Geological Modeling of Paleogene - Neogene Sequences From Akholjuni (Cambay Basin) to CACD Area (Mumbai Offshore Basin): An Integrated Approach*

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Search and Discovery Article #50745 (2012)*
Posted November 19, 2012

*Adapted from extended abstract prepared in conjunction with oral presentation at GEO-India, Greater Noida, New Delhi, India, January 12-14, 2011, AAPG©2012

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Abstract

Integrated geological model from Akholjuni in Western Onland Basin to CACD area of Tapti-Daman sector of Western Offshore Basin was jointly taken up to create an integrated geological model for these basins measuring about 28,000 km^2. An attempt has been made to correlate the sequence boundaries and genetically related depositional units from the basinal part of the offshore basin to the onshore areas for better understanding of the exploration plays and the petroleum systems in both the onshore and offshore areas.

The study has identified the sequence boundaries and integrated isochron maps were prepared for seven surfaces from basinal part to Onland areas. These maps indicate that the geometry of the rift system and the transfer fault system has been governed by the basement architecture of the Indian craton. While the NNW-SSE Dharwarian trend controlled the rift axis, the ENE-WSW Satpura-Aravalli trend controlled the transfer fault geometry. Isochronopach and isopach maps have depicted the major depocentres namely, Purna Low, Daman Low and Navsari low in the offshore areas and in the Onland area the Sayan low, Broach and Tankari depressions. Lithofacies, sand isolith and depositional model maps for studied sequences have brought out the areas of better reservoir facies. The isolith maps prepared for Lower Oligocene to Lower Miocene sands (Daman sands and Miocene Basal sands) show the configuration of the principal conduits for sand transport, which has continued to be through Narmada and Mahisagar River channels from Oligocene onwards. The facies and paleobathymetric maps show the depositional trend in the basin.

The principal plays identified in the basin are Paleocene-Eocene clastics, Oligo-Miocene carbonates and Oligo-Miocene sands. The Paleocene-Eocene clastics are best developed in the proximal part of the basin, where drainage from Proterozoic or Mesozoic provenance from Aravallis or Himmatnagar sandstone have dumped clean sands and are the best targets for the exploration. The Onland area is, therefore, best suited for this play. Paleocene carbonates are not ranked as good prospects because of poor porosity. The Oligo-Miocene Carbonates are most prospective in the southern part of the basin, to the south and west of B-12-10 and additionally in the vicinity of CD-1 to B-170A-1. The high impedance migration controlled by fault systems restricts the hydrocarbon occurrence to vicinity of mature source rocks. Mahuva limestones in the southwestern part of the basin, to the west and southwest of well B-12-10 are more promising. The Late Oligocene-Early Miocene sand geometry in Tapti-Daman area shows tidal influence, with tidal sand bars forming the best reservoir prospects. The entrapment is mostly strati-structural, with sand occurrence and fault closures playing major roles in hydrocarbon trap

formation. In the gulf area, the inverted structures south of well Gulf-4 appear to be promising for shallower prospects. In the Onland areas, apart from the structural closures, the rising flanks of the lows form good targets for exploration.

Introduction

The west coast of India has rich hydrocarbon resource and caters the major share of oil and gas production of the country. The coast comprises the giant Bombay basin in offshore, (dominantly, a carbonate reservoir) in the south and Cambay basin (exclusive clastic reservoir) in the north (Figure 1). These two basins are having close genetic relationship because of rifting that occurred during the Late Cretaceous with Deccan lava eruption. Further geostructural units of these two basins in junction area have transitional litho-bio facies and depositional set up. To be more precise, Tapti- Daman Sector of Bombay Offshore basin and South Cambay basin have almost similar geological setup. Though these sectors have been evaluated in detail separately, the integrated evaluation of G & G data of Onland and offshore part was not done earlier and the regional model was still to be evolved and relationship of these two basins are to be fully understood. While the lithostratigraphy of both Western Onland Basin and the offshore areas were established for over forty years, certain gray areas existed over the chronostratigraphy, more so in the Onland area. Another grey area for the Western Offshore had been for ascertaining the principal sand transport direction from among the river systems draining into the Gulf of Cambay. In Western Offshore, adequate paleontological data is available for establishment of chronostratigraphy with a fair degree of confidence. Besides, with a mosaic of available 3D seismic data, it was also possible to establish the third order sequences and sequence stratigraphic surfaces in the area. In the Onland areas, with the paucity of paleontological data, it had not been possible to work out the chronostratigraphy as well as the third order sequence boundaries with certainty. It was therefore required to correlate and analyze the details of the stratigraphic sequences from the basinal part of the offshore basin to the onshore areas, which will contribute to a better understanding of the exploration plays and the Petroleum systems in both the Onshore and Offshore areas of these basins. The paper documents the Integrated Geological model from Akholjuni in Western Onland Basin to CACD area of Tapti-Daman sector of Western Offshore Basin on regional scale for understanding the structural setup, facies variation and sedimentation pattern in

Data Input

The data used in this study includes approximately 2,000,000 LKM 3D seismic data and 20,000 LKM of 2D seismic data. Synthetic seismograms of over 30 wells were prepared to tie time stratigraphic surfaces to seismic data. Drilled well data of 170 wells including log data, lithology and production testing details along with available paleontological, palynological study reports were integrated. In addition, fifteen deep wells were studied in RGL, Mumbai exclusively for this project to determine the age relationships and depositional environment based on paleontological and palynological data. In addition, earlier existing reports on studies by JV organizations such as BG in Moon-1 and some of the other wells in Mid-Tapti, South Tapti, Laxmi, Ambe and Gauri were also incorporated to have a well-distributed sample for the Onland as well as offshore areas. The biostratigraphic picks were incorporated to demarcate the age boundaries and the fossil/ palynofloral assemblages were used to interpret the environment of deposition including paleobathymetry.

Regional Tectonic Set Up and Stratigraphy

The area of study relates to the Cambay Basin and its southward extension into the northern part of the Mumbai Offshore Basin. The stratigraphy of Cambay basin as well as Mumbai offshore has been studied by a number of geoscientists in the past. The litho-stratigraphy and chrono-stratigraphy in western offshore basin has been delineated by Zutshi et al. in a comprehensive way. The lithostratigraphy of Tapti-Daman area and its time equivalent in Western Onshore, Broach-Narmada tectonic block as classified by Zutshi, with minor modifications based on the current study is reflected in Table 1. The lithostratigraphic boundaries adopted in the two areas do not have an exact one to one correspondence in terms of geological age. The paucity of faunal record in the Onland areas has made demarcation of chronostratigraphic boundaries more difficult in Cambay basin.

Results and Discussion

The present study is confined to southern part of Cambay-Tarapur block along with Jambusar-Broach and Narmada blocks, extending to the Surat depression in the Mumbai Offshore Basin. The genesis of the Cambay rift basin is closely related to the evolution of western margin of the Indian Plate. The Indian Plate was the part of the southern hemisphere between the Africa, Antarctica and Australian plates, which forms the southern Gondwanaland Land. Mumbai Offshore basin is the southward extension of the Cambay rift basin, being contiguous and genetically linked to the latter. It is essentially an extensional passive margin basin. Its evolution can be summarized in two major stages, Rift stage and Post-rift thermal subsidence stage.

The stratigraphy of Cambay Basin and Mumbai Offshore basin has been studied extensively (Kalinin 1955-1965; Chandra et al, 1969; Basu et el, 1980, 1982; Rao and Talukdar, 1981; Biswas, 1982; Mohan et al, 1982, Nair et al, 1990; Pangtey, 1993; and Zutshi et al, 1993. (Figure 2) shows the lithostratigraphy of Tapti-Daman and its time equivalent in Western Onshore, Baroach –Narmada tectonic block as classified by Zutshi with modification based on the present study. The lithostratgraphic boundaries adopted in the two areas do not have exact one to one correspondence in terms of geologic age.

The entire area was mapped at H5 (Basement top), H4A (Synrift top), H4 (Panna top), H3A (Lower Mahuva top), H3G (Mahuva top), H3CGG (Daman top) and H1C (Mahim top) levels as these are correlatable and significant for the regional study. Middle Eocene top (H3B1) and Late Eocene top (H3B) surfaces have been identified on electrolog correlation based on log motif and biostratigraphic data. The time structure maps (Figures 3 to 9) bring out structural configuration of the basin at different stratigraphic levels and the structural disposition. The major structural features from north to south are parts of Central graben, Purna low, Navsari low, Baroach low and Tankari low along with minor uplift/horsts in between these depressions. These lows were areas of initial deposition during early Paleocene to Eocene and are major source rock areas in basin. Two sets of fault pattern crisscross the area. The ENE-WSW fault swings towards south and westward and is extension of Narmada-Sone lineament. The major uplift has taken place through these faults. The other set of faults are mostly north-south following the Dharwar trend and the main structural bounding faults. These faults are seen right from Paleocene to Oligocene time.

The isochronopach maps show the changing pattern of the basin fill from synrift to post rift phase. The synrift phase marks the distinct low where accommodation is accentuated. The depocenters, Purna low, Daman low and Navsari low in the offshore areas and Sayan low, Baroach and Tanakari depression in onshore part have rift fill sediments up to a maximum of 3,500 meters in Navsari low. The post rift marks the broad zones of sediments accumulation arising from thermal subsidence. This is manifested by in the sequence between Lower Oligocene to Miocene. The major lows, which were seen in Early Eocene time, appear to have been filled by Early Oligocene time i.e. Mahuva formation but it is clearly depicted by facies map with maximum sands having been deposited during Upper Oligocene (Daman formation).

Sand Isolith maps have been prepared for Upper Mahuva, Daman and MBS Formations (Figures 10 to 12). Sand isolith map of Upper Mahuva demonstrates that the principal source of deposition in the northern part was Mahi River, which deposited sand irrespective of the topography of this area. The same source has contributed in the Offshore Gulf area as well as the North Tapti, Umrat and Mid Tapti area. The other source of sediments seems to be Narmada River, which has contributed in the Narmada block as well as in the offshore areas. The maximum sand thickness is 200 m in Jambusar-Gandhar area. In Offshore area, the sand thickness reduces considerably and the maximum thickness encountered is 50 m in North Tapti and Umrat area. The sand isolith map of Daman Formation and its equivalent shows that the paleotopography controlled the sand deposition. The paleo-lows were the locales of maximum sand deposition except in Gandhar area The isolith map also shows the typical geometry of a tide dominated delta, with principal sand transport from Mahi, Narmada, Tapti and Sabarmati rivers. Sand isolith map of Miocene Basal sand & its equivalent shows that the dominant sand input direction is from Mahi River. The thickest sand development is in N-S direction in on land area from Bharkhodra-1 to Katpur. Multiple coarsening upward cycles and relatively thicker sand suggest the deposition under prograding deltaic conditions in shallow marine set up.

During Early Oligocene, development of limestone took place towards the eastern side of Narmada block extending in north-south direction from well Andada-1 to Mindhola-1. A maximum thickness of 30 m has been encountered in the well Valecha -1. In Offshore area, development of Early Oligocene limestone has been found in the well Umrat-2 and most of the wells in Daman area. The limestone development is generally in the form of thin streaks alternating with shales and at times with sandstone. The maximum thickness of limestone of about 100 m is developed in the southwestern part of the basin. A brief account is enumerated below.

Lithfacies maps (Figures 13 to 18) depict the areas dominated by clastic and carbonates in the study area. Our study shows that during Paleocene time most of the on land part was covered with synrift sedimentation of trap-derived sediments followed by coarser clastics. In the offshore areas, there was incursion of the sea marked by marine shale and sporadic limestone occurrences with the half grabens in Tapti Daman area.

The Early Eocene sequence is characteristically made of shale, which form the principal source rock both in Onland as well as in offshore area. In few areas, there is an alternation of shale and sandstone with occasional coal. First marine transgression in Cambay Basin on land part was in Early Eocene.

During Middle Eocene time deltaic sand were deposited in the Baroach block as well as in northern part of Narmada block. These sands are the main hydrocarbon producers in these areas. In offshore areas, the basal part of the sequence is dominated by widespread limestone occurrence, denoting presence of Epeiric Seas, followed by sea level rise and deposition of shales in neritic environments. However, on the eastern side of the offshore basin there is a predominant development of carbonates, which are equivalent to Bassein limestone of middle Eocene age.

During Late Eocene time progradation of delta continued in the Onland area and in the Offshore, silty shale were deposited in most of the area except the eastern part of the basin where limestone/carbonate deposition continued. Few of the sands that developed in the Narmada block are good hydrocarbon producers.

During the deposition of lower part of Early Oligocene (equivalent to lower Mahuva Formation) Offshore basin as well as south and southeastern part of Narmada block was under the influence of marine transgression, though the Baroach and northern part of the Narmada block received sands as a result of delta progradation. During later part of Early Oligocene the delta prograded in the offshore areas as well. However, the southern part of the offshore basin experienced deeper bathymetry and limestone was deposited along with sandstone and shales in this part of the basin. In the Narmada block, the equivalent formation consists of sandstone with bioclastic limestone in Ankleshwar, Motwan and Sisodra area. Towards southeast in Kosamba-Valecha-Mindhola area, it consists of limestone facies. The Early Oligocene sandstones are good reservoir rocks and are hydrocarbon producer in the offshore area.

The lithofacies map of Late Oligocene shows a total regression of the sea from Onland as well as offshore area. The delta progradation continued and deposited massive thickness of sandstones in the entire area from Onland to Offshore. These sandstones are very good reservoir and are the main hydrocarbon producers in Offshore and in Olpad, Bhandut and Hazira field of Narmada block of Cambay Basin.

The Cenozoic sedimentation in the area began after the cessation of Deccan Trap volcanism with the deposition of Middle-Late Paleocene to Miocene sediments in varied environments. Maps were prepared for depicting the depositional environments for seven major time intervals in the geological history of the basin. These are Paleocene to Early Eocene, Middle Eocene, Late Eocene, Early Oligocene, Late Oligocene, and Early to Middle Miocene (Figures 19 to 25).

The environment of deposition from Paleocene to present day has varied from fresh water to outer neritic. The marine incursion into the Cambay rift basin was initiated in Paleocene. It seems to have been controlled by the rift geometry as well as the transfer fault system. The major part of Narmada-Broach block was in a swampy environment. Sedimentation in most part of Tapti-Daman area seems to have been in marginal marine/paralic to inner neritic environment. Summarized status of the petroleum system in the study area is given in Table 2.

Exploration Thrust Areas

Based on integrated evaluation of the area, attempts have been made to depict the prospective plays and thrust area for exploration. The petroleum system in the different parts of the basin has been studied and play analysis has been carried out. The high impedance migration controlled by fault systems restricts the hydrocarbon occurrence to vicinity of mature source rocks. In terms of hydrocarbon plays, the thrust areas are as outlined below.

- Paleocene-Eocene clastics are best developed in the proximal part of the Onland basin where drainage from Proterozoic or Mesozoic provenance from Aravallis or Himmatnagar sandstone has dumped clean sands. Offlapping sequence marking delta progradation and low stand wedges are best targets for this play.
- The Oligocene Miocene sand geometry in Tapti Daman area shows deltaic and tidal channel and bar sands forming the best reservoir prospects. The entrapment is mostly strati-structural with sand occurrence and fault closure playing a major role in hydrocarbon entrapment.
- The Oligocene Miocene carbonates are most prospective in the southern part of Tapti-Daman sub basin. They are likely to form structural as well as diagenetic traps.
- In the gulf area, the inverted structures south of well Gulf-4 appear to be promising for shallower prospects. In the Onland areas, apart from the structural closures, the rising flanks of the lows form good targets for sands developed in wedges.

Conclusions

1. To arrive at a comprehensive geological model from Akholjuni in Western Onland basin to CACD in Tapti Daman area over an area of about 30,000 km^2 a large volume of gravity, seismic, sedimentological and Paleontological data has been churned. Depositional model, facies model and structural model have been prepared.
2. The facies and depositional maps show the depositional trend in the basin and help focus on areas of better reservoir development, which very often cannot be resolved on the seismic.
3. The principal plays identified in the basin are Paleocene-Eocene clastics; The Oligo-Miocene carbonates; Oligo-Miocene sands.
4. The Paleocene-Eocene clastics are best developed in the proximal part of the basin, where drainage from Proterozoic or Mesozoic provenance from Aravallis or Himmatnagar sandstone has dumped clean sands. Offlapping sequences marking delta progradation and Low stand wedges are the best targets for the Paleocene – Eocene clastic play. The Onshore area is therefore best suited for this play.
5. The Oligo-Miocene Carbonates are most prospective in the southern part of the basin. They are likely to form structural as well as diagenetic traps. To identify the continuity of the limestone reservoir and porosity prediction will be a key to successful exploration.
6. The area south of the already drilled Gulf wells is most prospective in terms of sand occurrence, proximity to the source, vertical faults to act as conduits for high impedance migration and presence of inversion related structure. This area is best suited for exploration in Oligo-Miocene sands. The entrapment in these sands is mostly in Tidal bars, which are often faulted. Fault seal analysis is essential in such traps to reduce the risk of dry wells, coupled with studies on stratigraphic inversion to predict continuity of pay zones.

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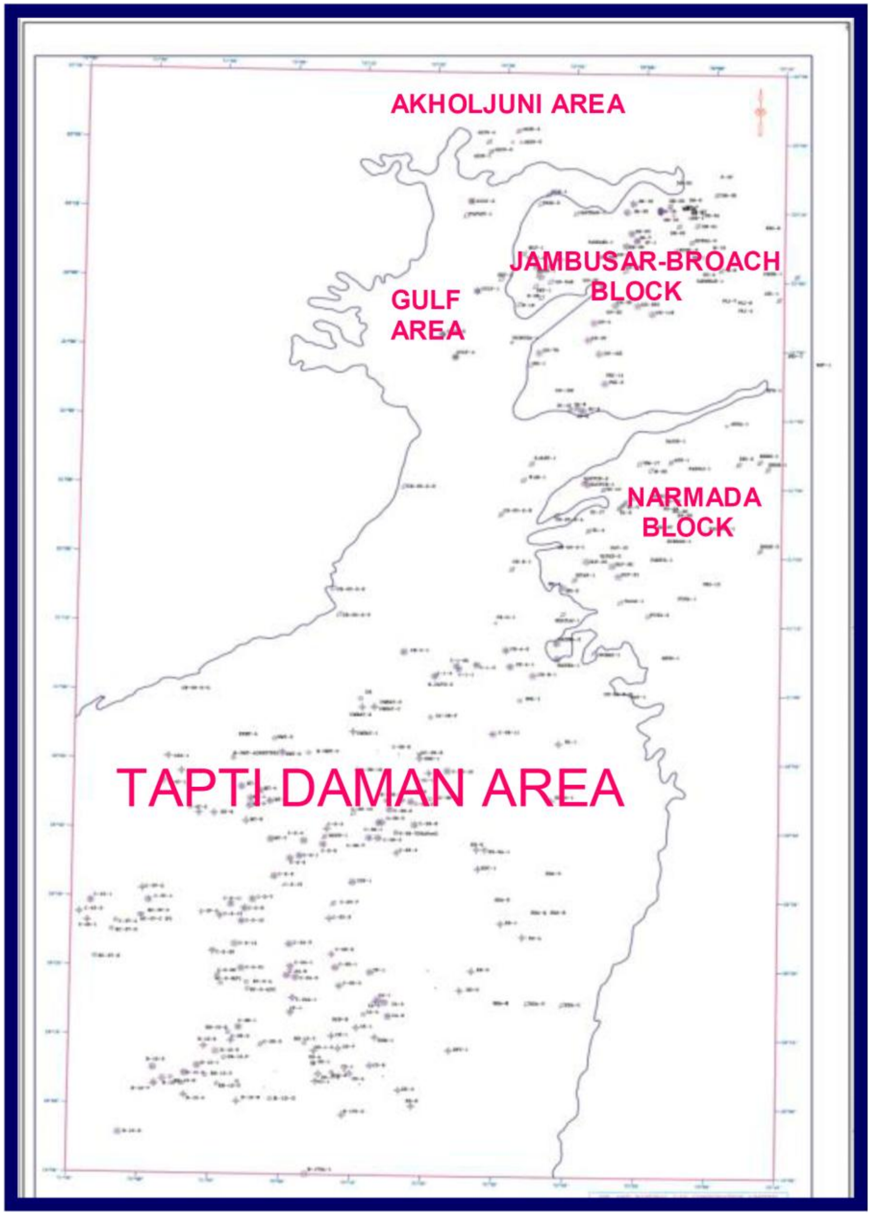


Figure 1. Location map.

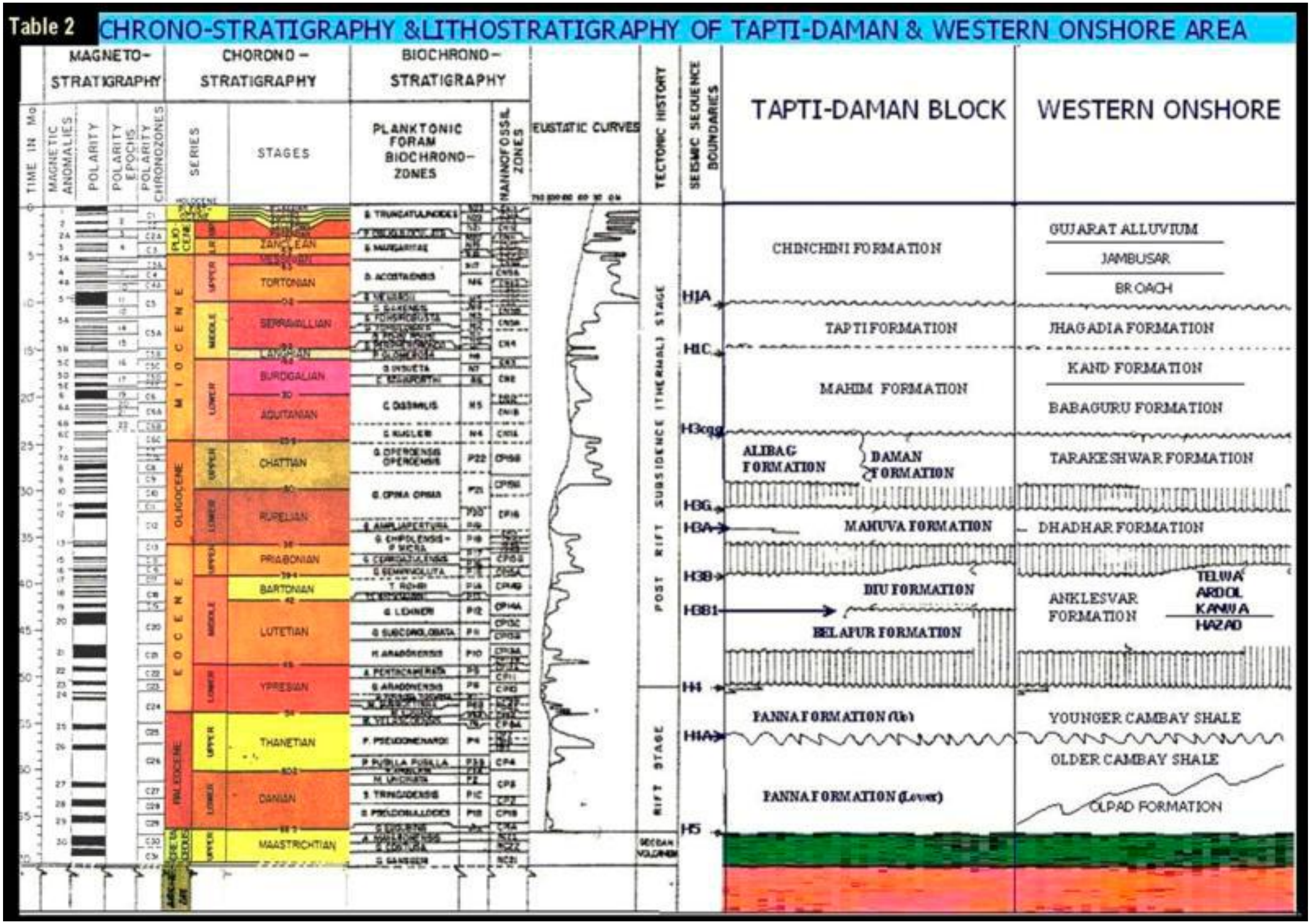
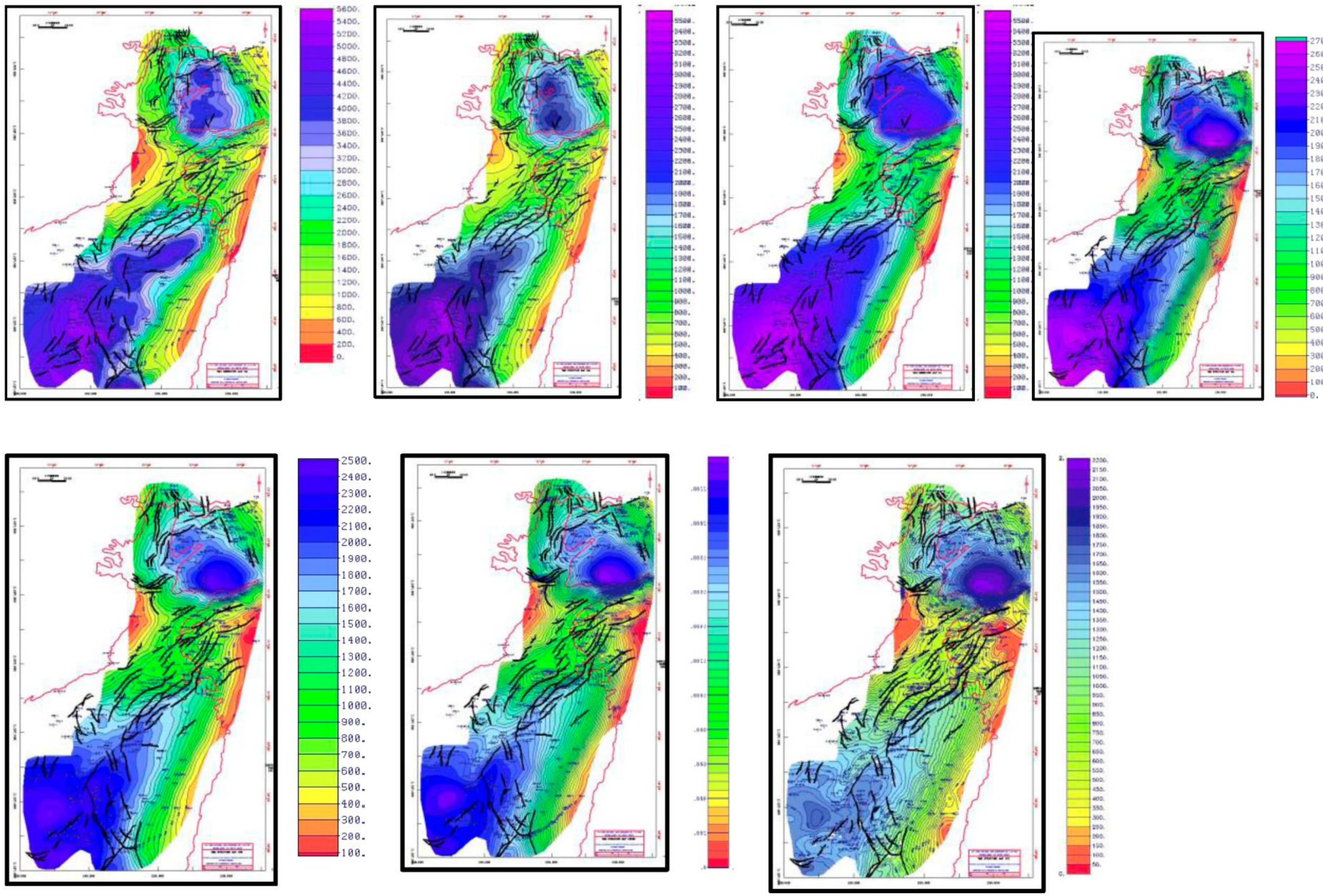
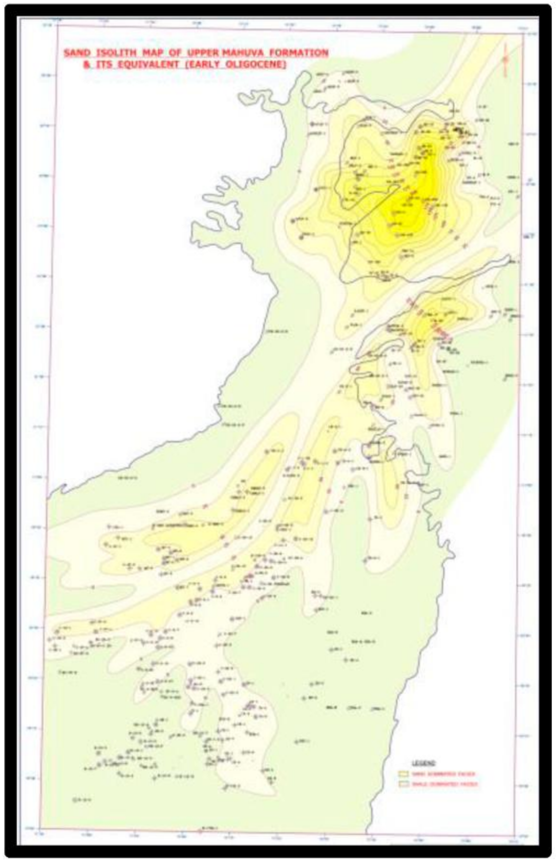
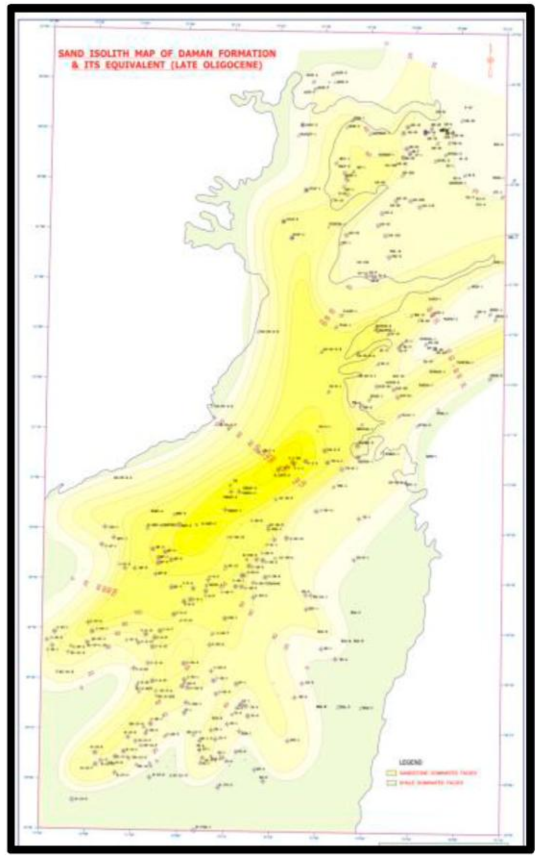


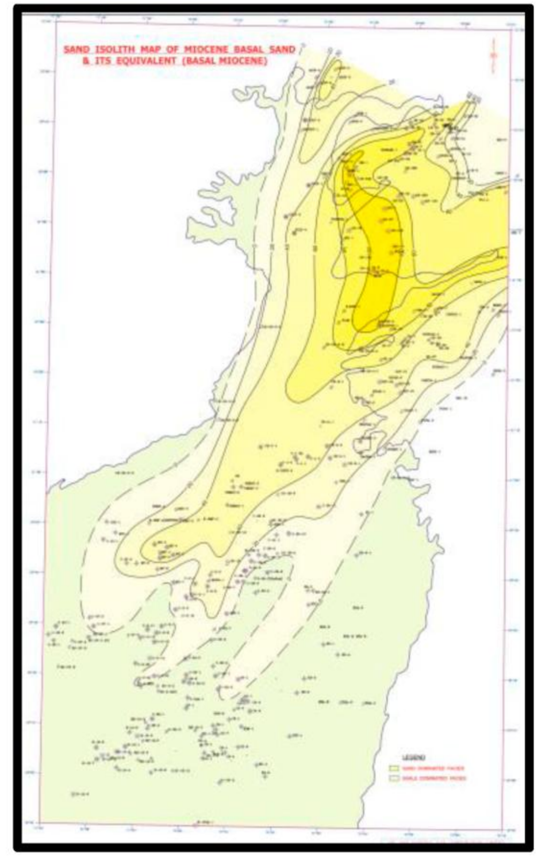
Figure 2. Generalized stratigraphy of Cambay Basin and Tapti Daman Basin.



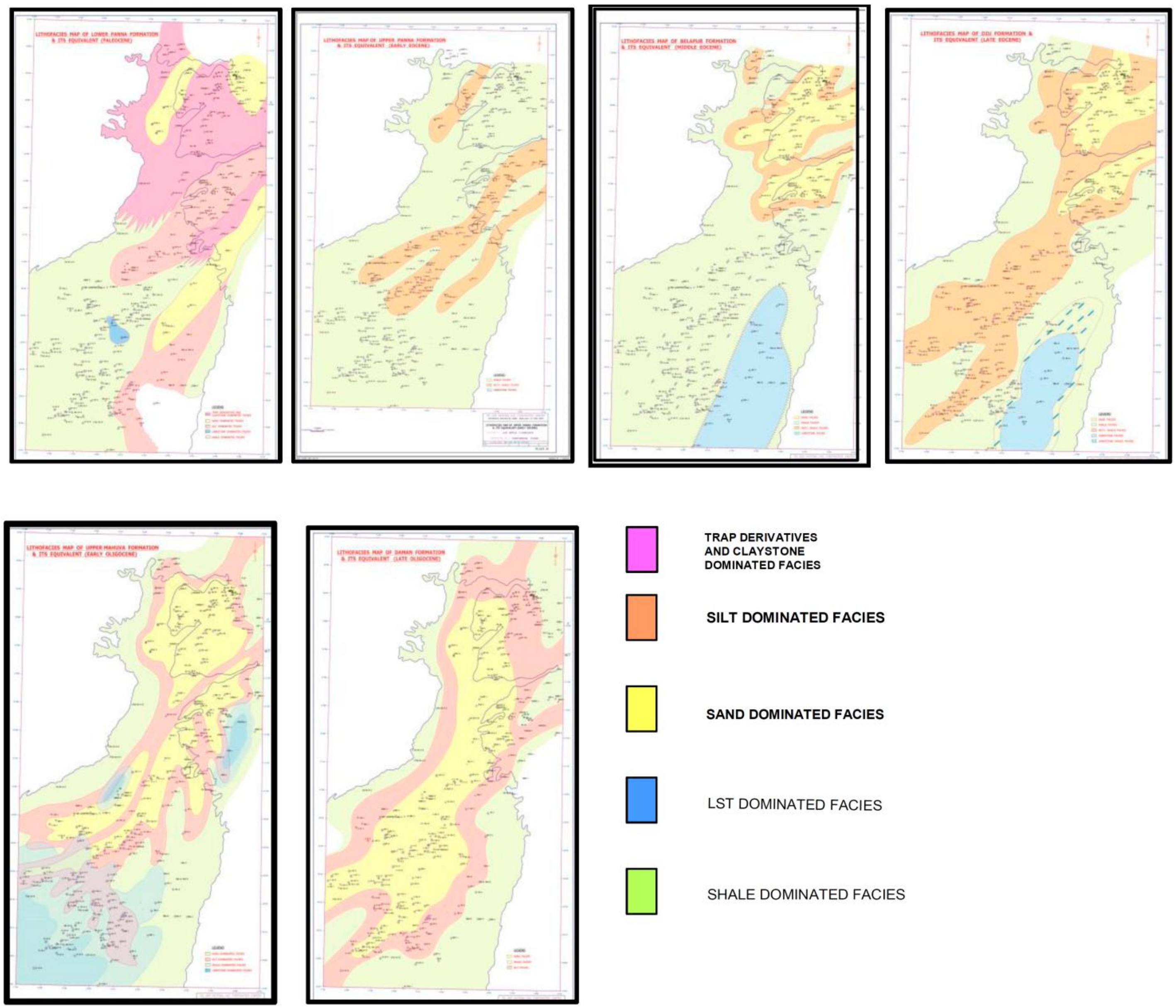
Figures 3 to 9. Structure contour maps on top of H5, H4A, H4, H3A, H3G, H3CGG and H1C showing the structural features and the fault pattern in the study area.



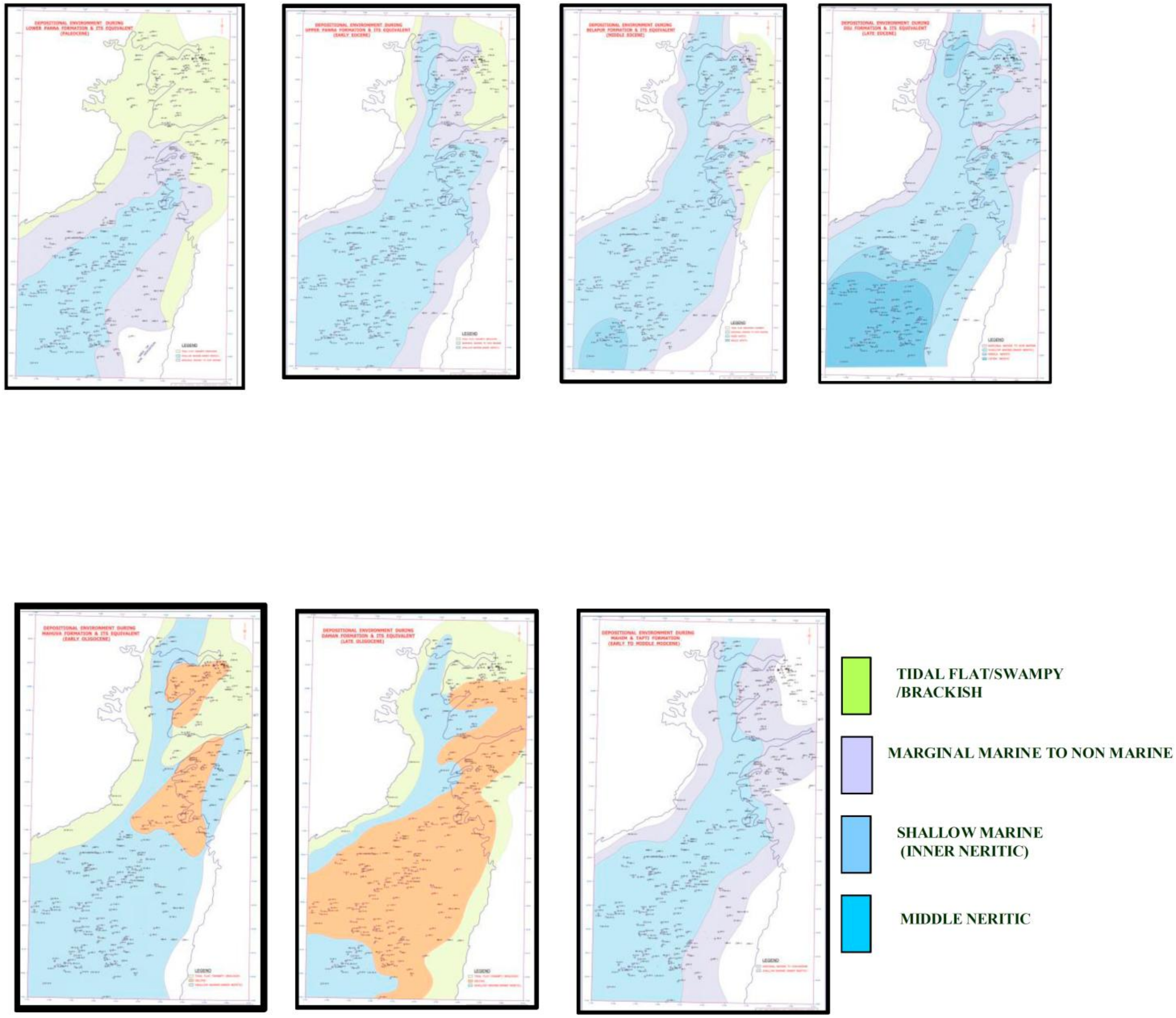




Figures 10 to 12. Sand isolith of Upper Mahuva, Daman & MBS.



Figures 13 to 18. Showing the lithofacies distribution from Paleocene to Oligocene.



Figures 19 to 25. Showing depositional environment from Paleocene to Miocene.

TABLE-1 TECTONO-SEDIMENTARY EPISODES IN CAMBAY& TAPTI-DAMAN

ERA	SYSTEM	SERIES		STAGE	AGE (my)	Tectonics	MAJOR EVENTS
TERTIARY	Quaternary	Holocene					Tectonic Inversion across Transfer faults continued, accompanied by erosion of younger strata on up warped structures.
				Sicilian		POST RIFT	Abrupt increase in clastics supply due to hinterland uplift? Continued subsidence of shelf. Inversion across transfer faults, reverse faulting. Hydrocarbon accumulations in structural traps mostly Post - Serravallian. Post Miocene uplift and erosion during Messinian in Onshore area. Undifferentiated siltstone and clay succession deposited in Offshore. H1A 11 My (Drowning surface)
				Emilian			
				Calabrian	1.8		
	Neogene	Pliocene	U	Placenzian	3.6		
			L	Zanclean	5.3		
		Miocene	U	Messinian	7.1		
				Tortonian	11.2		
			M	Serravallian	11.2 to 14.8		Collision between Indian –Eurasian plates along Baluchistan, resulting in Intra-plate stress, across pre-existing transfer faults, growth of inversion structures in Cambay basin and Tapti-Daman area. H1C 15 My (Third order Sequence boundary)
				Langhian	16.4		Deposition of channel sands and tidal bars, (Babaguru Formation and Miocene Basal sands, 1D sands) H3CGG ~22My (Ravinement surface)
			L	Burdigalian	20.5		
				Aquitanian	23.8		
	Paleogene	Oligocene	U	Chattian	28.5		Deposition of Deltaic sands along channels in Cambay basin and as tidal bars in Tapti-Daman area (Daman Formation) H3G ~25 My (Second order sequence boundary) Deposition of interbedded sandstones and carbonates in Tapti Daman area H3A~27My (Drowning surface)
			L	Rupelian	33.7		Dominantly shale with carbonates in south western part of the basin H3B - 36-39My (Second order Sequence boundary)
		Eocene	U	Priabonian	37.0		Hiatus in deposition.
			M	Bartonian	41.3		Basal part of sequence dominated by widespread limestone occurrence, denoting presence of epeiric sea, followed by sea level rise and deposition of shales in a neretic environment. In Narmada, Baroach blocks, deltaic sandstones deposited. H4 49.5MY (Second order Sequence boundary -top)
				Lutetian	49.0		
			L	Ypresian	54.8		Alternation of shale and sandstone, with occasional coal . Shales forming principal source rock. First marine transgression in Cambay basin Onland part in Early Eocene. H4A 54.8 MY (Third order Sequence boundary)
		Paleocene	U	Thanetian	66.5	SYN RIFT	Syn –Rift sedimentation of trap derived material followed by coarser clastics, incursion of sea marked by marine shales and sporadic limestone occurrences within the half grabens in Tapti Daman area. H5 66.5 My (First order Sequence boundary)
		Cretaceous		Maastrictian	70.0		Deccan traps volcanics/ flood basalts.

Table 1. Tectono-Sedimentary episodes in Cambay and Tapti-Daman

Basin	Petroleum System	Kitchen	Source	Reservoir	Organic Matter
SOUTH CAMBAY BASIN	Palaeocene – early Eocene – middle Eocene-late eocene (Jambusar Baroach block & northern part of Narmada block)	Baroach Depression & Tankari low	Olpad and Cambay shale of Palaeocene and Early Eocene	Sands of ankleshwar, Tarkeshwar & Babaguru Formations	TYPE II & TYPE III
	Palaeocene - early Eocene -Oligocene- Miocene (Olpad,Hazira trend of Narmada block)	Lows in surat depression	Panna shales of Paleocene and Early Eocene	Sands of Tarkeshwar and Babaguru Formations	TYPE III & TYPE II
TAPTI DAMAN AREA	Palaeocene - early Eocene – Early Oligocene - Late Oligocene – Miocene	Purna low Daman low & Navsari low	Panna shales of Palaeocene and early Eocene	Sands of Mahuva, Daman & MBS Formations	TYPE III & TYPE II

Table 2. Summarized status of the petroleum system in the study area.