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Depositional model of the Cenozoic succession: Kachchh-Saurashtra Basin

Abstract

The Cenozoic sediments representing the passive margin setup in the geologically contiguous Kachchh and Saurashtra basins are exposed in the western part of the Kachchh mainland and extend offshore into the present day continental shelf in Kachchh and Saurashtra offshore. As a result of extensive exploratory efforts through drilling of wells, a wealth of geological information is now available on these sedimentary successions. The present paper brings out a comprehensive regional scale depositional model based on geological laboratory analysis integrated with electro logs and seismic data.

Introduction

The Kachchh and Saurashtra basins are geologically contiguous rift basins with hydrocarbon potential in Cenozoic and Mesozoic sequences. The Kachchh Basin is a pericratonic embayment through a marginal graben between Nagar Parkar and Saurashtra uplifts, respectively from north to south (Biswas, 1987). The Saurashtra Arch bounds the Saurashtra Basin to the North and the Son-Narmada lineament forms the southern extent of this basin (Kunduri Sriram et al**.,** 2006) **(Fig.1)** .The Mesozoic sediments ranging in age from Middle Jurassic to Recent are exposed in the mainland Kachchh and encountered in wells drilled offshore. A major part of Saurashtra mainland is covered with Deccan Trap basalts with thin veneer of Miocene and younger sediments, exposed along Porbandar coast.

The entire succession of Cenozoic sediments has been encountered in the wells drilled in the offshore Kachchh and Saurashtra basin. Some of the deeper wells have also penetrated the Mesozoic strata .The Mesozoic and Cenozoic sedimentary successions are separated by Deccan volcanics. Reactivation of the rift associated faults of the Dahrwar and Satpura trend and are linked to the Himalayan orogeny and these faults act as conduits to charge reservoirs and also effective seals along with faults of the the Aravalli-Delhi trend.

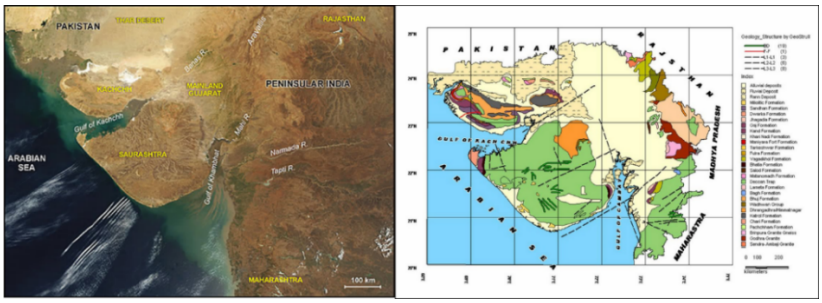


Fig.1: Satellite Image (L) and Geological Map(R) showing Kachchh Saurashtra Basin in a regional Perspective with present day exposed formations in the Onland Basin (Gujarat Waterboard)

Inputs for Current Study

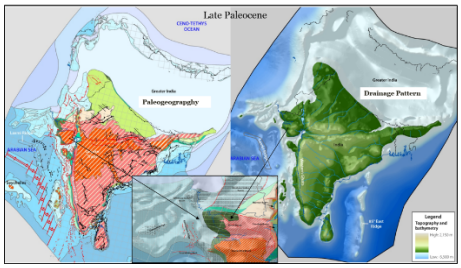
The depositional model of Kachchh and Saurashtra Offshore basins was reconstructed for a study area more 150000 sq.km, using well data of over 60 wells drilled by Oil and Natural Gas Corporation. Sedimentological and biostratigraphic data were integrated with electrologs for regional correlation. The chronostratigraphically constrained electrolog correlation across the Kachchh and Saurashtra Shelf and Deep water wells was used in conjunction with isopach maps to bring out a

meaningful and sequential depositional reconstruction of the Cenozoic sedimentary succession of these basins. A few wells penetrated the Mesozoic succession; however this data is clustered in the Kachchh shelfal region. This paper focuses on the reconstruction of a regional scale depositional model of Cenozoic sequences as there is a good distribution of wells through the shelf and deep water Kachchh-Saurashtra offshore that have encountered the Cenozoic sequences.

Paleogeographic setup and Reconstructed Depositional Model

Paleocene

The Mesozoic sedimentation in the basin commenced in a Tethyan realm with the deposition of dominantly clastics from Aalenian (early Middle Jurassic) in a rift setup. The rifting culminated in Early Cretaceous followed by major tectonic events in Late Cretaceous, marked by late to post tectonic Deccan Trap volcanism during Late Cretaceous-Early Paleocene. The Indian plate moved rapidly towards Eurasia during the late Paleocene, was surrounded by relatively large expanses of ocean on all sides. This was the time of rifting and drifting of Seychelles from India.



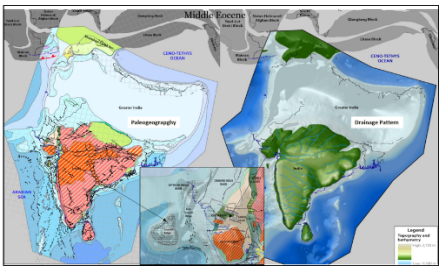


Fig.2(L): *Paleographic position and Existing Drainage pattern of the Indian subcontinent during Middle Eocene to Late Oligocene.* ***Fig.3 (R):*** *Paleographic position and Existing Drainage pattern of the Indian subcontinent during Miocene. (The Palaeogeographic Evolution of India,Kerri Wilson,GETECH Group plc., Leeds, U.K., Unpublished Report)*

Middle Paleocene to Early Eocene times was a post-rift period of a slow subsiding passive margin along the western margin of India contemporaneous with the northward drift phase of the Indian plate **(Fig.2, Fig.3**). During this time, both Kachchh and Saurashtra basins subsided westward as one block, along with the newly formed oceanic crust of the Arabian Sea, differentiating the basin into slope and floor. The eastward tilting of the Indian plate during Late Paleocene as it passed over the Reunion plume caused a major drainage divide redirecting streams and rivers to the east and restricting deposition to the west.

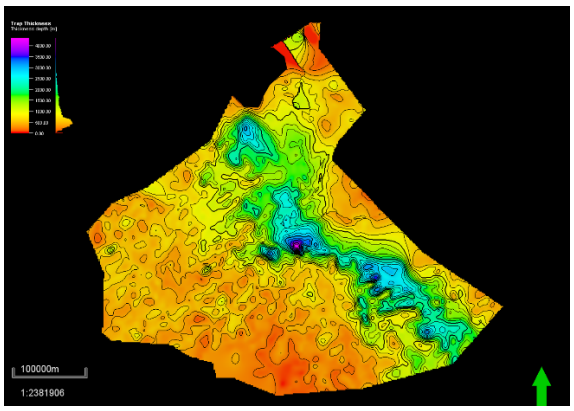


Fig.4: Thickness of Deccan traps in Kachchh Saurashtra offshore

As the basin entered passive margin setup in Late Cretaceous-Paleocene, thick pile of Deccan basalts were extruded coinciding with the passage of Indian plate over the Reunion Hotspot **(Fig.4).**The Deccan basalts exposed in mainland Kachchh and Saurashtra craton are also encountered in wells drilled in the Kachchh offshore. Maximum thickness of traps is seen towards the present day shelf slope

break and thinning towards the East and West of the rift axis. The Deccan traps have been found missing in the northwest corner of the basin. There is evidence in some wells along the shelfal region that the basalt was extruded subaerially *(ONGC unpublished reports)*. Trap erosion was followed by first marine transgression in Late Paleocene-Early Eocene. Early Cretaceous clastics of Bhuj Formation were eroded during Paleocene depositing sands in the Kori creek and was redistributed by tides in the north.

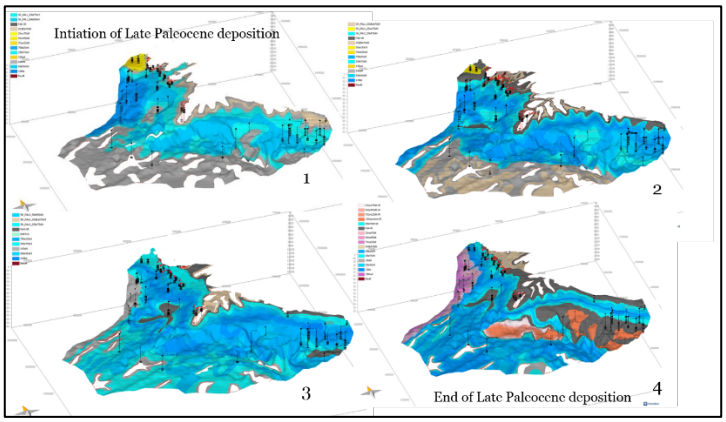


Fig. 5: Reconstructed Depositional model of Late Paleocene

The Paleocene sediments off the Kutch and Saurashtra coast are represented by finer clastic in shelfal area with carbonate buildup in present day shelf and deep water (Fig. 5). Paleocene in outcrops is mostly fluvial to marginal marine facies up to Kachchh mainland fault *(Catuneanu and Dave, 2017)*. Source rock potential is poor in the Kachchh basin but has shown maturity in Saurashtra Offshore due to increased depth of burial *(ONGC unpublished reports)*. Fluctuating Paleocene shoreline is marked by interbedded coal, carbonates and clastics in a lagoonal setup *(ONGC unpublished reports)*. Gentle slope of continental shelf accentuates the degree of shoreline fluctuation.

Eocene

Initiation of the India-Eurasia collision during Middle Eocene **(Fig.3)** brought the position of India within the warm latitude belt with thick and wide- spread carbonate deposition. The Eocene is marked by a period of first widespread Cenozoic marine transgression punctuated with local regressions during the Early Eocene forming a barrier bar complex along the shelf of the present day Kachchh offshore region and envisaged to extend towards Saurashtra offshore. A number of cycles of relative sea level changes have been identified from the Early Eocene to early-Middle Miocene, as indicated by the numerous unconformities of various magnitudes and extent. In the slope region, hemi-pelagic and pelagic deposits are inferred, with pinnacle reefs situated on topographic highs and carbonate dominated turbidite fans as interpreted from seismic profiles.

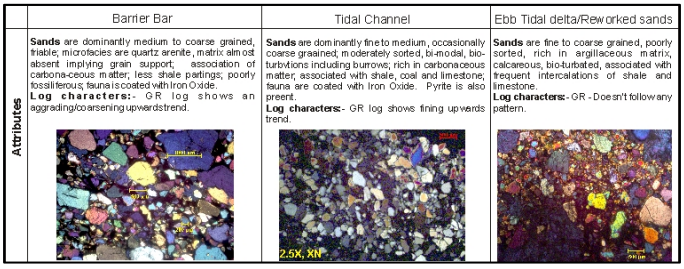


Fig.8. Depositional setups inferred from study of clastic Early Eocene reservoir (Unpublished ONGC reports).

Renewed transgression is conspicuous during this time. This succession has yielded a diverse suite of larger and smaller benthic foraminifera *(Unpublished ONGC Reports)* indicating deposition in a shallow marine setup in a bathymetry of 10-20m. Early Eocene succession is represented by three litho-units **(Fig 6)**, the Lower thick sandstone with alternation of shale, siltstone, thin limestone and minor coal. The Middle monotonous carbonates with interbedded shale and the Upper dominantly sands, siltstone,

thin limestone, shale/carbonaceous shale with minor coal. Based on the litho-facies association, microfacies analysis and electro log patterns three distinct depositional set ups have been inferred for the deposition of “Lower” and “Upper” clastics in the Early Eocene succession. The major depositional regimes of these sands are Barrier bar, Tidal channel and Ebb tidal delta **(Fig.7)**.

Tidal channels and Ebb tidal delta are the main hydrocarbon bearing reservoirs in these settings. Inner shelf-Foreshore-Shoreface is broad, gently sloping with Limestone, sandstone and Shale. Shoreline is parallel to present day coastline. Backshore is broad and wide up to the mainland as characterized by the finer clastics in Naredi area, Kachchh Onland. The deposition off the Saurashtra coast is expected to be similar to that in Kachchh but dominated more by finer clastics. The Shoreline is also fluctuating marked by several cycles of Coal, Carbonates and Clastics. The lagoonal area behind it has marginal source rock potential. Carbonate-clastic interface defined to lie in the northern Kachchh Basin extend upto the present day opencast lignite (with bitumen) mines in Kachchh Onland *(Catuneanu and Dave, 2017)*. These thick lignites represent tidal flats/marshes/lagoonal setup with marginal source rock potential.

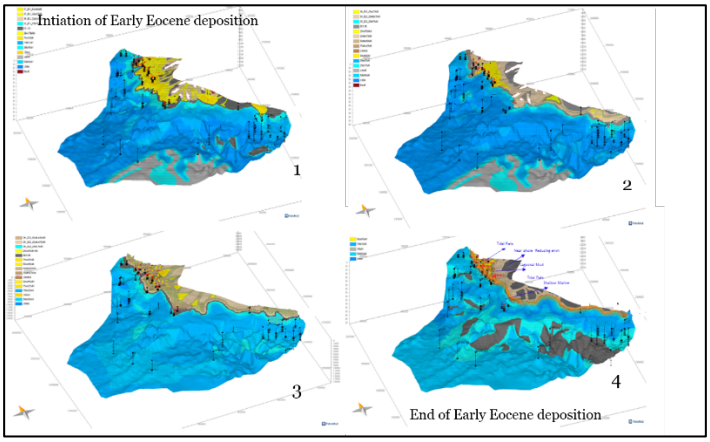


Fig.7. Facies reconstruction of Early Eocene Formation

Extensive transgression covering the mainland up to Kachchh Mainland Fault is characteristic of Middle to Late Eocene. No backshore facies is developed within the depositional limit of this sequence up to the traps (along the KMF extending across the mainland in a broad E-W trend). Shale facies (with Nummulites obtusus band- Harudi Formation) dominates the succession onland. The upper part of Middle to Late Eocene witnessed extensive carbonate development with entire mainland covered by carbonates (Fulra Limestone) *(Catuneanu and Dave, 2017)*. The subcontinent occupied the warm latitude belts conducive for development of massive carbonate platforms from Middle Eocene to Late Oligocene building a thick stable carbonate platform **(Fig.8)**.

Oligocene

The carbonate precipitation from Late Eocene continued into the Oligocene **(Fig.8, Fig.9)**. The presence of arid climate as India moved a further northward has impeded secondary diagenesis of the carbonate forming poor reservoirs. Late Oligocene was the intermediate stage of collision between the Indian and Eurasian plates **(Fig.9)**. The Late Oligocene period saw an increase in clastic influx with the beginning of the Himalayan uplift. **(Fig.8)**

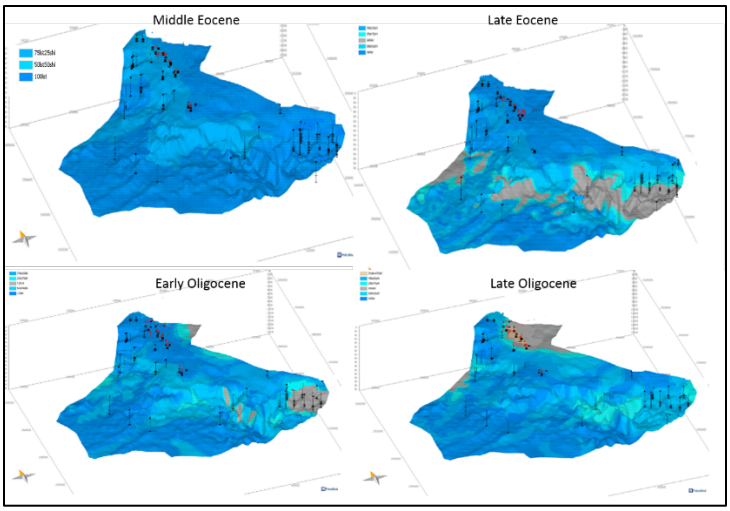


Fig.8. Facies reconstruction of Middle Eocene to Late Oligocene Formation.

In the outcrops (type section - Waior) *(Catuneanu and Dave, 2017)* finer clastics dominate, indicating clastics towards mainland. Sands in Kachchh Basin may be similar to glauconitic sands of lower part in Onland Waior area. A few hydrocarbon occurrences have been reported in drilled clastics of Oligocene *(Unpublished ONGC Reports).* However carbonate precipitation continued unimpeded in most of Saurashtra and Kutch offshore.

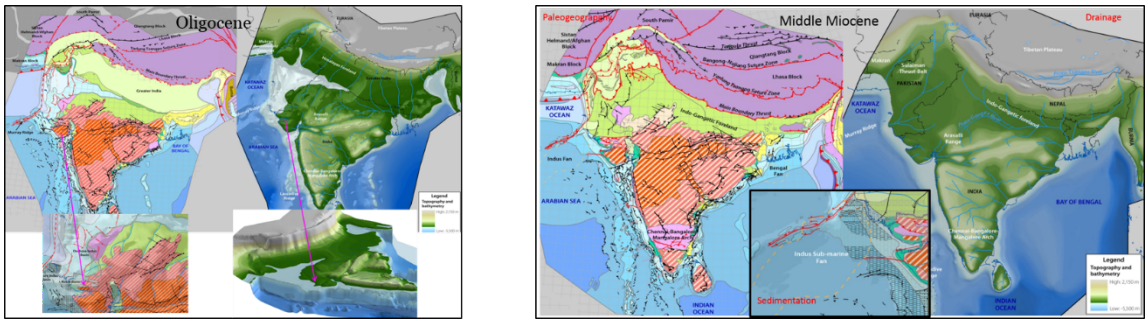


Fig.9(L): Paleographic position and Existing Drainage pattern of the Indian subcontinent during Middle Eocene to Late Oligocene. Fig.10 (R): Paleographic position and Existing Drainage pattern of the Indian subcontinent during Miocene. (The Palaeogeographic Evolution of India, Kerri Wilson, GETECH Group plc. Leeds, U.K., Unpublished Report)

Miocene

The collision between the India and Eurasia plates was well established during Middle Miocene time **(Fig.10).**The Indus Fan was established during this period, with increase in the supply of terrigenous clastics. The post collision tilting of the Indian plate towards the west caused drowning of the carbonate platform and marked the beginning of clastic deposition in the Kachchh-Saurashtra Basin.

The period witnessed diminishing carbonate precipitation and increasing influx of clastics in Kutch and Saurashtra. Early Miocene sees the deposition of limestone and shale intercalations. The overlying Middle Miocene marks the westward tilt of the western Indian continental margin basins as a result of the Himalayan orogeny. The Middle Miocene is characterized by drowning of the entire carbonate platform and initiation of the Proto-Indus river system sediments bought in as a result of the Himalayan orogeny (Fig.11). The significant fall in relative sea level triggered a major shift in depositional setting in the basin from a shallow water carbonate platform to a fluvial system along with an increase in sediment supply to the basin. This period has also defined the present day shelf slope break of Kachchh and Saurashtra Offshore and the reactivation of the Saurashtra arch forming a diving barrier between the Kutch and Saurashtra Basins.

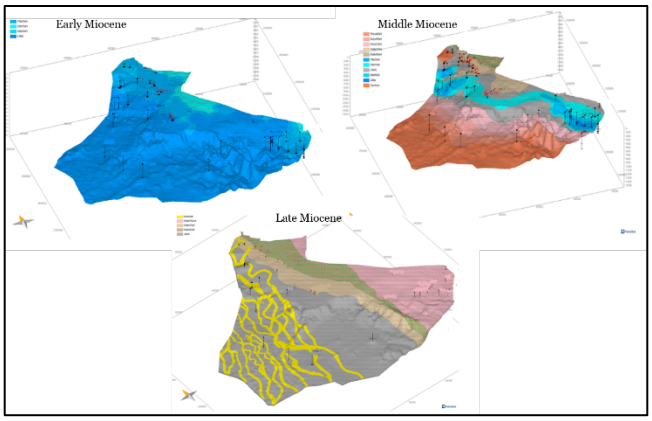


Fig.11. Facies reconstruction of Miocene Formation

Conclusions

Integrated interpretation of outcrop well, laboratory data integrated with electrolog and seismics has bought out an understanding of Cenozoic facies architecture in the geologically contiguous Kachchh and Saurashtra Basins.

The Cenozoic successions in the area represents a passive margin setup. The Paleocene sedimentation over the Deccan trap basalts commenced with a weak transgression and dominantly clastic succession in shallow shelf. In the distal part however carbonate platform has been mapped.

The unconformably overlying Early Eocene sediments (the major hydrocarbon reservoirs of Kachchh) are represented dominantly by clastic regime comprising sandstone, siltstone with minor coal of a barrier bar complex.

The Middle Eocene- Early Oligocene period witnessed extensive carbonate precipitation and deposition of thick carbonate both onland and offshore. The Late Oligocene witnessed increased clastic influx and cessation of carbonate platform growth.

During the Middle Miocene the westward tilting of the basin resulted in the initiation of the Proto Indus river systems and rapid influx of clastics in the offshore depositing thick clastics in the offshore depositing thick pile of sands and silts in shoreface regime.

Acknowledgments

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