Hydrocarbon prospectivity of Mesozoic and Tertiary Sequences in Kutch Offshore area, Gulf of Kutch, India.

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Summary: *Focused exploration for Mesozoic prospectivity in the Kutch Offshore Basin began after discovery of commercial quantities of both liquid and gaseous hydrocarbon. Offshore part of the Kutch-Saurashtra Basin forms the northern part of Western Offshore Basin of India and is located in a divergent margin setup. It is a pericratonic rift basin which came into existence during the breakup of India from Africa. A significant amount of Mesozoic sediments are likely to be present in addition to Tertiary sequences. The Kutch Offshore is characterized by dominantly NNW-SSE striking faults. The rift evolution and synrift sedimentation continued through the Jurassic and Cretaceous time and subsequently into Passive Margin setup during Late Paleocene – Early Eocene time with the formation of Self-Slope setup. The Offshore Kutch Basin has a dual Petroleum System; a Mesozoic-Mesozoic petroleum system and a Mesozoic-Tertiary petroleum system with good source and reservoir facies.*

In the present study, the focus was on the identification of possible structural and strati-structural plays within the Tertiary and Mesozoic sequences. To enhance the seismic image of the subtrappean portion within Mesozoic, the data was reprocessed. A perceptible improvement was observed post reprocessing. The Basement architecture of the basin along with faults was brought out through detail mapping of a marker close to Basement/DMR top on seismic. The marker is consistent throughout the mapped area with a prominent horst in the NNE part of the study area bounded by two NW-SE trending faults with opposite dips. A prominent central graben present on the western side of the horst is trending in NW-SE direction. Also, a marker likely corresponding to that of the Synrift Top is mapped. It is observed that this marker is affected by basement faults and an inversion structure has been generated against this graben bounding fault. The sediment thickness of the Mesozoic is maximum in this graben.

Probing these shallow as well as deeper prospects within Tertiary and Mesozoic sequences of Gulf of Kutch may open up new areas for exploration and early monetization of this block, thereby converting Kutch- Saurashtra Basin into a Category-I Basin.

INTRODUCTION

Kutch Offshore basin forms northern part of Western Offshore basin of India and is located in a divergent margin setup (Biswas, 1982). The Kutch Offshore basin covers an area of about 28,000 Sq.Km upto 200m bathymetry and is bounded by Saurashtra arch to the south and Indus basin of Pakistan to the north, Arabian Sea to the west and Kutch onland to the east (Fig1).

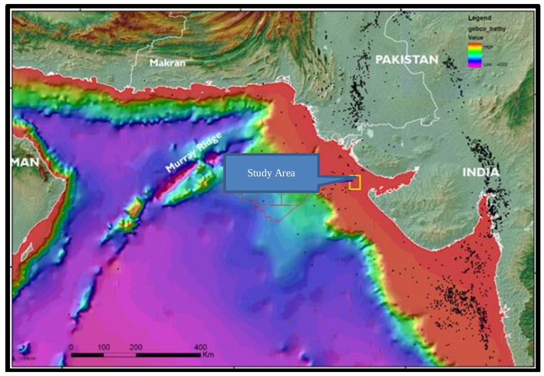

Fig1: Location map and area of study in Kutch Offshore Basin

It is a pericratonic rift basin which came into existence during the breakup of India from Africa. The Kutch Offshore is characterized by dominantly NNW-SSE striking faults, corresponding to Dharwarian grain (Talwani and Gangopadhaya, 2001). The rift evolution and synrift sedimentation continued through the Jurassic and Cretaceous time. The rift extended from north to south by successive reactivation of faults. The movement of Indian plate during the rift stage induced horizontal stress and the faults bounding the half graben became wrench faults with divergent strike slip movements. The blanketing sediments drape over the major faults and marginal flexures are seen. The sense of movement was thus oblique slip along the reactivated faults. In Cretaceous, the Kutch basin experienced regression of sea and intense tectonic activity accompanied by Deccan Trap volcanism.

Subsequently, post trappean Sedimentation started in Late Paleocene in Kutch Offshore (carbonate and claystone with sandstone) and these marine Cenozoic sediments are encountered in almost all the near and far offshore wells. The thickness of Pre-Cretaceous (Jurassic), Early Cretaceous sediments and Trap is increasing towards the coast in the east, whereas the Tertiary sediments are thickening towards west. The increase in thickness of Post Miocene sediments towards west is most conspicuous. Thus, two phases of block tilting and tectonic reversal; one Post Cretaceous and the other Post Mid Miocene can be

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inferred from the thickness variations. The last phase is responsible for the reactivation of the faults trending parallel to the coast.

Hydrocarbon discovery in commercial quantity had already been established both in Tertiary and in Mesozoic sediments in Kutch and Saurashtra Basins; however, the success is limited, sporadic and smaller in size. The generalized stratigraphy of the area is shown in Fig2.

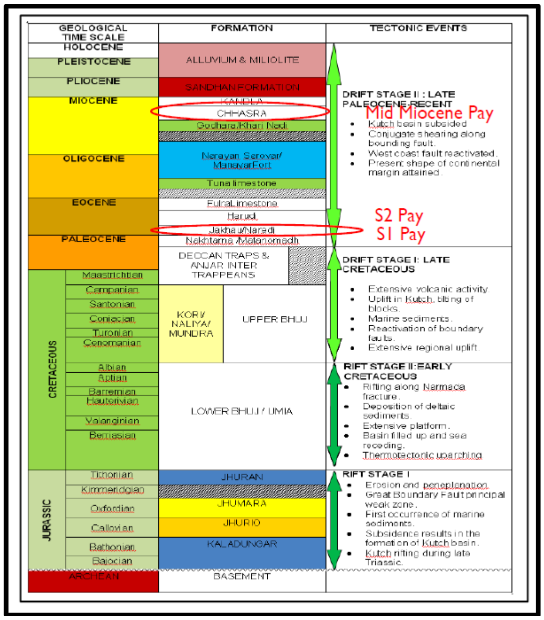

Fig2: Generalized Stratigraphy of Kutch Offshore Basin. Main target: Mesozoics and E. Eocene and Mid Miocene.

Seismic data:

The offshore part of Kutch Basin is covered with 2D/3D seismic data with varying fold through different campaigns. Among those merged PSTM data of two 3D seismic volumes with combined area of around 2000 SKM is considered for the present Study. The data is of 36 fold with sampling interval 2ms and record length of 5sec. Quality of seismic data is fair to good and band width of 5-71Hz in the shallow zone of interest and 5-30Hz in the deeper zone within Mesozoic section.

Well data:

The present study was covered both Mesozoic and Tertiary section and in particular E. Eocene and Mid Miocene pay sand. Total twenty two wells were used in this study. Conventional logs (GR, RT, RHOB, NPHI, DT) were available for all the wells. All the well logs were conditioned before using for the interpretation and all the producing wells were processed for PIGN, Vshale and SUWI. Synthetic seismogram was prepared for tying seismic with well data in the study area.(Fig3)

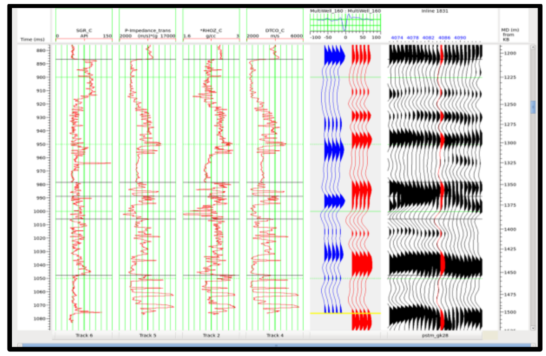

Fig3: Synthetic seismogram of a well in the study area showing well to seismic tie.

PRESENT STUDY

Electrolog Correlation:

To carry out the log correlation, all the stratigraphic picks starting from Deccan Trap top to Chassra Formation were correlated on each wells. In addition to this the pay picks of Middle Miocene, Early Eocene S-I and S-II and Paleocene Fm. were also correlated. In the NW-SE log correlation profile (Fig4), it is observed that Early Eocene S-II sand is thicker in the north GK-28 area but thickness decreases towards south in the GK-42 area. On the other hand, in Early Eocene S-I sand the thickness remains almost same without much variation but in the GK-42 area occurrence of coal band within the sand is quite noticeable. In case of Mid Miocene Pay sand, the thickness decreases from north to south.

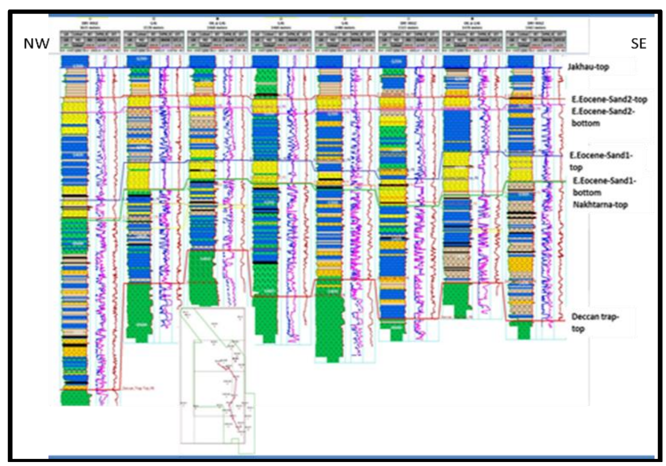

Fig4: NW -SE Stratigraphic log correlation profile along wells (Flattened at Jakhau top).

The SW-NE log correlation in GK-28 and GK-42 area (Fig5), shows that the Early Eocene S-I sand is thicker and cleaner towards west while it became thinner towards east. On the other hand, Sand S-II is relatively thinner towards west and thicker towards east.

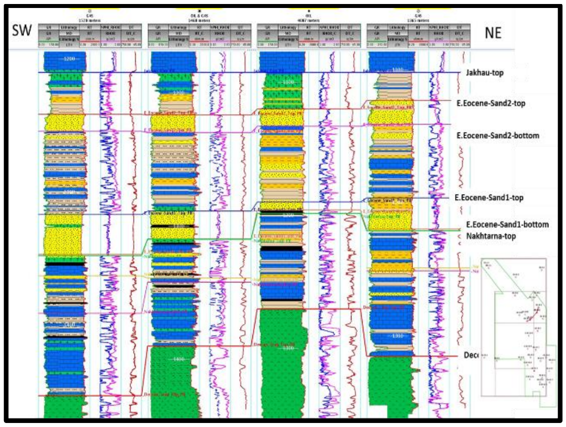

Fig5: SW-NE Stratigraphic log correlation profile along wells (Flattened at Jakhau top).

However, gas accumulation in the area is mainly within Early Eocene sand S-II. The Mid Miocene pay equivalent section is separated from Early Eocene clastics by a thick section of mainly monotonous limestone. Overall, the stratigraphic units attain maximum thickness towards west and thin towards east in the block.

Six wells in and around the area were considered for stratigraphic correlation within Mesozoic level as these wells have penetrated below Trap but none has penetrated the fundamental basement.

For Mesozoic log correlation, all the stratigraphic picks starting from Deccan Trap Botton/Mundra Top to Jhuran Formation were correlated on each well. In addition to this, the pay top picks of Mundra and Jhuran Formation were also marked.

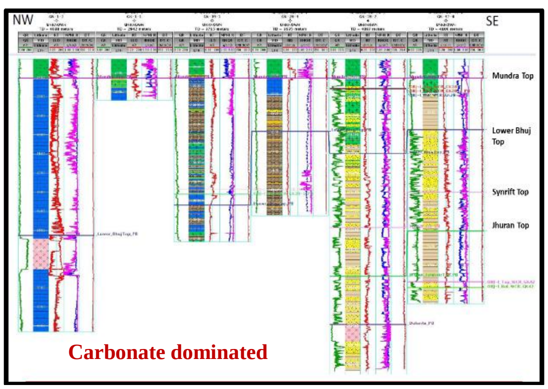

Fig6: NW-SE Stratigraphic log correlation profile along wells for Mesozoic level (Flattened at Mundra top).

In the NW-SE log correlation profile (Fig6), it is observed that the Mesozoic section in the eastern wells are clastic dominated whereas the western wells are carbonate dominated with intrusives of Dolerite and Dacite dykes. Good porous sandstone reservoirs are encountered in wells of eastern side and are HC bearing in Mundra Formation and Jhuran Formation respectively.

Seismic Interpretation

The present study is carried out using the merged volume of PSTM 3D data. To enhance the data quality for good interpretation, Structure oriented filter (SOF) is applied to reduce the noise in PSTM merged volume. Filtered data is good for horizon correlation as well as for fault mapping.

To bring out the structural disposition of the area, structural attribute analysis was carried out. Different attributes like Discontinuity, Ridge enhancement, Most Positive / Most Negative Curvature, FS-Similarity were generated on Dip Steered Median Filter (DSMF) seismic volume. The DSMF volume was generated from the original PSTM volume after using structure oriented filtering (SOF). The time slice of discontinuity attribute clearly brought out the regional structural trend on the merged PSTM volume (Fig.7).

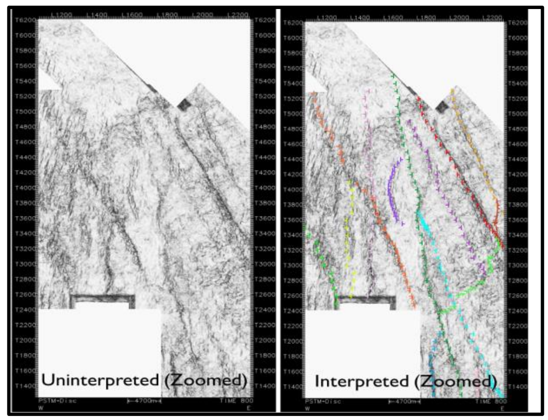

Fig7: Discontinuity attribute at TS-800ms for fault analysis.

The faults are mainly oriented in the NNW-SSE direction and dipping towards west while two faults in the east of GK-28 area are dipping towards east. Only one cross fault trend was seismically resolvable and is visible near GK-42 area. In the western part of the area there are some faults/ fractures which are oriented N-S and oblique to regional fault trend. These faults and/or fractures could be the manifestation of the intra rift fault systems that are sub perpendicular to the extension direction. These features are common with rift basins that are formed by "**Oblique Rifting**". Also, in vertical section the faults are seen all along the Tertiary sequences. All these faults are either steeply dipping or near vertical, suggestive of strike slip to oblique slip movement along the fault plane. This also suggests that these faults are part of an oblique rifting system. Subsequently Discontinuity volume was generated and faults were correlated on that volume. It is observed that, there are mainly two sets of fault system in this area one set for the Tertiary section which extend down the base of the Trap and the other set which are for the Mesozoic and are mainly oriented in the NNW-SSE direction and form horst and graben structures (Fig8). These faults could be

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the manifestation of the synrift fault systems that are sub perpendicular to the extension direction. The Tertiary fault systems merge with the Mesozoic fault system close to Trap bottom (Fig9).

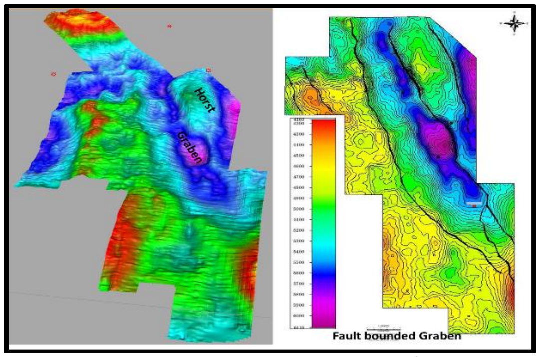

Fig8: 3D perspective view and Map view of Horst and Graben architecture of the Mesozoic section (with and without faults).

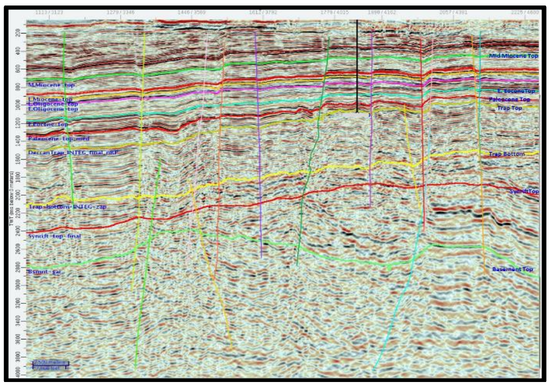

Fig9: RC line showing the correlated horizons and two sets of fault (Shallow Tertiary and Deeper Mesozoic). Some of the faults are merging with each other at Trap bottom level (Yellow Horizon).

TWT/ Structure maps for all important sequence boundaries were generated. All the maps are showing almost similar structural disposition near the Formation tops. It is observed that the formations are deepening towards west while shallowing towards east and south. It is also observed that localized lows and highs are generated close to the faults due to strike slip to oblique slip movement along the fault plane and these highs, mainly the four way closures and/ or fault closure, turned out to be hydrocarbon bearing both in GK-28 and GK-42 area. It is observed that there is a graben feature running through the study area at basement level. Basement/ (DMR) is mapped corresponding to seismic trough. The marker is consistent throughout the mapped area with a prominent horst in the NNE part of the area bounded by two NW-SE trending faults with opposite dips. A prominent central graben is present on the western side of the horst trending in NW-SE direction. Another graben also exists in the eastern side of the horst; however, its axis lies beyond the study area. At the extreme west there is a small ridge feature running in NW-SE direction. All these faults together brought out the Mesozoic rift architecture of the area. The TWT map and the Depth map of the Basement are consistent and both depict the same architecture of the area.

Inversion Studies

Post stack Acoustic Impedance volume was generated using the merged seismic volume and the available wells at Tertiary level.

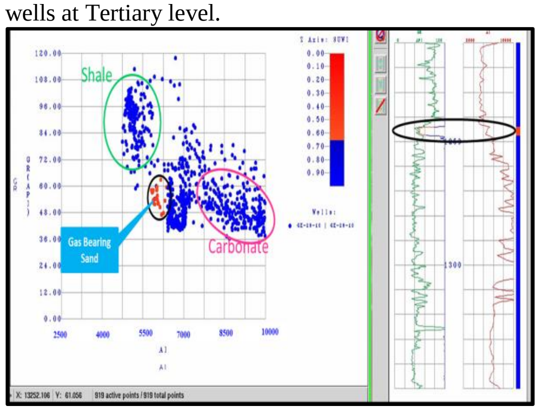

Fig10: Cross plot of P-Impedance Vs GR for Early Eocene Sand (S-II) in a well of GK-28 area.

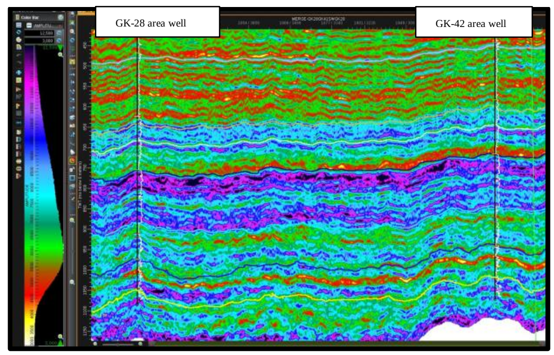

Fig11: Inversion result along wells of GK-28 area and GK-42 area with P-impedance log overlaid (White).

Cross plot between P impedance verses GR overlaid with SUWI suggests that the Early Eocene S-II sand has a GR value in the range of 48-60 API and shows medium impedance ranging from 5500 to 6500 (m/s)*(gm/cc) (Fig10). This range has been considered for delineating the same sand on impedance volume in GK-28 area. Inversion result across the study area is shown in Fig11.

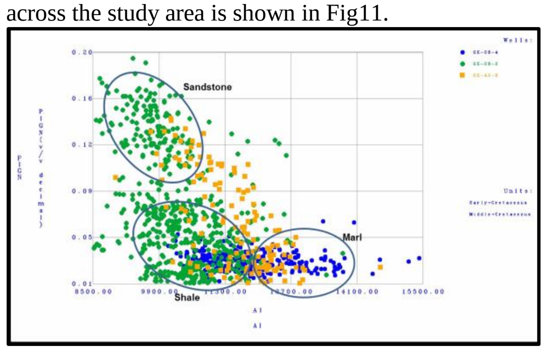

Fig12: Cross plot of P-Impedance Vs PIGN for Mesozoic sequence in a well of GK-28 area. Lithology like Sandstone, Shale and Marl/ Carbonate can be separated using this cross plot.

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Cross plot between Acoustic Impedance (AI) and effective porosity (PIGN) was generated for 3 wells in the area that has penetrated Mesozoic section. It is observed that for the Middle Cretaceous section (Mundra Fm.) sandstone, shale and Marl/ Carbonates could easily be distinguished from the plot. Sandstone falls in the impedance range of 8500 to 10000 (m/s)*(g/cc), the shale fall in the range of 10500 to 11500 (m/s)*(g/cc) while Marl/ carbonates fall in the range of 12000 to 14000 [(m/s)*(g/cc)] (Fig.12).

It is also observed that, below Trap bottom moving from East to West the clastic dominance gradually changes into carbonate dominance. The transition zone is likely to be near the center of the section since both the wells located there had encountered Marl/ calcareous claystone below Trap within the Mundra / Naliya Fm (Fig.13). Based on the observations, Post stack Acoustic Impedance volume was generated using the merged seismic volume and the available wells that had penetrated Mesozoic sequences. The impedance slice equivalent to Mundra pay sand was generated which suggest that this pay sand is spatially restricted in the Eastern part of the study area.

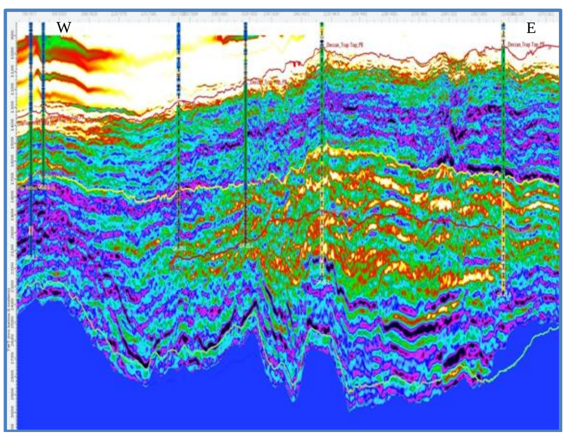

Fig13: Arbitrary line on Impedance volume showing lateral facies variation from Clastic in the East to Carbonate in the West within the study area.

PETROLEUM SYSTEM ANALYSIS

The source rock studies have suggested that shale litho facies present in Mesozoic (Lower Bhuj and Jhumra Fm.) and Tertiaries (Nakhatrana Fm.) have the potential of generating hydrocarbon in the study area. The Mesozoic sequences had already reached the gas generation stage in the area under study. The discovery of Oil and Gas in Tertiary and Mesozoic sequences in Kutch offshore and fluorescence in different drilled wells suggest that oil has been generated in the Kutch offshore region. Source rock studies conducted for Tertiary sediments in the area reveal that both Paleocene and Early Eocene sediments possess rich organic matter having good hydrocarbon generation potential. The Organic material is mainly Type-III and /or combination of Type-III +Type-II. Though these sediments are thermally immature but are capable of generating hydrocarbon in deeper parts of the basin.

Mid Miocene and Early Eocene fine grained sandstones/siltstones with porosities ranging 24-30% are considered to be a good reservoir rock in this area. Further, the recent discovery in the fractured Basalt and Paleocene sediments including limestone can also act as a good reservoir. Occurrence of hydrocarbon in the Mundra/ Naliya Fm. of Middle Cretaceous age within both clastic and carbonate reservoir rocks are evident from the testing results. Presence of clastic reservoir in Jhuran Fm. of Late Jurassic age is also evident from the drilling and testing result of recently drilled well.

The Shale /Claystone lying above the sandstones/siltstones may act as a cap rock. The trap section is fractured and faulted which might have acted as conduit for the gas and oil generated within Late Cretaceous shale to get entrapped in the Mid Miocene, Early Eocene and/or Paleocene reservoirs. Basalt and the shale /claystone within Late Jurassic and Early to Mid-Cretaceous can act as a seal for Sub-trappean reservoirs.

The structural as well as strati-structural traps are the main locales for hydrocarbon accumulation both in Tertiary and Mesozoic sequences. These structural traps are either fourway or fault closures mainly associated with major NW-SE trending faults.

PROSTECTIVITY PERCEPTION

The Offshore Kutch Basin has a dual Petroleum System; a Mesozoic-Mesozoic petroleum system and a Mesozoic-Tertiary petroleum system with good source and reservoir facies separated by Deccan Volcanism that has prevented mixing of the two. The medium to coarse grained, well sorted sandstones of the Bhuj Formation are considered the main reservoir in the Mesozoic petroleum system. The reservoir character of the Bhuj Formation is moderate quality which may be attributed to climate. The warm wet climate established in the Late Jurassic continued into the Early Cretaceous, promoting intense chemical weathering and producing clays. However slope failure due to tectonism has allowed some coarse clastics to be eroded from the hinterland and transported into the Kutch Basin. A potential secondary target is the Upper Jurassic Jhuran Formation. Provenance of the Jhuran Formation is envisaged to be derived from both the Aravalli Range and the Nagar - Parkar Range. The Bhuj Formation has a general thickening not only to the east but also to the southwest, while the Jhuran Formation only thickens to the east with sediments thinning to the south.

Within the Mesozoic-Tertiary petroleum system, commercial quantities of both oil and gas have been discovered in Paleocene and Eocene sandstone and limestone. Sandstones were deposited directly after the Deccan Trap plume activity. Short-headed rivers feeding into the Kutch Basin drained from this

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volcanic province, when combined with a warm wet climate that allowed vegetation and soil development, suggests chemical weathering would dominate. Therefore, sandstones may be lithic in nature. Seismic profiles have demonstrated the presence of carbonate build-ups on topographic highs of the preexisting Deccan topography. However, while geometries and distribution of the various seismic packages may be mapped, uncertainties still remain regarding reservoir quality and the extent of the source kitchen. Middle Eocene to Oligocene times was a period of extremely restricted clastic supply and the offshore Kutch Basin witnessed carbonate sedimentation. These limestones may be considered as having reservoir potential in areas which have been subjected to leaching and secondary porosity as a result of episodic lowering of sea-levels. Eocene and Oligocene carbonates have been tested, with a small oil flow from the well close to study area. The analysis of well data suggest that the Kutch Basin does not have a regionally extensive Tertiary source horizon. Small grabens and localized depressions, which formed as a result of rifting during the Deccan volcanics may have been filled with organic-rich shales within a sheltered shallow marine shelf. Coupled with subsidence within the Kutch Basin, these depressions may have preserved some Type III organic matter during the Paleocene to Early Eocene times, although with little fluvial input they are likely to be thinner and less organic-rich. Sediments in the Kutch Basin sedimentary lows have undergone thermal maturation, reaching gas maturity over much of the offshore area and may source contiguous reservoirs. Interbedded within these organic rich horizons sands derived from localised highs may provide reservoir potential, although this may largely depend on the nature of provenance and climate.

CONCLUSIONS

The Offshore Kutch Basin has a dual Petroleum System; a Mesozoic-Mesozoic petroleum system and a Mesozoic-Tertiary petroleum system with good source and reservoir facies separated by Deccan Volcanism that has prevented mixing of the two. Improved Subtrappean imaging by focused PSTM merged reprocessing has enhanced the confidence of mapping Mesozoic Basin architecture more accurately. The study established Jurassic and Cretaceous source sequences as the main source layers. Paleocene and younger source rocks have not reached the main oil window.

Structural traps in the form of anticlines, faults blocks and fault seals are likely to be found within the Mesozoic section when tectonic activity was stronger.

During the study, a large inversion structure was observed within the Mesozoic section lying over the graben against the graben bounding faults. These may still be in combination with stratigraphic traps such as lateral facies pinchout/ variations. Cenozoic sections are largely layer cake. Around the Kutch coast, Tertiary sediments show evidence of folding as a result of differential movements of fault blocks under the sedimentary cover. The fault uplifts and subsidence occur more or less along old lines of weakness. Stratigraphic traps may also occur with carbonate build-ups situated on highs. Clastic reservoir with in Early Eocene sequence is the main pay for Tertiary level. They are strati-structural in nature.

Therefore, probing these shallow as well as deeper prospects within Tertiary and Mesozoic sequences of Gulf of Kutch may open up new areas for exploration and early monetization of this basin, thereby converting Kutch- Saurashtra Basin into a Category-I Basin.

ACKNOWLEDGEMENTS

We wish to convey our sincere thanks to Shri Ashutosh Bharadwaj, ED-HOI-GEOPIC and Dr. Harilal, GGM (GP), Head INTEG, for giving us the opportunity and guidance, during the course of the work and its review. Thanks are also due to the Group Members of the Special Studies Group of INTEG, GEOPIC for carrying out Post Stack Inversion. We also thank the management of ONGC for giving permission to present and publish this paper in SPG, Jaipur-2017.

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