CHAPTER V

STRATIGRAPHY AND THE LITHOLOGY OF THE ROCK UNITS

The area is largely devoid of surface exposures except in the eastern part near the Sabarmati river wherein the gritty sandstones of Mesozoic age overlain by Deccan Trap are known. These exposures are sporadic and are mostly covered by alluvium. The present study does not cover these patchy exposures.

The stratigraphy of the Cenozoic sediments of the area is entirely based on the subsurface data from deep drilling for hydrocarbons. The data are mostly from the cuttings of rocks collected during drilling, wire line logs recorded in the wells after drilling and the cylindrical cores cut through the rocks. The cores and cuttings have been examined for lithological studies and biostratigraphical studies but the stratigraphy

is very much based on the wireline logs (fig V. 1) supported by the study of the cuttings and cores of the rocks. The basic log for the study is the spontaneous potential and normal resistivity, sometimes supported by microresistivity logs and radioactive logs. The S.P and resistivity log provides reliable information on the lithology and the porosity of the clasitc section penetrated. The radioactive logs further provide clarity on the differences within shales, the quantitative estimation of shale content in a sand etc.

Based on this methodology, the stratigraphy of the basin was first published by Rao (1969) for the southern part and by Chandra and Choudhary (1969) for the total basin. Subsequently, different authors have augmented to the stratigraphic studies with more details.

The Deccan Trap forming the basement of the Cenozoic sediments, occurs in the subsurface all over the study area. This is established from the subsurface data of the wells which have touched this basement in the margins as well as the middle of the basin. The seismic data incorporating the well data by which the Trap surface below the sediments has been traced, also clearly show the presence of the Trap all over the study area. Although the Deccan Trap is known to be basic volcanic lava flow, the acidic differentiates of these flows also occur as syenite and in the form of intrusives as in the case of a North Kadi well.

Olpad Formation

The formation overlies the Deccan Trap and is separated

by a non-conformity (fig V. 2). Lithologically, it is a trap conglomerate or trapwacke, the distinction depending on the size of the trap pebbles and trap grains which are embedded in a chloritic matrix.. The trap conglomerate/wacke is interbedded with greenish grey to chocolate brown claystone/shale. Along the eastern margin of the basin, the trap conglomerate occurs with volcanic ash/clays in the lower part and with buff red chocolate brown greenish grey claystone/shale in the upper part. The trap pebbles/grains are invariably altered into chlorite.

The thickness of the formation is known at a few points only, as in many exploratory wells, the formation has been only partly penetrated. The seismic data have been used to trace the thickness of the formation but this has limitations of the interpretation.

On the Mehsana horst, the Olpad formation is not deposited at all, but on both sides of the horst, thick trap conglomerates of the formation are deposited. The thickness of the formation is more on the eastern flank of the horst (+375 m) than on the western flank (192 m). Such an occurrence of the formation on both sides of the horst is as expected. The formation is well developed on the eastern flank of the basin across the marginal fault scarp faces of Deccan Trap as revealed by well data. It is also deposited across the fault scarp faces of Deccan Trap in Becharaji, Asjol and Detroj areas under identical tectonic setting.

The formation is interpreted to have been deposited as a fanglomerate by the deposition of detritus brought across the scarp

STRATIGRAPHIC TABLE FOR THE AREA

Fig V.2

TIME UNIT					ROCK UNIT (FORMATION)	BRIEF LITHOLOGY
ERA	PERIOD		EPOCH			
CENOZOIC	QUATERNARY		HOLOCENE PLEISTOCENE		GUJARAT ALLUVIUM	
	TERTIARY	NEOGENE	PLIOCENE		POST JHAGADIA	GRITTY AND GRAVELY BEDS WITH THIN CLAY BEDS.
			MIOCENE		JHAGADIA	THICK GRITTY SANDSTONE AND CLAYSTONE
					KAND	CLAYSTONE WITH THIN SANDSTONE.
		PALEOGENE	OLIGOCENE		BABAGURU	COARSE GRAINED, SANDSTONE AND CLAYSTONE.
			EOCENE	LATE	TARAPUR	GREY SHALE
				MIDDLE	KALOL	MEDIUM TO COARSE GRAINED MODERATELY SORTED SANDSTONE
					KADI	FINE TO MEDIUM GRAINED, POORLY SORTED SANDSTONE
				LOWER	CAMBAY SHALE	BLACK AND GREENISH GREY SHALE.
			PALEOCENE		OLPAD	CONGLOMERATE AND VARIEGATED CLAYSTONE
					DECCAN TRAP	BASALTS AND SOMETIMES ITS DIFFERENTIATES.

faces of Trap terrain with only a short transportation. These scarp faces have been probably brought up by faulting in the Trap. Hence, the thickness of the formation is more, adjacent to the faults on the down thrown side than in the other parts of the basin which remained stable. The same can be noticed adjacent to the horsts in the Trap basement. This leads to the obvious conclusion that the thickness of the coarse clastics of the formation is more near the paleohighs and the finer clastic intercalation in the relatively deeper part of the basin.

The petrography and the nature of the occurrence of the formation indicate that it is deposited under continental environment.

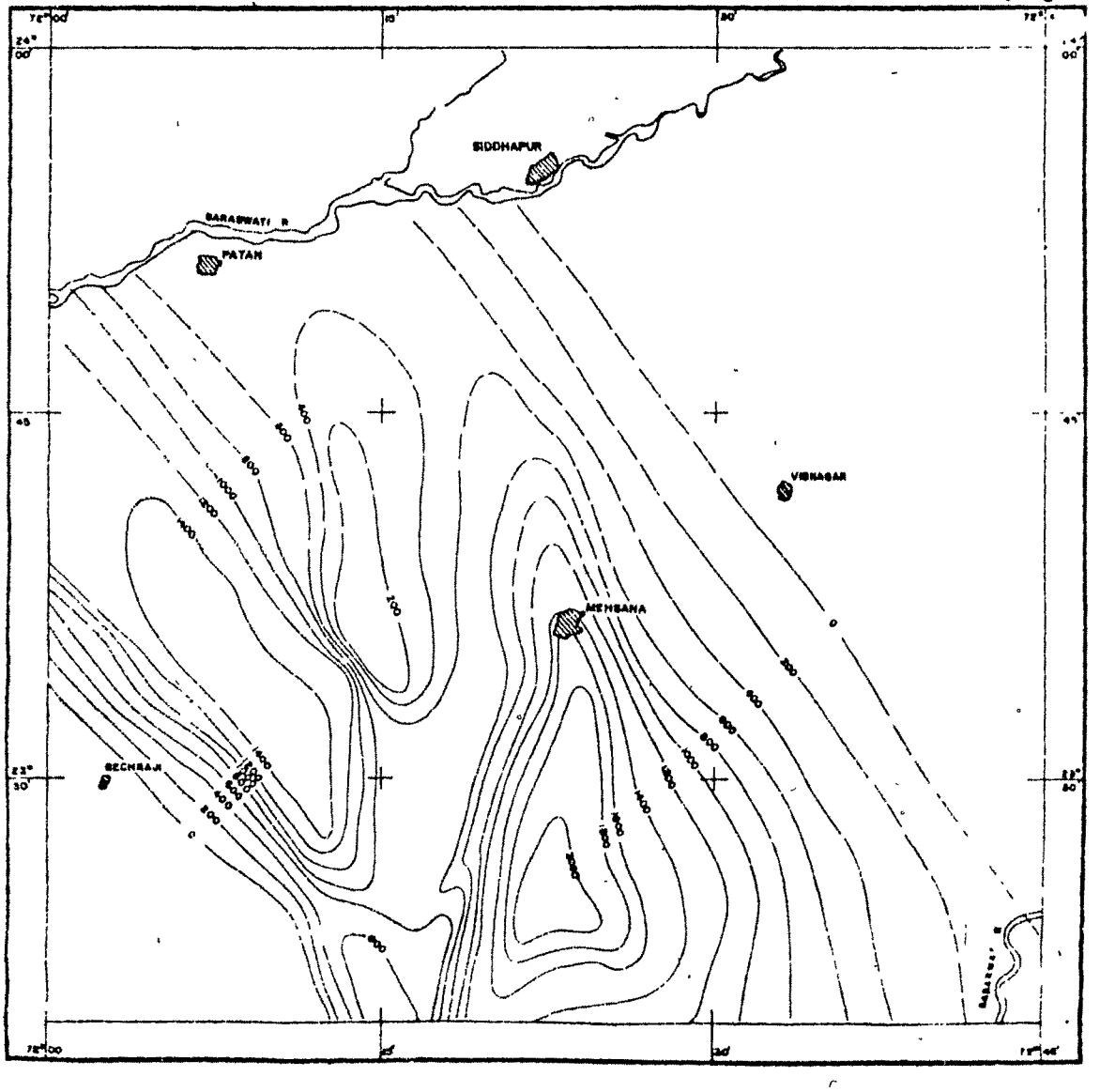
Cambay Shale Formation

The formation overlies the Olpad formation with an unconformable relationship. The sediments of this formation are deposited in the widespread transgression that commenced the depositional history of marine Cenozoic sediments. The formation is thickest in the early troughs formed in the basin in which the total section is well preserved (fig V. 3). It is a monotonous shale section showing sometimes a gradual change in lithology from the underlying Olpad formation's conglomerate. The shale located in the deeper part of the basin and the conglomerate located on the flanks of the basin at a topographically higher level (due to its nature of deposition) give the impression of intertounging of the formations. The top of the shale coincides with an electrolog marker. In some seismic profiles, south of the study area, the marker

ISOPACH MAP OF CAMBAY SHALE FORMATION

(IN M)

Fig V. 3



coincides with an unconformity. The analogy is extended into the study area as in no specific seismic profile of the study area such unconformable relationship is noted. In the axial part of the basin the unconformity may be represented by a disconformity. In some parts of the area, the formation shows strong seismic reflection facies suggesting layering within the shale. On the margins of the basin, an erosional truncation of the formation is noted accompanied by strong seismic reflector facies associated with faults and shale diapirism.

The shale is mainly dark grey to black, massive and pyritic. Sideritic shales with grey claystone are also noted. Pyrite indicates deposition in reducing environment. Kaolinitic clays are reported in several parts of the formation. There is no indication of deltaic sedimentation of coarse clastics during the deposition of the formation.

The shales have sufficient organic carbon content to be called as source rocks for petroleum. The average total organic carbon content is 2.5%. The shales have also been proved to be mature enough in the burial depths of the study area to generate hydrocarbons.

Age and environment

The shale formation is mostly devoid of microfossils. In a few wells, diagnostic ostracodes are picked up suggesting an Early Eocene age. The fauna also suggests that the deposition of this formation took place in fluctuating marginal marine to deep inner shelf conditions.

Kadi Formation

Overlying the Cambay shale formation unconformably is the Kadi formation. The formation is divided into the following members - Viraj shale, Mandhali sand member, Lower shale tongue, Mehsana member and Upper shale tongue.

Viraj shale

This is lithologically similar to the shales of the underlying formation. It is spread over a larger area than the underlying shales.

Mandhali member

This unit consists of sands and shales; the shales are grey to dark grey, laminated, carbonaceous, micaceous and silty but occasionally siderític and pyritic.

The shales also show flaser bedding, parallel and contorted laminations, scour and fill structures, burrows and wavy laminations.

As may be seen from the electrolog correlation and its inferences on the lithology, the member has sandstone beds varying in thickness from 5 m to 20 m. The sandstones are normally fine to medium grained, quite often argillaceous, loosely packed and friable. The sorting of the grains is moderate to very good. In many cases the sands are interbedded with very thin shale and coal partings and also specks and scales of carbonaceous matter. Sedimentary structures like ripple marks, cross beddings, shale/clay partings, cut and fill structures, parallel and wavy laminations are often exhibited by these sands. Roots and twigs

and other carbonised plant matter are quite common. The coals associated with the sands are black and anthracitic with shining lustre and conchoidal fracture.

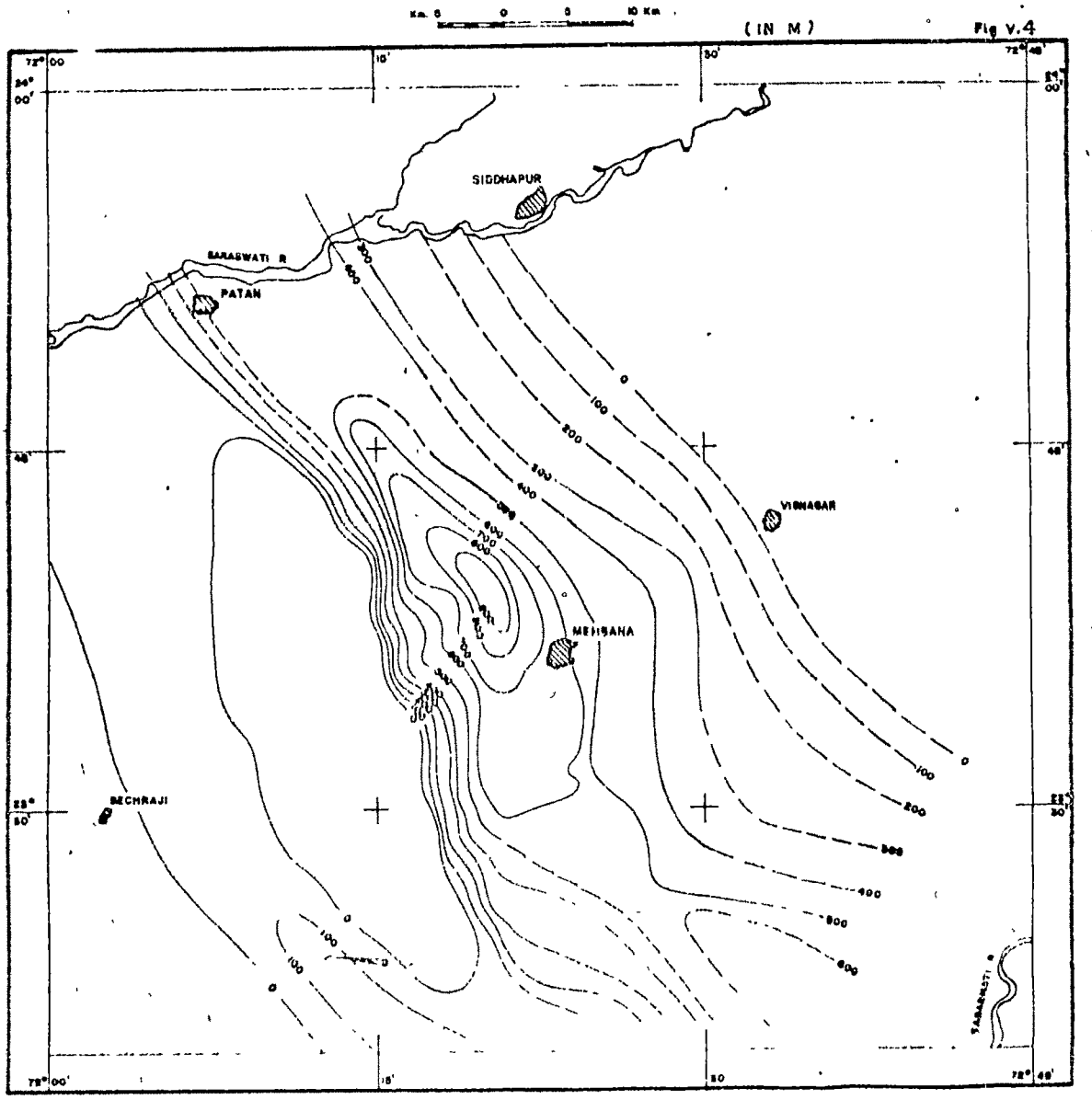
The thickness map and the sand isolith map (figs V. 4 and 5) of the unit show that the sediments are transported from the north and northwest and that the sands are spread as distributary channels extending from the north to the south. The sand spread is mostly in the central and western parts of the basin of the study area. The eastern part has less sand content and more carbonaceous shale and coal content.

The Mandhali sand member is conformably overlain by the lower tongue of Cambay shale which is present all over the area. Where the underlying Mandhali member and the overlying Mehsana member are not distinct, the lower tongue of Cambay shale looses its identity. Lithologically, the shale is mainly a dark grey chocolate brown claystone with carbonaceous laminae in it.

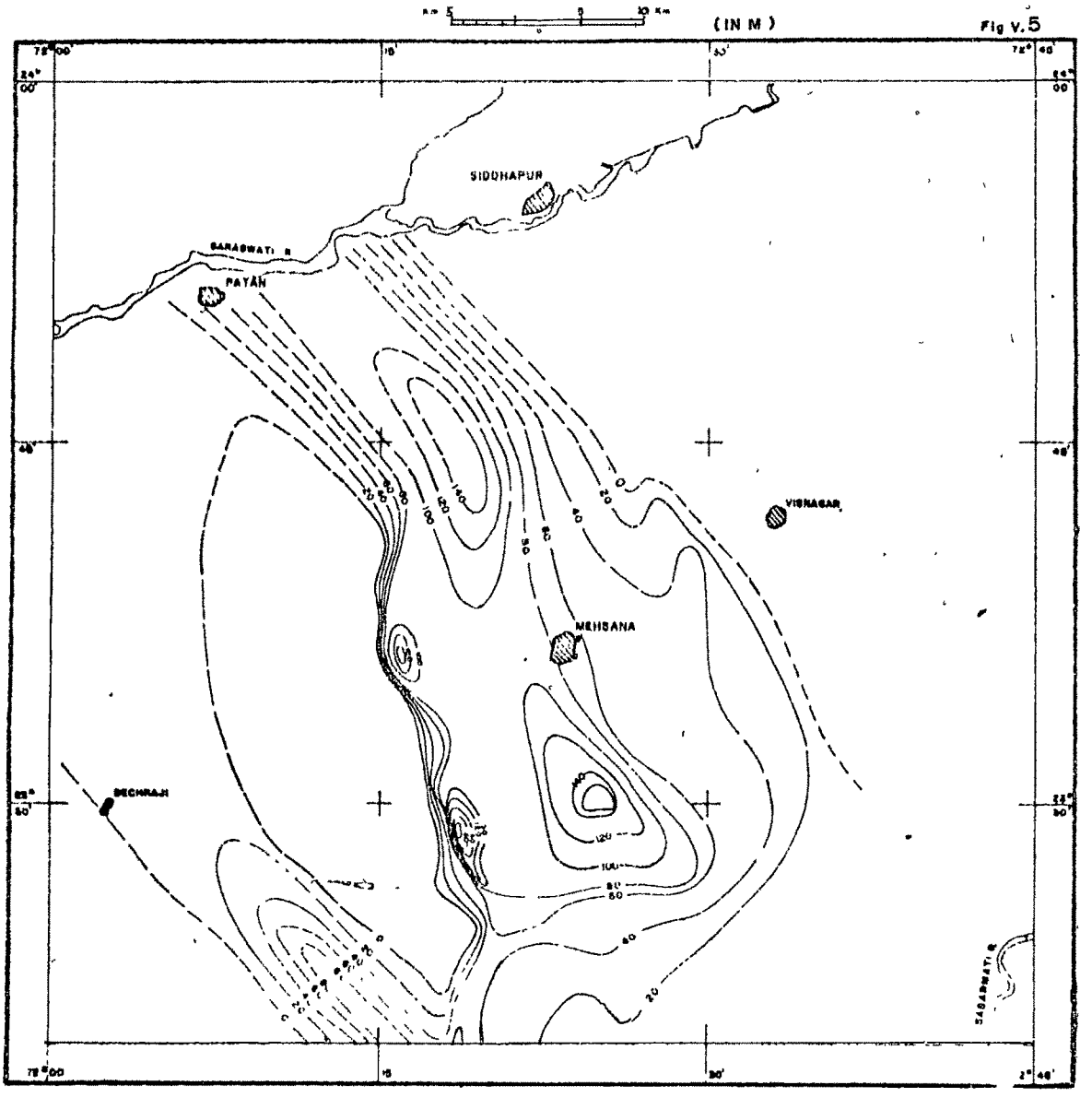
Mehsana member

The sand member overlies the lower Cambay shale tongue conformably and is restricted in its depositional extent to the western part of the basin in the study area. The sands of the member seem to have been transported from north to south, mostly along the western margin of the basin. In the eastern part of the basin, the shale coal lithological association is very common with thick coals at the top and thin sands and shales at the bottom of the section. The coal bands

ISOPACH MAP OF KADI FORMATION



SAND ISOLITH MAP OF KADI FORMATION



are black, massive, lustrous with conchoidal fracture and resinous matter, the bands varying in thickness from 10 m to 50 m.

The shales are grey to dark grey, occasionally brown and black, at times highly laminated, splintery and carbonaceous with parallel and subparallel, contorted, wavy laminations, scour and fill structures and erosional truncations.

The sandstones are grey to brown, fine to very fine grained, often silty and argillaceous, moderately hard and friable. The grains are subangular to subrounded and well to moderately sorted. Sedimentary structures noted in the sands are intercalations of irregular and inclined shale partings, tabular and wedge type cross laminations, typical channel fills and scour and fill structures. Fining up sequences are many times noted in the sands.

The depositional history and features of the Kadi formation as a whole, are studied by the preparation of its isopach map and isolith map (figs V. 4 and 5).

The Kadi formation is overlain and separated by a tongue of Cambay shale called the upper tongue from the overlying Kalol formation. Both the upper and lower contacts are conformable. The shale is lithologically similar to the lower tongue and is widely present over the entire area under study except on the horsts of basement such as Mehsana horst, Kadi syenite plug, etc.

Kalol Formation

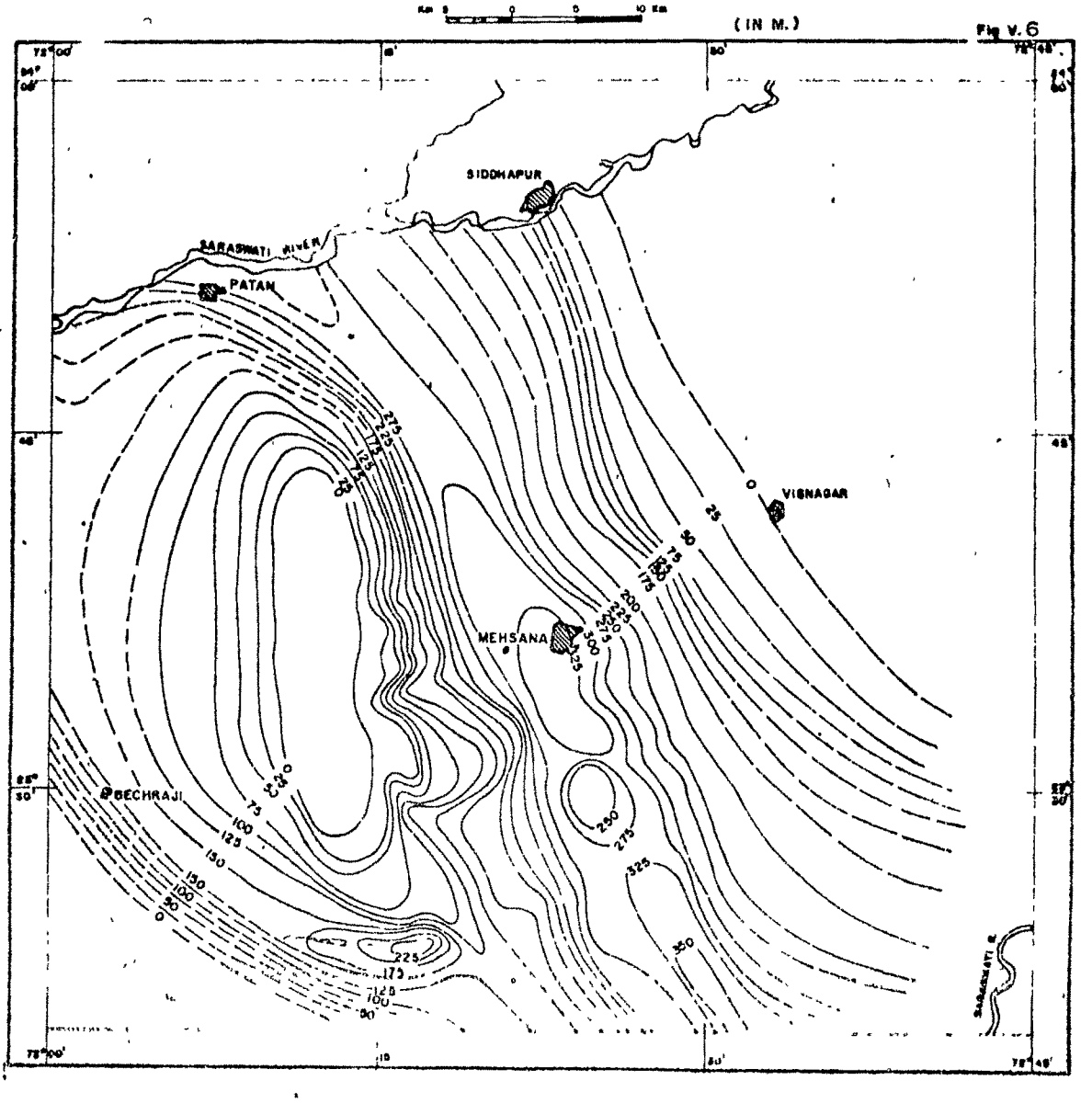
The formation is extensively deposited and is traced in the subsurface over most of the northern part of Cambay basin with minor lithological variations. On the flanks of the basin and on the horst features of Deccan Trap, it is not typically deposited and its homotaxial equivalents are present (figs V. 6 and 7).

The formation is divided into three sand members (Chatral, Sertha and Wavel) which are separated from each other by thin shales. The shales are sometimes indistinguishable. Separate studies are not made for individual members but their pattern of distribution and their characters are discussed.

The Chatral sand consists of layers of shale and carbonaceous matter. The sandstones are dirty white to dark grey and moderately compact. The member is deposited all over the area. From its isopachs and sand content, it can be seen that the sedimentary input has largely come from the north northwest to southeast skirting the Mehsana horst due to its topographical nature. Further south, the sand content reduces. The eastern margin of the basin is gentler than the western margin during this time of deposition and the sand dominated part of the unit is along the western margin.

The Sertha and Wavel sand members have lithologically similar characters compared to the underlying member. The units are represented by sandstone, siltstone, shale, claystone and coal with oolitic limestone

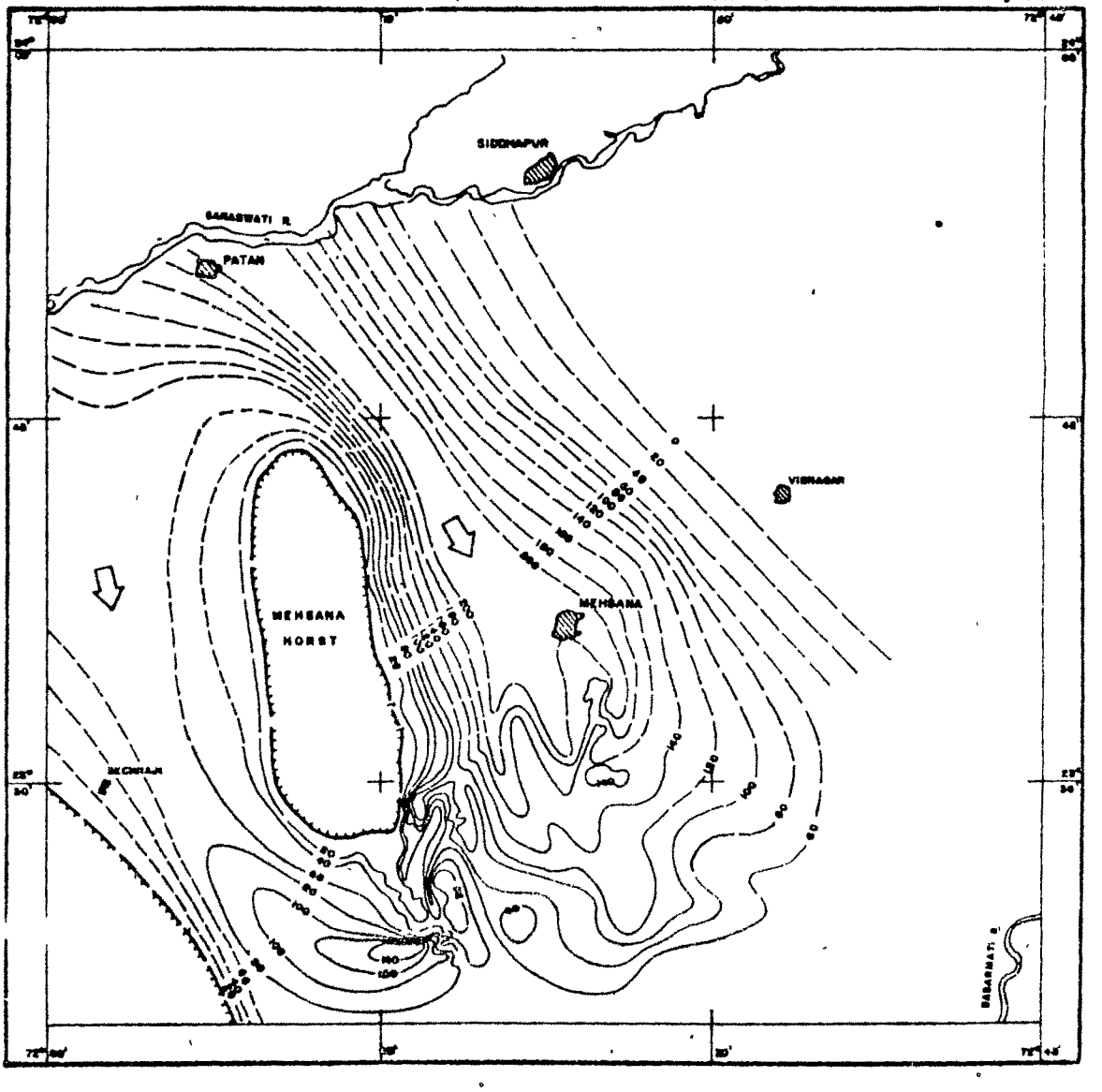
ISOPACH MAP OF KALOL FORMATION



SAND ISOLITH MAP OF KALOL FORMATION

(IN M)

Fig v. 7



towards the top in a restricted area. The sands are fine to very fine grained, sometimes medium to coarse grained. The sand grains are moderately sorted and are subangular to subrounded. The siltstones are dirty white to grey and brownish grey and mostly sideritic. Shales are dark grey, carbonaceous, occasionally micaceous and pyritic. Pockets and lenses of sand and silt are noted in these shales. The coal is dark grey to black, brittle to slightly hard showing blocky fracture. The oolitic limestone, noticed in one subsurface point only, is brownish grey and friable. It has abundant oolites and small amount of clay. The oolites have quartz grain as their nucleus and show concentric rings of calcareous matter, probably sideritic.

During the deposition of these sand members, the slope of basin margins has changed and the eastern margin has become deeper with thicker sediments. The sands of these units continue to be deposited near the western margin and then dispersed in the rest of the area. Although the input of sediment was also from the eastern margin, the sand input from this direction was less. As a result, the coal shale facies of these units have increased in the eastern margin. During the deposition of these units, the basin paleoslope was gentle. From the shapes, the deposition of the sandstone bodies appears to be very much controlled by the tidal currents due to which the bodies are parallel to the depositional strike and perpendicular to the general coast line. The inter tidal channels are the locations of thick swamp growths due to which thick deposits of coal have formed.

It may be seen that the coarse clastics of Kalol formation represent the deltaic deposition within a regressive phase of the basin. In the early part of the formation the sediment input is mostly from the western flank of the basin and the delta build up into the sea is also from the same direction. In the subsequent stage of the deposition of the formation, the basin gently tilted to the east and sediment input was from both the margins of the basin, with larger amount entering from the eastern margin. However, the coarse clastics, during delta build up into the basin, were received from the western margin of the basin as seen from the predominent occurrence of sands. In the eastern part of the basin, the formation is represented by more fine clastics and coal. Thin shales within the formation are possibly formed by short duration marine transgression. From the south to the north, these marine shales thin indicating that the transgression is from the south to the north. The upper section of the formation yielded arenaceous foraminifera such as Haplophragmoides Ammobaculities, Trochamina and Arenobulimina indicating Middle Eocene age for this upper part of the formation.

Tarapur Formation

The formation is lithologically a shale with thin sands noted in very few places as in the west of Balol over the Mehsana horst. The shales are greenish grey to dark grey with thin occasional siderific bands. The isolated thin sands could have formed as offshore bars, as interpreted from the shape of the bodies and their parallelism to the shore line. No deltaic deposition is indicated in any part of the formation.

The shale is a prominent marker formation deposited all over the study area of the basin. It is thickest along the eastern margin of the basin and denotes a continuity of the basin character from the underlying formations. The formation is deposited in a major transgression. The lower part of the formation yielded larger foraminifera viz. Nummulites, Discocyclina and Operculinoides. This section is overlain by a thin section with shell fragments and by a section rich in benthonic foraminifera, viz. Uvigerina, Lenticulina, Cibicides, and then with planktonic foraminifera represented by Globigerina, Globorotalia, Pseudohastigerina, Chiloguembelina and Hantkenina. The planktonic formainifera are found in association with larger foraminifera such as Nummulites fabiani, Pellatispira and Operculina sp. The distribution of the faunal assemblage shows that in the study area of the basin, the middle part extending in a N-S direction is deeper (outer shelf conditions) shallowing on the eastern and western directions towards the margins. The age of the formation is fixed as Late Eocene. The formation varies in thickness from 50 m on the flank of the basin to 250 m in the deeper part of the basin.

Faunal studies of Paleogene Formations

The frequency of occurrence and the size of microfauna in the formations depend upon many factors such as bathymetry, salinity, dissolved oxygen content, Ph, temperature, rate of sedimentation, etc. The Olpad formation is devoid of fossils and the same is expected as the formation is deposited under continental/fluviatile environment. The Cambay shale formation is also devoid of fauna in most of the

area where subsurface data points are available. However, in a few wells located in the southern part of the study area, the shale contains ostracodes such as Leguminocythere Oveytheridea Cambayensis suggesting an Early Eocene age. The faunal evidence also suggests that the deposition of this unit took place under fluctuating marginal marine to deep inner shelf conditions.

The overlying sedimentary section of Kadi formation is devoid of fauna. The floral assemblage indicates fluctuating marginal marine to non-marine environment for sediments of the formation. This is expected as Kadi formation is basically deposited as a deltaic buildup in a transitional to inner shelf environment fine clastic sedimentary section. The overlying Kalol formation has the same environmental characters in its basal part. In view of the absence of fossil record between the sparsely fossiliferous Cambay shale formation and the marine record in the upper part of the Kalol formation, an unconformity is interpreted within the Kalol formation just below its top (figs V. 8, 9 and 10).

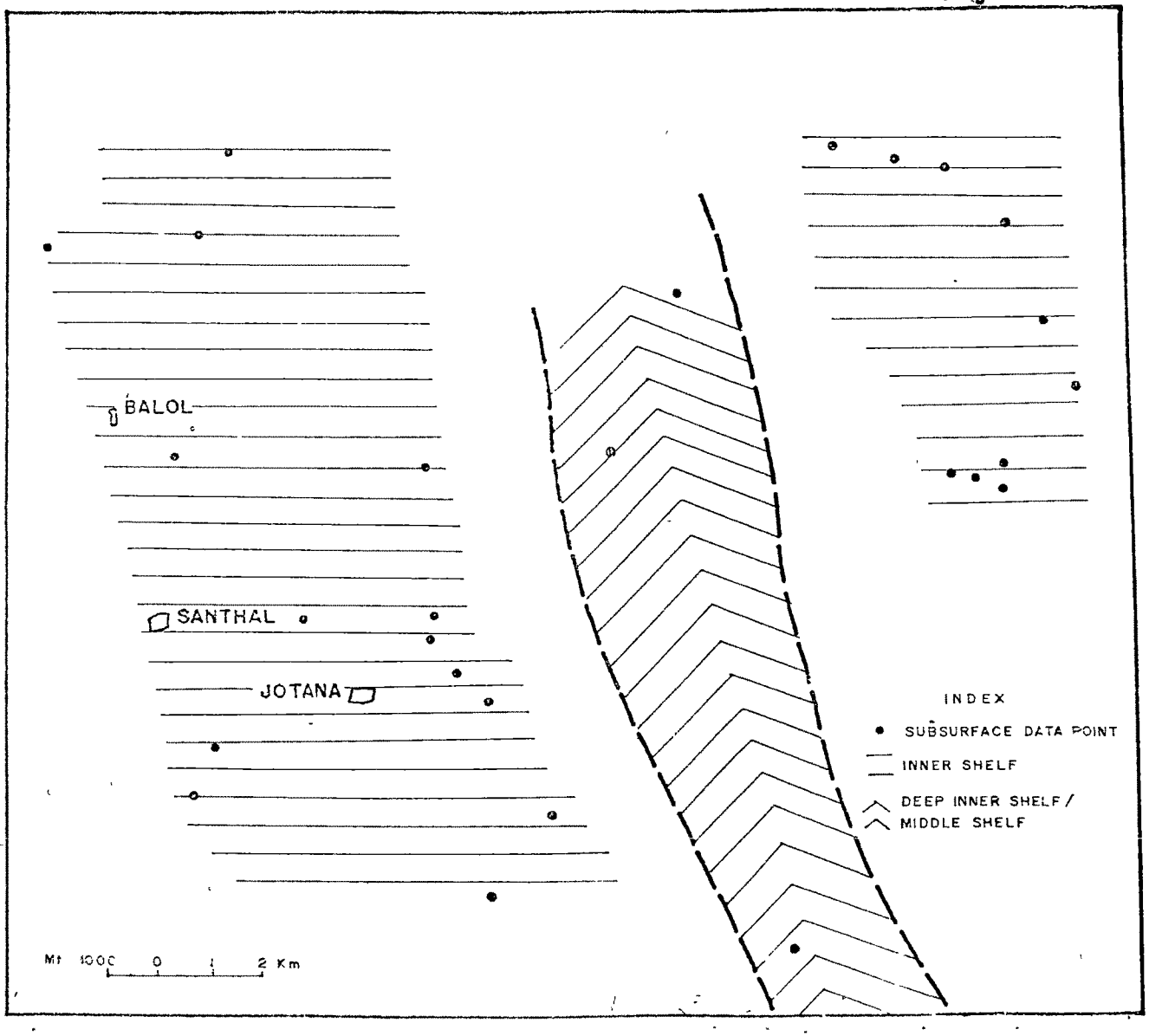
Babaguru Formation

The formation is first identified in the exposed Tertiary rocks between Narmada and Tapti rivers near Babaguru Dongri hill. The lower part of the formation is a cherry red friable sandstone, whereas the upper part of the formation is a cherry red lateritic sandstone with agate pebbles, outcropping over a large area of the Tertiary exposures.

PALEOENVIRONMENT DURING LATER PART OF MIDDLE EOCENE IN NORTH CAMBAY BASIN

(Based on faunal data)

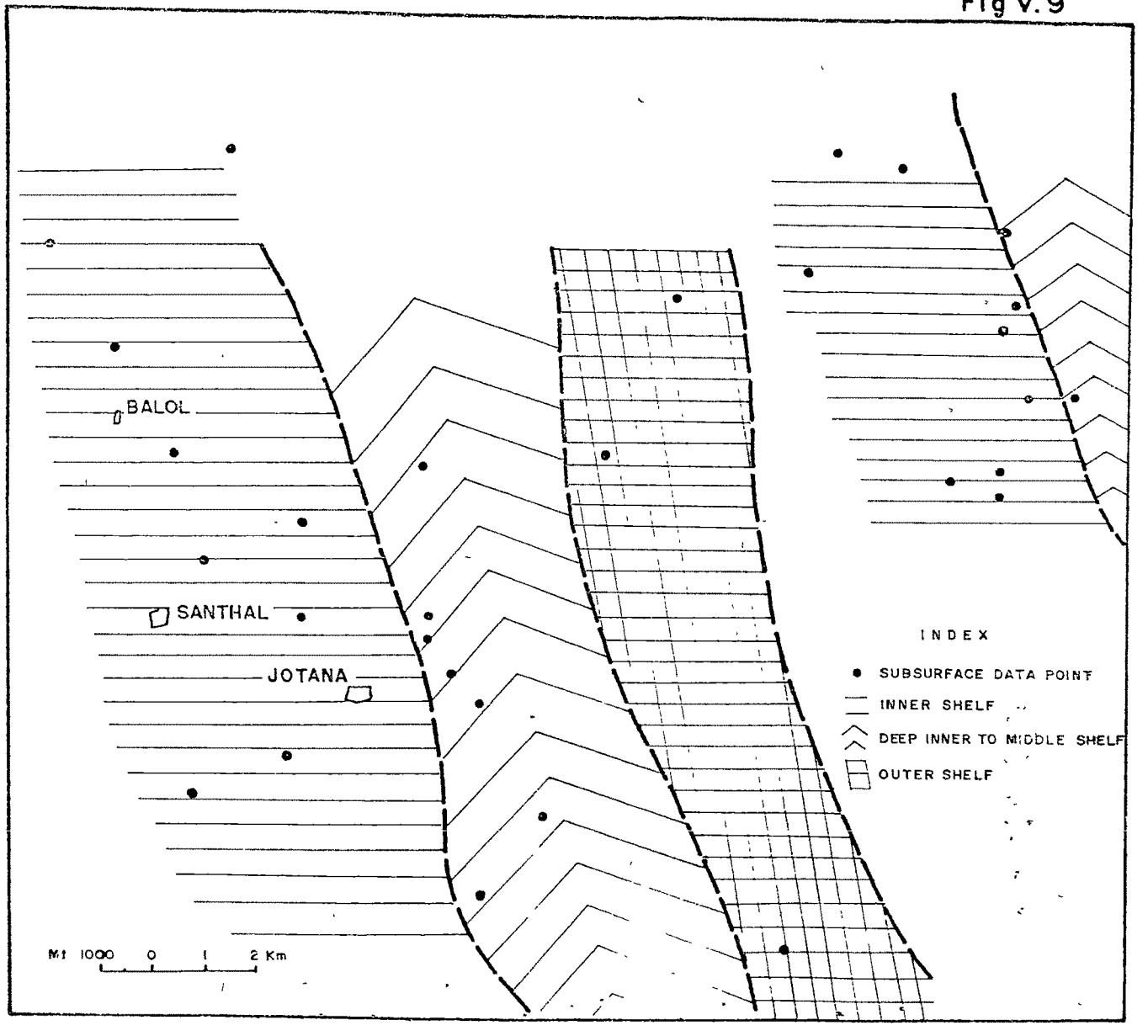
Fig V.8



PALEOENVIRONMENT DURING LATE EOCENE IN NORTH CAMBAY BASIN

(Based on faunal data)

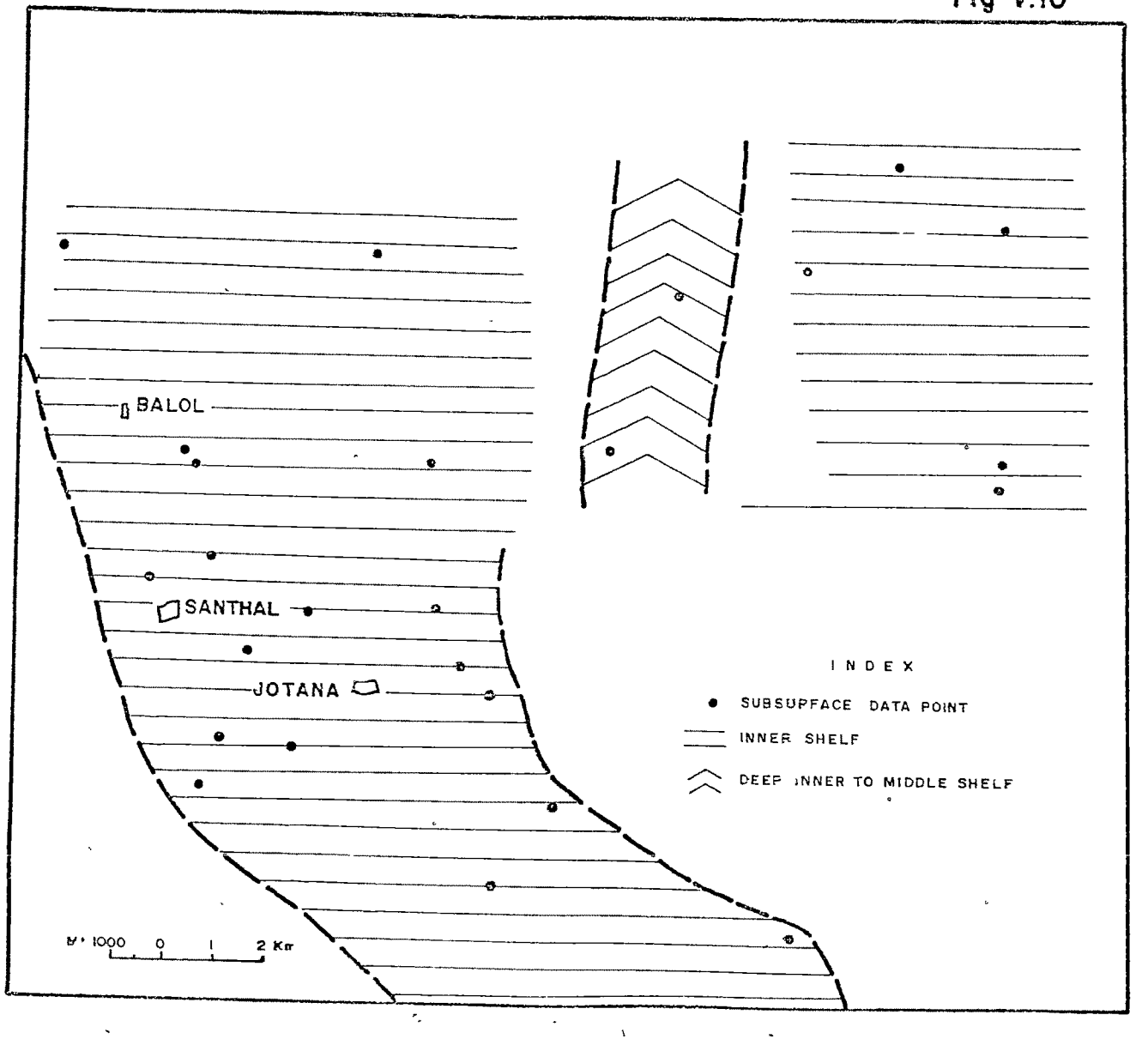
Fig V.9



PALEOENVIRONMENT DURING EARLY OLIGOCENE IN NORTH CAMBAY BASIN

(Based on faunal data)

Fig V.10



The agate pebbles are derived as weathering products of the cavity filled agates of the nearby Deccan Trap terrain without much transportation. No fossil evidence is available from these outcrops but from the overlying and underlying fossiliferous formations, the age of the outcropping formation is put at Lower Miocene. These exposed rocks are correlated with the subsurface geological data from the nearby wells drilled on Ankleshwar and Dinod structures and the formation is traced in the subsurface. Subsequently the formation is traced in the subsurface all along the Cambay Tertiary basin towards the north into the study area.

The formation varies in thickness from 160 m to 100 m and is very well traceable in the subsurface of all the study area with the help of electrologs and the cuttings collected during drilling. The formation overlies the Tarapur shale formation separated by a prominent unconformity, noticed over a large part of the basin. This unconformity is the result of a widespread regression. The sediments of the formation are deposited in a transitional environment in most of the study area. From the extent and distribution of the environment of deposition of the formation, it can be inferred that the sedimentary input was from northeastern direction, indicating it to be the direction of paleodrainage during this geological time. The formation is overlain by Kand formation unconformably with a sharp boundary denoted by a lithological change. The environment of deposition remained the same throughout the formation.

Lithology-

The formation consists mainly of sandstone beds with intercalations of claystone, beds of one or two metres. The quartz grains of the sandstone are colourless, dirty white, milky and light yellow. The grains are normally coarse to medium, sometimes very coarse grained; they are subangular to subrounded and at places very well rounded. In a few places only, thin beds of fine to very fine grained sandstone are noted. The claystone is light grey to greenish grey, chocolate brown, buff coloured and at places moderately compact; pyrite is also noted in a few places. As a whole, the formation is a coarse to medium grained arenaceous unit.

The basalt part of the formation is fossiliferous and has yielded larger foraminifera namely Nummulites fitcheli and shell fragments. The overlying section yielded remains of arenaceous globular bodies, tubes and a few indeterminate arenaceous foraminifera. The larger foraminifera and the shell fragments together give the age of Early Oligocene (?) to the basal part of the formation.

Kand Formation

The formation is basically an argillaceous unit varying in thickness from 150 m to 200 m and is met with in the subsurface all over the study area.

The formation takes its name from the outcrops of Tertiary sedimentary section between Narmada and Tapti rivers. It is typically

exposed around Kand village as fossiliferous limestones and calcareous clays unconformably overlying the Babaguru formation. In these outcrops it contains pebbles of cherry red sandstone of Babaguru formation embedded in its conglomerate and is assigned an age of Lower Miocene on the basis of its fossil assemblage.

In the study area, the formation is deposited in the transitional to shallow inner shelf conditions, as evidenced by the shell fragments, arenaceous globular bodies and indeterminate arenaceous foraminifera, in continuation of the regressive phase of the basin noted in the underlying formation. An unconformity is suspected within the lower part of the formation corresponding to the separation of the Late Oligocene sedimentary section from the Lower Miocene section based only on shell fragments.

Lithologically the formation comprises of clay and claystone with a few thin sand bands. The claystone is light grey to greenish grey and also variegated in buff, red and brick colours. The shales are also sometimes calcareous and pyritic.

The age of the formation ranges from Late Oligocene (?) to Lower Miocene. It unconformably overlies the Babaguru formation and is overlain conformably by Jhagadia formation.

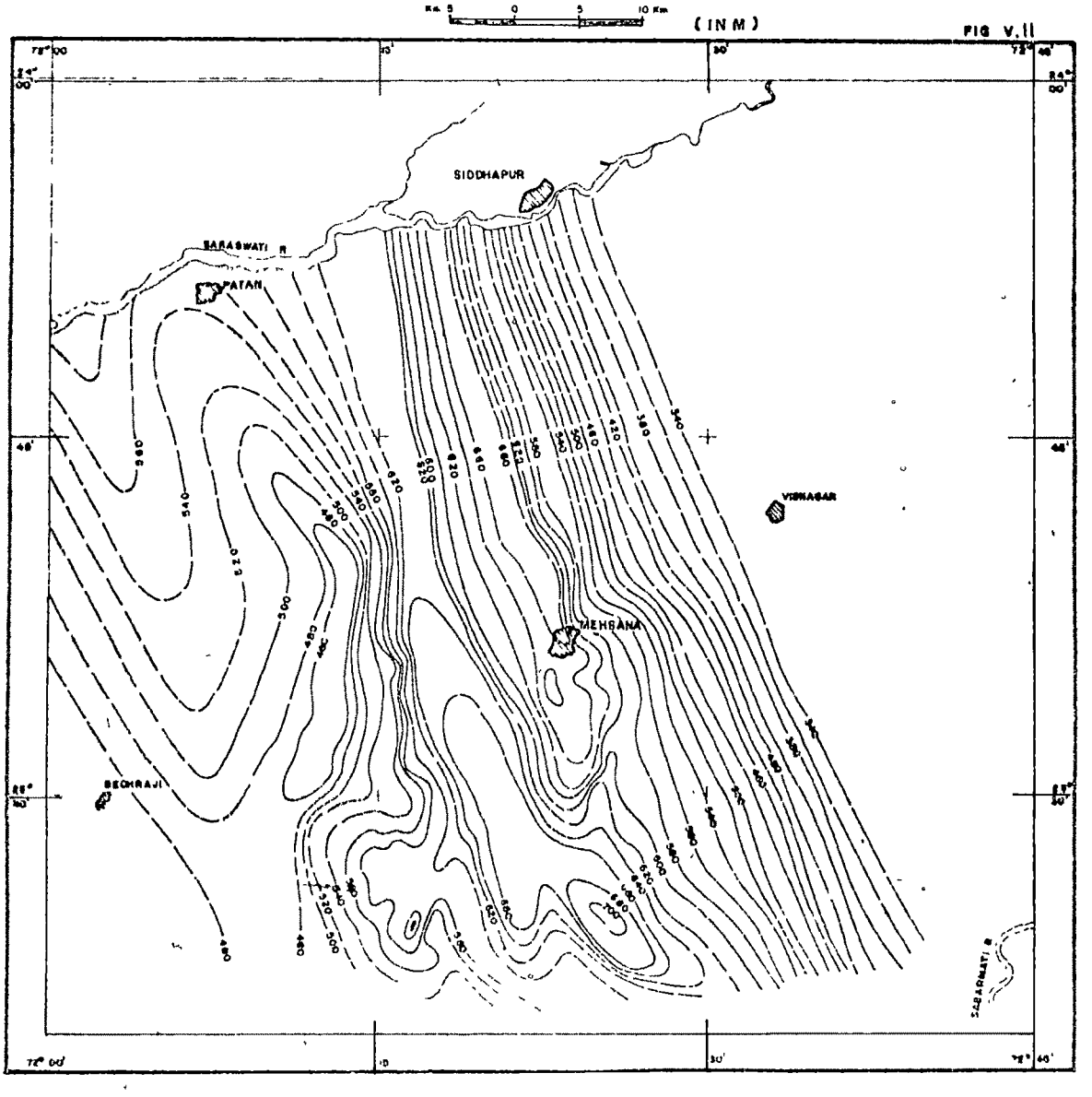
Jhagadia Formation

The formation gets its name from the exposures of the Tertiary

sedimentary rocks just south of Narmada river near Jhagadia town. It outcrops as sandstones, gritstones and cobble conglomerates, generally soft and friable, but massive with calcareous bands; it is considered to be a continental deposit.

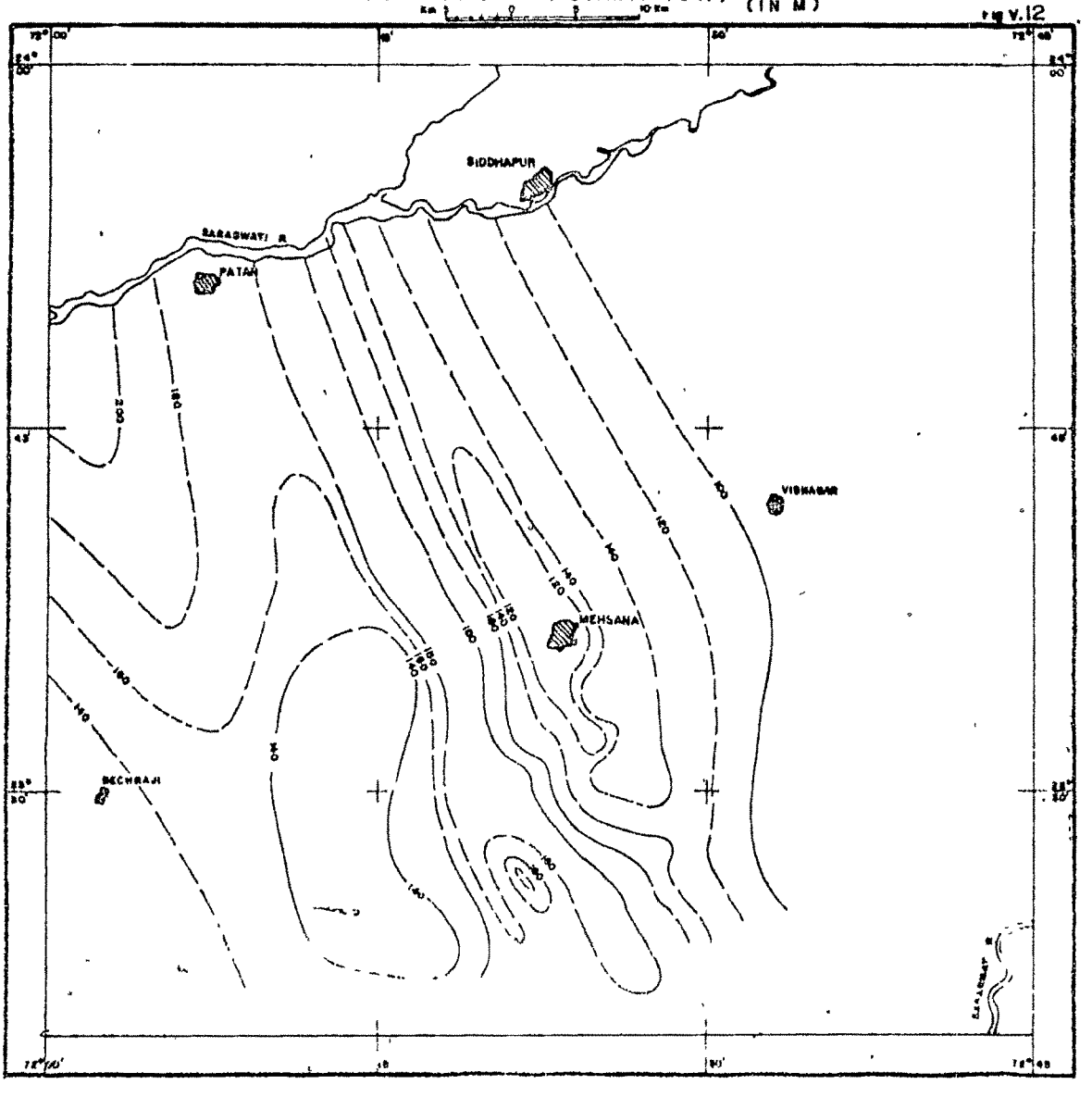
In the study area, the formation is traced all over in the subsurface. It is basically an arenaceous unit with thick sandstone beds and thin claystone bands varying in thickness from 2 m to 5 m. The formation is about 200 m in thickness increasing to 300 m also in some places. The boundaries are clear and can be identified both on the electrologs and from the rock cuttings of the wells. The quartz grains in the sandstone are colourless milky, bluish, pinkish, yellowish and greenish, The grain size varies from medium to coarse and very coarse and sometimes pebbly. The grains are subangular to subrounded and transparent to transluscent. The claystone is greenish grey, soft and fissile. A few shell gragments are also noted. Clacareous matter is present in a few places. Sporadic occurrence of gastrapods and lamellibranchs have been noticed. Some reworked benthonics such as Ammonia and Cibicides have also been recorded. From the lithology and the faunal record it can be suggested that the deposition of this unit took place under continental to marginal marine conditions. Its age is Late Miocene. Fig V.11 shows the spread of the three formations of Miocene age (?) and fig V. 12 of the spread of Jhagadia formation of Late Miocene.

ISOPACH MAP OF BABAGURU, KAND AND JHAGADIA FORMATIONS



ISOPACH MAP OF UPPER MIOCENE SEDIMENTARY SECTION

(JHAGADIA FORMATION) (IN M)



Post Jhagadia Formation

Jhagadia formation is unconformably overlain by a sedimentary section of Plio-Pleistocene age of about 400 m thickness. This unit consists of about 100 m of sand section in the basal part and clay and claystone with sandstone beds in the upper part. The lithology of this section is not properly studied as rock cutting samples are not available in the section due to non collection. Only in a few places some samples are available. The sandstones contain quartz grains which are subangular to subrounded and poorly sorted. The grains vary in size from medium to coarse and sometimes gravelly beds are also noted. The quartz grains are mostly colourless but some grains are pinkish, yellowish and bluish. The clay is yellowish to brownish and is soft and sticky. Carbonised woody matter is noticed at shallow depth of about 50 m to 100m from surface.

The lower part of the formation yielded some rolled and probably reworked fauna in low frequency while in the upper section small benthonic foraminifera such as Ammonia, Cibicides, Florilus, Elphidium, Discorbis, Rosalina and Quinqueloculina in good frequency are noted. Smooth ostracodes are also reported in association with benthonic foraminifera. Considering the lithology and the foraminifer/ ostracode assemblage, it is considered likely that the sediments of the formation are deposited in a shallow inner shelf marine environment during Plio-Pleistocene age in a part of the study area from where samples of this depth range are available. More detailed study is needed to

decipher the extent of this Plio-Pleistocene sea, which probably regressed during Late Pleistocene as seen from the deposition of the Gujarat Alluvium brought by rivers in Holocene time.