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Facies analysis, depositional environment and hydrocarbon accumulations in Early Eocene sediments (Jakhau Formation) in Kutch Offshore, India

Abstract

Recent gas discoveries from Tertiary and Mesozoic sequences of Kutch offshore basin has given impetus towards focussed exploration in the area. Understanding the petrography of reservoir rock, spatial distribution and lateral facies variation of reservoir in an area is essential for exploration and production of hydrocarbons. Upper sand layer S-II with in Jakhau formation belonging to Early Eocene is the main pay in Kutch offshore area. Detailed litho facies analysis of this pay sand was carried out integrating all well data and seismic data and brought out the limit of sand prone better reservoir facies area for exploration of Early Eocene Sand-II pay. The clastic reservoir facies is deposited as longitudinal coast parallel barrier bar sands cut by tidal channels in inner shelf environment. In western part of the area where shale and limestone are deposited, identification of porosity pods with in limestone is a challenge. Hydrocarbons generated within Mesozoic sediments have migrated through NW-SE trending faults and charged low amplitude fault closures formed due to reactivation of pre-existing faults and mild inversion.

Introduction

Kutch offshore basin covering an area of 28000 SKM up to 200m isobaths is situated in the western continental margin of India. The basin is a poly history basin involving rift, drift and collision tectonics. Geometrically, the Basin is an asymmetric rift tilted due south, bounded by Nagar-Parkar fault in the north, Radhanpur-Barmer Arch in the east and the North Kathiawar fault in the south. Kutch basin is filled with Mesozoic, Tertiary and quaternary sediments. This basin is classified as Category-II basin in India with “Medium to High Risk and low-medium Reward under risk reward categorisation. Initial exploration efforts were focussed on structural highs mapped on 2D seismic data and subsequently after acquiring 3D seismic data, Mesozoic exploration became thrust area. Momentum of exploratory activities picked up in the area with discovery of substantial gas volumes from Tertiary sequences in GK-28 area which will lead to upgradation of this basin from Category –II to Category-I basin soon. Hydrocarbons have been discovered from all stratigraphic levels from Jurassic sediments to Miocene sediments including Deccan Basalt. Clastic facies of Jakhau Formation is the main pay in the area.

Figure1 Location map of the study area (Kutch Offshore)

Geological setting, Tectonics and sedimentation

Kutch offshore basin is an east-west oriented pericratonic rift basin in the north-western part of the western continental margin of India (Fig.1). Tectonic evolution of Kutch basin is divided into four stages, two stages of rifting and two stages of drifting. During the first rift stage break-up of Gondwana land occurred in the Late Triassic to Middle Jurassic. East Gondwana (including India) drifted away from West Gondwana (including Africa) from the Middle Jurassic, with a component of anticlockwise rotation. During the second rift stage East Gondwana split up further in the Early

Cretaceous (~130 Ma), with Antarctica and Australia rifting away from India, Seychelles and Madagascar. Rifting occurred along the west coast of India, including opening of the N-S striking Cambay Rift and the EW striking Narmada Rift with separation of the Kathiawar Block from the Indian craton (Biswas, 1981). The Kutch Rift widened and the basin developed (Biswas, 1982). Madagascar began rifting from western India during the Middle Cretaceous (~ 90Ma) along the NNW-SSE striking Dharwar trend. Thick shallow marine to deltaic sediments were deposited during the Mid Jurassic-Early Cretaceous period. In the Early Cretaceous, rifting failed and clastics of prograding delta were deposited. Volcanic intrusive episode is observed during Middle to Late Jurassic period

During the first drift stage India and the Seychelles continued to drift in the Late Cretaceous, and had completed 50° anticlockwise rotation (Biswas, 1982). Predominant carbonate deposition was observed during Late Cretaceous period. The Deccan/Réunion Hotspot became active in western India at ~ 66 Ma, with extensive subaerial eruptions of the Deccan Trap flood basalts (Biswas, 1982). Seychelles separated from mainland India at ~ 63 Ma, possibly in response to the weakened lithosphere in the vicinity of the mantle plume. Laxmi ridge was created during break-up between India and the Seychelles.

During the second drift stage, collision between India and Eurasia started in the Late Palaeocene (~ 66 Ma) which has resulted in reactivation of deep seated NNW-SSE faults Reverse movements have taken place along these faults giving rise to structurization throughout the basin. This late tectonics has overridden and masked the earlier structurization in the area. Collision caused N-S contraction in the Kutch Basin, with the development of E-W striking folds and reverse faults.

Tectonic activity during Tertiary was mild and cyclic. A number of sea level changes have influenced sedimentation patterns till Early Mid Miocene. Late Palaeocene transgression is widespread in Kutch offshore. Mainly shales with minor carbonates were deposited towards east and on the other hand mainly carbonates were deposited towards west. This indicate that the western part appears to have been attained stabilization to facilitate carbonate build up much prior to the eastern part where clastic influx continued for a longer duration. The eastern part of the block appears to be within the tidal shore face regime during major part of Early Eocene as evident from the deposition of clastic facies. This area has attained stabilization after this as evident from the commencement of carbonate deposition during Mid and Late Eocene. On the other hand carbonate deposition continued from late Paleocene to Early Eocene and up to Mid and Late Eocene in the western part. The carbonate sedimentation continued in the entire area up to Late Oligocene. The onset of Early Miocene transgression brought the eastern part of the area under marine regime whereas in the western part carbonate deposition continued. The reduction in clastic input favoured carbonate build up in the later part of Early Miocene. After the Early Mid Miocene, heavy influx of terrigenous sediments was seen resulting in the deposition of monotonous shale/clay

Stratigraphy

The general stratigraphy of the area with hydrocarbon discoveries is shown in Fig.2. Hydrocarbon discoveries were reported from Mesozoic and Tertiary sediments up to Miocene. Most of the Tertiary gas discoveries are from sands within Jakhau and Chhasra formation.

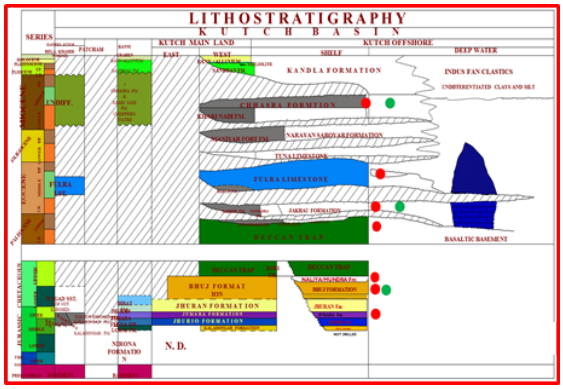

Figure 2. Generalised Stratigraphy of the Area

Petroleum System

Geochemical data suggests Mesozoic – Mesozoic and Mesozoic – Tertiary petroleum system are operative in Kutch offshore. Mesozoic Petroleum system is represented by Jhumara – Bhuj (Early Jurassic-Early Cretaceous) Petroleum system. Jhumara shales are the main source, coarser clastics in Bhuj are the main reservoir and intercalated shales and Deccan trap basalts is the seal for this system. In the western and northwestern part, Upper Cretaceous Limestone overlying Bhuj is additional target to explore the system. From laboratory analysis it is evident that the Jhuran sediments in the basin have matured in Late Cretaceous (~65my), the Early Cretaceous sediments have attained maturity around 45my and the Late Cretaceous sediments have matured as late as 10my before present. Sandstones within Jakhau and Chhasra formations are the main reservoir rocks and many hydrocarbon discoveries were reported from these reservoirs. The generation and migration of charge appears to be late (probably Miocene) when all structuration were in place in the basin. The deep seated faults which were reactivated have acted as conduits of migration and entrapment has taken place along fault closures developed due to compression. Shale and hard limestone layers present in Paleocene, Eocene and Miocene have acted as cap rock for Tertiary accumulations and Cretaceous shales / hard limestone have acted as cap for the Mesozoic section. Tertiary-Tertiary petroleum system is speculative. Potential source facies is present in Paleocene and Early Eocene sediments but they are not mature enough to generate hydrocarbons. KD-KI low in north western part of Kutch offshore could be an area where hydrocarbons might have generated from Palaeocene sediments with good source potential and maturity which is yet to be conclusively established.

Data Input

Available seismic data (6400 SKM of 3D Data) and data of 65 wells incorporating the laboratory data was analysed to understand the spatial distribution and facies variations in Jakhau formation.

Jakhau Formation (Early Eocene)

Jakhau Formation belonging to Early Eocene is unconfirmably overlain by Fulra limestone and underlain by Nakhatarna Formation of Palaeocene. The upper part is characterised by 20-25m shale. Two sand units are present which are separated by intervening limestone and shale. Thin coal beds are also present with in this unit. These sands are named as Sand-I and Sand-II from bottom. Sand-II is the main gas pay in the area. The upper part of Sand-II is occasionally more silty and clayey and exhibits fining upwards log signature. Log correlations profiles across the area from north to south and from west to east were studied to understand the facies variation of Jakhau formation in the area (Fig.3a and 3b). Sand-I is more extensive in the area compared to Sand-II. Thickness of limestone increases towards west in the basinal side.

Conventional core samples of Sand-II and Sand-I are shown in Fig.4.The sands range from Quartz wacke to Quartz arenite and are white to light grey, hard, compact with subrounded to moderately sorted quartz grains with argillaceous matrix and noncalcareous (Fig.5).Shallow open marine to inner neritic depositional environment with bathymetry ranging from 5 to 20m. Sand-I is coarse grained, occasionally fine grained, unconsolidated and poorly sorted. This sand is clean without any shale layers and occasionally coal bands are observed. This sand is mostly water bearing except one well in GK-42 area which flowed gas.

Time structure map of Early Eocene shows low towards west and northwest. The eastern part of the area shows gentle slope whereas the basinal part towards west shows relatively steep slope. The fault trend is mostly NW-SE (Fig.6). The laboratory studies and data from wells of the PML and NELP areas of Kutch offshore were considered envisaging a barrier bar complex' model (Fig.7) for Sand-II. The barrier sands are clean and are cut by tidal channels which can be identified on GR logs. At some places these sands are cut by ebb tidal delta. The Sand-I also follows the similar trend as that of S-II sand in the area. S-I sand is thicker and coarse grained in comparison with S-II sand.

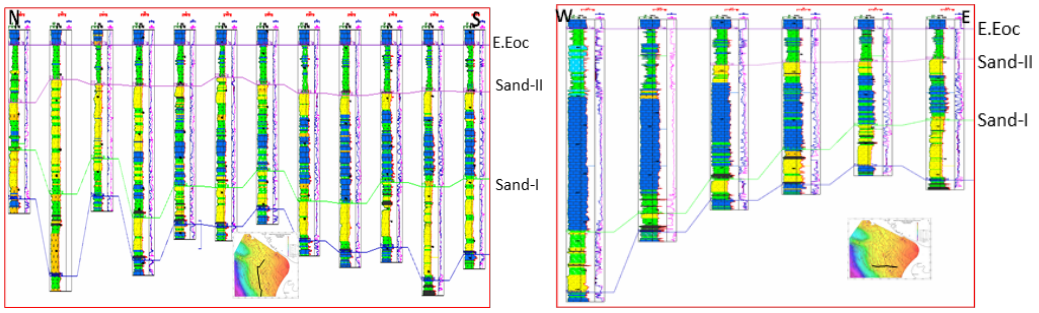

Figure 3a Log correlation profiles of Early Eocene section from Kutch offshore showing distribution of sands, flattened at Early Eocene top

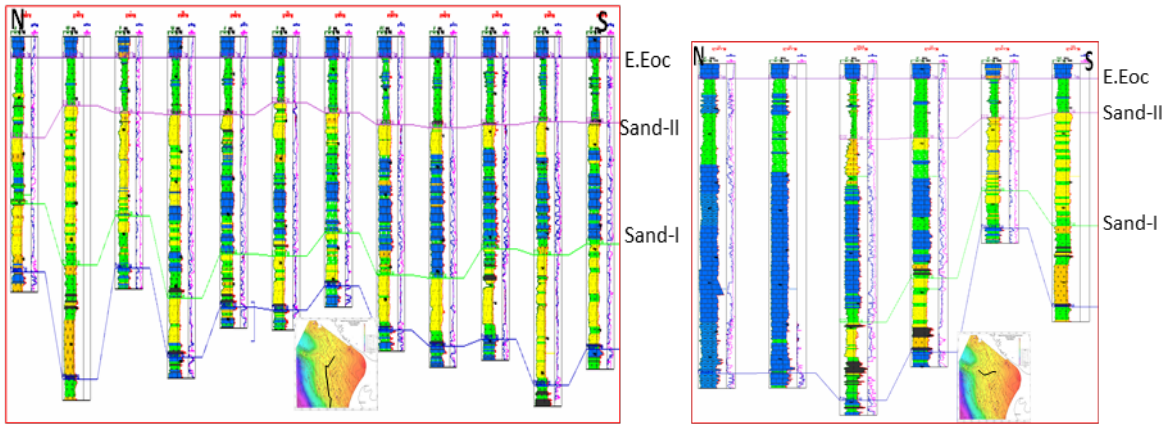

Figure 3b Log correlation profiles of Early Eocene section from Kutch offshore showing distribution of sands, flattened at Early Eocene top

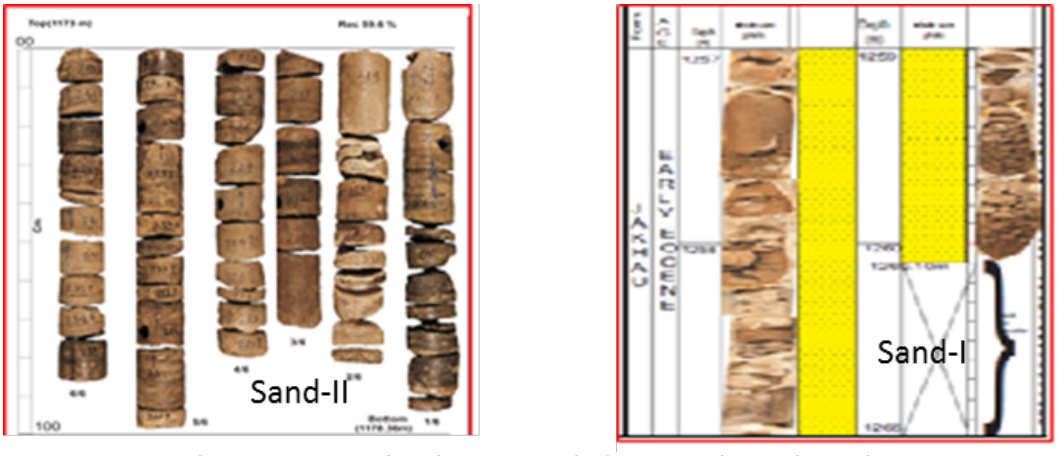

Figure 4 Conventional core sample from Sand-II and Sand-I

Figure 5 Petrography of S-II sand of Early Eocene showing Quartz Arenite and Quarz wacke (Source: sedimentalogical report from RGL,Panvel on wells from GK-28/42 area)

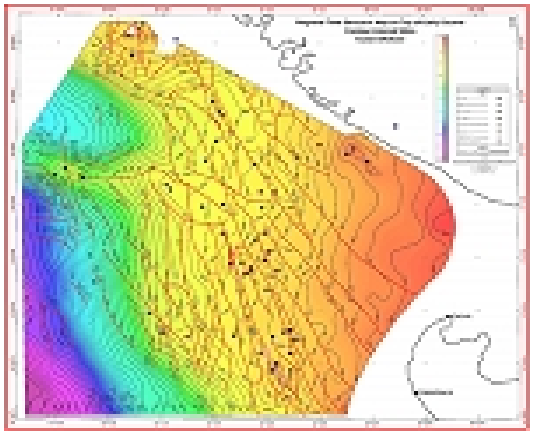

Figure 6 Time Structure map on top of Early Eocene

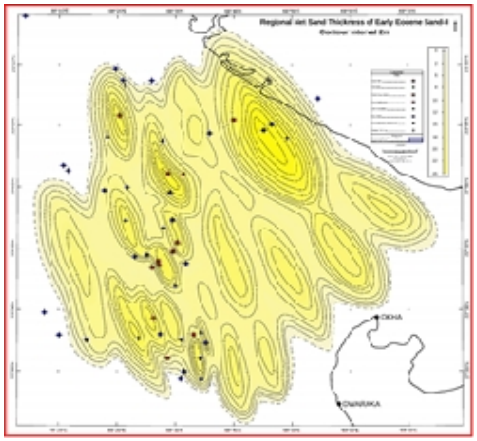

Figure 7 Net sand thickness map of Sand-II

Seismic Facies Analysis

Arbitrary 3Dseismic line from west to east is shown in Fig.8 with Early Eocene horizon and reflector corresponding to sand-II. Seismic facies analysis for Early Eocene Sand-II has been carried out. A window of +18ms to +40ms from Early Eocene horizon has been considered. The study area is divided into ten classes and the result indicates presence of clastic facies in the eastern part and absence of clastic facies in the western part with clear demarcation of the boundary. The results of this study are validated by the well data. Seismic facies map of Early Eocene integrating the available 3D volumes in the area is shown in (Fig. 9). Integrating the well data and seismic facies map, litho facies map of the area for sand-II of Early Eocene (Fig. 10) has been prepared.

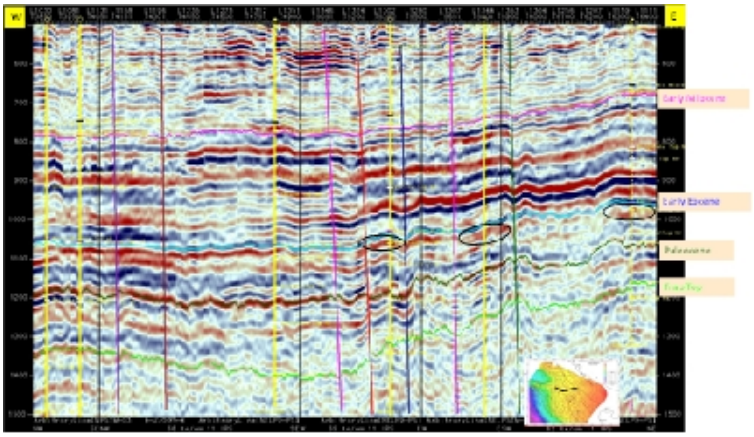

Figure 8 Arbitrary seismic line showing seismic signature of Sand-II below Early Eocene horizon

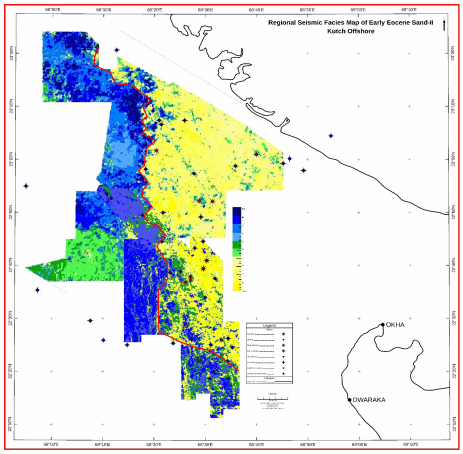

Figure 9 Seismic facies map of the area
Showing clastic and carbonate boundary in red line

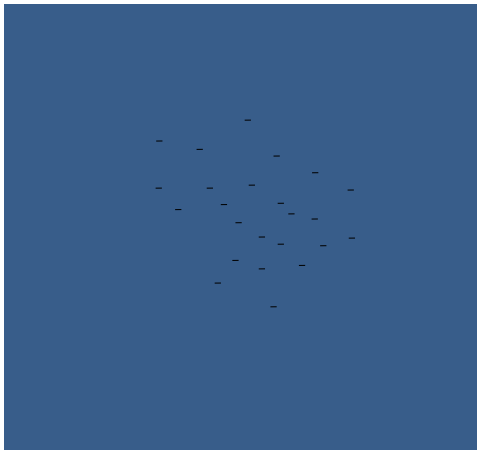

Figure 10 Gross Lithofacies map of the area

Hydrocarbon accumulations

Accumulation of hydrocarbons in Sand-II of Early Eocene (Fig.11) is dominantly in four way closures and fault closures against NE-SW trending faults. Some of these faults are deep seated and are connected to Mesozoic source. These reservoirs are under charged with different contacts in different fault blocks suggesting that each fault block behaves differently. Accumulations are generally in silty sands with sand-shale juxtaposition against the fault. Sand-I is thick and clean and is mostly water bearing.

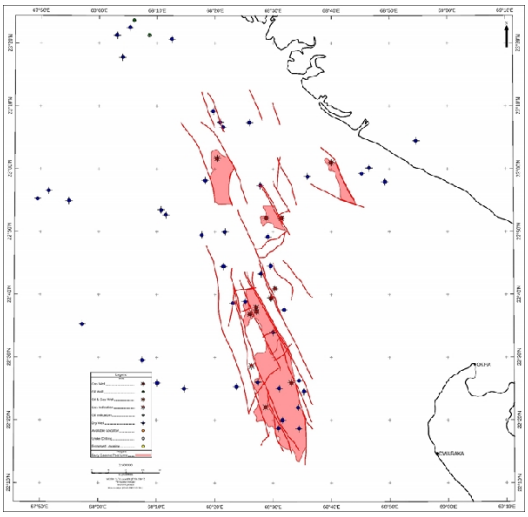

Figure 11 Early Eocene Hydrocarbon accumulation map

Conclusions

Sandstone of Jakhau formation from Kutch offshore (shallow water) area, India was studied in detail using well data and seismic data to understand petrographic characters of the sand unit, thickness variation and facies change of the reservoir rock across the area. Lower sand S-I is more extensive, relatively clean and water bearing. The upper sand S-II is the main pay in the area and is shaled out towards the west in the area. Sand thickness map and facies map over the area were prepared and brought out boundary between clastic dominated area and shale/carbonate dominated area which helps in focussing of exploration activity in the area.

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