Assessment of Hydrocarbon Potential of Kutch Offshore Plays through Petroleum System Modelling of Kutch Basin

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Summary
Petroleum system modeling (PSM) study along two seismic sections (approx. 165km and 342km each) has been undertaken to model paleohistory reconstruction and to access hydrocarbon generation and migration from the source rocks and Hydrocarbon accumulations in deepwaters of Kutch Offshore Basin.

The study established that assigned speculative source rocks in Paleocene and Eocene sequences are mostly in immature window in deep water areas, Thereby possibility of existence of a petroleum system in deep water areas seems unlikely. In the shelf area, where maturity is observed along with kerogen transformation ratio of >50%, Migration vectors shows that major part of any generated hydrocarbon is not able to move out much distance from the assigned speculative source rock layer. Migration vectors shows that major part of generated hydrocarbon is lost since generation as top and sideways losses.

Biogenic scenario based on present day temperature regime recommends that if we are able to detect good reservoirs in vicinity of methanogenic activity zone there could be a chance of getting Biogenic gas accumulations.

Introduction
Kutch and Saurashtra are the poly-history basins situated in the Western Continental part of India. The basins extend from onland to adjoining offshore areas and witness geological history from Mesozoic to Tertiary sequences. The Mesozoic and Tertiary sequences are punctuated by number of unconformities and characteristically at the end of Mesozoic sedimentation is marked by thick Deccan Trap lava flow which erupted episodically over a long period of time from Late Cretaceous to Early Paleocene. The Trap thickness generally increases from east to west - southwest in the range of 80m to >4000m. Tertiary sedimentation commenced over erosional surface of Deccan Trap and thickness of Tertiaries increase basinwards.

Hydrocarbon discoveries have already been established both in Tertiary and in Mesozoic sequences in Kutch and Saurashtra Basin, however, the success has been very limited, sporadic and smaller in size. The structures, GK, GSS and KD have confirmed hydrocarbon accumulation within Mid Miocene, Early Eocene, Paleocene, Cretaceous and Jurassic sections in Kutch-Saurashtra offshore. These discoveries have created a new vista of hydrocarbon exploration in the Kutch shallow water area. Deep water exploration in the area has resulted by drilling of five deep water wells without any success.

Area of Study
PSM study was done along 2D geological sections which are both in the strike as well as dip directions, covering shallow and deep water areas of Kutch Offshore basin (Fig-1).
Assessment of Hydrocarbon Potential of Kutch Offshore Plays through Petroleum System Modelling of Kutch Basin

PETROLEUM SYSTEM MODELING

Description of Petroleum Systems:

A petroleum system is defined as a natural system that encompasses a pod of active source rock and all related oil and gas, which includes all the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist. (Magoon and Dow, 1994) The term ‘system’ describes the interdependent elements and processes that form the functional unit creating hydrocarbon accumulation. The essential elements include: A petroleum Source rock, Reservoir rock, Seal rock and Overburden rock.

The processes are: Trap formation and the ‘generation-migration-accumulation’ of petroleum. These essential elements and processes must occur in time and space so that organic matter included in a source rock can be converted to a petroleum accumulation. A petroleum system exists whenever the essential elements and processes occur.

Based on the geochemical studies and hydrocarbon occurrences, mainly two Total Petroleum System (TPS) were identified in Kutch Basin in the PSM Study by KDMIPE (2016):

➢ Early Cretaceous TST – Early Cretaceous HST petroleum system (?)
➢ Paleocene-Middle Eocene Petroleum system (?)

The Early Cretaceous in Kutch represents late rift phase with the deposition of thick fluvial clastics in the Kutch mainland, that extend to the shallow shelf. In the shallow shelf area, the clastics are dominated by shales with subordinate sands deposited in supra-tidal to inter-tidal setup. The organic rich rift sediments in Kutch basin are Early Cretaceous sediments deposited in fluvial to shallow lacustrine settings having mainly terrestrial organic matter and these are possible source rock. The reservoir rocks are possibly Early Cretaceous sands which are very thick in Kutch Basin. The Paleocene sediments in the low between the KD and KI structures are mature and possible source rock for the KD oils. The Paleocene sediments were deposited in a lagoonal setup and attained maturity in late Neogene.

From litho-stratigraphy point of view, the source rocks include shales of the Bhuj and Jhuran formations of Mesozoic and Shales of Nakhataran, Jakhau and Fulra formations of Ceneozoic.

Reservoir rocks are present throughout most of the stratigraphic section in the Kutch-Saurashtra Basin. Reservoir rocks include the sandstones and limestones of Late Jurassic to Late Cretaceous (Jhuran Formation and Bhuj Formation) for Mesozoic; and sandstones and limestones of Late Paleocene to Middle Miocene (Nakhatarana, Jakhau, Fulra, Godhra and Chhasra formations) for Ceneozoic.

Traps are primarily anticlines and faulted anticlines with a few subtle stratigraphic traps.

Seals include interbedded Paleocene, Eocene, Miocene shales and clays, and the thick clays of Kandla Formation.

MODEL BUILDING / INPUT

The basic workflow (Fig. 2) in the study involves:

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Data Type And Sources

Static model (depth surfaces of key stratigraphic horizons and faults) and corresponding facies model form the primary inputs for building a petroleum system model. Data obtained from wells drilled
Assessment of Hydrocarbon Potential of Kutch Offshore Plays through Petroleum System Modelling of Kutch Basin

within the basin including information available in public domain has been integrated.

**Model Geometry**
2D geological models was built using six depth horizons and faults.

**2D-Modeling In The Study Area:**
2D-modeling constructs the GME cycle and leads to better understanding of hydrocarbon generation, expulsion, migration and accumulation/loss through geologic time. A 2D-Petroleum system modeling (PSM) study along two seismic sections (approx.165km and 342km each) has been undertaken to model paleo-history reconstruction and to access hydrocarbon generation and migration from the source rocks and Hydrocarbon accumulations in deepwaters of Kutch Offshore Basin (Fig. 3). The location map and modeled Seismic sections are shown in Fig-1 and 3, that depicts the interpreted horizons and faults and passes through drilled well DO-A. The profile displays passive shelf to deep water setting

Figure-4: Seismo-geological section through Wells

**Source Rocks:**
The earliest known source rocks encountered in the basin are from Middle Jurassic epoch. The shallow marine shales of the Early Cretaceous Bhuj Formation indicate predominantly type III organic matter with minor type II inclusions. In the deep water areas, Mesozoic successions have not yet been penetrated. Thus the assessment on presence of source rocks in Mesozoic successions is speculative.

In the Tertiary succession, the Paleocene Nakhtarana Formation overlying the Deccan Trap and the Early Eocene Jakhau formation host source rich facies. The coal shale alterations in the near shore regions comprising GK and adjoining areas are organic rich. Further west in well GK-BA, TOC is ~0.41% with very poor HI values (Fig-5). Most of the source rich Paleocene sediments are near shore but are immature and in deeper areas where the threshold maturity is attained the source quality is poor. However, the assessed lows may be of some hope to Tertiary-Tertiary petroleum system as some speculative thermally mature source rich facies can be envisaged in a hypothetical PSM model.

**Input Data:**
Two NW-SE seismic sections were used as input for building the model. Each formation/layer is assigned with its relevant lithologies and facies pertaining to Petroleum system elements. The lateral variation of facies across the section was taken into account (Fig-4).

Fig-3: Seismic section with interpreted horizons and faults

Fig-4: Seismo-geological section through Wells

Fig-5: HI vs OI cross plot of the studied wells
Assessment of Hydrocarbon Potential of Kutch Offshore Plays through Petroleum System Modelling of Kutch Basin

For Eocene source rock, a default type III kinetics, Pepper & Corvi (1965), T-III-H-(DE) has been assigned in the model.

**Heat Flow**

Thermal calibration of present day heat flow regime was made using observed corrected BHT values from wells.

**Maturity and Transformation Ratios of Source Rocks**

Source rock layer modelled within Early Eocene Sequence is observed to be mostly in immature window except north of proposed location where early oil window maturities are seen (Fig-6) with negligible transformation ratios (TR%).

**Petroleum Accumulation in Modeled Section**

In Modeled 2D sections little hydrocarbon accumulation is observed as the source rock is not able to attain sufficient maturity in larger areas and required kerogen transformations (Fig-7) in the deep water area.

**Additional scenarios with Mesozoic sediments below Deccan Trap**

Mesozoic extent is envisaged (Fig-8) and modeled from GM data till the COB. Assigned speculative source rock layers in Mesozoic sequences have attained sufficient maturity (Fig-9) and Migration vectors show that generated hydrocarbons have the capacity to move through Faults into Tertiary sequences.

**Biogenic Modeling**

Geochemistry studies

As per the WCR of MBS-A, the gas hydrate phase plot indicates conditions favourable within the sediments to a depth of 1200m (theoretical BSR) to
form gas hydrates. However, the same is not seen on the seismic data. LWD logs indicated possible presence of shallow gas. Also, seepages and small crater at the wellhead indicate presence of gas. Therefore, there exists the possibility of shallow gas or gas hydrates being present at the location.

One Biogenic scenario was modeled based on present day temperature regime, in which few zones are identified as probable generative centers of biogenic gas. In this scenario, Biogenic gas generation window is observed within the sediments of Middle Miocene age (Fig-10) as assigned biogenic source rock layers are showing biogenic gas migration vectors. Therefore if we are able to detect good reservoirs in vicinity of methanogenic activity zone there could be a chance of getting Biogenic gas accumulations based on this study.

![Fig-10: Isotherm for section-1 indicative of the Present day Temperature regimes which may lead to Biogenic activity](image)

**Conclusions**

- PSM studies brought out paleo-history and assessed the timing and sequence of geologic and tectonic events since 65Ma onwards, vis-à-vis, hydrocarbon generation and migration to evaluate the prospectivity in Deep waters area of Kutch Offshore basin.

- Tertiary sediments got deposited in a stable passive margin set up. Deeper areas of shelf are dominated by argillaceous limestone / shale intercalations.

- Late Paleocene and younger source rocks are barely reaching the main oil window in deep water areas, due to less overburden sediments. In the shelf area, Late Paleocene and younger source rocks are in main oil to wet gas window.

- Main hydrocarbon generation maturity window falls approximately below 2400m and which vary in depth depending on present day water depth i.e. for Shallow water areas generation window is below 2400 m and for deeper water areas it is starting from ~5000m onwards.

- Additional scenarios with Mesozoic sediments below Deccan Trap have attained sufficient maturity.

- Biogenic gas generation window is observed within the sediments of Middle Miocene age. If we are able to detect good reservoirs in vicinity of methanogenic activity zone there could be a chance of getting Biogenic gas accumulations based on this study.

**References**


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