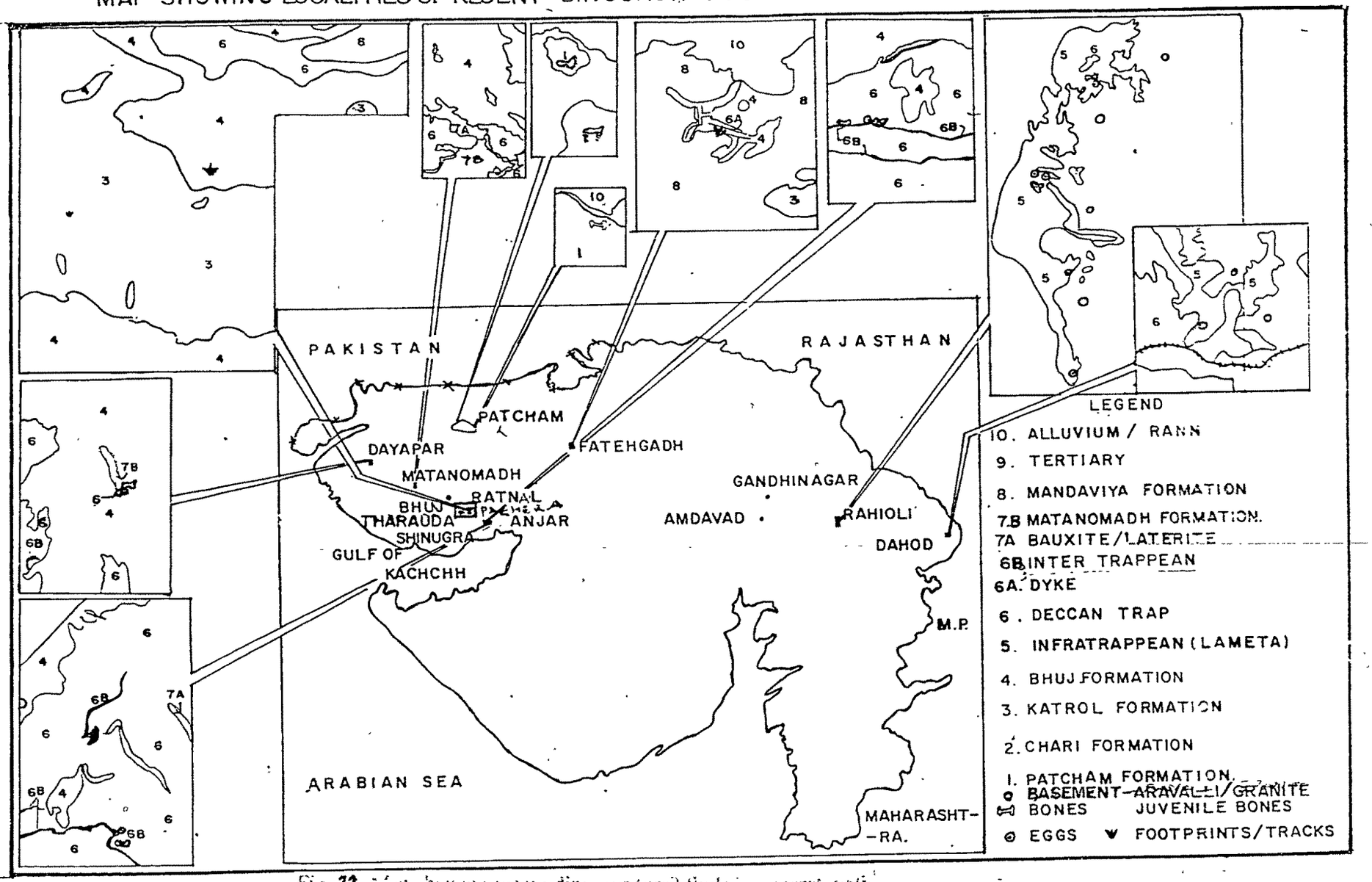


Fig. 11. Map showing recent dinosaur fossil finds in Gujarat, with insets showing detail geological maps of each area

The siltstone and shale contain plant fossils of Upper Gondwana types (*ptylophyllum*). The pinkish white burrowed sandstone bed become quartzitic close to the basic dyke intrusion. The top surface of this burrowed quartzitic sandstone contains foot prints of quadruped herd of *dinosaurs* (Plate-IV/1, 2, 3, 4; V/1, 2). The foot prints are also borrowed. A sequence of events can be reconstructed on the basis of the available details which suggest movements of herds on the post-depositional unlithified, strand line / lake shore after post depositional burrowing caused by organisms.
