CHAPTER II-A

BACKGROUND INFORMATION

PREVIOUS STUDIES

A brief account of the geological investigation on the Cambay basin is reviewed here covering (1) tectonics (2) stratigraphy, and (3) sedimentation, to provide a background information for the present study.

The northern part of the Cambay basin is largely covered by alluvium. On the boundaries of the basin, a few scattered exposures of Mesozoic sedimentary rocks are noticed. The basin is now well known as a petroliferous Tertiary sedimentary basin which is studied in great detail for its stratigraphy, the environment of sedimentation of its lithological units, the prediction of sand geometry, etc.

Earlier publications have covered only one aspect or other of the geology of this area but the integrated picture of the geological history and the geomorphology of the area is not provided by any one of the workers.

As the tectonics of the area can be investigated only by the subsurface geological data of the wells drilled for petroleum and by the seismic data collected and processed for petroleum exploration, the published data are very limited. In fact, the geology of this part of the basin came to be better known only in the last one decade. However, the data are available for analysis since the mid sixties. The first comprehensive study and publication on the tectonics of the basin is in 1967 (Mathur et al, 1967). The basin is considered as an intracraconic basin and is divided into four tectonic blocks : (1) the Narmada block (2) the Jambusar-Broach block (3) the Cambay- Tarapur block and (4) the Ahmedabad-Mehsana block (fig II.1). A fifth block namely the Patan-Tharad block further to the north is also proposed and considered by many workers as a block. The tectonic elements in each of the blocks are discussed in detail and the genetic explanation is given. The northern part of the Ahmedabad-Mehsana block which encloses the area of study is less discussed as very few subsurface data are then available.

Raju et al (1971) studied the geological framework of the Cambay basin and indicated that three main tectonic trends parallel to the Dharwar, Satpura and Aravalli lineaments determine the structural

TECTONIC MAP OF CAMBAY BASIN

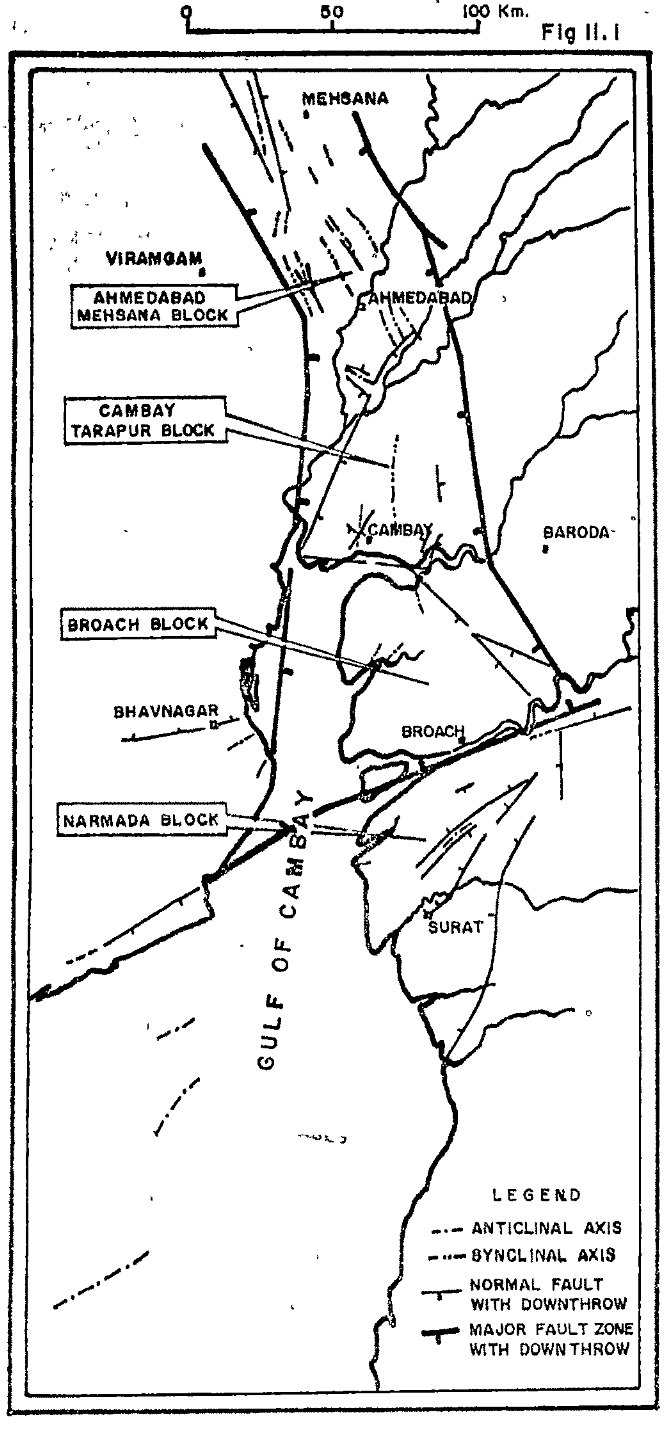


Fig II.1

setting of the basin. The author has also suggested that Trap tectonics controlled the lithology of the overlying stratigraphic section.

Kaila (1982) with the Deep Sounding Studies along a N-S profile in the Cambay basin indicated the top of the Deccan Trap and the top of the granitic basement below the sedimentary section, besides giving the Mesozoic sedimentary thickness under the Trap. The DSS data have provided knowledge about deeper geological formations, not normally available by the seismic studies of ONGC.

Biswas (1982) has postulated three craton margin embayed basins namely Kutch, Cambay and Narmada formed as grabens, filled with clastic sediments. The Cambay basin is postulated to have been formed in Late Cretaceous.

Rao and Talukdar (1982) while describing the petroleum geology of the Bombay High field, discussed some structural aspects of the Cambay basin, observing that the Cambay basin appears to terminate south of Narmada river and the structural grain of the basin is NNW-SSE (Dharwarian). They have also suggested that the western marginal fault of the offshore basin continues into the eastern margin of the Cambay basin.

Gambir (1975) studied the tectonics of the northern part of the Cambay basin and indicated that the Paleogene sedimentary section has N-S horst graben features, and on the whole can be divided into two blocks.

Babu (1977) studied the Quarternary geology on aerial photographs and identified black cotton soil, sandy loams, flood plain deposits, levees, swamps, barrier spots etc. The trends of fluviatile and aeolian deposits are NE-SW and of the marine deposits NW-SE. The morphostructural distribution is studied on the basis of tonal contrasts and drainage pattern and this indicates NE-SW pattern of structural trend in conformity with Aravalli grain. The landscape of the basin area and the youthful mantle fails to hide the dominant features of the underlying structural forms.

Raju et al (1982) studied the lithological associations, sedimentary structures and petrographic data of the northern Cambay basin and concluded that the sedimentary environment changed from shallow marine to littoral and then to deltaic marsh to fluviatile from Lower Eocene to Middle Eocene as represented by shale-quartz arenite association through quartz wacke carbonaceous shale, sideritic claystone-coal association to coarse grained quartz wacke-sideritic claystone and carbonaceous shale association. Short lived marine transgressions indicated by the well defined shale tongues are noted.

Madanlal and Singh (1984) studied the palaeoenvironment and provenance of Kalol formation of Mehsana area. They described the lithology of the rock types as quartzwacke with a few quartzarenites and with rare glauconitic sandstone. They studied the grain sizes of the sandstones and interpreted the data by various plots and concluded that the rocks of the formation have been formed under various rapid cycles of transgression and regression in a broad regional framework.

During transgression, shales were deposited and during regression silts and sands and deltaic swampy deposits were formed. Clay mineralogical studies of the Kalol formation showed that kaolinite is the most abundant mineral with a rare occurrence of montmorollinite, kaolinite indicating continental environment or an abundance of the mineral at the source.

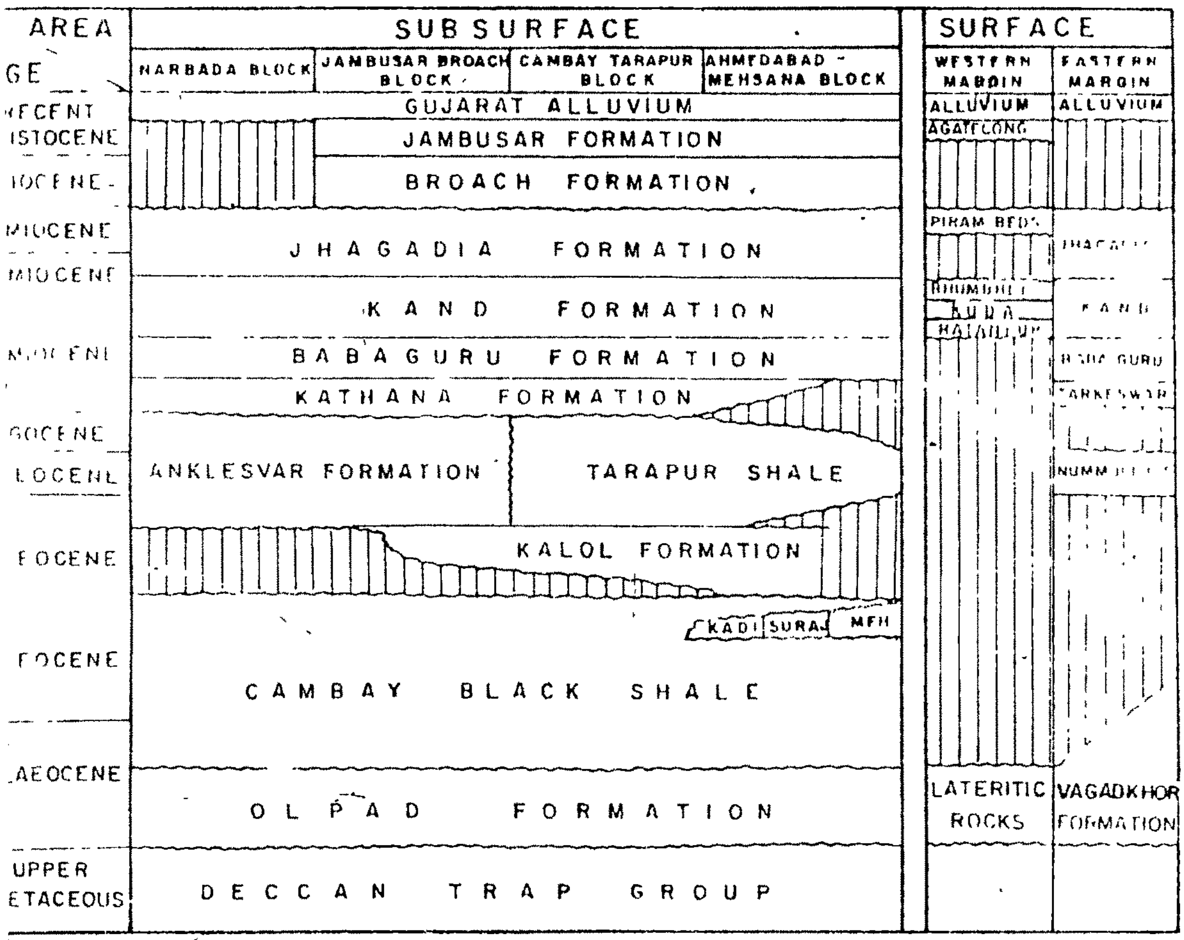
Chandra and Choudhary (1969) published the first study on the stratigraphy of Cambay basin in which the entire Paleogene and Neogene sedimentary section is divided into fifteen mappable units, of which Deccan Trap and three Neogene formations are exposed and the rest are identified in the subsurface only (fig. II.2).

SYNTHESIS OF THE PREVIOUS DATA ON ADJACENT AREAS IN THE CAMBAY BASIN

The author has summarised in the following lines the salient features of the geology of the adjacent areas in the Cambay basin synthesising the data provided by the various previous workers.

A large part of the basin is covered by alluvium. To the north northwest and to the south southeast of the study area, subsurface geological data are available in widely spaced localities and more closely in a few localities where oil production goes on. In the northern adjacent area, north of Saraswati river, subsurface geological data are available from seven localities, namely Dasavara, Sampra, Wara, Deodar, Dalwada, Tharad and Serau. Here, the Deccan Trap with a maximum thickness of 580 m is underlain by dirty white sandstone, current bedded and micaceous with ferugeneous stains. Protoquartzites are common in the upper

Fig II.2


AREA
SUB SURFACE
SURFACE
NARBADA BLOCK
JAMBUSAR BROACH BLOCK
CAMBAY TARAPUR BLOCK
AHMEDABAD - MEHSANA BLOCK
WESTERN MARGIN
EASTERN MARGIN
GUJARAT ALLUVIUM
ALLUVIUM
ALLUVIUM
AGATE CONG.
JAMBUSAR FORMATION
BROACH FORMATION
PIRAM BEDS
JHAGADIA FORMATION
KAND FORMATION
KAND
BABAGURU FORMATION
KATHANA FORMATION
ANKLESVAR FORMATION
TARAPUR SHALE
KALOL FORMATION
KADI
SURAJ
MEH
CAMBAY BLACK SHALE
OLPAD FORMATION
LATERITIC ROCKS
VAGADKHOR FORMATION
UPPER
ETACEOUS
DECCAN TRAP GROUP
ISTOCENE
MIOCENE
EOCENE
AEOCENE

and lower part whereas subgreywackes are characteristic of the middle part. The upper part of this coarse clastic section consists of thin alternations of splintery chert, cherty siltstone and intercalations of pyroclastics, like sandy tuff, calcareous sandy tuff and volcanic greywacke. The clastic section underlying the Trap is about 370 m thick in Serau and overlies the granitic basement.

The Palaeogene stratigraphy here is similar to that of the study area and the sequence is divided into four formations. The basal formation is made up of conglomerate and sandstones with a few clay beds, a product of fast weathering and transport from Trap terrain. The upper formation is an Oligocene shale spread over the vast area of the basin as a marker formation. The middle formations are represented by sugary sandstone, hard siltstone and claystones with coal bands. The most prominent thick marine shale that overlies the Trap in a large part of the Cambay basin is absent to the north of Banas river and is represented by a coarse clastic section. Sedimentological studies of these coarse clastic formations show that these are deposited in a deltaic environment with a dominant transportation by saltation and suspension mechanism in the lower part and winnowing by wave energy in the upper part.

The overlying Neogene sedimentary section is divided into four formations with Gujarat Alluvium overlying them. The older three formations are of Miocene age and are separated by the overlying and underlying sections by unconformities. The lithology of these formations is mainly sandstone with thin shales and a few coal bands and claystones in the middle. Gravel beds with thin clays and claystones are also met with in a few localities. The younger formation comprises of grey plastic calcareous silty clays with coarse grained poorly sorted sandstones.

The tectonics of this part of the Cambay basin is similar to the rest of the basin in the south and is controlled by block faults and the marginal faults. The grain of the crystalline basement is very well seen in Bouger anomaly maps wherein the Aravalli grain cuts across the Cambay basin continuity. The Tharad ridge is one such prominent cross feature which breaks the continuity of the Cambay basin with Sanchor depression in the north wherein one exploratory deep well for hydrocarbons has been drilled down to the crystalline basement. In fact, Tharad ridge may represent the northern limit for the Paleogene section of Cambay basin.

The southern adjacent area is an intensely explored part of the Cambay basin for hydrocarbons. The area is devoid of outcrops and the geology is interpreted from the subsurface data only. Deccan Trap forms the floor of the Tertiary basin all over and is 300 m thick near Viramgam, on the western flank of the basin where it overlies the Mesozoic rocks, penetrated partially by a well. No data are available on the probable thickness of Trap in the middle part of the basin.

The stratigraphic column in this area is almost the same as the one in the study area being contiguous in the geological history of the basin, unlike the northern adjacent area. The sedimentary environments of these units are also very similar to those of the study area and hence is not discussed in detail here.

Due to the nature of the intracratonic basin particularly during the early stages of the basin formation, the Paleogene column is thickest in the middle thinning towards the eastern and western flanks and also towards the crystalline basement/Deccan Trap horsts. The tectonics of the basin here is controlled by block faulting causing horst graben features in the early geological history of the basin. Although deltaic sedimentation is the cause of much of the coarser clastics of the stratigraphic section, the tectonics of the basin has not been affected as the delta growth was slow unlike the large Narmada delta that built up into the basin.

The grain of the Deccan Trap basement here is NNW-SSE. Two prominent horst trends are noticed and these are Sanand-Jhalora-South Kadi and the Ahmedabad-Kalol-Nandasan trends with an intervening syncline. No clear cross trend is discernable.

CHAPTER II-B

GEOLOGICAL SET UP OF THE STUDY AREA

REGIONAL GEOLOGY

The northern part of Gujarat State has no surface geological exposures except in the vicinity of Himmatnagar where outcrops of volcanic rocks of Late Paleocene age, sedimentary rocks of Jurassic age and the Precambrian shield are well known. Various scientific agencies of India have mapped the surface exposures and also collected geophysical data that could be interpreted in terms of tectonics and regional geology of this part of Gujarat State. The extension of the volcanic rocks exposed near Himmatnagar, Kapadvanj, Rajpipla and Jhagadia towards west underneath the Gujarat alluvium, as subcrops connected with the Deccan Trap volcanics exposed on the Saurashtra Peninsula, is known.

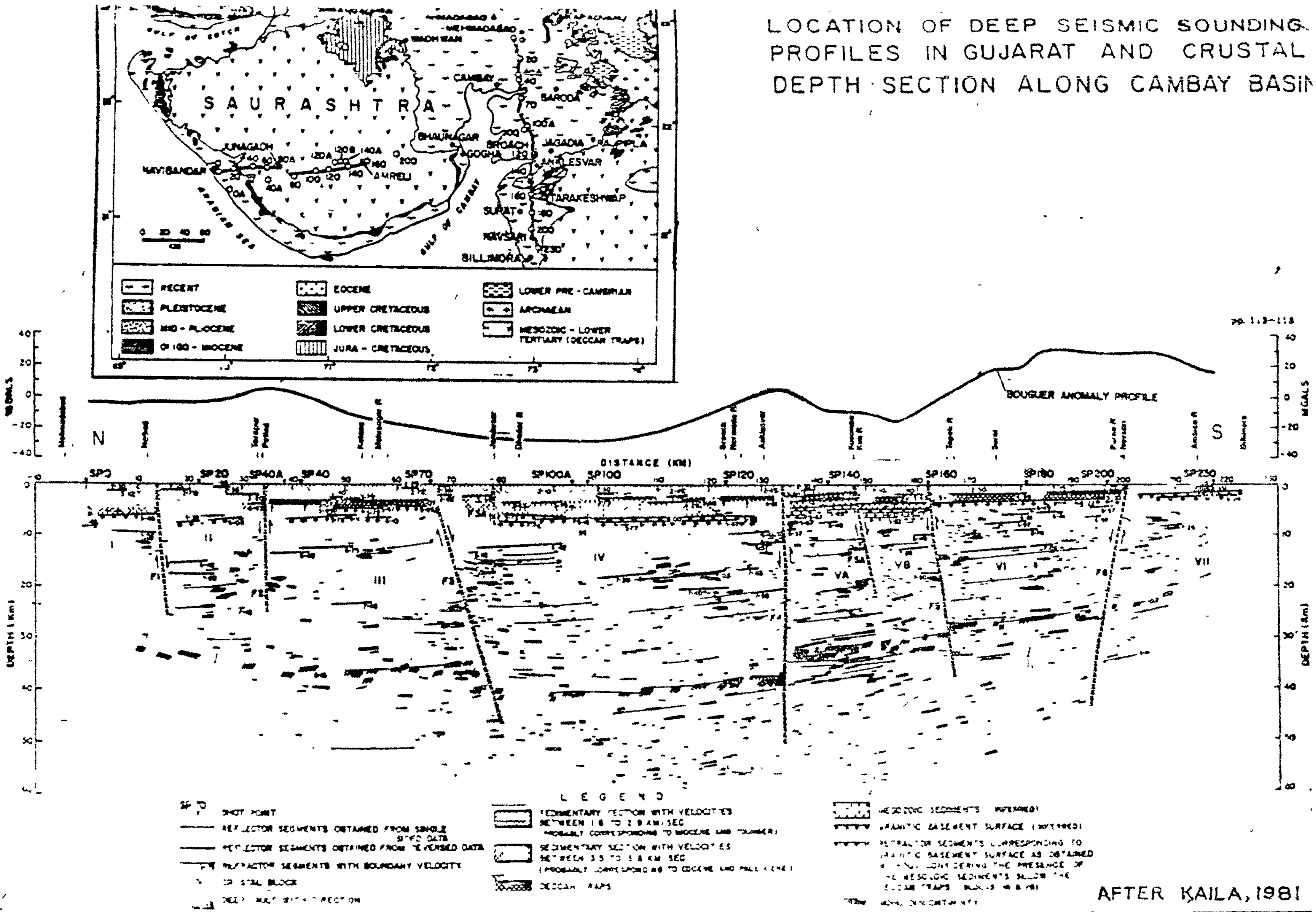
The subcrop of Deccan Trap is confirmed by wells drilled for oil exploration and by seismic surveys for oil exploration in which the velocity variations down to different depths provide a clear clue.

The Trap thickness in the area is not known with as much accuracy as in the southern part of Cambay basin, where deep sounding seismic data are available with a few well data control. The thickness increases from a few meters along the eastern flank of the basin, south of Narmada river near Dinod to almost 2000 m at the coast near Kim village. The occurrence of subcrop Deccan Trap between Narmada and Mahi rivers is not supported by the seismic surveys but the outcrops of the basaltic rocks all along the eastern flank of Cambay basin and the occurrence of the same basalts in the subsurface north of Mahi river and south of Narmada river leads one to the conclusion that the basaltic Traps are present in the subsurface between Narmada and Mahi rivers. North of Mahi river, basaltic Traps are met with below the alluvium on both margins of the Cambay basin near Dhanduka and Padra and in the central part of the basin at Cambay, Bareja and a few other places. The thickness of the basalt near Dhanduka and Padra, the western and eastern flanks of the basin respectively is 424 m and +325 m respectively and more than 1100 m in the middle part of the basin near Cambay. As for the existence of the Mesozoic rocks in the area below Deccan Trap the data are not clear. The deep seismic sounding surveys by N.G.R.I. (Kaila, 1982) have shown that the Mesozoic rocks which are very likely to occur below the subcrop volcanic rocks, west of Anklesvar and Tarakeshwar, do not extend to the north of Narmada river. The single line deep sounding seismic study (fig II. 3) in the basin extends to the north upto Mehmedabad without any indication of the presence of Mesozoics. Further, deep sounding seismic studies indicate that the deep seated fracture along Narmada lineament extends down to Moho boundary and this fracture was active in different geological times. During Mesozoic era, the area to the south of lineament is downfaulted receiving sediments whereas to the north, the land was exposed. The Mesozoic basin probably extended from Nepanagar-Popotkheda area in the Tapti valley towards west into Ankleswar-Surat area and continued across the gulf to the Saurashtra. Due to the above reason, it is considered unlikely that the Mesozoic sediments extend to the north of Narmada river in the alluvial tracts of Gujarat into the area of study. Moreover, the palaeocurrent direction of the Dhrangadra sandstones of Mesozoic age (Bhandari and Kumar, 1970) is prominent from east to west indicating that the drainage, carrying sediments was from the crystalline complex of Aravalli mountain range to the west towards gulf of Kutch, ruling out the possibility of a graben in Mesozoic era, in this location of Cambay basin. As such, the presence of Mesozoic rocks in the subsurface, south of Mehsana and north of Narmada river is not expected. The floor of the Mesozoic sediments is the Precambrian. Where the Mesozoic sediments are absent, the Deccan Trap overlies the Precambrian basement.

DEVELOPMENT OF BASIN CONFIGURATION

The basin extends on the land from Bilimora to Tharad in the north and into the gulf of Cambay upto Gogha. On the western

LOCATION OF DEEP SEISMIC SOUNDING PROFILES IN GUJARAT AND CRUSTAL DEPTH SECTION ALONG CAMBAY BASIN



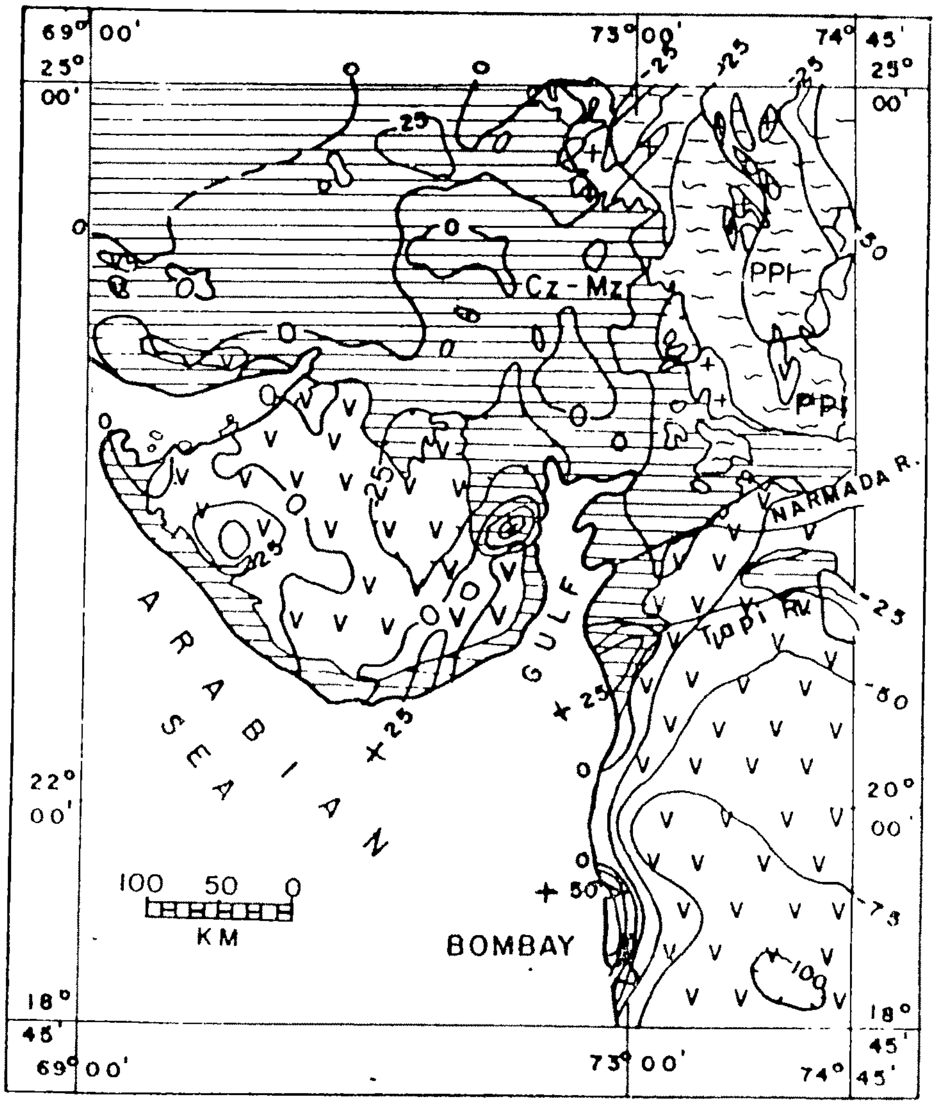
AFTER KAILA, 1981

margin it extends from the mouth of the Sabarmati river to Dholka then to Viramgam and further towards northwest. On the eastern margin it extends along the boundary of the Deccan Trap with alluvium and then towards Padra. Beyond it extends towards west of Himmatnagar in a northwesterly direction. It fringes the northwestern margin of the Indian Precambrian shield. The basin is flanked on the northeast by Aravalli Precambrian shield and on the east and west by the Deccan Trap. The last orogenic cycle experienced by this part of the Indian shield is the Delhi cycle, after which, the edge of the shield remained a platform, responsive to epirogenic movements only. Subsequent to the Delhi cycle, the basin and the area adjacent to the basin experienced sedimentation in Upper Carboniferous time (Umaria beds) the marine transgression having taken place along Narmada geofracture. In the Upper Jurassic period and the Cretaceous period sedimentation took place in some parts, on the northwestern side of the Precambrian peninsular shield. Marine sedimentation took place in the area south of Narmada river and extended towards east, as already discussed. However, fluviatile deposition took place in the Dhrangadhra area, the sediments having been transported from east northeast (Aravalli range) towards the embayment of the gulf of Kutch. It is unlikely that marine Mesozoic sediments occur in the large part of Cambay basin north of Narmada river below the Deccan Trap. The basin formation did not take place at all in the Mesozoic Era prior to the eruption of Deccan Trap and during the deposition of Bagh beds; the Cretaceous sea has not crossed Narmada river to the north but skirted round the Saurashtra Peninsula.

The development of the basin appears to be related to the tensions created by the northward drift of the Indian plate, and its counter clockwise rotation. These tensional faults developed along ancient basement fracture trends submerging parts of the platform. These movements are accompanied by large scale volcanic activity whose basaltic rocks form the floor of the Tertiary basin. The volcanic rocks occupied a vast area of the northwestern edge of the Precambrian shield. From deep seismic and gravity studies, it is concluded that Moho near Bilimora is hardly 18 km deep and the basaltic layer (Sima) is as shallow as 6 km deep. The Bouger anomaly (fig II. 4) indicating this feature runs from Bombay to Surat along the coast for 300 km distance and turns to the east. As the crustal column is comparatively less thick, a thin granitic layer overlies the basaltic layer (Kaila, 1982). This molten basaltic layer is probably the source of magma that erupted out of deep seated faults and fractures. As the major source of Deccan Trap eruption lay along Bombay Surat line parallel to the present coast, it is likely that the same weak zone of eruption extended beyond Surat towards north northwest also to some distance. The continuity of the weak zone through which molten lava erupted out is borne out by the gravity data. The Tertiary basin is originated by the formation of basin marginal step faults along the same weak zones and fractures which sourced the molten basaltic flows. The basin is an intracratonic basin as its formation is connected with the tensional movements of the craton only. The basin is elongated in the north south direction near the gulf, then gently swerves towards north northwest and then to the northwest losing its identity in the vicinity of the Rann of

Fig II.4

BOUGUER ANOMALY SUPERPOSED ON A CONDENSED REGIONAL GEOLOGY MAP OF WESTERN INDIA



L E G E N D

CENOZOIC MESOZOIC, Cz - Mz

LOWER GROUP METAMORPHOSED SEDIMENTS & CRYSTALLINES, PPI

INTRUSIVES

EXTRUSIVES

STRUCTURAL TREND

50 BOUGUER ANOMALY CONTOURS, 25 MGL INTERVAL.

Kutch. It is 85 km wide in the south near Narmada river and is 43 km in the north, near Tharad. The marginal faults are discernable in gravity magnetic data but they are not continuously traceable as these comprise en-echelon zone of faults. The zone however can be well traced. The eastern marginal fault zone has a greater down throw to the west than the western marginal fault zone with down throw to the east, since the weak zone along the west coast of India, which sourced the basaltic lava flow continues as a weak zone to the north along the eastern margin of the basin. The western marginal fault is much less prominent and is much less severe all along the length of the basin. This marginal fault does not probably coincide with any crustal weak zone. As such the basin is normally described as a half graben.

In the course of the development of the basin as the site of Tertiary sediments, different blocks of the basin developed characteristics typical to each block. These characteristics include the fault trends (the horst-graben trend) the direction of the grain of the Deccan Trap basement, the nature of the sedimentation in the early Tertiary period reflecting the vertical movements and the paleo-drainage pattern etc. The characteristics of the blocks fade out by the end of the Palaeogene period and the block concept cannot be discerned in the basin during subsequent times. Neverthless, the marginal faults remained partially active even later.

The evolution of each block has a separate history although all of them retain a common identity. The Narmada block is unique as it is the only one with surface geological exposures of sedimentary rocks overlying Trap which have been mapped and carried over in the subsurface in atleast the Upper Tertiary sequence of the basin. The ENE - WSW trend (Satpura strike) of the exposed rocks, the faults within the sediments just above the Deccan Trap, the fold axis of the prominent anticlines and the Narmada river point to the strong tectonism experienced by this block throughout the geological period. Even the Plio-Pleistocene sediments are faulted with the strike paralleling the Satpura trend. The Deccan Trap is also folded along with Tertiaries and the underlying Cretaceous sequence (Pascoe, 1964). The repeated earthquakes experienced by Broach town even the last one a few years back, gives a lead to the tectonism experienced by this block. The block is probably the only one in which marine Mesozoic sediments could be expected due to the Narmada geofracture playing a role in the evolution of the block. Another interesting tectonic feature of the block is that the south-southeast trending faults are invariably cut by reverse faults hading towards north northwest thereby indicating that this block of Cambay basin experienced compressional force. Such compressional forces are not noticed anywhere else in the basin.

The Jambusar-Broach block is also unique in the sense that in this part exists the Broach Syncline, wherein more than 8 km of sediments are deposited. The syncline is basically the result of sinking of this block in the post Miocene period. This subsidence is evidenced in the various minor faults parallel to the strike of the beds seen all around the syncline. The faults affect mostly the Paleogene sediments. Such faults are recorded in the subsurface near Dahej, Atali, Jambusar and also in the Gulf of Cambay. The gulf forms a part of this block and represents the western flank of the Broach syncline. A number of faults along the western flank of this syncline are noticed in the sediments within the gulf. The Narmada river took the path of the geofracture for its drainage throughout the geological history and its delta during the different periods of Tertiary, spread over a large part of the area to the north and south of the course of the present Narmada river. The sinking of the area north of Narmada river to form a syncline is due to the Narmada block getting uplifted and the river course shifting much to the north of the present course during the Miocene and Pliocene periods dumping a large volume of sediment.

The Broach Jambusar block is separated from the northern Cambay-Tarapur block by a deep seated fault along Mahi river. The fault is proved by the occurrence of Deccan Trap at a relatively shallow depth of about 2000 m north of the river and at more than 3000 m south of the river. The block is characterised by a north northwest south southeast trend in the grain of the Deccan Trap basement. The marginal faults and the various anticlinal trends also take the same direction. In this part, the basin takes the shape of a typical intracratonic graben, the middle part deeper and the margins gently rising. It appears that Mahi river was not an important drainage feature in the Early Tertiary period as very little delta buildup took place in its lower course.

The Cambay-Tarapur block is separated from Ahmedabad-Mehsana block by a less prominent tectonic feature and is deduced on indirect evidence. During the early sedimentation of the basin till atleast the end of Eocene period, the basin floor was sloping towards north as revealed by a large thickness of this sedimentary unit near Kalol in comparison to the same near Bareja or Mehmedabad. It is therefore natural to expect a tectonic separation within the basin somewhere north of Bareja and south of Ahmedabad city along a line which separates the strike of marginal faults from north northwest to northwest.

The Ahmedabad-Mehsana block extends almost upto Banas river. The characteristic features of this block are the thick Paleogene sedimentary section in the middle of the basin, the northwest-southeast trending grain of Deccan Trap basement and the reflection of the same tectonic trend in the overlying sedimentary section, the coarse clastic prisms within a monotonous Paleogene shale section, depending upon the paleodrainage.

Having dealt with the factors dividing the basin into different blocks, it is necessary to have a look into the stages in which the basin was filled up. The first stage is the formative stage for the sedimentation. Thick volcanic conglomerates, siltstones, claystones and trapwash products derived entirely from Deccan Trap are formed. The distribution of these sediments is confined to the fault zones.

Lateral facies variation within the stratigraphic unit is not uncommon. The limited areal extent and the thick prisms of this unit signify its deposition close to the site of weathering across fault scarps. Accordingly, the locale of these sedimentary units are found close to the prominent faults in Deccan Traps. Normally this unit of lithology changes into the marine sedimentary shale away from the basin margins and the fault scarps, meaning thereby that while marine sedimentation is going on in the relativeldy deeper parts of the basin, fanglomerates and Trap conglomerates are getting deposited in some other parts of the basin. The sediments of this stage are of Paleocene age.

The second stage in the evolution of the basin is the main marine transgression very likely from the south to the north. A uniform lithologic unit developed all over the basin upto Banas river in varying thickness depending upon the basin floor configuration of the block. The unit is composed of dark grey to black fissile shale, pyritic and rich in organic matter, overlain by greenish grey chloritic shale. Sandstone beds are generally absent but in the northern part of the basin where the marine transgression is not prominent and paleodrainage brought the coarse clastics, sandstone prisms are very well noticed. Since the lithology of this unit of rocks is uniform, a regional subsidence accompanied by a supply of detritus from the same terrain, probably Deccan Trap exposures, is interpreted. This stage of deposition is not seen on the margins of the basin, to which the marine transgression has not reached. The thick shale section is deposited under euxinic conditions and as such bears all the characters of a source rock for the generation of hydrocarbons. The sediments of this stage are of Middle to Upper Eocene age.

The next stage in the development of the basin is the unstable stage during which the basin experienced different localised environmental conditions of deposition, shallow marine in some places, lower deltaic, marshy in other places, etc. The basin has shallowed up as a whole and the suite of light grey to dark grey fissile shale, chlorific shales, carbonaceous shales, coals, sideritic bands is commonly met with. In the northern part of the basin, the vast area comprising of thick coal beds is the part of this suite. In Kalol area, a rythemic sedimentation is noticed starting from dark shales to siltstones to sideritic mudstones, carbonaceous shales and coal. The sediments of this stage are of Late Eocene to Oligocene age.

The last stage in the evolution of the basin is represented by an arenaceous suite of rocks with olive green, greyish green, brownish grey and vareigated coloured claystone, pebbly sandstone conspicuous in the upper part. Flint, Jasper and agate are found in the gravel. The provenance for these sediments was the metamorphics and Deccan Traps. Minor marine incursions are recorded but basically the section is deposited in a transitional to lower deltaic environment in the large part of the basin and in marine environment in a few parts. The fact that the detritus for the formation of these sediments is mostly received from metamorphics in comparison to the previous sedimentary section which received its sediment supply from Deccan Trap terrain, shows a change in the drainage direction. In contrast to the early stage of the evolution of the basin, the floor of the basin started sloping towards south, as a result of which the sea gradually regressed. The epirogenic movements subsequently emerged the basin into a land surface.