CHAPTER-I

1.1 INTRODUCTION

The present investigation is the outcome of the palynofloral studies carried out by the author on the subsurface Paleogene sediments encountered in wells drilled by ONGC at Gandhar, Pakhajan, Dahej, Palej and Matar areas, Broach Depression Cambay Basin (Fig.1.1). As is well known, Broach Depression in the southern Cambay Basin lying between Gandhar river in the north and Narmada river in the south started developing at the end of Mesozoic, simultaneous to the formation of Cambay Graben and the associated volcanic activity. The volcanic rocks known as Deccan Basalts ultimately acted as the technical basement over which a thick pile of Tertiary sediments were deposited.

Intensive exploration in Paleogene sequences carried out by the ONGC has led to discovery of commercial qualities of hydrocarbon in several potential structural features. The first Cambay Well-1 was drilled in 1958 and oil was discovered in an anticline strucutre northeast of Cambay Town which further promoted detailed paleontological, palynological, Geological and Geophysical investigations on the Paleogene sequences forming the main producing horizon. Since then, the large volume of subsurface data has accumulated enabling the proper understanding of the tectonics and structural features of the basin. It is generally considered that the paying horizons of this region range in the age from Paleocene to Oligocene.

Although several studies were undertaken on the biostratigraphy of the Paleogene sediments of Cambay Basin, western India, there has remained a gap in our knowledge of the palynostratigraphy and depositional environments

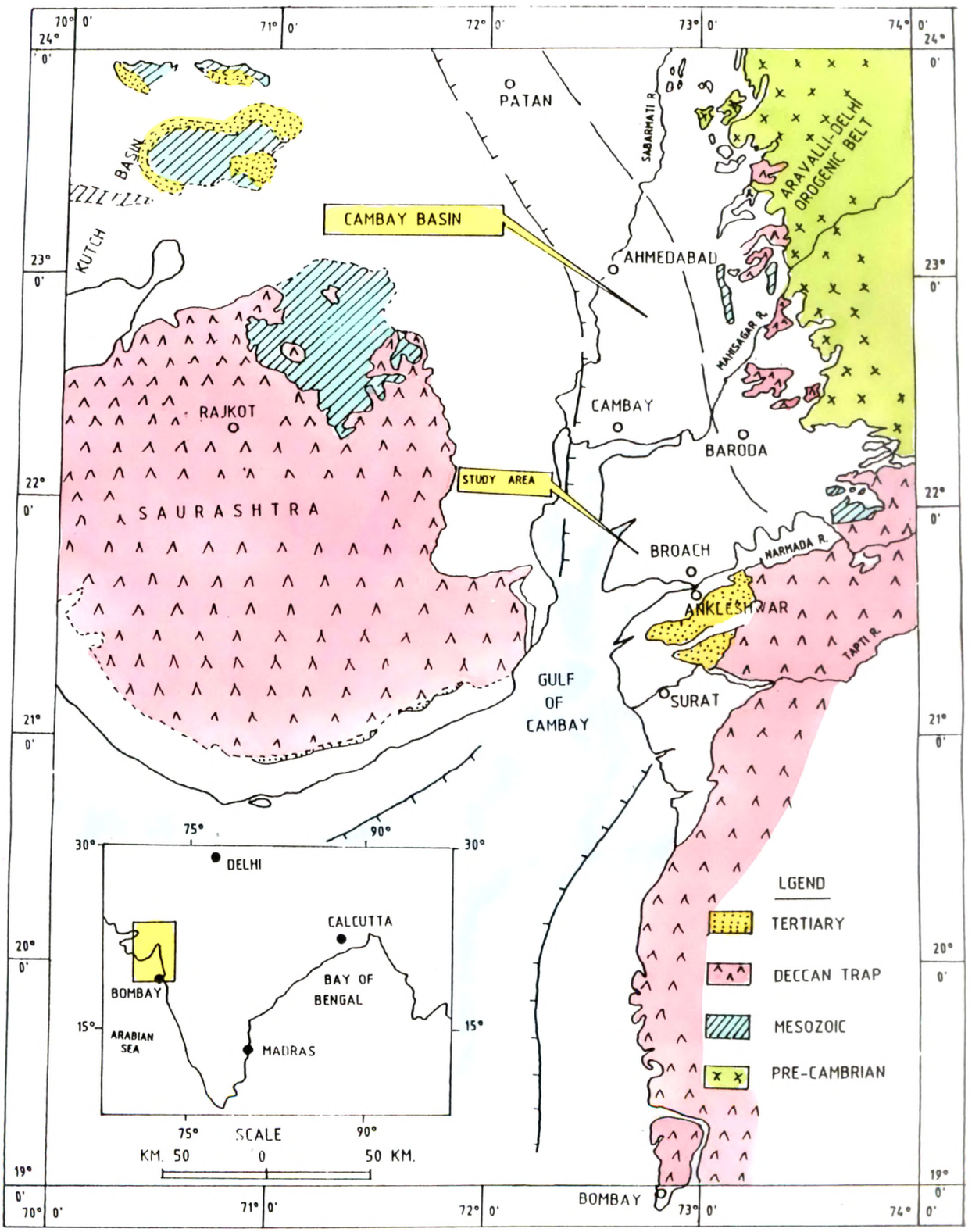


FIG. 1·1 LOCATION MAP OF CAMBAY BASIN, INDIA.

of Paleocene-Oligocene interval. This interval is represented by Olpad Formation, Cambay Formation, Ankleshwar Formation and Dadhar Formation in Broach Depression, south Cambay Basin. These formations are especially well developed in subsurface crop as revealed in the shallow wells drilled by Oil and Natural Gas Commission at Gandhar (Gandhar-A, B, C & D), Pakhajan (Pakhajan-A), Dahej (Dahej-A), Palej (Palej-A) and Matar (Matar-A) areas in Broach Depression, south Cambay Basin (latitude 21° 40' - 22° 15' N and longitude 72° 30' - 73° 15' E). The whole area which formulates author's area of investigation covers approximately 3800 sq.km and contains considerable thickness of Paleogene sediments (approximately 0.7 km).

Cores and cuttings obtained from these wells (750 samples) were processed and analysed for detailed palynofloral distributions to establish palynostratigraphy and paleodepositional environments prevailing during the Paleocene to Oligocene stratigraphic period.

The aim of the study has been to evolve biostratigraphic zonations based on the palynofossils, establish stage boundaries for the different statigraphic sections and postulate the possible paleodepositional environments and finally attempt correlation for the Paleogene sequence in Broach Depression of south Cambay Basin. The work is intended to provide a proper lead in support of future hydrocarbon exploration in the basin.

1.2 SCOPE OF WORK

Gandhar, Dahej and Pakhajan areas in the western rising flank of the Broach syncline of Jambusar-Broach block of Cambay basin have gained considerable importance because of the commercial grade oil discovered here in several potential oil bearing structures by the Oil and Natural Gas Corporation Ltd. of India. Many of the geological studies covering this block

have revealed that the accumulation of oil in several of the identified structures is selectively controlled by the lithofacies distributions, various other reservoir characteristics and tectonic variabilities in the Basin. As a result and especially from the hydrocarbon point of view, the Paleogene including the Paleocene, Eocene (Lower, Middle and Upper) and Oligocene sedimentary sequences are considered to be of prime importance for the commercial oil exploration. Many of the earlier investigations are therefore aimed at confirming the tectonic framework and Basin configuration of the Broach Depression, south Cambay Basin and are based on seismic data supplemented by lithologs and electrologs, their evaluation and interpretations. Additional information based on petrographic and litho-biostratigraphic data considering the foraminiferal studies of the well sections of the above area have also been worked out by the ONGC Regional Geological Laboratories, Baroda and by the Keshav Deva Malaviya Institute of Petroleum Exploration, Dehradun. Thus, a wealth of data is generated on the various aspects of the basin. However, detail information and inventory on palynofossils and their further implications for the basinal evaluation still remains to be emphasised.

With the above objectives in mind, the present author has selected eight exploratory wells drilled by the Oil and Natural Gas Corporation Ltd. viz. Gandhar-A, B, C, D, Pakhajan-A, Dahej-A, Palej-A and Matar-A to carry out his palynological investigations. The main aim of the investigation, being to present a Paleogene Biostratigraphic zonation, based on palynofossils, recognition of various strata boundaries in different well sections, interpretation of paleodepositional environments and finally to bring out correlation of the Paleogene sequence of Broach Depression of the south Cambay Basin. His studies are likely to provide a lead and support towards the hydrocarbon exploration in future. It is worth mentioning here that palynofloral assemblage and their space and time relationship in the area of authors study have been presented in detail for the first time in this thesis.

1.3 AREA OF STUDY

(a) Geology of Broach Depression

The interacratonic Cambay Graben is known to have formed at the close of the Mesozoic period by development of tentional faults along its margin accompanied by large scale volcanic activity. This was further evolved into five tectonic blocks, namely Narmada Block, Jambusar-Broach Block, Cambay-Tarapur Block, Ahmedabad-Mehsana Block and Patan-Tharad-Sanchor Block (Mathur et al, 1968), each with different degree of tectonic intensity controlled by basement faults. The tectonic block between Dadhar and Narmada river of the Broach Depression which forms the basis of the present study experienced a prolonged tectonic activity which continued till as late as Early Pleistocene. The Tertiary sedimentary cover unconformably overlying the Broach Depression is quite thick and is approximately mroe than .7 kms. in the deepest part of the depression in the vicinity of Gandhar area.

The Paleogene stratigraphy of Broach Depression was originally evolved by Chandra and Chaudhary (1969, fig.3.7) and later modified by Rao (1969) and Sudhakar and Basu (1973, fig.3.1). The other important workers who have contibuted significante work for the Cambay basin include, Mehrotra and Ramakrishna 1981, Madan Mohan 1982, Mehrotra et al.,(1983),Sastry et al.,(1984),Sharma 1991, and Pandey,1993 (Figs.3.2,3.3,3.4,3.5,3.7,3.8).

(b) Present area of work

The present study is confined to Paleogene sequence encountered in Gandhar, Pakhajan, Dahej, Palej and Matar areas of Broach Depression, South Cambay Basin. These areas are situated on the western rising flank of the Broach syncline of Jambusar-Broach block of Cambay Basin. The block

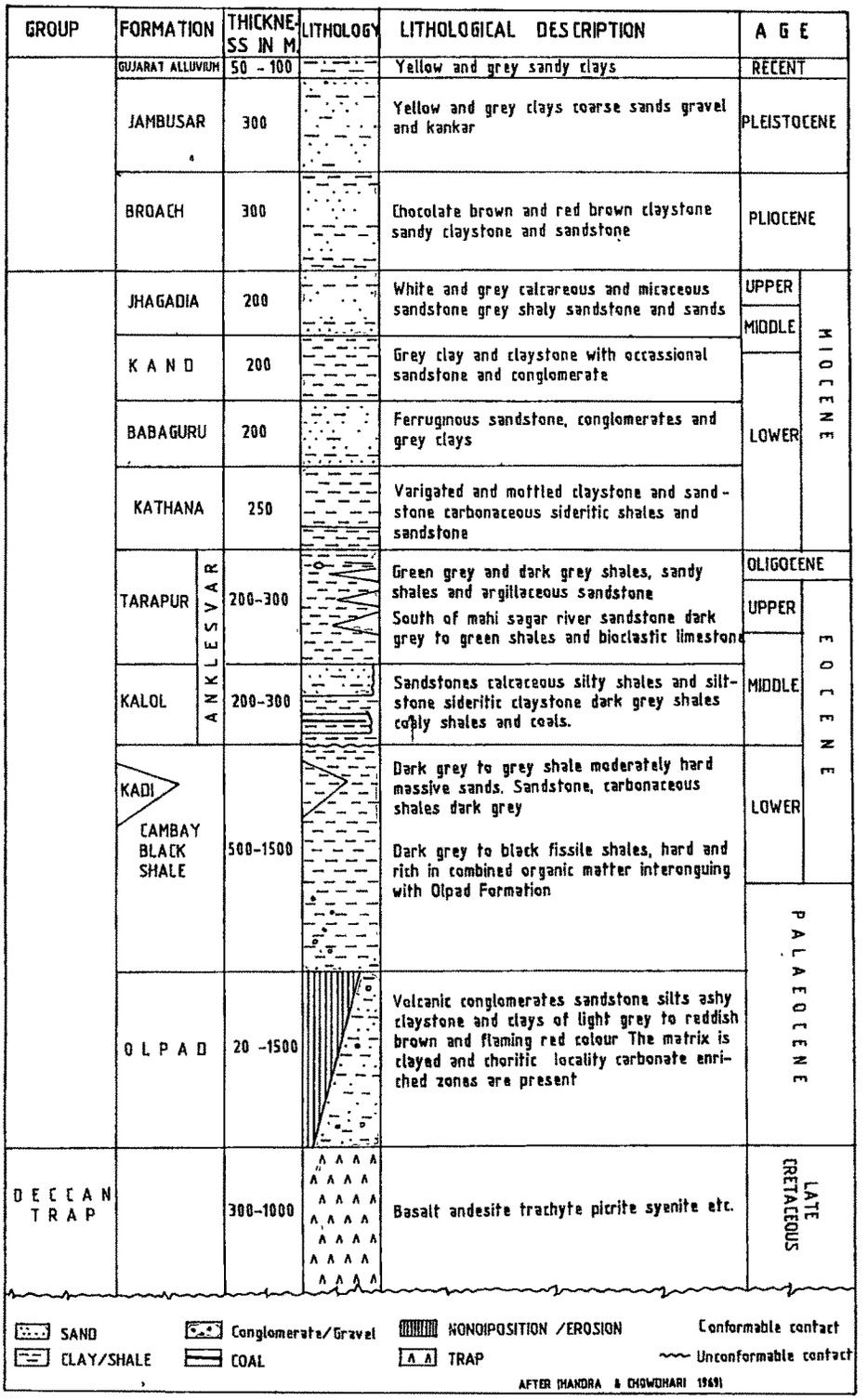


FIG.3·6 GENERALISED STRATIGRAPHIC COLUMN OF THE CAMBAY BASIN

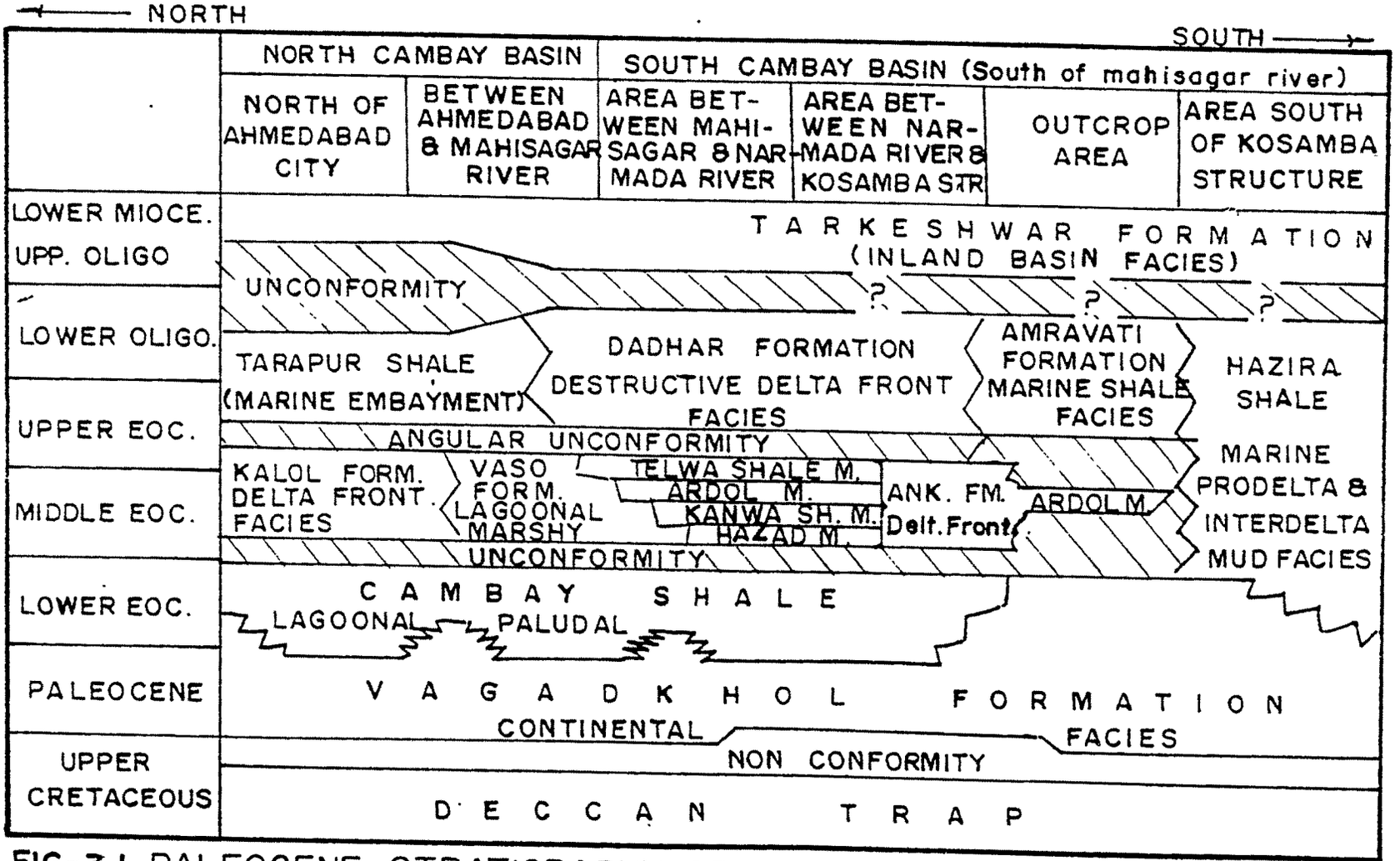
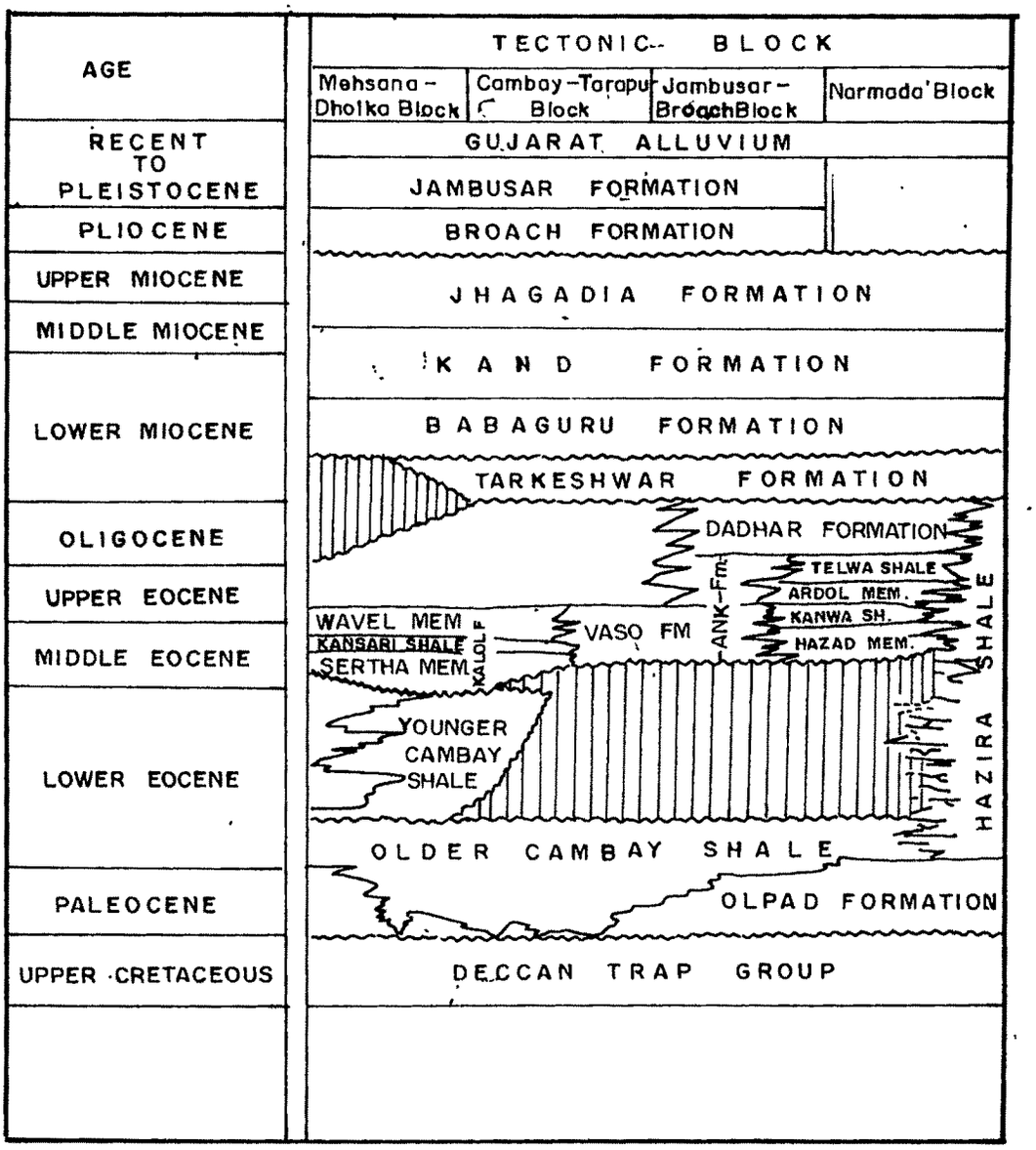


FIG-3.1 PALEOGENE STRATIGRAPHY OF CAMBAY BASIN.

(AFTER SUDHAKAR & BASU 1973)



(AFTER MEHROTRA & RAMAKRISHNA, 1981)

FIG-3.2. STRATIGRAPHY OF CAMBAY BASIN

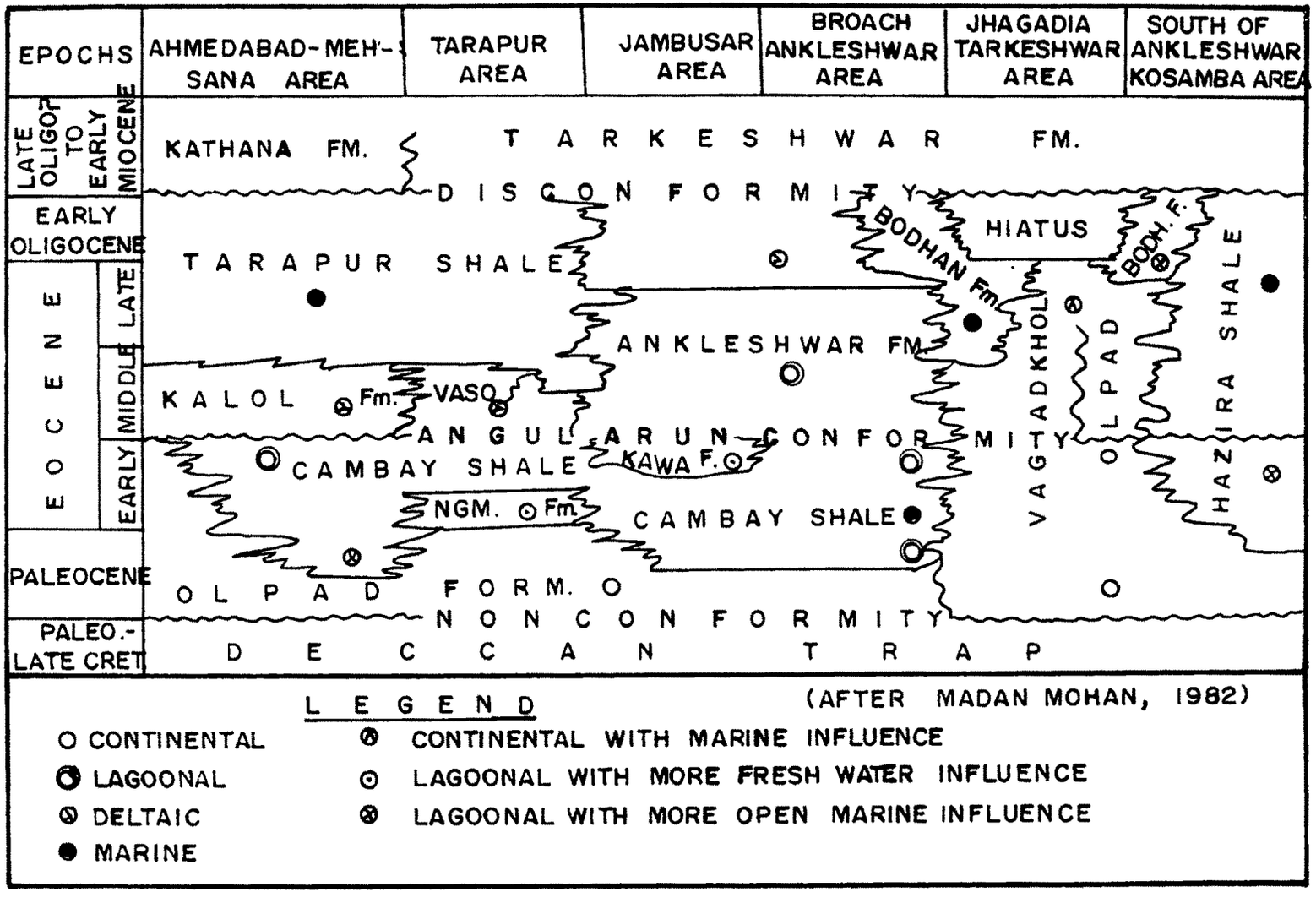


FIG-3.3. STRATIGRAPHY OF CAMBAY BASIN

STRATIGRAPHIC CORRELATION CHART OF CAMBAY BASIN

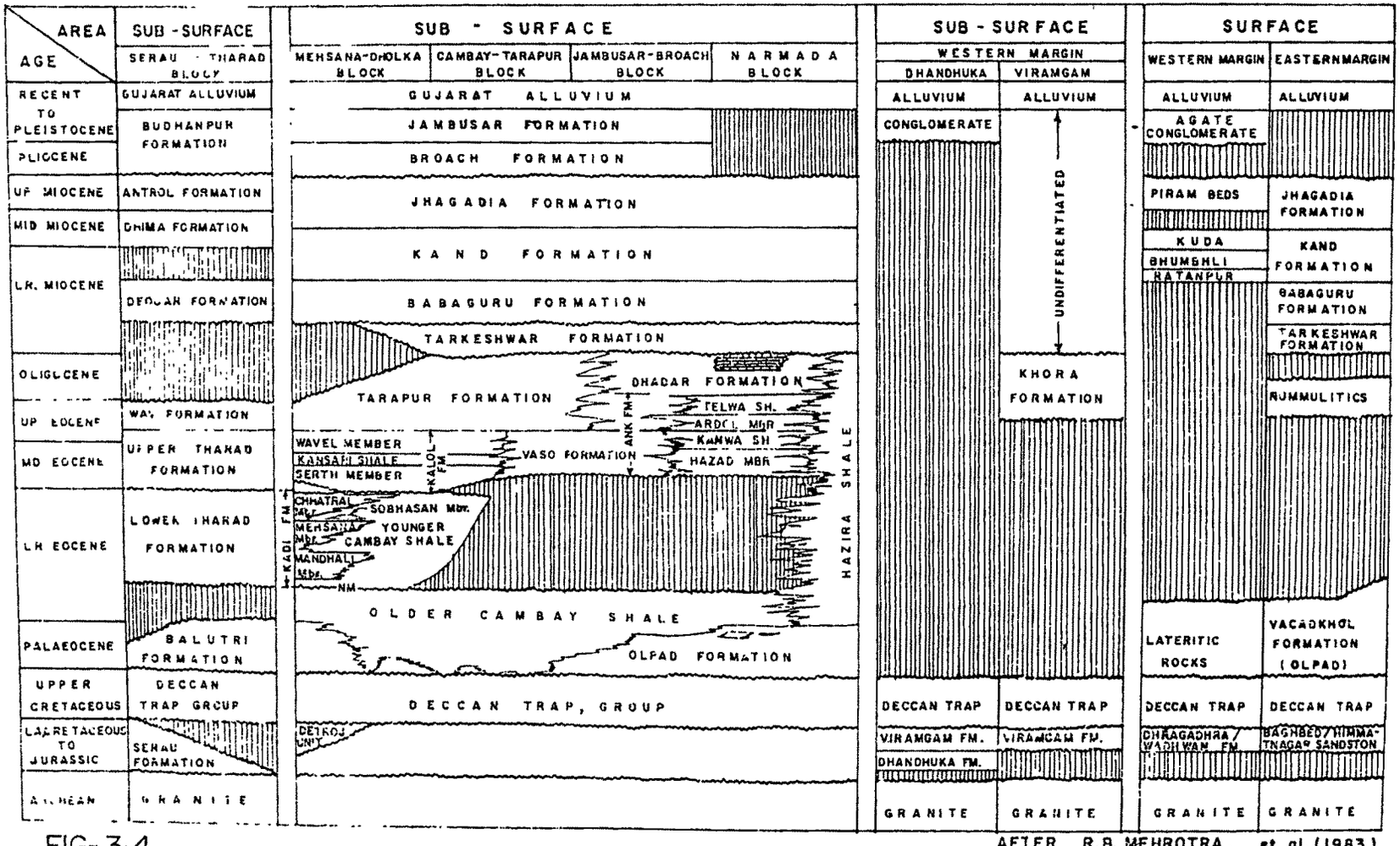


FIG-3·4

AFTER R.B. MEHROTRA, et. al. (1983)

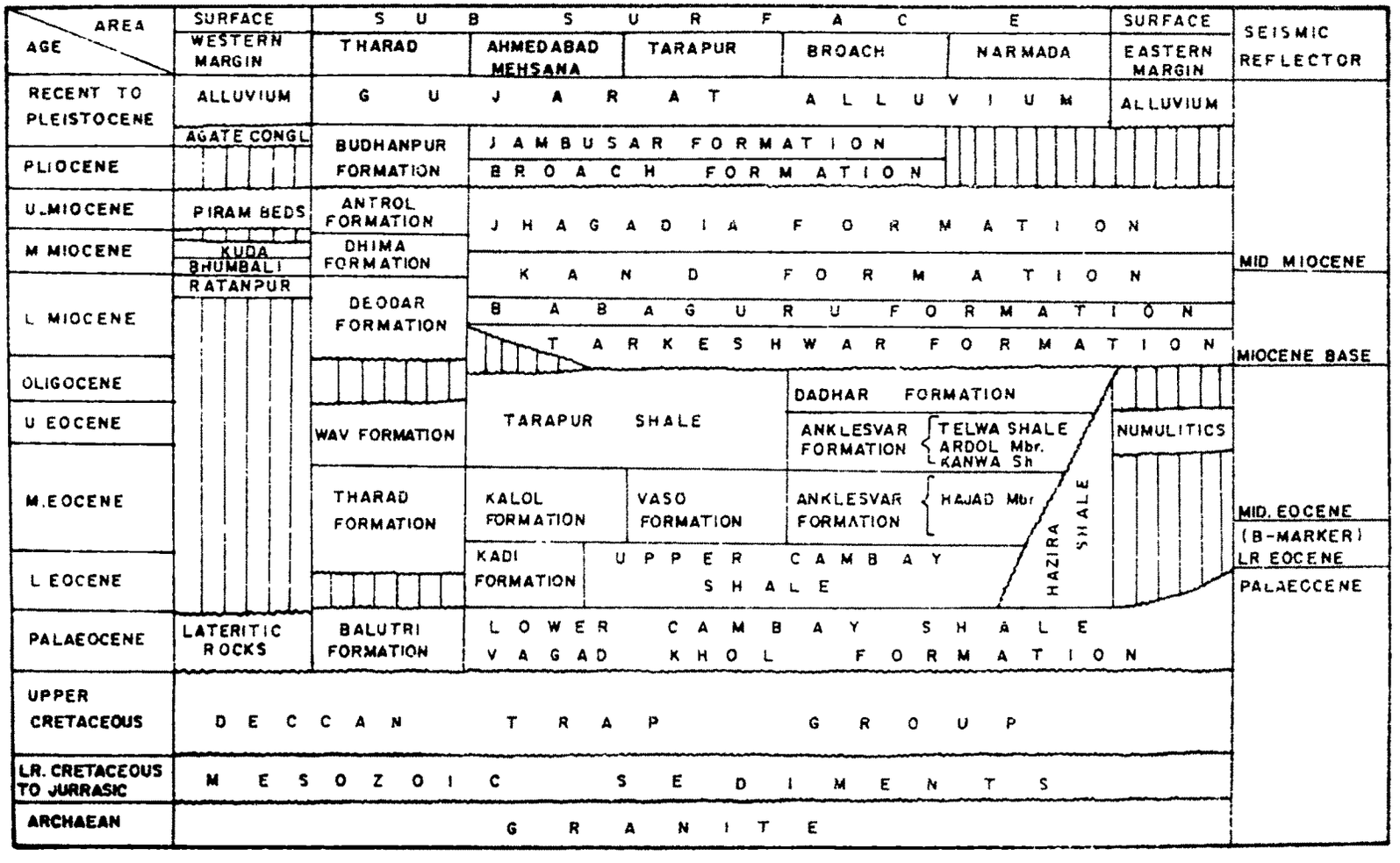


Fig. 3·5. GENERALISED STRATIGRAPHY OF CAMBAY BASIN (after C.V.S. Sastry et. al., 1984)

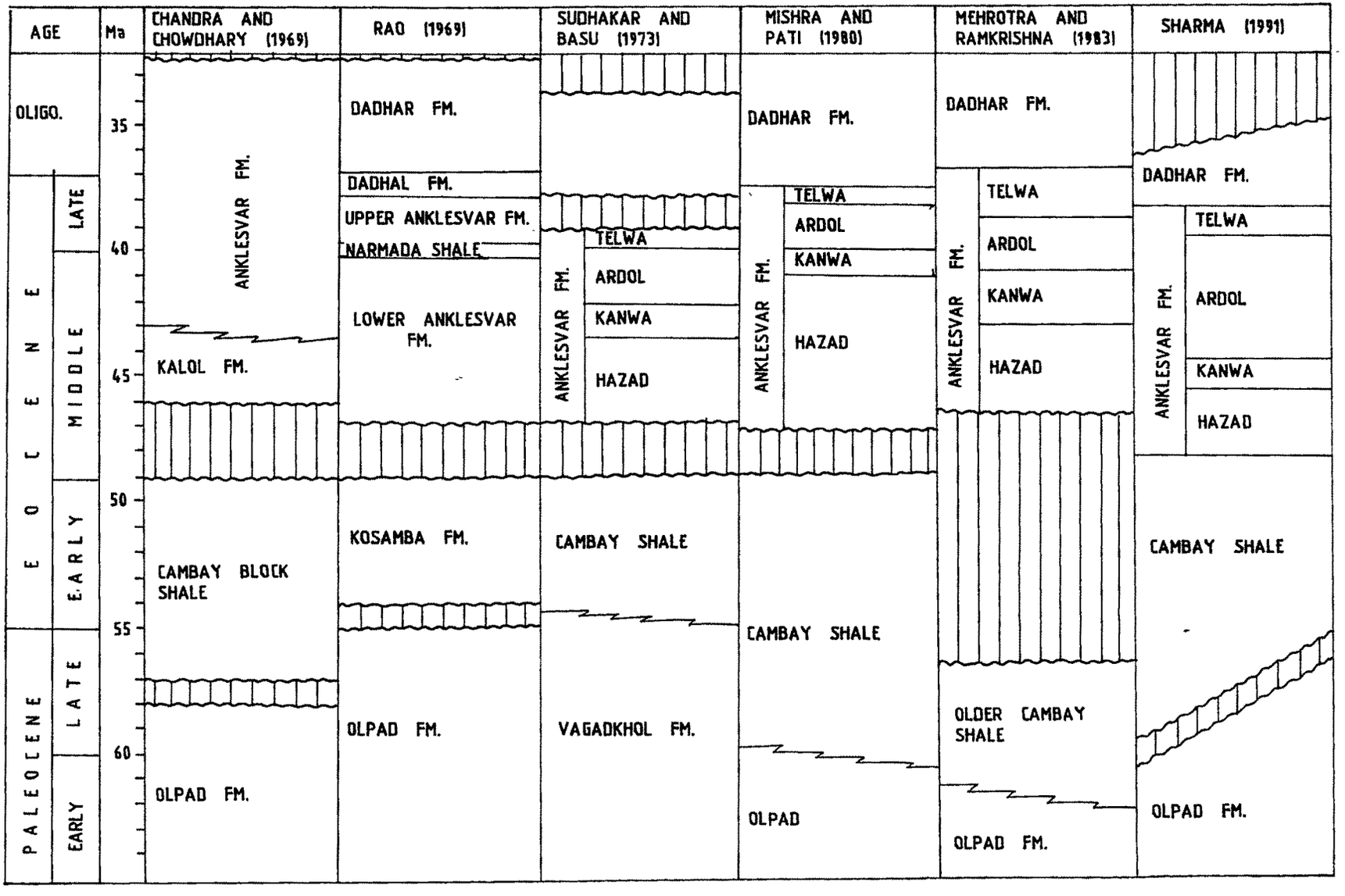


FIG. 3·7 – SUBSURFACE PALEOCENE STRATIGRAPHY OF BROACH DEPRESSION (AFTER SHARMA, 1991)

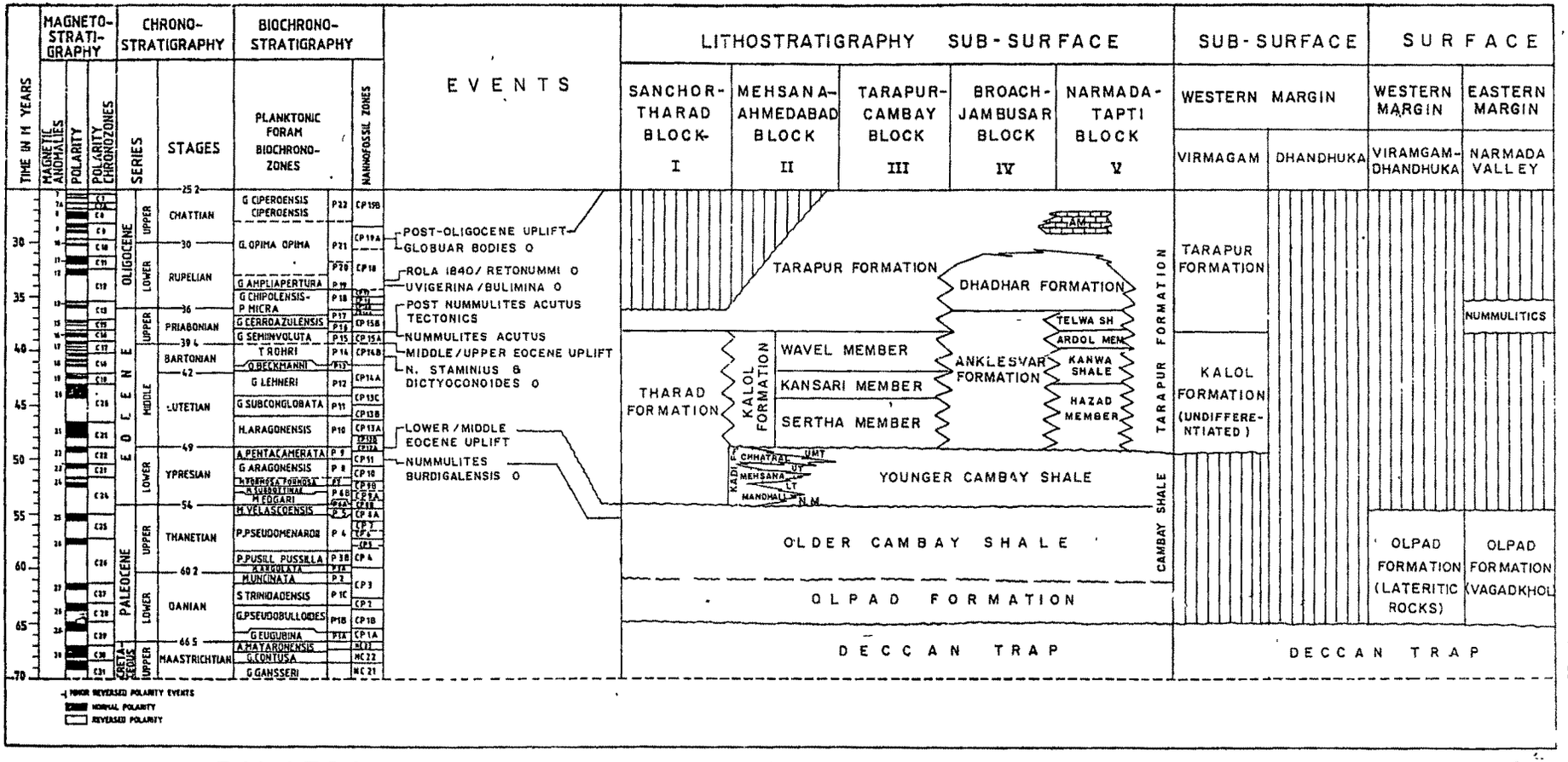


FIG-3·8 PALAEOGENE STRATIGRAPHY OF CAMBAY BASIN (AFTER PANDEY et al, 1993)

is bounded by Mahisagar river in the north and Narmada river in the south, Aravali swell in the northeast and Deccan Trap exposures in the east-south-east and west.

Gandhar, Dahej and Pakhajan areas on the western rising flank of the Broach syncline of Jambusar-Broach block of Cambay Basin are considered to be very important because commercial quantities of oil is discovered in several potential structures developed in these areas. Detailed geological studies have revealed that the accumulation of oil in several structures have been selectively controlled by the lithofacies variations, variable reservoir characteristics and tectonic features. As such from hydrocarbon point of view Paleocene, Eocene (Lower, Middle and Upper) and Oligocene sediments are considered to be very important in these areas. With this background, a detailed palynological study of the Paleogene sediments has been undertaken by the present author. Attempts have been made to refine the chronoboundaries of these Paleogene stratigraphic units with the latest palynostratigraphic evidences.

The study pertains to 8 exploratory wells drilled by ONGC in the Broach Depression, south Cambay Basin. Fig.1.2 shows the locations of these wells alongwith the structural framework of the area.

The present study by the author is restricted to the four formations: located in the well secton 1. Olpad Formation, 2. Cambay Formation, 3. Ankleshwar Formation and 4. Dadhar Formation. These are briefly described below:

Olpad Formation

Rao (1969), and Chandra and Chawdhary(1969)have defined Olpad Formation with the designated type section in Olpad well between the interval 1468 and 2443 m. In the study area, this formation is encountered in three wells

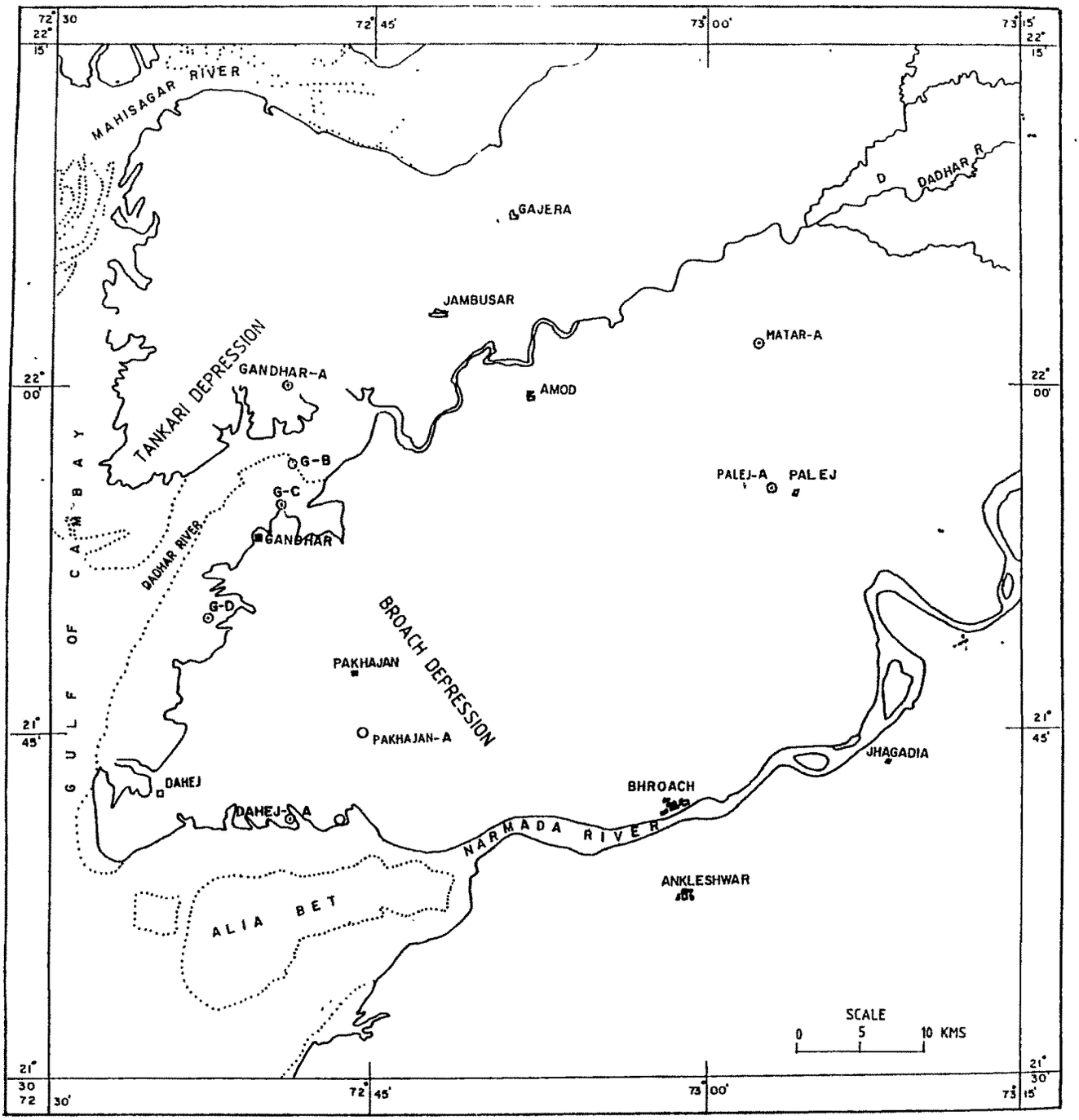


FIG. 1·2 MAP SHOWING LOCATIONS OF THE STUDIED WELLS IN BROACH DEPRESSION, SOUTH CAMBAY BASIN.

between the interval 4320-4500 m, 1835-2000 m and 1541-1800 m of Gandhar-A, Palej-A and Matar-A respectively. The Olpad Formation unconformably overlies the Deccan Trap and has gradational and intertonguing relationship with overlying Older Cambay Shale. However, along the basin margins and Mehsana Horst, its lower contact is unconformable with an erosional unconformity while the gradational contact is clear in Ankleshwar and Kosamba wells at the deeper part of the basin. Lithology of Olpad Formation mainly consists of volcanic conglomerate, sandstone, silt, shale, claystone and clays exclusively derived from Deccan Trap Basalt.

Cambay Shale Formation

This formation is first proposed without designation of any type section by Zubov et al. (1966). It shows extensive development in the subsurface core samples throughout the Cambay and is not exposed on the surface outcrops. The formation has unconformable relation with overlying Kalol Foramtion in the north and Ankleshwar Foramtion in the south. It has conformable, gradational and intertonguing contact with the underlying Olpad Formation. At places it directly overlies unconformable the Deccan Trap. The lithology is mainly of dark grey, black, fissile, frequently laminated and bituminous shale with occasional bands of sands and siltstones. Shales are often pyritic and rich in organic matter. Oolitic claystone is occasionally present towards its lower part.

Ankleshwar Formation

This formation was first defined by Rao (1969) who divided it into the Lower and Upper Ankleshwar Formation separated by a Shale unit. Chandra and Chowdhary (1969) redefined these formations as Ankleshwar Formation

by designating a type section in Ankleshwar well between the interval 800-1190 m without any formal subdivision. This formation is well developed in south Cambay Basin in Jambusar-Broach and Narmada-Tapti blocks. The extent of the lower part of formation is in the area around Ankleshwar, Narmada-Tapti Block while the upper part of the formation extends towards Jambusar, Kosamba and Jagadia areas in Jambusar-Broach Block in south Cambay Basin. The Ankleshwar Formation is conformably overlain by Dadhar Formation and unconformably underlain by Cambay Shale. The lithology of the lower part of the formation is mainly composed of alternating sequence of shale sandstone and claystone. The upper part of the formation in its type section consists of claystone, shale, subgreywacke, sand, carbonaceous shale and arenaceous limestone.

In the study area, this formation is encountered between the intervals in wells Gandhar-A (2573-2904m), Pakhajan-A(3445-3835m), Dahej-A(2485-3086m), Palej-A(1697-1835m) and Matar-A(1396-1500m).

Dadhar Formation

This formation was first defined by Rao (1969) and subsequent workers have retained this nomenclature. The type section is designated in Dadhar well between the interval 2265 m and 2381 m. Dadhar Formation conformably underlain and overlain by Ankleshwar Formation and Tarkeshwar Formation respectively. This unit mainly consists of coarse to medium grained, friable sandstone and moderately hard dark grey shale.

1.4 SAMPLING PROCEDURE AND METHODOLOGY

The core and cutting samples from the eight wells (Gandhar-A, B, C, D, Pakhajan-A, Dahej-A, Palej-a and Matar-A) were collected from the ONGC repository at Regional Geological Labs.,Baroda and Ankleshwar Project. Samples thus collected are further analysed for detailed palynological studies. The locations of these wells are shown in Fig.1.2. The details of the procedure followed and the methodlogy used are given below:

PROCESS FOR RECOVERY OF ORGANIC WALLED FOSSILS :

Extraction of Pollen Microfossils

The processing techniques adopted in this study are mainly those procedures as described by Mathur et al. (1991) and Staplin et al (1960). The different steps involved in the maceration techniques are as below:

About 50 grams of material was taken and thoroughly cleaned by using distilled water to avoid atmospheric contamination. After washing, it was transferred to an enamelled bowl and kept in an electric oven at 80°C for drying.

The dried material was then crumbled in a contamination free iron pestle and mortor upto the size of 2 to 3 mm granules and transferred to propylene beakers of 500 ml.

The material was then treated with 10% hydrochloric acid (HCL) to remove the carbonates. The samples were treated till the effervescence ceased and were thoroughly stirred with plastic rods to maintain

uniform chemical reaction. Distilled water was then added to the material and was then kept an hour for settling.

After complete removal of carbonates the residue was treated with 40% hydrofluoric acid (HF) which was added slowly drop by drop to remove silicates and the whole residue was then allowed to stand for 6 to 8 hours to dissolve silica. The macerated residue was washed several times with distilled water to remove all traces of acids.

OXIDATION OF ORGANIC MATTER :

After washing, the material was treated with concentrated Nitric acid (HNo_3) to oxidise the organic material. The material was then allowed for 6 hrs. to oxidise properly. Then the acid was decanted slowly and residue was washed several times with distilled water to free it from acid.

During the next stage, the macerated material was transfered into 50 ml capacity polypropylene centrifuge tube and centrifuged at 2000 rpm for 4 minutes. The material was then washed several times with distilled water till the material become acid free. Finally, the residue was treated with potassium hydroxide (KOH) and mixed thoroughly for cleaning the dark organic matter and kept for 15 minutes. Material thus recovered was then rotated at the speed of 2000 rpm for five minutes. The residue was again washed several times through centrifuge till the decanted liquid become colourless. After washing, the tube was inverted over the blotting paper for maximum removal

of liquid from the residue.

After the above step, sufficient volume of heavy liquid (Zinc iodide, potassium iodide and cadmium iodide 2:1:1) was added to moist acidified residue and mixed thoroughly by using plastic rod for good separation. After balanacing each centrifuge tube through additional heavy liquid, centrifuged the material between 800-900 rpm for 30 minutes.

After heavy liquid separation, the fossil rich residue was transferred into the 15 ml centrifuge glass tube and washed residue with distilled water by using centrifuge. Then the glacial acetic acid was added to the residue and centrifuge. The acetolysis material was decanted. This was followed by several washings with distilled water. Seive technique was also employed wherever it is found necessary.

PREPARATION OF PERMANENT SLIDES :

Slides were prepared by smearing the macerate mixed with polyvenyl alcohol on a microscopic cover glass 22x50 mm no.'0'. These were then placed in a dust free electric oven till the smears dried. A few drops of Canada Balsam sufficient enough to cover the area of cover glass containing dried smears was then gently placed over the Canada Balsam and dried by using electric oven till the cover glasses were firmly fixed to the micro-slides. Depending upon the yield of fossiliferious residue 4 to 5 slides were prepared by using complete residue. After cooking the slides in a heating chamber suitably labelled.

The palynological slide thus prepared were used for scanning, counting and photomicrographical studies. All these slides were scanned under leitz orthoplan microscope.

To facilitate the locating of the spore and pollen grains, the stage reading to the microscope was noted. Identifiable and well preserved specimens of various species belonging to different genera were counted, recorded and microphotgraphed. Almost all the microphotographs have been taken using 40 x and 100 x objective with 10x eye piece.

For the detailed studies, the frequency corresponding to the absolute number of palynofossils occurring at different depths was taken into consideration for a better comprehension. The vertical distributional patterns of taxa and their quantitative variations are depicted in frequency diagram (Charts 1.1A, 1.1B, 1.1C, 1.1D, 1.1E).

The type material has been catalogued as BDG-1, BDG-2, BDP-1, BDD-1, BDPJ-1, BDM-1 and are at present in the personal collection of the author. For the catalogue, the following abbreviations have been used:

BDG-1 : Broach Depression Gandhar (Gandhar-A).

BDG-2 : Broach Depression Gandhar (Gandhar-C).

BDP-1 : Broach Depression Pakhajan (Pakhajan-A).

BDD-1 : Broach Depression Dahej (Dahej-A).

BDPJ-1 : Broach Depression Palej (Palej-A).

BDM-1 : Broach Depression Matar (Matar-A).

1.5 BRIEF DESCRIPTION OF THE WELL SECTIONS AND DETAILS OF CORES AND CUTTINGS

The core and cutting samples from the eight wells were collected from the ONGC repository at Regional Geological Labs.,Baroda and Ankleshwar Project,Ankleshwar and were analysed for detailed palynological studies. The location of the eight wells is shown in Fig.1. About 750 core/cutting samples each weighing 50 grams dry weight were used for the study. The details of these wells and the lithological description of cores and well cuttings are given below:

Well No.1 (Gandhar-A)

The well Gandhar-A is located on the rising flank of Tankari syncline in Jambusar-Broach block. The well was drilled down to depth of 4500 m and it has penetrated Olpad Formation (4320-4500 m), Cambay Formation (2904-4320 m),Ankleshwar Formation (2573-2904 m) and Dadhar Formation (2212-2573 m).

Dadhar Formation 2212 -2573 m)

It is characterised by alternation of sand/shale sequences. At the upper section, it consists of sand, shale alternations and thick sand bands. At the lower portion the sands are very fine to coarse grained, subangular to subrecounded, poorly sorted. The shales are of light grey to dark colour, moderate, fissile and feebly calcareous. The upper section is rightly fossiliferous with abundance fo foraminifera, lower section consits predominantly sand and globular bodies. In thin section, sand colourless to dirty white (average 75%), moderate to coarse grained, angular to sub-rounded, moderately sorted and calcareous is often observed.

Ankleshwar Foramtion (2573- 2904 m)

The Ankleshwar Foramtion includes four members :

Telwa Shale Member (2573-2606 m)

This member includes shales (60%) which are of light grey, greenish grey, moderately fissile in nature and often hard. Sandstone which contains 20% of the total thickness is white to dirty white, fine to medium grained, subangular to sub-founded, moderately sorted and calcareous, while claystone which comprise about 20% are greenish grey to greyish white occasionally reddish brown, moderately hard.

Ardol Member (2606-2740 m)

The Ardol Member represented in the above interval mainly consists of sandstone, shale/siltstone alternations. Sandstones are dirty white, medium to coarse grained moderately sorted, subangular to sub-rounded mostly calcareous Shales are dark grey to greenish grey in colour,non-fissile,feebly calcareous.

Kanwa Shale Member (2740-2777 m)

This member mainly consists of grey to dark grey, moderate hard non-fissile and non-calcareous shale.

Hazad Member (2777-2904 m)

This member consists of sandstone/sand layers with intevening shale. Sands are fine to very fine grained rarely coarse grained, angular to sub-angular. Shales are grey to dark grey moderatley fissible and hard. All the twelve sand shale layers within this member are present here, though the bottom sands are thinned. The total thickness of this Member is found to have decreased when compared with the thickness developed in other part of Gandhar area.

Cambay Shale Formation (2904-4320 m)

This formation is characterised by monotoneous shale with thin layer of coal and claystone interbedded occasionally. Shales are of light to dark, dark to very dark, moderately hard to compact feebly to non - calcareous. Coal is black, brittle and striated. Siltstone is dark brownish grey, modera-

tely hard occasionally containing carbonaceous matter, sandy and noncalcareous. Sandstones are often dirty to brownish and dirty to greyish white, fine to medium grained subangular to sub-rounded moderately sorted and calcareous in nature.

Olpad Formation (4320-4500 m)

Mainly consits of variegated claystone and trap wash and thin sand bands.

Well No.2 (Gandhar-B)

This well is situated 6 km away from Gandhar-A in western margin of Broach depression. The well was drilled down to depth of 3297 m and it has penetrated Cambay Formation (2934-3297 m), Ankleshwar Formation (2312-2934 m) and Dadhar Formation (2212-2312 m, chart 1.2A, 1.2B).

Dadhar Formation (2212-2312 m)

It is characterised by alternation of sand and shale. At the upper section sand, shale alternations are thick while at the lower portion, sands are very fine to coarse grained, subangular to subrounded, poorly sorted. Shales are of light grey to dark grey colour, feebly calcareous.

This section is richly fossiliferous with abundance of foraminifera. Lower section consits of predominently sand (2275-2312 m), and globular bodies are observed.

Ankleshwar Formation (2312-2934 m)

Telwa Shale Member (2312-2330 m)

In Gandhar-B, thin section of Telwa Member is developed which predomi-

nently consists of shales. The thickness of this member is about the same as that of Gandhar-3 but is considerably reduced as compared to Gandhar-1 and Gandhar-2. Shales are light grey to dark grey, greenish grey, moderately fissile and moderately hard.

Ardol Member (2330-2741 m)

This section consists of sandstone,shale/siltstone in alternations. Sandstones are dirty white, medium to coarse grained, subangular to subrounded mostly calcareous. Shales are light grey to dark grey and greenish in colour, nonfissile, feebly calcareous.

It has been observed that thickness of this member is considerably increased as compared to Gandhar-1 and Gandhar-2. Bottommost sand which is proved to be hydrocarbon bearing at Gandhar-3 is poorly developed in this well.

Kanwa Shale Member (2741-2752 m)

This section consists mainly of shale. Shales are grey to dark grey, moderately hard, nonfissile calcareous.

Hazad Member (2752-2934 m)

This section consisting mainly of sandstone/sand layers with intervening shale. Sands are fine to very fine grained rarely coarse grained and angular to subangular.

Shales are grey to dark grey, poorly fissile, moderately hard and compact. Bottom sands have thinned. The total thickness of sand member has also decreased when compared with the thickness developed in Gandhar-1 and Gandhar-2.

Cambay Shale Formation (2934-3297 m)

This formation is characterised by monotonous shale with thin layer of coal and claystone interbedded occurrence. Shales are of light to dark to very dark, moderately hard and compact, feebly to noncalcareous.

Well No.3 (Gandhar-C)

The well Gandhar-C is located in the north western part of Gandhar structure. This well was drilled down to a depth of 3048 m and it was cored continuously in the Hazad Member. It has penetrated Cambay Formation (2990-3050 m) and Ankleshwar Formation (2750-2790 m). The drilled cuttings/core samples are not available above 2750 m for the study.(Chart 1.3).

Ardol Member (2750- 2790 m)

This member is characterised by alternation of sand and shale. Sands are medium to fine grained, colourless to dirtywhite, subangular, moderately sorted and noncalcareous, dark grey, poorly fissile, moderately hard, silty, feebly calcareous.

Kanwa Shale Member (2790-2802.5 m)

This section is characterised by light to dark grey colour shale, moderately hard, well fissile, with some dark brown bands of siltstone.

Hazad Member (2802.5-2990.5 m)

This member predominantly consists of sand and shale altertions of varying thickness. Shale is light grey to dark grey, moderately hard and compact, fissile, noncalcareous. Sand is colourless, dirtywhite to yellowish white, medium to coarse grained, subangulrar to subrounded, moderately well sorted.

Argillaceous sandstone dirty white to greyish white mixed with clay matrix are sometimes observed.

Cambay Shale Formation (2990-3050 m)

This section predominently consists of shale. It is in brownish grey to black sometimes dark grey in colour, hard and compact, fissile brittle noncalcareous and includes carbonaceous matter.

Well No.4 (Gandhar-D)

This well is situated on the southwestern part of main Gandhar prospect and it has penetrated Cambay Formation (3052-3125 m), Ankleshwar Formation (2538-3052 m) and Dadhar Formation (2319-2538 m). The well is terminated within the Cambay Shale.

Dadhar Foramtion (2319-2538 m)

This formation is characterised by alternation of shale and sand beds. Sands are colourless to white, fine to coarse grained, poorly sorted and calcareous. Shales are grey to dark grey, well fissile and feebly calcareous.

Ankleshwar Formation (2538-3052 m)

Telwa Shale Member (2538-2548 m)

Predominently shale, intercalated with thin sand layers. Shales in light to dark grey, occasionally greenish grey, soft to moderately hard and moderately fissile.

Ardol Member (2548-2877.5 m)

This member is characterised by alternation of thick beds of sand

and shale with intermingling siltstone bands. Traces of calcareous matter are present. Sands are medium to fine grained occasionally coarse grained. colourless to dirty white, occasionally pinkish and yellowish, subangular, moderately sorted and non-calcareous. Dark grey, poorly fissile, moderately hard, silty, feebly calcareous at places, shale from 2600 m downward.

Kanwa Shale Member (2877.5-2894.5 m)

This member is characterised by shale light to dark grey in colour, moderately hard, well fissile some with thin greenish to dark brown siltstone bands. These shales are occasionally calcareous.

Hazad Member (2894.5-3052 m)

This member is characterised by alternation of sand and shale beds of varying thickness. Sandstones are fine to medium grained occasionally grading into siltstones, moderately hard and fairly sorted. Shale is light grey to dark grey, moderately hard, compact and fissile.

Cambay Shale Formation (3052-3125 m)

This section is characterised by monotonous shale with thin lamination of silt and sand. Shale is dark grey to greyish black, hard and compact, occasionally carbonaceous and moderately fissile, at places pyritiferous and calcareous.

Well No.5 (Pakhajan-A)

Pakhajan-A is located north east of Dahej on the western rising flank to the west of the deepest part of the Broach Depression (Fig.1.2). This well has been drilled down to 4021m, 6km SSE of village Pakhajan. It has

penetrated Cambay Formation (3835 -4000 m), Ankleshwar Formation (3445-3835 m). and Dadhar Formation (3210-3445 m , chart 1.4A, 1.4B).

Dadhar Formation (3210-3445 m)

This formation mainly consists of shale. Shale is in light grey to grey bluish and sometimes reddish brown, moderate, hard, compact, fissile and non-calcareous. Sand is in dirty white, brownish, fine to medium grained occasionally coarse grained, subangular to subrounded, poorly sorted, feebly calcareous, occasionally variegated very poor to moderate fissility. Limestone is buff coloured at places dark grey hard and comapct, fossiliferous and highly calcareous. Coal, ferrugenous and calcareous matter in traces.

Ankleshwar Formation (3445-3835 m)

Telwa Shale Member (3445-3515 m)

Telwa Member predominently consists of shale. It is light to dark grey occasionally reddish brown moderate, hard and compact, fissile and non-calcareous. Sand/sandstone is 10-15% dirty white to milky white, pale yellowish-medium to fine grained subangular to subrounded and poorly sorted.

Ardol Member (3515-3615 m)

This member consists of shale (60-80%) which is light to dark grey, moderately hard and compact, fissile and calcareous occasionally calcareous. Sand with 5-20% is dirty white occasionally yellowish white fine grained mostly. Occasionally it is medium grained subangular to subrounded, fairly well sorted and calcarious.

Kanwa Shale Member (3615-3670 m)

This member predominently consits of shale (60-80%). Shale is in

dark grey sometimes light brownish, moderate hard and compact, fissile brittle feebly and calcareous occasionally reddish brown. Sand/sandstone is in dirty white to milky white fine to medium grained subangular to sub-rounded, fairly sorted and calcareous.

Hazad Member (3670-3835 m)

It mainly consists of shale, light to dark grey occasionally black in colour, hard and compact, brittle fissile feebly calcareous sometimes carbonaceous. Sand is in dirty white to white sometimes yellowish colourless to silky white in colour, fine to medium grained subangular to sub-rounded moderately sorted and calcareous. Sometimes claystone, siltstone, calcareous matter are found in traces.

Cambay Shale Formation (3835-4000 m)

Cambay Shale Formation predominently consits of shale. It is brownish grey to black occasionally dark grey in colour, hard and compact, fissile, brittle non-calcareous and carbonaceous. Sand in minor properties when present are dirty white to milky white, colourless or yellowish, fine to medium grained occasionally coarse grained subangular to sub-rounded moderately sorted feebly calcareous. Occasionally claystone, siltstone and calcareous matter are present in traces.

Well No.6 (Dahej-A)

This well is located in the vicinity of Dahej village, on the rising western flank of the Broach Depression and it has penetrated Cambay Formation (3086-3132 m), Ankleshwar Formation (2485-3086 m) and Dadhar Formation (2300-2485 m). The drilled cuttings are not available between 3086-3132 m for the study, chart 1.5).

Dadhar Foramtion (2300-245 m)

It is characterised by alternations of thick sands separated with shale beds. A fossiliferous limestone is present towards the top of the formation in the interval 2321 to 2327 m. Sands are colourless to light grey Shales are light grey to grey, occasionally bluish grey and greenish grey poorly fissile with specks of carbonaceous matter. The formation is richly fossliferous with Nummulites sp.

Ankleshwar Formation (2485-3086 m)

Telwa Shale Member (2485-2515 m)

It consists of grey to light bluish grey shales with moderate to poor fissibility. In some core and cuttings, it is associated with thin siltstone bands.

Ardol Member (2515-2850 m)

This consists of sandstone separated by shale in between. The sands are dirty white in colour, mostly fine grained and occasionally medium, and coarse grained. Shales are light, occasionally carbonaceous, moderate to poorly fissile hard and calcareous. Siltstone are also developed in this section.

Kanwa Shale Member (2850-2866 m)

It consists of shale with rare development of sandstones and siltstones. The shales are grey to dark grey occasionally silty moderate to poorly fissile and at places calcareous. Sandstones are fine to very fine grained at places calcareous. Siltstones are grey to light brown, hard and calcareous, is present in traces.

Hazad Member (2886-3086 m)

The member consists of sandstone and shale siltstone. Sandstones are generally fine to very fine grained but medium to coarse grained sandstones are also noted. Shales are grey to dark occasionally silty, calcareous, carbonaceous and rarely pyritic.

Cambay Shale Formation (3086-3132 m)

This section could not be studied due to nonavailability of samples.

Well No.7 (Palej-A)

The Palej-A well is situated towards the eastern margin of Broach Depression. This well was drilled down to a depth of 2000 m and it has penetrated Olpad/Cambay Formation (1835-2000 m). Ankleshwar Formation (1697 -1835 m) and Dadhar Formation (1645-1697 m, chart.1.6).

Dadhar Formation (1645-1697 m)

Dadhar Formation in well Palej-A predominantly consists of claystone sandstones and shale alternations. Claystones are ash grey, bluish grey, dark grey, brown, hard, compact, non-fissile, non-sticky and non-calcareous. Sandstones are usually transparent to translucent, occasionally brown, colourless or yellowish, medium to coarse grained, subangular to sub-rounded moderate to wellsorted and non-calcareous. Shales are light grey, bluish grey occasionally brown, moderate hard to soft compact, non-fissile and non-calcareous.

Ankleshwar Formation (1697-1835 m)

Telwa Shale Member (1697-1706 m)

This member mainly consists of sandstone (80-90%) and rest shale. Sand is often colourless or yellowish, transparent to translucent medium to coarse grained, subangular to subrounded moderate to well sorted and non-calcareous. Shales are dark grey to greenish black, moderately hard and compact, fissile, non-calcareous and occasionally carbonaceous. Pyrite is found in traces.

Ardol Member (1706-1765 m)

This member consists of sandstone and shale intercalations and thin bands of claystone in between. Sand/sandstone are colourless to dirty white occasionally yellowish transparent to translucent, fine to medium grained, occasionally coarse grained subangular to sub-rounded well sorted sometimes ill-sorted. Shales are light to dark grey, dark grey to blackish, moderate hard, compact moderate fissile and noncalcareous. Sometimes pyrite nas been found as traces.

Kanwa Shale Member (1765-1789 m)

This member predominantly consists of shale with minor silty sands. Sand/siltstones are nearly 75-90%. Sand is often colourless to dirty white, medium to coarse grained, angular to subangular moderately sorted to ill-sorted. Shales are light to dark grey, moderately hard and fissile and non-calcareous.

Hazad Member (1989-1835 m)

This member predominently consists of sand and shale alterations with

thin coal intercalations. Sand is colourless to dirty white, brown, medium to coarse grained, angular to subangular and illsorted. Shales are dark grey to black, hard, compact and fissile, non-calcareous hard and compact. Pyrite rarely present.

Cambay Shale/Olpad Formation (1835-2000 m)

This section consists of variegated claystone and trapwash and thin sand bands. Shale is dark grey black in colour, moderately soft, well fissile and feebly calcareous. Sands are brown to yellowish brown, transparent to translucent, medium to coarse grained, angular to sub-angular and ill sorted. Claystone/trapwash is in ashy grey, brown to deep brownish yellow moderately soft, calcareous, variegated clay, colour of all shades, brown, blackish, grey, white chips hard compact, non-calcareous and non-sticky. Coal is got blue in colour with low specific gravity, soft sometimes.

well No.8 (Matar-A)

The well Matar-A is situated towards the eastern margin of Broach Depression. This well was drilled down to a depth of 1800 m and it has penetrated Olpad Foramtion (1541-1800 m), Cambay Formation (1500-1541 m), Ankleshwar Formation (1396-1500 m) and Dadhar Formation (1331 -1396 m, chart 1.7).

Dadhar Foramtion (1331-1396 m)

This section mainly consists of shale in light to dark grey, moderately hard and fissile non-calcareous in natrure. Sand is white, greyish white, occasionally with pink and yellow tinge, transparent to translucent, medium to coarse grained occasionally very coarse grained sub-angular to sub-rounded moderately to poorly sorted with calcareous matter as traces

Ankleshwar Foramtion (1396-1500 m)

Telwa Shale Member (1396-1409 m)

This member consists of sand which is colourless to dirty white often granular, sub-angular to subrounded medium to coarse grained moderate to poorly sorted and poorly calcareous. Shales are dark greyish black to black, moderately hard, fissile, soft and noncalcareous.

Ardol Member (1409-1445 m)

This member mostly consists of sand colourless to dirtywhite sometimes milky white, fine to medium or coarse grained with fraction sub-angular to subrounded and poorly sorted. Shales are dark greyish black, moderately hard, moderately fissile noncalcareous sometimes bluish to dark greyish black in colour.

Kanwa Shale Member (1445-1471 m)

It consists of shale black, bluish to greyish and greyish black in colour, soft, moderate to poorly fissile, well compact and noncalcareous. Shales which are colourless are dirty white to yellowish white fine to medium grained occasionally coarse subangular to sub-rounded and moderately sorted.

Hazad Member (1471-1500 m)

This memebr mostly consists of shale, however, rare coal bands are also observed. Shales are greyish or dark black, hard and compact. Thinly laminated shales are carbonaceous at places with leaf impressions. At places thinly laminated shales with thin streaks of sandstone and carbonaceous matter are also observed. Sands are colourless to dirty white or

yellowish white, medium to coarse grained, subangular to sub-rounded moderately sorted with clay matrix.

Streaks of coal in jet black, colours are observed in some cores.

Cambay Shale Formation (1500-1541 m)

This formation consists of shales which are greyish black to bluish black, hard, compact, well fissile and non-calcareous and silty at places. Sands are colourless to dirty white, fine to medium grained sub-angular to sub-rounded and poorly sorted. Between 1505-1510 m, 90% of the core matrix consists of coal in jet black to brownish black in colour it is brittle, soft and lignitic. Pyrite, calcareous matter and quartz are observed as traces.

Olpad Formation (1541-1800 m)

This formation mainly consists of claystone and shale, with pieces of trap and trap derivatives, chert, pyrite and calcareous matter. Occasionally thin lenticles of fine to medium grained, moderately sorted, sands are present.