CHAPTER IV

STRUCTURAL CONSIDERATIONS

GENESIS OF THE BASIN

The Cambay basin is an intracratonic basin bounded on the east by the Precambrian shield, a continuation of the Aravalli orogenic belt, the Kathiawar uplift and Kutch embayment on the west separated from the basin by the Rathanpur arch and continuing into the Bombay Offshore basin as a graben and merging into it. The three prominent structural trends of the Western India are very much discernible within the basin and the area adjacent to it. These are the Aravalli, the Dharwarian and the Satpura. The Aravalli structural trend is the oldest orogenic trend in the region that left its impress. It is seen in the gravity map, continuing across the basin with a break within the basin. The trend continues on the west till the outcrops of the Deccan Trap and the underlying Mesozoic sediments. The structural fabric of the basin follows the Dharwarian trend obviously meaning that this orogenic cycle is of later age and cuts across the Aravalli structural trend. The Satpura is youngest of the trends which affected the basin. This orogenic activity affected only the southern part of the basin.

PLATE TECTONICS VIS-A-VIS THE CAMBAY BASIN

The genesis of the Cambay basin, with the Deccan Trap as the basement for the Cenozoic sediments and the probable occurrence of Mesozoic sedimentary rocks below the Deccan Trap atleast in some parts of the basin, leads every one to search for the relationship of the basin's evolution to the plate movement in which Indian precambrian shield is involved after the break up of Gondawana land and the shield's movement towards Eurasia. All the scientific workers who believe in continental drift agree that 1) Gondawana land has broken up from its orginal shape 2) the Indian plate has moved northward with the spreading of the Indian ocean floor and 3) of the subsequent collision of the Indian plate with Eurasia and the underthrusting of the Indian plate. The geological time of each event is very much debated. The recent papers on the subject are published by Smith and Hallan (1970), Dretz and Holden (1970), Stocklin (1977) and Powell (1979). The differences in the interpretation of these authors lie only in the commencement of the breakup of Gondawanaland ranging from the end of Triassic to Cretaceous but most of the authors agree that the collision of the Indian plate with the Eurasia took place in Paleocene - Early Eocene. The three stages of drifting as per Powel (1979) after the break of Gondawana land are (i) rapid northward flight of India during Cretaceous to Early Eocene (ii) small counter-clock wise rotation of Indian shield during the Eocene (iii) slower northward movement after collision with Eurasia from Oligocene to the present. Klootwijk concluded that during the Mesozoic, on the northward movement, Indian shield rotated anticlock wise by 50° but remained in position between 50° south and 20° south.

The western margin of Indian plate has probably separated out in Late Triassic as is evidenced by the occurrence of thin sediments of this age in Kutch. Subsequently due to the northward and anticlock-wise movement of the plate, the rifting in the Dharwarian trend parallel to the western coast took place resulting in the graben of Northern Cambay basin in Early Cretaceous. Subsequent Cretaceous is marked by reactivation of the Narmada fracture zone resulting in a marine transgression in Narmada valley and subsequent intense volcanic activity culminating in the surface flow of Deccan Trap basic lavas. According to Dietz and Holden (1970) in the northward drifting, the western margin of Indian plate crossed the thermal centre of the earth's mantle in Late Cretaceous-Paleocene time, resulting in the volcanic activity.

The collision of Indian plate with Eurasia in Paleocene-Early Eocene causing the initial uplift of the Himalayas coincides with the time of the formation of Cambay Tertiary basin as the Deccan Trap has faulted, forming the graben. Both the activities are connected probably one resulting from another.

From the above, it can be seen that the Cambay Tertiary basin located on the northwestern edge of the extensive Precambrian platform is formed synchronous with the first major tectonic activity of the Himalayan Orogeny. Such platform basins are not uncommon in the other parts of the world, the typical ones being the Rhine graben and the Suez graben. A study of such basins by Russian geologists led to classify these basins as "avlakogens". Platform structures (basins) of this type are characterised by pronounced subsidence in the early stages of their development sometimes accompanied by volcanism. Invariably, zones of elongated elevations (ridges, swells, etc) produced as a result of tectonic inversion are the characteristics of such basins. Fault bounded structures are therefore common. Cambay Tertiary basin is similar to this type of basins.

The basin evolved with the normal faulting in Deccan Trap along ancient (Precambrian) fracture trends and the commencement of sedimentation in selected areas across the fault scarps. These normal faults are traceable with gravity maps which show en echelon zone of faulting. The eastern marginal fault zone with the downthrow to the west is the more prominent as it is in continuation with the weak zone along the west coast of India which sourced the basaltic lava flows. Although the genesis of the basin as a whole is based on the same large scale tectonic forces, the different parts of the basin have reacted differently to these forces resulting in separate characteristics. This is very obvious when the patterns of the faults at the Trap level and within the Paleogene sedimentary section are studied along with the basinal depressions. One or other of the three tectonic trends (Delhi, Dharwarian and Satpura) has a prominent play in the different parts of the basin. Based on this approach, the basin is divided into five tectonic blocks - Narmada, Broach-Jambusar, Cambay-Tarapur, Ahmedabad-Mehsana and Tharad. The structural and sedimentary characteristics of each block are discussed in an earlier chapter. The identity of each block remained in the early geological history of the basin only and ceased at the end of Paleogene period. Overriding these differences in the tectonic blocks, the basin has a uniform evolutionary history. The first stage is the formative stage in which the sedimentation is controlled only by the faulting in Deccan Trap, the drainage limited to the Trap terrain and hence the typical lithological suite of coarse clastics and derivatives of Deccan Trap. In the second stage, a uniformity in the sedimentation of the whole basin started with the marine transgression in the Early Eocene. A thick shale section varying in thickness depending upon the location in the basin is deposited and is traced from the southern part of the basin south of Tapti river right upto the Banas river. At the end of this second stage, coarse clastics are deposited in some areas, where delta development took place. Some authors call this part of the basin development as an unstable stage. The later part of the unstable stage is marked by a trangression and after the deposition of a widespread shale which is a marker bed in most parts of the basin, the basin experienced a regression. The subsequent part of the development of the basin is marked by the deposition of olive green, greyish green claystone, pebbly sandstone and gritty sandstone containing flint, jasper and agate. In the early stages of the Neogene, the basin slope was towards south as reflected by the isopach map of Miocene sediments for the whole basin. This has resulted in a change in the environment of deposition of these sediments from north to south. The earlier concept that most of the Neogene sedimentary section in the Cambay-Tarapur block and Ahmedabad-Mehsana block is continental, is now to be modified with the data of some of the wells in the study area giving typical marine fauna even in Pliocene section.

The most important geological events that developed in the Miocene period are the formation of Broach depression between Mahi and Narmada rivers and the simultaneous uplift of Narmada block.

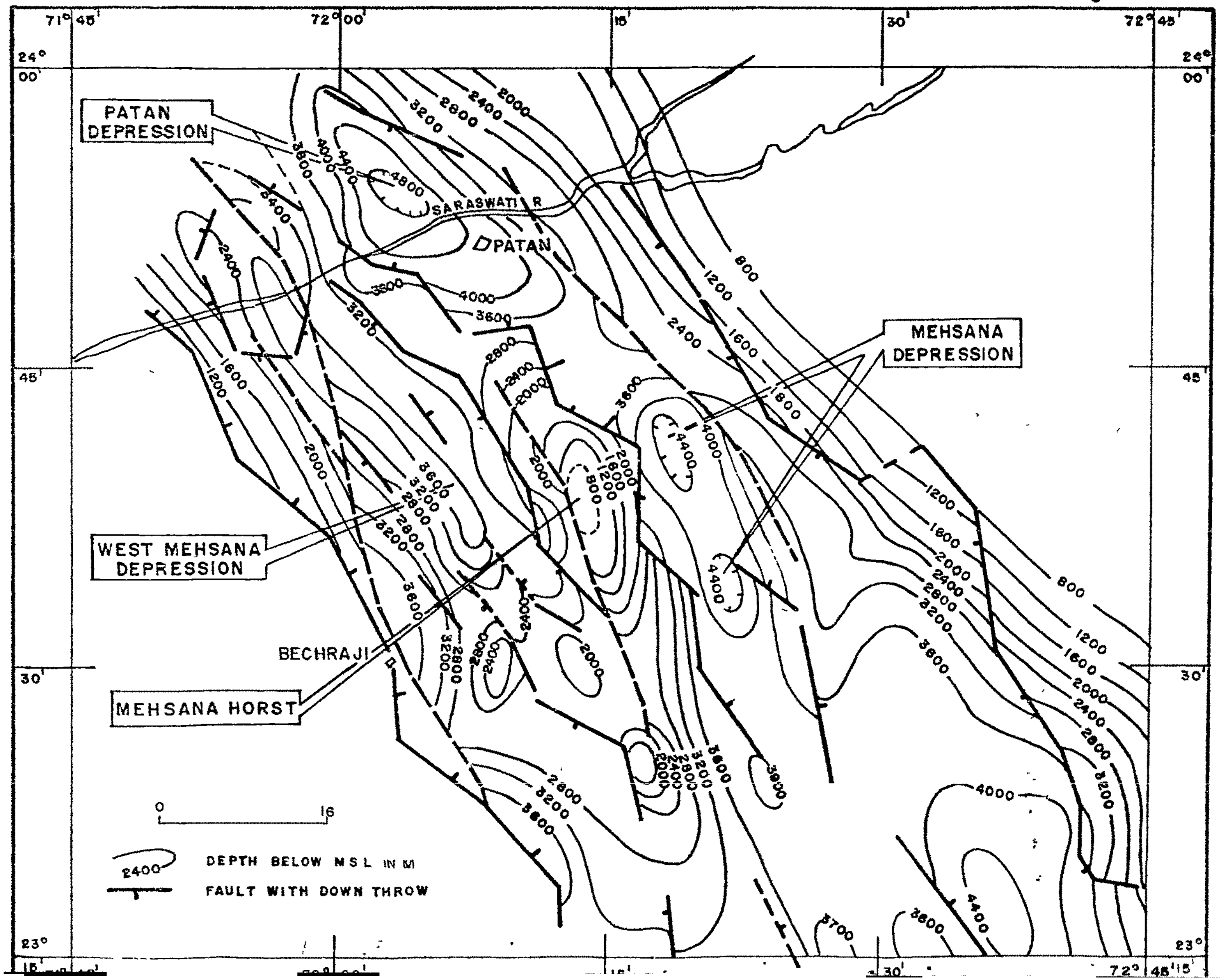
The folds in the basin area are controlled by the basement tectonics. There are two types of folds. One is the direct result of drape over the pre-existing Deccan Trap feature. The other is formed by a drape over the faults formed due to differential compaction. Hence, it is very common to observe the anticlinal folds (without roots in Deccan Trap) accompanied by faulting on the flanks. It is interesting to note that in many cases, the coarse clastics in an anticlinal fold are confined to the fold only, indicating that they themselves are the cause for folding. In the Narmada block of the basin, the folding, however, indicates the effect of compressional activity similar to the indications from the faults. As expected, the fold axes of the anticlines are parallel to the grain of the Deccan Trap basement in the structural block. The main synclines (depressions) are known only in the lower part of the Tertiary stratigraphic section and are entirely due to the basement tectonics paralleling the basement grain. The smaller synclines are aligned as per the shape of the anticlines originated by the differential compaction of the sediments. Most of the faults in the basin have roots in Deccan Trap. These faults are identifiable in seismic sections when they have a throw of about 35 m or more. These faults are traced up into the overlying sediments in many cases, but in a monotonous shale section the interpretation of the faults on the seismic section becomes difficult. Above the thick shales over the basement where sand shale sequence is known, the fault interpretation again is feasible.

Invariably the main faults in the sedimentary section are basement faults which extend into the sediments or adjustent faults which have resulted out of the main basement fault. These faults are all parallel to the grain of the basement, specific to the tectonic block, Some other important faults are generated as a result of sedimentary tectonics, such as the deposition of a large volume of coarse clastics (deltaic sands) and due to the differential lithification of the sediments; gravity faults are generated on the flanks of the coarse clastic spread and within the spread. The only part of the basin where compressional forces have caused the faulting is the Narmada block, south of Narmada river. Here, some of the faults are reverse faults mapped on the surface in the exposed rocks of Paleogene and Neogene age or in the subsurface by the well data easily identifiable by repetition of beds.

An examination of the sedimentary fill map (fig. IV. 1) of the study area shows that the eastern flank of the basin has the maximum, thickness of sedimentary section exceeding 4400 m. Of this thickness

STRUCTURE CONTOUR MAP ON TOP OF DECCAN TRAP
(SEDIMENTARY FILL OF THE BASIN)

Fig IV.1



the early Paleogene sedimentary section is represented by a major part indicating that the basin was sinking on the eastern flank and this is accompanied by a large influx of sediments from the east which is the direction of paleodrainage. It is likely that in the Early Paleogene period after the marine transgression, the influx of sediments is from the adjacent terrain resulting in the fine clastics and the provenance from which the sediments are transported, is generally stable. It is only in the later part of Paleogene that the provenance became active and coarse clastics are transported into the basin. It is also relevant to note that in the later part of the Paleogene, the transport of sediments is from two directions, one from the north eastern side and other from the north-western side. This is revealed by isopach maps made for the Kalol and Kadi formations. It is likely that during this period the Kutch-Sasurashtra horst blocks were actively rising and that the coarse clastics are transported towards the western margin of the basin. Accordingly, one can see in the isolith maps of Kadi and Kalol formations, a large thickness of the sand on the western flank of the basin in the study area. Subsequent to the Paleogene period and the unconformity following it, the direction of transport is not very obvious, but the Aravalli orogenic belt has contributed the maximum sediments. The tectonism of the basin from the depositional history will be more evident after the chapter on stratigraphy is also perused.

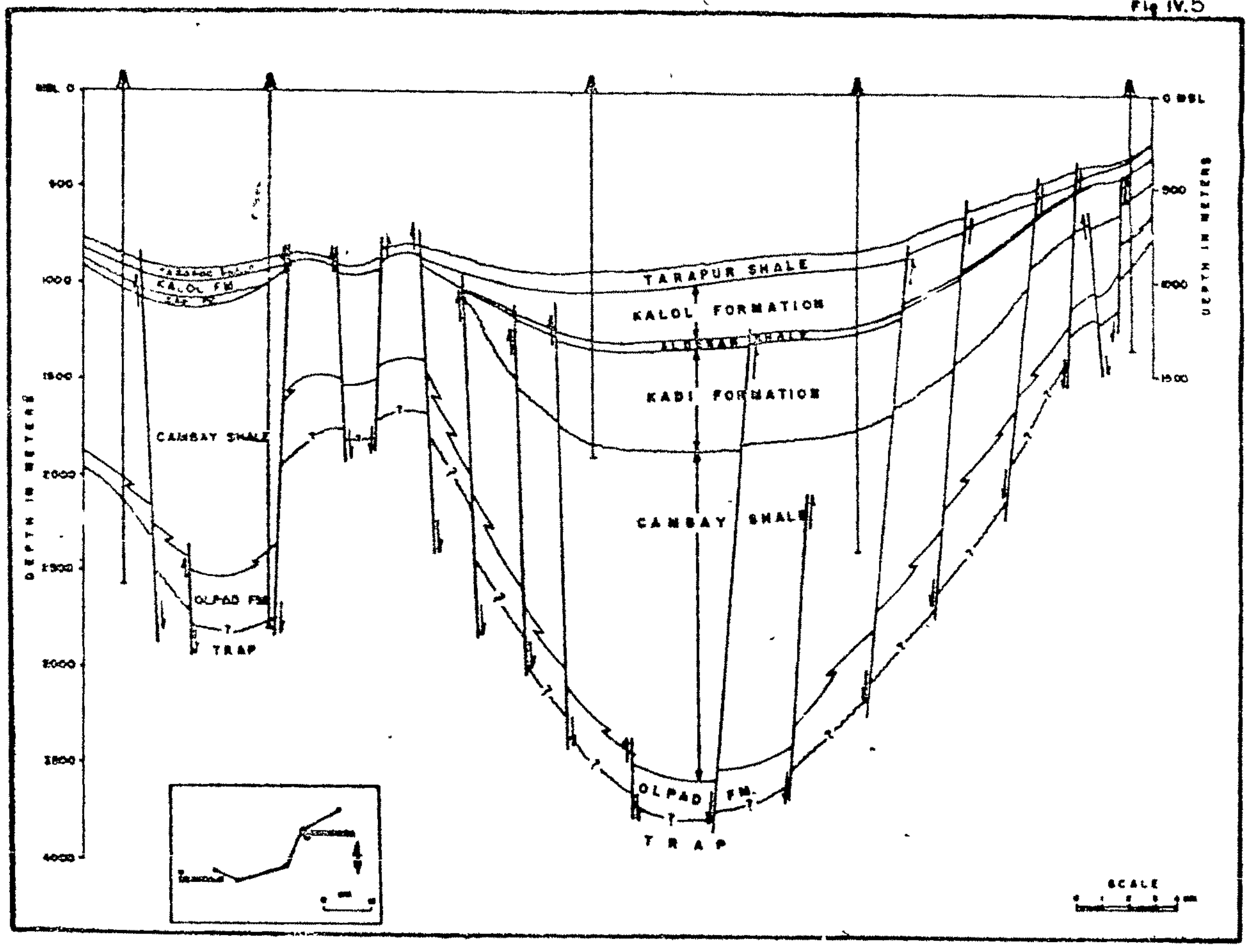
STRUCTURAL FEATURES OF THE STUDY AREA

The striking structural feature of the Northern Cambay basin is the reduced width of the basin compared to it near Narmada and Mahi rivers and the narrowing of the basin further northwest with the clear cut eastern and western margins.

As the basin is totally covered by alluvium except near the eastern margin, the gravity map (both Bouger and Residual) (fig. IV.2) is found to be very useful in deciphering the main structural elements. In the study area, the basin is open to the northwest and southeast and is marked to the east and west by marginal faults which limit the Early Tertiary sedimentation in the basin and within which the sediments are very thick. The basin marginal fault is not one single fault but comprises of a zone in which one forms the main fault. This can only be traced by detailed reflection seismic surveys across the margin (fig. IV. 3 and 4). In the absence of such surveys, the marginal faults noted in one seismic profile are extended along the margin with the help of gravity map. The position at which the reversal of gravity gradient is noted, is taken as the position of the marginal fault for extending along the margins. It is not feasible to say as to which sedimentary section extends beyond the marginal faults towards the edges of the basin. This can be brought out if close grid seismic profiles crossing both marginal faults are shot and subsurface geological data are available near the seismic profiles. Along one line across the basin at the southern boundary of the study area, such detailed data are available. These data show that the upper part of the Paleogene section, very much reduced in thickness, extends beyond the fault with only a minor variation in the thickness of Neogene sedimentary section (fig. IV. 5 and 6).

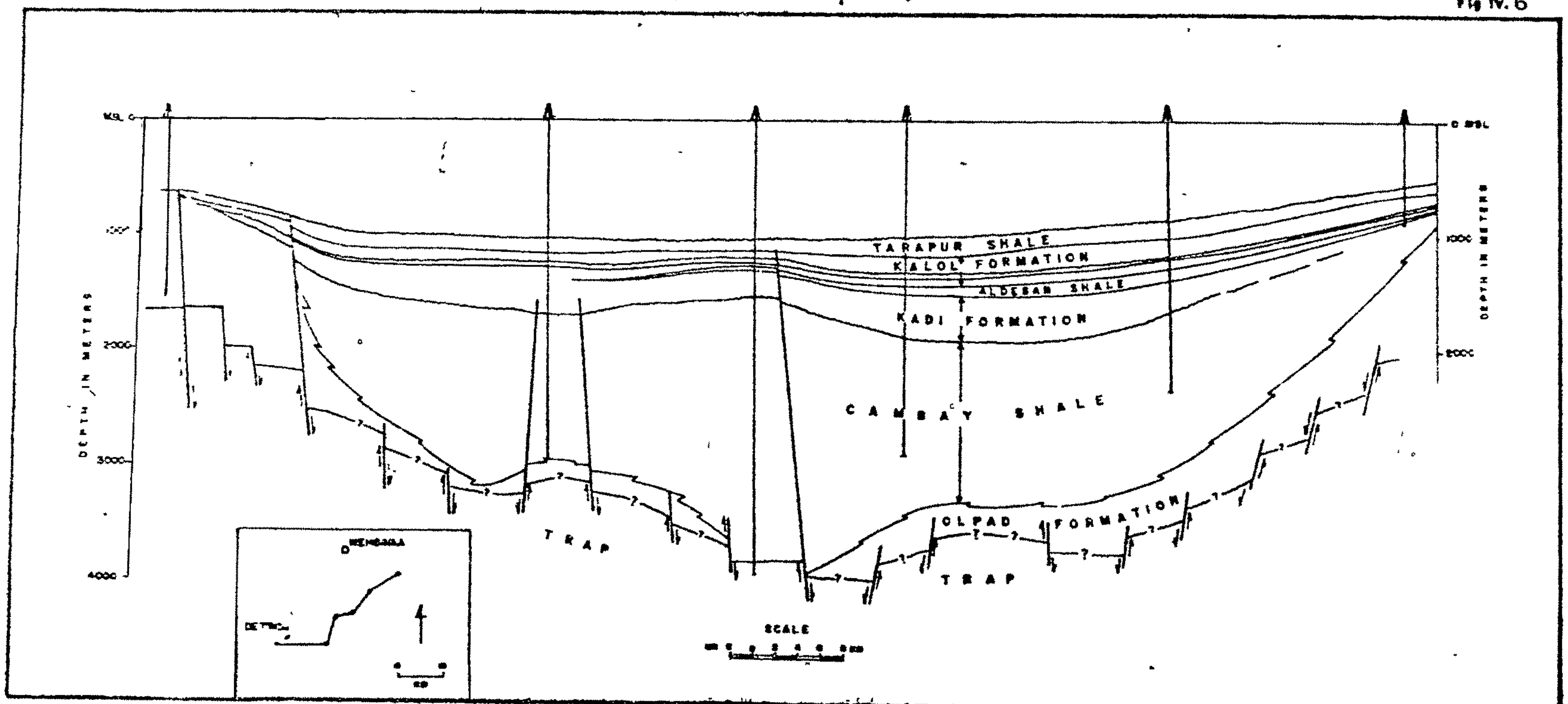
GEOLOGICAL SECTION ACROSS THE BASIN OF THE STUDY AREA
(Middle part)

Fig IV.5



GEOLOGICAL SECTION ACROSS THE BASIN OF THE STUDY AREA
(Southern part)

Fig IV. 6



An interesting feature brought out by the gravity data is the strong Aravalli trend on the north eastern margin of the basin, which sharply swings to southeast showing the marginal area of the basin and the marginal fault zone along the straight edges of the gravity contours.

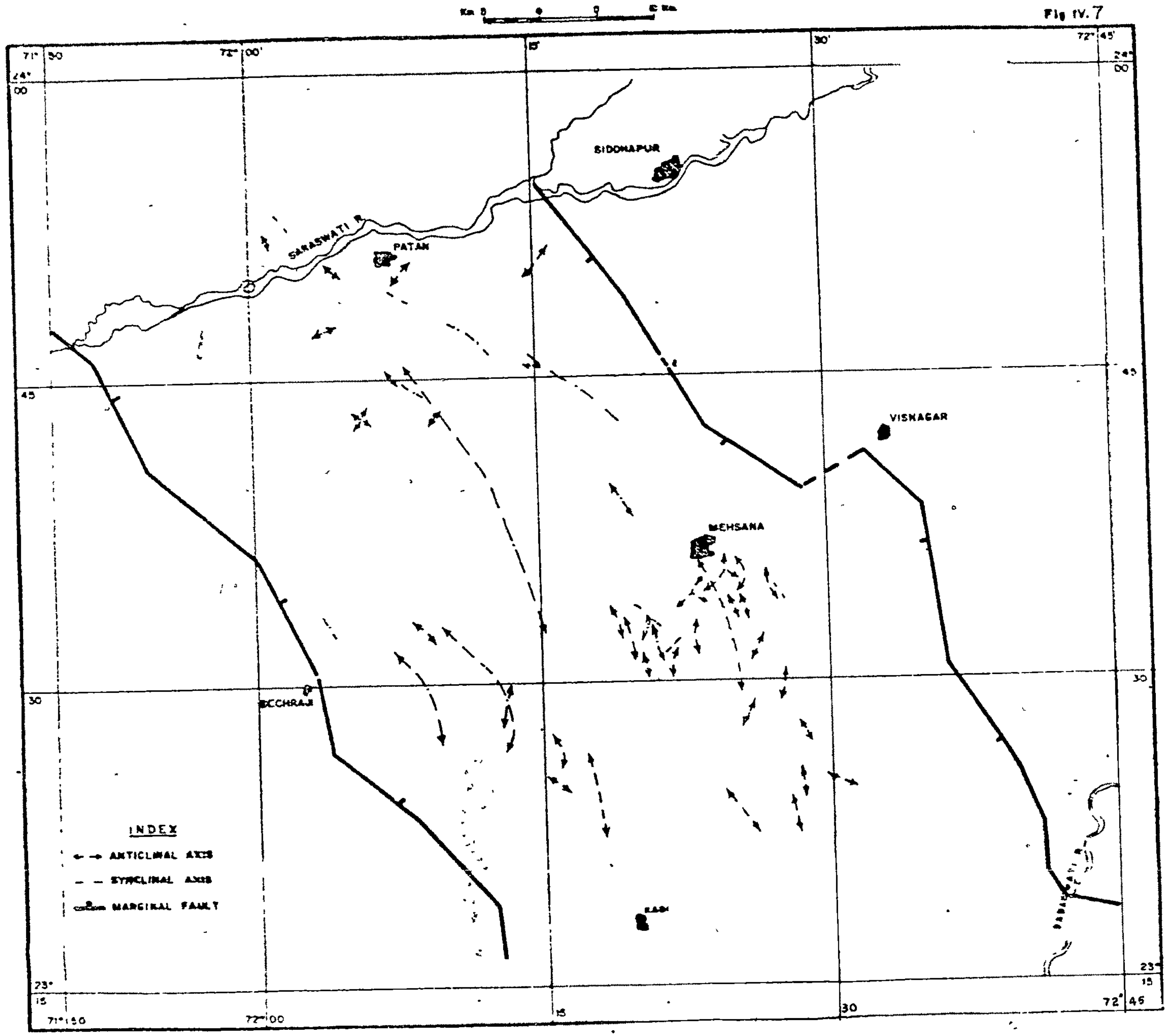
Mehsana horst

The most prominent structural feature of the area is a horst (fig. IV. 7) in the middle of the basin and parallel to it. This is the Mehsana horst. To the northwest, the horst plunges gently, fading and merging into other small structural features. To the southeast, the horst branches out loosing its sharp manifestation. However, on the gravity map, the horst and the branched out domal features to its south have come out sharply and the feature is known as central Gujarat gravity 'High'. On both sides of the horst with its branches, the basin is deep and is represented by gravity 'Lows'. The eastern 'Low' is deeper than the western, with a sedimentary fill of more than 4400 m.

The Mehsana horst is 30 km long and 8 km wide at the level of the base of the formation of Oligocene age which is deposited over the entire horst. The formations of Eocene age are not fully represented over the horst and are met with on the flanks of the horst and the limit of these formations on the flanks is taken as representing the horst. The eastern and western flanks of the horst are faulted, the eastern one being more prominent. The faults have mainly affected the Deccan Trap, whereas the overlying sediments upto the level of the formations of Eocene age are gently faulted. It may be pertinent to state here

MAP OF THE FOLD TRENDS

Fig IV.7



that the central Gujarat gravity 'High' may represent a horst in the middle of basin caused by upwelling of the magma during the formation of the basin and this horsting in the Deccan Trap continued subsequently dying out in Post Miocene by which time most of the tectonic activity of the basin ceased (fig. IV. 8).

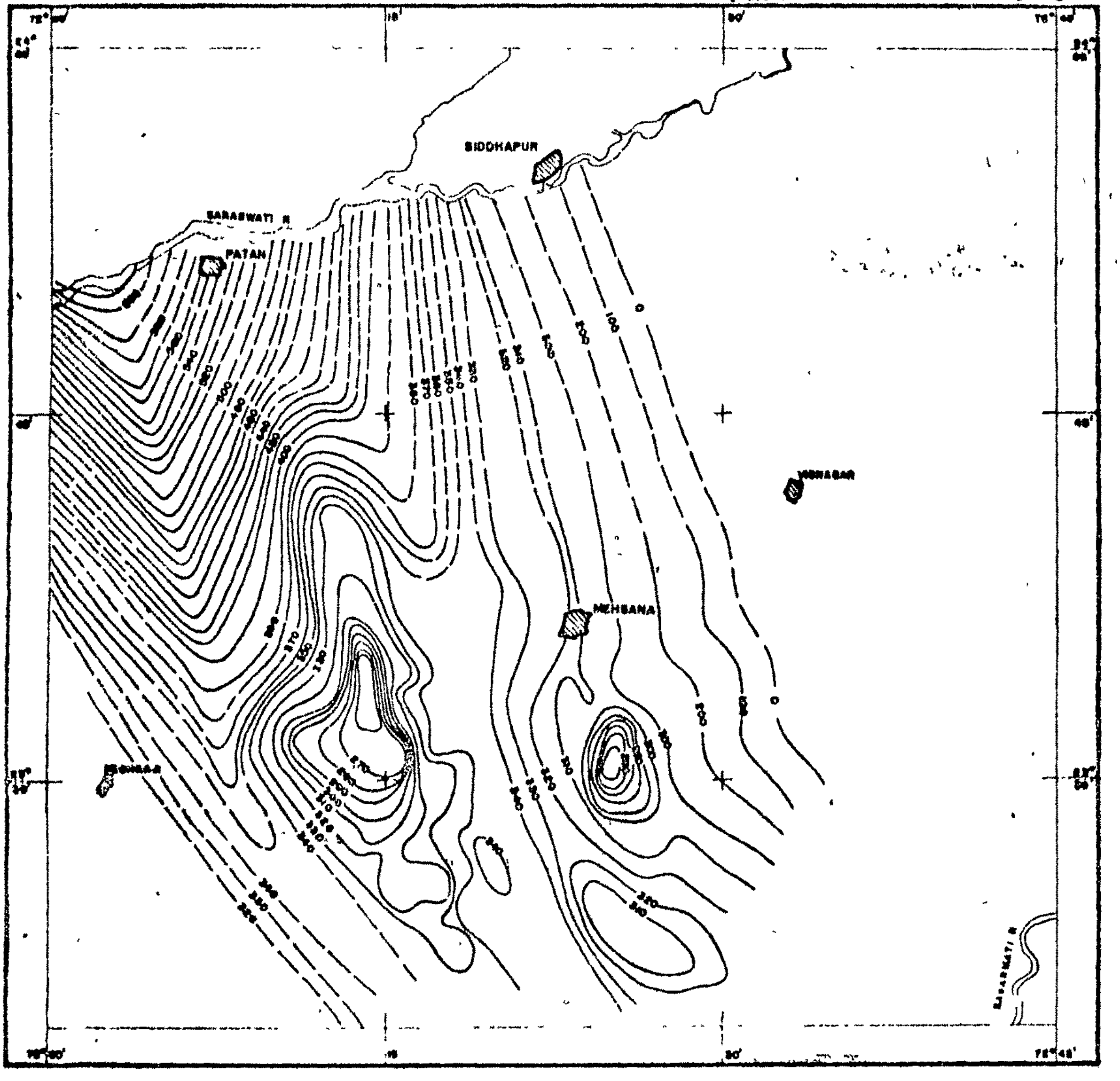
The eastern and the southern flanks of the horst are well delineated by seismic data but the western flank is not well mapped being less prospective for oil exploration. An embayment appears on the south western flank of the horst with another anticline to the west of it.

Mehsana depression

Another important structural feature is the depression to the east and south east of the Mehsana horst and west of the eastern marginal fault, which is called the Mehsana depression. Gravity data clearly brings about the shape of the depression and the maximum thickness of the sediments of Cenozoic age, in the southeastern part of the study area, the thickness reaching 4400 m. The depressioin narrows to the northwest and extends beyond Saraswati and Banas rivers by a short distance. Paleotectonic analysis of the basin shows that most of the sediment fill in the depression is of Early Tertiary age (Paleocene to Middle Eocene) and by Early Oligocene, the depression has disappeared. The map of the structural lineaments of the area (fig. IV. 9) shows the prominent faulting along the eastern flank of Mehsana horst and along the eastern margin of the basin which brought out the depression.

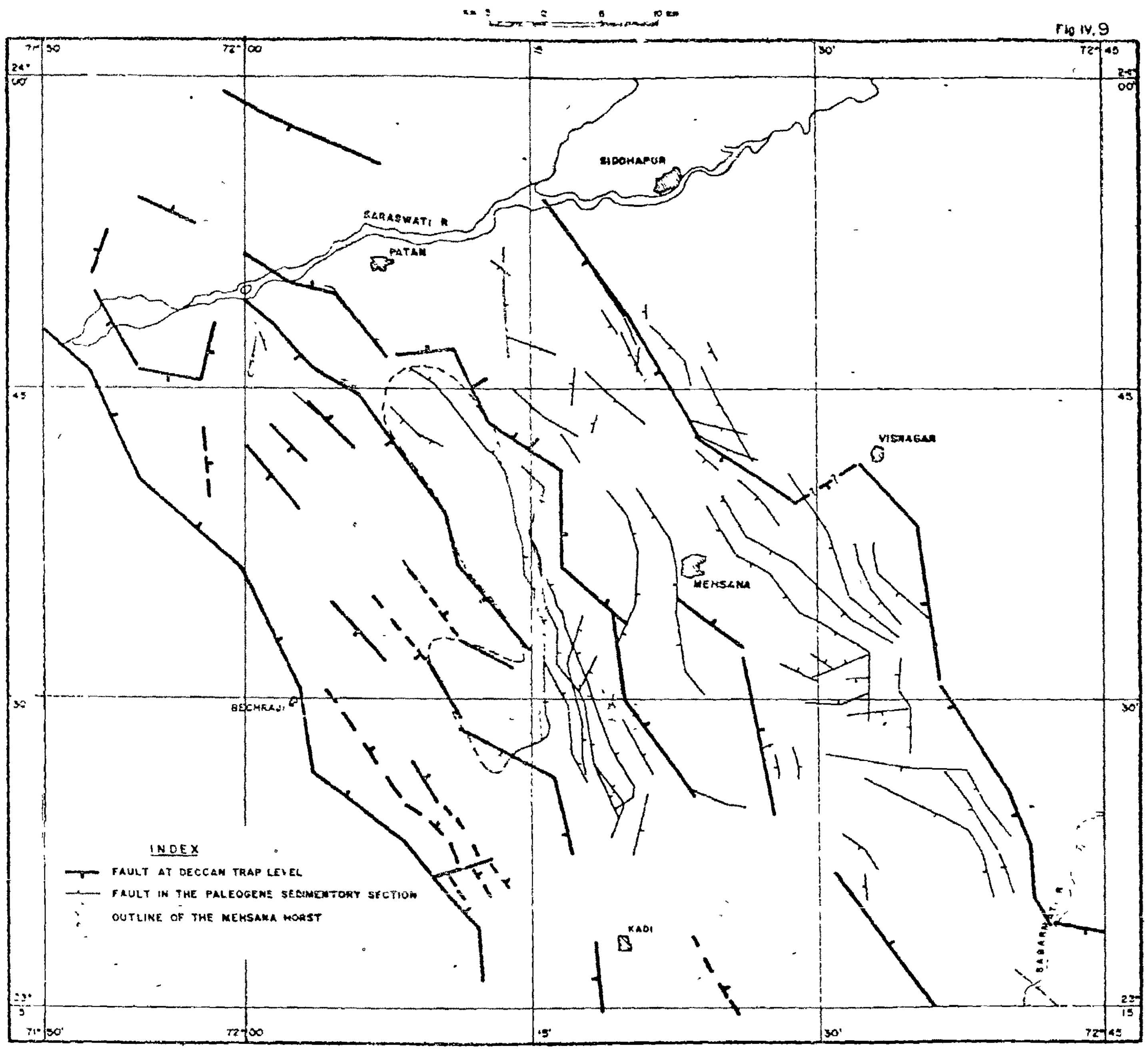
STRUCTURE CONTOUR ON A MARKER NEAR THE TOP OF MIOCENE SEDIMENTS

(IN M BELOW MSL) Fig IV.8



FAULT PATTERNS IN NORTH CAMBAY BASIN

Fig IV.9



Since the Aravalli uplift is known to be a positive area just to the north east of Cambay basin, it is natural for the drainage to flow from the northeast and carry a large volume of sediments into the basin and deposit it in the nearest depression of the basin namely the Mehsana depression. Ofcourse the nature of the sediments will depend on the provenence, the slope of the drainage and the energy of the depositional medium etc. which is not discussed here.

West Mehsana depressioin

West of the prominent Mehsana horst and east of the western marginal fault, another depressioin exists. This is not as large as Mehsana depression and also does not contain as thick a sedimentary section. The sedimentary fill is of the order of 3600 m. This depression also narrows rapidly towards northwest and disappears within the study area itself. Although a large volume of sediments is transported from the east into the basin, considerable evidence is available to conclude that the basin received sediments from the northwestern part of the study area also, if not in the early history of the basin but in the later part of the Paleogene period. The two depressions meet south of the Mehsana horst.

Patan depression

Just north of the Saraswati river, in the strike continuation of the Mehsana depression is the Patan depression, which narrows down further to the northwest, disappearing in its identity, a few kilometers away. Since most of this feature is outside the study area, it is not proposed to discuss details of this.

Faults

The map of the structural elements of the study area shows all the important faults at the different stratigraphic levels of Paleogene section. The faults at the Deccan Trap level are delineated by the gravity and seismic reflection data. The important of these such as the marginal faults and the faults on the flanks of Mehsana horst are only shown on the map. Besides, some faults at Deccan Trap level are in the northern extension of Mehsana horst and in the West Mehsana depression. All these faults are normal tensional faults formed in the course of the initial development of the basin.

The other faults shown in the map are identified in the sediments of the different formations of Paleogene period. The end of the Paleogene period is marked by a prominent unconformity and most of the faults do not extend above the unconformity. The recognition of the faults, observed in the upper part of the Paleogene sedimentary section is difficult in the lower part as this lower sedimentary section is basically a fine clastic section and the response of seismic signatures to the faults in a monotonous section is feeble. The faults in the sediments and at the Deccan Trap level are all vertical, sometimes with a gentle hade. In most of the cases the faults are linear.

All the faults at the level of Deccan Trap shown in fig. IV.6 are trending northwest southeast, this being the strike of the basin. These faults are reflected in the gravity maps. Most of these faults extend into the overlying sedimentary section upto the top of Paleogene sequence by which time all tectonic activity has ceased in the basin.

The faults in the sediments are also parallel to the strike of the basin. These are affecting the sediments at different stratigraphic levels but all of them end at the top of Paleogene sequence. It is not clear if some faults in the sediments are rooted in the Deccan Trap basement as the seismic reflection data in the lower part of the Paleogene sequence are hazy.

Folds

Mehsana anticline

Details of the Mehsana horst are discussed earlier. Draping the horst, a subsurface anticlinal structure is developed at the level of the formations in Upper Paleogene sequence. As expected, this anticline plunges towards south southeast and north northwest. The southeastern segment of the fold merges with another anticline, at the youngest level of the Paleogene sequence. At a lower stratigraphic level, the formations are not deposited on the horst. The eastern flank of the anticline is slightly steeper than the western flank. The length of the anticline is 30 km and the area is about 230 km^2. The Deccan Trap is met with at 821 m depth at the structural top.

Kadi anticline

Separated by a spur from the Mehsana horst, Kadi subsurface anticline occurs to the north of the Kadi town. The anticline occurs at all stratigraphic levels above Deccan Trap upto the top of Paleogene sequence (835 m depth below msl.) above which the beds are nearly flat. The anticline extends over a maximum area of 33 sq km and has an amplitude of 74 m. The Deccan Trap is met with at 1471 m depth below msl. The axis of the fold is 7 km long and trends north-northwest south-southeast. The eastern and western flanks are gentle with a dip 4° to 6°. An interesting feature of the anticline is the occurrence of a syenite plug met with in the first exploratory well for oil drilled on the structure. The plug is interpreted to be a differentiate of the basic lava flows of Deccan Trap. The shallow depth of the Trap and the shape of the syenite plug appears to control the size and shape of the structure in the sediments.

Separated by a small spur from the anticline and at distance of 3 km to the west, two small subsurface anticlines are also noted. These anticlines, each of the size of 1 sq km are part of the larger Kadi anticlinal closure.

Sobhasan anticline

The anticline is situated just to the south of Mehsana town and trends in north-northwest south-southeast direction. The axis is about 12 km long and the structure has a width of 1 to 3 km and extends over an area of about 18 sq km with a maximum amplitude of 45 m. The Trap basement in this structure is expected to be deep and of the order of 4.5 km although none of the exploratory wells reached the depth. The seismic data indicates this depth for the basement. The subsurface structure is mapped at three stratigraphic levels in the depth range of 1100 m to 1500 m below msl. The possibility of the structure existing even in deeper sediments cannot be ruled out. The seismic data to interpret the same are missing due to a monotonous shale section and without a contrast in the physical parameters. The flanks of the structure have a very gentle dip and of the order of 2°.

The structure is located near the eastern margin fault. It is likely that the fold got generated by the adjustment faults during the consolidation of the thick Paleogene sedimentary section in this part of the basin.

Becharaji anticline

In the western part of the basin, and to the east of the marginal fault, the subsurface Becharaji anticline is mapped. It is well brought out at the top of Paleogene Section and has an area of 22 sq km with an amplitude of 30 m. The anticline has the regional northwest south-eastern trend with gently dipping flanks and dips of the order of 1/4°. This anticline is also genetically related to the faulting in the Deccan Trap, the basement of the sediments. As in the case of other anticlines, the fold is mapped at the level of the formations near the top of Paleogene sequence. The fold is also seen at the lower stratigraphic levels down to the Deccan Trap.

Besides the above, several small anticlinal features and faulted anticlinal limbs are also mapped, all of them trending in the regional north northwest-south southeast direction.