Characterization of the Paleocene-Eocene petroleum system of Upper Assam Shelf and assessing the probability of discovery in near field exploration

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Petroleum System, Play Probability, Paleocene-Eocene Play, Near Field Exploration

Abstract

The Upper Assam Shelf is a prolific petroliferous basin and is one of the oldest of the 26 sedimentary basins in India. OIL has been continuously exploring for extended years in OIL's Main Producing Area (MPA) in the northeast India, where near-field exploration has become quite challenging. Paleocene to Middle Eocene petroleum system of Assam Shelf Basin is the latest to be discovered and the oldest to be formed. The present contribution of the Paleocene-Eocene reservoirs is around 45% (oil) and 56 % (gas) of the total production from OIL's MPA. However, the percentage contribution of the same is only about 25% (oil) and 23% (gas) of the cumulative hydrocarbon produced so far from the established reservoirs of OIL's main producing area indicating huge possibility of finding prospective hydrocarbon accumulations within these reservoirs.

The probability of hydrocarbon discovery is dependent on the presence and effectiveness of the elements of the petroleum system and the processes associated with it. Characterization of the established elements and processes is significant in geological assessment and estimating resource potential of hydrocarbon prospects. Oil and gas exploration has a considerable degree of uncertainty associated with it. Therefore, estimating probability of discovery in exploration studies become very crucial. The chance of hydrocarbon discovery in near field exploration is governed by the component probabilities of well-defined geological factors which are estimated with respect to the presence and effectiveness of geological processes associated with them.

This paper focuses on characterization of fundamental elements and processes of the established petroleum system existing in the Paleocene-Eocene reservoirs of OIL's MPA using probabilistic evaluation methods. The outputs derived from this methodology are influenced primarily by data availability, quality & control, reservoir depth and structural complexity.

A probability matrix has been generated representing four play probability schemes of Paleocene to Lower Eocene Petroleum System of OIL's MPA. Based on the Play Probability matrix, two cases are identified based on reservoir depth. For each of the two cases, four scenarios have been taken considering the structural complexity and type of seal. Monte Carlo simulation is then carried out using for each scenario and eight play probability schemes are generated. This approach of petroleum system analysis would aid in evaluation of the geological factors that are critical to the discovery of hydrocarbons. This will further contribute to decision analysis considering the associated geological risk and in establishing commercial viability of any drillable prospect within the play.

Introduction

The Assam shelf Basin covering an area of 56,000 sq. km. is a prolific petroliferous basin. Geologically, it is an inter-mountainous basin with the eastern Himalayas in the north, the Mishmi Hills to the north-east, The Assam- Arakan thrust belt to the south-east and the Shillong Plateau to the South-west (Figure. 1). Various episodes of tectonic activity have modified the basin, which consequently has influenced the sediment deposition also. The sedimentary sequence with thickness ranging from around 3.0 km to 10.0 km (Mandal and Dasgupta, 2013) starting from Permo-Carboniferous period to recent times has been reported from the basin. The structural evolution in the basin exerted a major influence not only on stratigraphic development but also on petroleum occurrence as well (Sahoo and Gogoi, 2011). The presence of hydrocarbon has been established in the fractured Pre-Cambrian rocks, the

Paleocene-Eocene age, Oligocene age and the Miocene age sedimentary rocks.

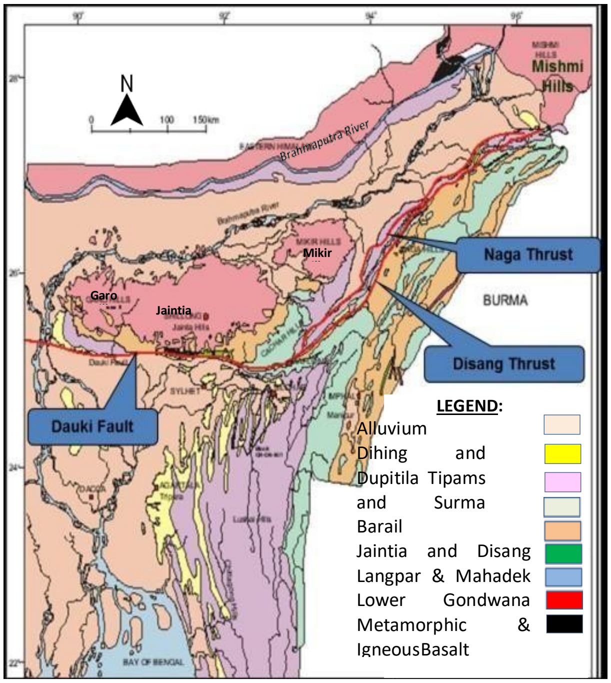


Figure 1: Geology of Assam-Arakan Basin

Method

For characterizing the established elements and processes of the petroleum system of Paleocene-Eocene plays, the matrix between input parameters to the volumetric calculation is followed. The petrophysical parameters of drilled wells such as, porosity, permeability, thickness, saturation etc. in OIL's Main Producing Area (MPA) area of Assam is used as the input parameters for the probabilistic approach.

The probability of the simultaneous occurrence of several independent events is equal to the product of their individual probabilities (the multiplication rule). The probability of discovery of a play is the product of the probabilities of the individual petroleum system elements and the processes associated with it.

i.e P = PS x PR x PT x PM x PRn

where,

P= Probability of discovery
PS =Probability of Source Rock
PR= Probability of Reservoir Rock
PT= Probability of Trap and Seal
PM = Probability of Migration
PRn= Probability of Retention

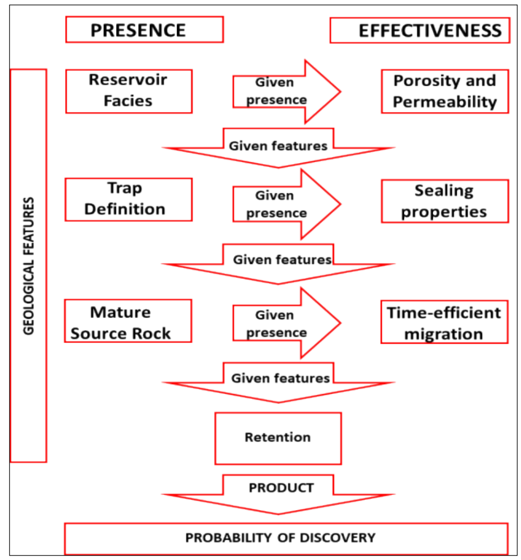


Figure 2: Methodology Chart (Ref: Adopted from The CCOP Guidelines)

Established Plays:

In OIL's operational areas, the presence of hydrocarbon has been established in the Paleocene-Eocene (Langpar, Sylhet and Kopili Formations), the Oligocene (Barail Arenaceous and Barail Argillaceous Formations) and the Miocene (Tipam and Girujan Formation) Reservoirs (Figure- 3). The study focuses on the Paleocene-Eocene reservoirs. Potential plays are developed where source rock, hydrocarbon migration pathways, reservoir rocks, and seals are developed in conjunction (Lambiase and Morley, 1999). The study is an attempt to probabilistically characterize the established elements and processes that make the Paleocene-Eocene reservoirs a highly potential petroleum system.

Petroleum System:

Two Petroleum systems are considered to be present in Assam shelf as well as the oil fields of MPA in OIL's operational area. They are 1) Paleocene to Middle Eocene- Paleocene to Middle Eocene (!) and 2) Late Eocene to Oligocene – Oligocene (!).

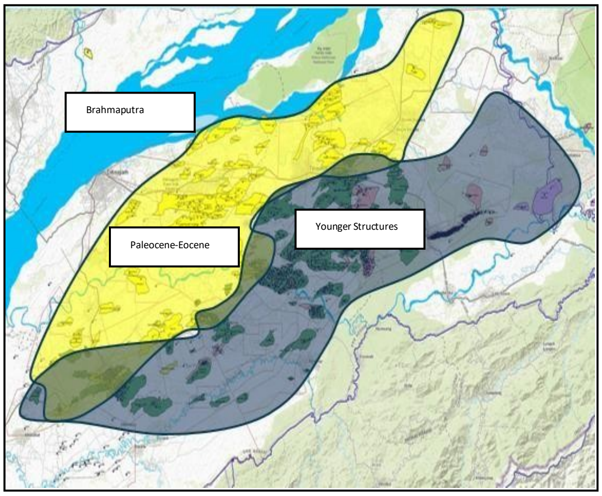


Figure 3: Map of showing Paleocene-Eocene and Younger structures in MPA area of OIL in Upper Assam Basin

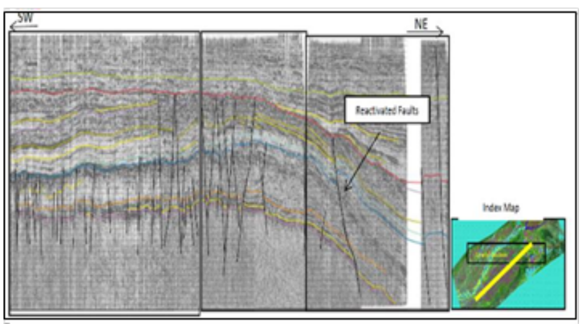


Figure 4: NE-SW Seismic Section through OIL's Operational Area

Paleocene to Middle Eocene- Paleocene to Middle Eocene (!) Petroleum System:

The Paleocene to Middle Eocene- Paleocene to Middle Eocene (!) Petroleum System is the latest petroleum system discovery wise and the earliest formation wise.

Source Rock:

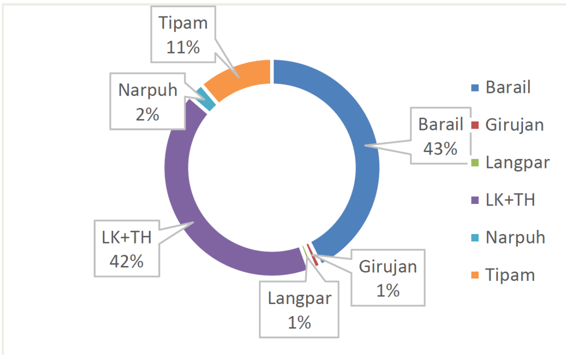
The Lakadong+Therria member of the Sylhet Formation comprises of thin carbonaceous shales and coal units that are interbedded with the thin sandstone beds and shales. These thin bands of carbonaceous shales are considered to be the source rock for the petroleum system. The geochemical analysis of the source rocks in the main producing area suggest Total Organic Carbon (TOC) values of 0.5-0.6, with Type II/III Organic matter (Raju and Mathur, 1995).

Geochemical investigations of oil and source rocks of Upper Assam shelf indicates that all oils of different reservoirs in the shelf area are characterized by similar thermal maturity, whereas the source rocks in the shelf area are low to marginally mature. It is envisaged that hydrocarbons might have been generated in the sub thrust area in the Schuppen zone and migrated towards the shelf area.

Reservoir Rock:

The Paleocene-Eocene reservoir rocks are present throughout the Main Producing Area (MPA) of OIL in Upper Assam Basin viz. the sandstones of Langpar Formation and Lakadong + Therria Member, the siltstones of Narpuh Member. Commercial establishment of hydrocarbon in sandstones of Kopili embedded within Shales is yet to be found. The potentially productive reservoirs of Paleocene-Eocene are the Langpar sandstone Formation with porosity ranging from 10% to 20%. The Lakadong + Therria Member with porosity ranging from 10% to 21% and the Narpuh Member with porosity ranging from 10% to 15%. The Net to Gross (NTG) ratio of these reservoirs ranges from 0.20 to 0.60. The present contribution of the Paleocene-Eocene reservoirs is around 45% (oil) and 56 % (gas) of the total production from OIL's MPA. However, the percentage contribution of the same is approximately only 25% (oil) and 23% (gas) of the cumulative hydrocarbon production from the established reservoirs of OIL's main producing areas (Figure 5 and Figure 6).

The probability of the presence of an effective reservoir rock with minimum properties as assigned in the volumetric estimate of the prospect comprises of two components. The first of these is the probability of the existence of reservoir facies with minimum properties such as net/gross ratio and thickness. The second is the probability that the reservoir parameters will be effective in terms of porosity, permeability and hydrocarbon saturation. The Wells drilled in the MPA of OIL has been thoroughly studied for this purpose. For the presence of effective reservoir facies, probability scheme (Table1) is followed. Considering the environment of deposition vis-à-vis the availability of data, the Paleocene-Eocene reservoirs in terms of its presence are assigned a probability 0.8 – 1.0 and 0.9 – 1.0 for shallow marine & coastal, deltaic, tidal respectively,



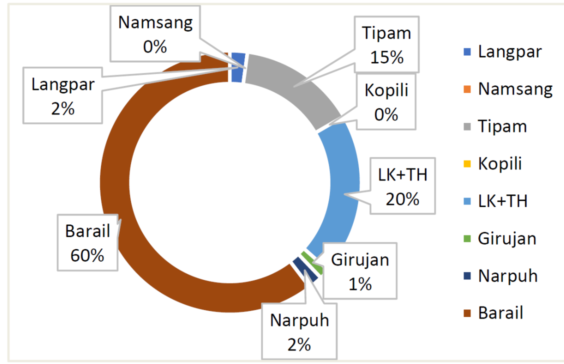
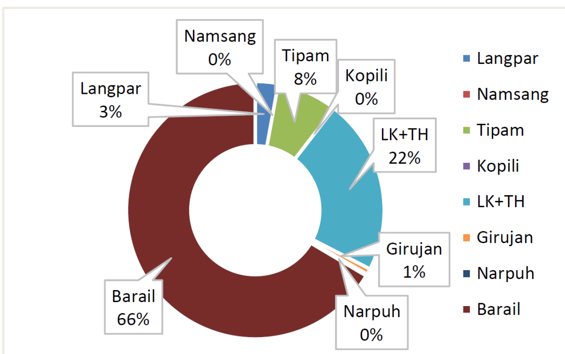


Figure 5: Present Production Contribution of different formations of OIL from MPA (Main Producing Area) showing: Oil (Left) Gas (Right)



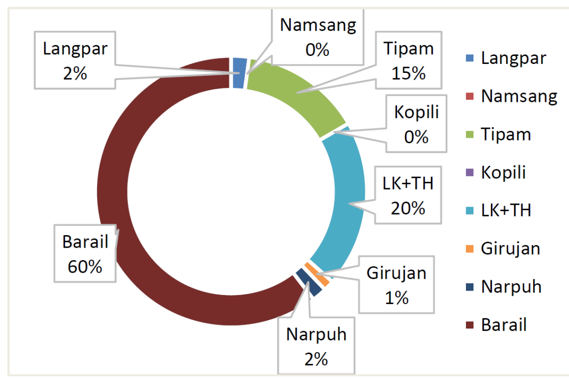


Figure 6: Cumulative production contribution from different formations of OIL from MPA (Main Producing Area showing: Oil (Left) & Gas (Right)

Depo-sitional Environment / Data-Reliability		Direct Data, proximal deposits	Direct Data, more distal deposits	Limited data, dis-continuous deposits	Indirect data seismic sequence analysis
Marine	Shallow marine, "blanket"	0.9 - 1.0	0.7 - 0.8	0.6 - 0.7	0.4 - 0.6
	Coastal, deltaic, tidal	0.8 - 1.0	0.7 - 0.8	0.6 - 0.7	0.4 - 0.6
	Submarine fan	0.7 - 0.8	0.5 - 0.6	0.3 - 0.5	0.1 - 0.3
	Carbonates	0.8 - 1.0	0.6 -0.8	0.5 - 0.7	0.3 - 0.5
Continental	Lacustrine deltaic	0.7 -0.9	0.5 - 0.7	0.4 - 0.6	0.3 - 0.5
	Alluvial fan, braided stream, meand. Chan.	0.7 - 0.9	0.5 - 0.7	0.4 - 0.6	0.3 - 0.5
	Eolian	0.8 - 1.0	0.6 - 0.8	0.4 -0.6	0.4 - 0.6
Others	Fractured basement	0.4 - 0.6	0.3 - 0.5	0.2 - 0.4	0.1 - 0.3
	Fractured porous lava	0.4 - 0.6	0.3 - 0.5	0.2 - 0.4	0.1 - 0.3

Res. Depth, (pressure, temp.) / Data-Reliability		Direct Data, proximal deposits	Direct Data, more distal deposits	Limited data, uncertain correlation	Indirect data
1-3 km	Homogeneous, clean reservoir	0.9 - 1.0	0.8 - 0.9	0.7 - 0.8	0.6 - 0.7
	Mixed, unclean reservoir	0.8 - 1.0	0.7 - 0.8	0.6 - 0.7	0.4 - 0.6
3-4 km	Homogeneous, clean reservoir	0.8 - 0.9	0.7 - 0.8	0.5 - 0.7	0.4 - 0.5
	Mixed, unclean reservoir	0.7 - 0.9	0.6 - 0.7	0.5 - 0.6	0.3 - 0.5
>4 km	Homogeneous, clean reservoir	0.7 - 0.9	0.5 - 0.7	0.4 - 0.6	0.3 - 0.5
	Mixed, unclean reservoir	0.6 - 0.9	0.3 - 0.5	0.2 - 0.4	0.1 - 0.3

Table 1: Probability Scheme. Presence of effective Reservoir Facies (left) and Effective Pore Volume (right)(Adopted from The CCOP guidelines)

and a probability of 0.8 – 0.9 and 0.7 - 0.9 for reservoir < 4 km & > 4 km depth respectively considering the effectiveness of the reservoirs.

Trap and Seal:

Structural traps viz. anticlines, faulted anticlines; Stratigraphic viz. pinch-outs and strati-structural i.e a combination of both structural and Traps have been known till date in the MPA areas of OIL (Figure. 7). The majority of the Paleocene- Eocene oil bearing structures are associated with anticlines and the faulted anticlines. The purely stratigraphic traps are associated with the shallow reservoirs of mainly Barail and Girujan Formations.

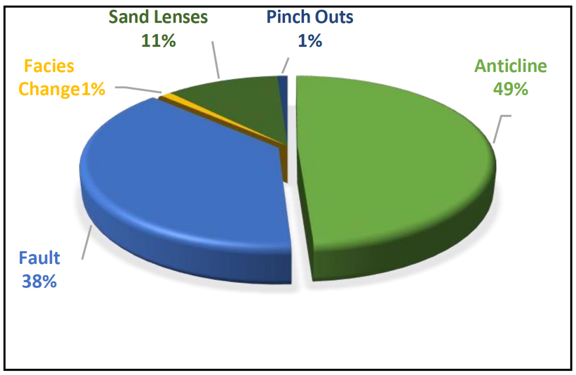


Figure 7: Distribution of trap types in MPA of OIL (Wandrey, 2004)

The anticlines are associated with the faults that trends parallel to the Belt of Schuppen. These faults have two major regional trends; the NE-SW trending normal faults that are basement rooted and may be attributed to the rifting of the Indian Plate from the Australian Plate, the ENE-WSW faults are attributed to the collision of the Indian Plate with the Burmese Plate (Figure 4).For the Paleocene-Eocene reservoirs, the overlying thick shales of Kopili is a regional seal. In addition to it, the interbedded shales of Lakadong and Therria and shales of Narpuh Member also acts as a seal.

The probability of the presence of an effective trap, is the product of the probability of the existence of the mapped structure as a valid geometrical closure, and of a sealing mechanism which acts in such a way that the trap's bounding surfaces enclose the minimum rock volume as defined in the volumetric calculation. An optimum probability value of 0.9 -1.0 for presence of efficient structural closure and with respect to the Effective Seal Mechanism, a probability of 0.8 – 1.0 and 0.5 and 0.8 for simple seal & combined seal respectively is considered.

		3Dseismic	2D-seismic Dense grid size	2D-seismic Open grid size	2D-seismic Very open grid
Good corr., nearby wells	Low structural complexity	0.9 - 1.0	0.9 - 1.0	0.8 - 1.0	0.7 - 0.9
	High structural complexity	0.7 - 1.0	0.6 - 0.9	0.5 - 0.8	0.4 - 0.7
	Low relief, uncertain depth conversion	0.6 - 0.9	0.5 - 0.8	0.4 - 0.7	0.3 - 0.6
Uncertain corr, distant wells	Low structural complexity	0.9 - 1.0	0.8 - 1.0	0.7 - 0.9	0.5 - 0.8
	High structural complexity	0.7 - 0.9	0.6 - 0.9	0.4 - 0.8	0.3 - 0.7
	Low relief, uncertain depth conversion	0.5 - 0.8	0.4 - 0.7	0.3 - 0.6	0.2 - 0.5
Unreliable corr. Analogue model	Low structural complexity	0.9 - 1.0	0.7 - 1.0	0.6 - 0.8	0.4 - 0.7
	High structural complexity	0.4 - 0.7	0.3 - 0.6	0.2 - 0.5	0.1 - 0.4
	Low relief, uncertain depth conversion	0.3 - 0.7	0.2 - 0.6	0.1 - 0.5	0.1 - 0.4

Seal mechanism	Top surface	Bottom, side	Structural style	Very good	Good	Acceptable	Poor
Simple Seal	Conform	N/A.	Anticline, buried highs,	0.9 - 1.0	0.8 - 1.0	0.6 - 0.8	0.4 - 0.6
	Uncon -form	N/A.	Faulted structures	0.8 - 0.9	0.7 - 0.8	0.5 - 0.7	0.3 - 0.5
Combined Seal	Conform	Unconform	Onlap, lowstand wedge	0.5 - 0.7	0.4 - 0.5	0.3 - 0.4	0.1 - 0.3
	Conform	Faults	Downfaulted structures	0.6 - 0.8	0.5 - 0.6	0.3 - 0.5	0.1 - 0.3
	Conform	Facies shift	"shale out"	0.6 - 0.8	0.5 - 0.7	0.4 - 0.6	0.1 - 0.3
	Uncon -form	Conform	Subcrop structures	0.4 - 0.5	0.3 - 0.5	0.2 - 0.4	0.1 - 0.3

Table 2: Probability Scheme. Presence of efficient Structural Closure (left) and Effective Seal Mechanism (right) (Adopted from The CCOP guidelines)

Hydrocarbon Generation, Migration and Accumulation:

It is reiterated that various geochemical investigations of oil and source rocks of Upper Assam shelf indicates that all oils of different reservoirs in the shelf area are characterized by similar thermal maturity, whereas the respective source rocks extracts in the shelf area are low to marginally mature. Thus it is believed that Kitchen area lies below the belt of schuppen and migration have taken place to this part of the Basin.

effective migration and 0.9- 1.0 is assigned for effective retention.

Effective Migration is a critical factor that must be considered while characterizing the process of petroleum system. Most of the existing structures of Paleocene-Eocene charged with hydrocarbon in operational areas of OIL were formed during collision of the Indian Plate with the Burmese plate during post Oligocene time i.e prior to hydrocarbon migration. Under normal pressure regimes,

Migration	The trap is formed before onset of hydrocarbon migration	Time of trap formation and time of migration are overlapping	The trap is formed when the source rock is supposed to be "overcooked"
Local migration	0.9 - 1.0	0.4 - 0.8	0.1 - 0.4
Lateral migration without barriers	0.8 - 0.9	0.4 - 0.7	0.1 - 0.3
Lateral migration with barriers	0.5 - 0.8	0.2 - 0.5	0.1 - 0.3
Vertical migration without barriers	0.7 - 0.9	0.3 - 0.6	0.1 - 0.3
Vertical migration with barriers	0.4 - 0.6	0.2 - 0.4	0.1 - 0.2
Long-distance "fillspill" migration	0.4 - 0.6	0.2 - 0.4	0.1 - 0.2
The trap is in the "shadow" of migration	0.2 - 0.4	0.1 - 0.3	0.1

Geological Processes after accumulation / Data Control		Positive unambiguous data (seismic, wells, etc.)	Data control and interpretation is poor to fair	Negative unambiguous data (seismic, wells, etc.)
No late activity	No tectonic activity after accumulation	0.9 - 1.0	0.8 - 1.0	0.7 - 1.0
	Shallow traps, possible biodegradation	0.8 - 0.9	0.4 - 0.7	0.1 - 0.3
Erosion	Trap in connection to generating source	0.7 - 0.9	0.3 - 0.6	0.1 - 0.3
	Trap not connected to generating source	0.5 - 0.8	0.2 - 0.5	0.1 - 0.2
Uplift and tilting	Form, volume, toppoint not changed	0.7 - 0.9	0.4 - 0.7	0.2 - 0.4
	Form, volume, toppoint changed	0.5 - 0.6	0.3 - 0.4	0.1 - 0.2
Reactivated faults	Compression and/or transpression	0.5 - 0.7	0.4 - 0.5	0.3 - 0.4
	Tension	0.4 - 0.6	0.3 - 0.4	0.1 - 0.3

Table 3: Probability Scheme. Probability of effective migration and timing (left) and Probability of effective retention (right)

It is also believed that the timing of migration took place during 29 Mya to 17 Mya. For hydrocarbon accumulation, the structures must have already formed prior to migration of hydrocarbon. Considering this, a probability of 0.4 – 0.6 is assigned for probability of effective migration and timing. In addition to it, after accumulation of hydrocarbon, effective retention is an important factor for a hydrocarbon pool to be present. The major upliftment and re-activation of faults in parts of the basin (Figure 3) are considered to have occurred prior to the significant accumulation. Moreover, evidence of re-activation is found to be restricted to only parts of the basin and therefore not considered to have significant effect on retention of hydrocarbon. A probability ranging from 0.4 – 0.8 for hydrocarbon migrate upwards. The tentative migration pathway of the basin is shown in Figure 8.

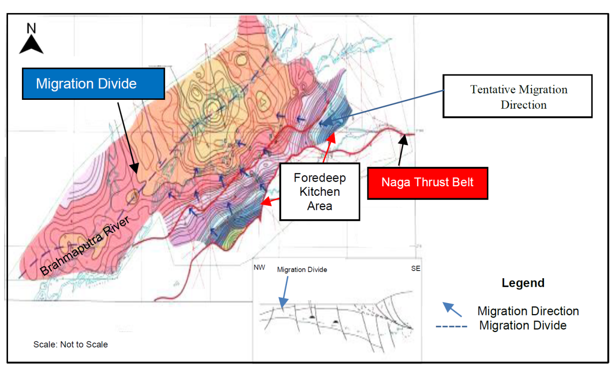


Figure 8: Form Map showing migration pathway of hydrocarbons

Discussion and Conclusion:

The simultaneous occurrence of several independent events is equal to the product of their individual probabilities (the multiplication rule). The probability of discovery of a Play is the product of the probabilities of the individual Petroleum System Elements and the processes associated with it.

i.e P = PR x PT x PM x PRn

A probability matrix has been generated representing 4 (four) play probability scheme of Paleocene to Lower Eocene Petroleum System of OIL's MPA in Upper Assam Basin. The distribution has been done based on the existing understanding of the basin and acquired hard data through drilled wells.

Based on the play probability matrix (Table- 4), two cases are identified based on reservoir depth. For each of the two cases, four scenarios have been taken considering the structural complexity and type of seal. Monte Carlo simulation is then carried out using hundred (100) iterations for each scenario and eight (8) play probability schemes are generated (Table-5). This approach of petroleum system analysis would aid in evaluation of the geological factors that are critical to the discovery of hydrocarbons in an identified prospect. This will further contribute in decision analysis considering the associated geological risk and in establishing commercial viability of any drillable prospect within the play.

PR	Depositional Environment (Shallow Marine, Coastal, Deltaic, Tidal)			
	0.8 - 1.0			
	Homogeneous Clean Reservoir (<4 km)		Homogeneous Clean Reservoir (>4 km)	
	0.8-0.9		0.7 - 0.9	
PT	Low Structural Complexity	High Structural Complexity	Low Structural Complexity	High Structural Complexity
	0.9 - 1.0	0.7 - 1.0	0.9 - 1.0	0.7 - 1.0
	Simple Seal	Combined Seal	Simple Seal	Combined Seal
	0.8- 1.0	0.5 - 0.8	0.8 - 1.0	0.5 - 0.8
PM	Long-distance "fill-spill" migration and lateral migration with barriers			
	0.4 - 0.8			
PRn	No late activity			
	0.9 – 1.0			

Table 4. Play Probability Matrix of Paleocene to Middle Eocene- Paleocene to Middle Eocene (!) Petroleum System of OIL's MPA in Upper Assam Basin

	For Paleocene-Middle Eocene Play in MPA			
	For Homogeneous Clean Reservoir (< 4 km Depth)		*Homogeneous Clean Reservoir (>4 km)*	
	Play Category	**Play Probability**	**Play Category**	**Play Probability**
	With low complexity & Simple seal	0.37	With low complexity & Simple seal	0.34
	With low complexity & Combined seal	0.23	With low complexity & Combined seal	0.25
	With High complexity & Simple seal	0.35	With High complexity & Simple seal	0.30
	With High complexity & Combined seal	0.20	With High complexity & Combined seal	0.21

Table 5. Play Probability Scheme using Monte Carlo Simulation

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