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Source Rock Evaluation and Petroleum System Modeling in a part of Bengal basin, India

The Bengal basin, the largest fluvio-deltaic sedimentary system on Earth, is located in the Himalayan foreland at the junction of the Indian, Eurasian, and Burmese plates. It is broadly divided into a stable shelf and a foredeep separated by a deep seismic hinge zone. The narrow elongated hinge zone separates the thick post Eocene sediments in the east from the shelf zone of the west. The study area covers NELP-VII blocks WB-ONN-2005/2 and WB-ONN-2005/4 covering both the shelfal and basinal part on both sides of hinge zone. (Fig. 1). During Gondwana times most of sedimentation took place towards western side and later the depocentre shifted towards east. Increasing supply of sediments from rising Himalayan range in the north, transported by developing river systems, led to molasses type of basin. The high load of sediments towards south-east caused the main tilt of entire western margin plate (Moore and Lyenberger, 1994). The approx. 22 km thick Early Cretaceous–Holocene sedimentary succession has long been of interest for hydrocarbon exploration.

All hydrocarbon shows are from onshore wells and distributed in Cretaceous to Pliocene indicating that hydrocarbon generation has taken place in the basin. But there has been no sustained flow except in wells IP-1 and GG-1 (gas and oil) and GP-1 (gas). The liquid hydrocarbon from IP-1 (Oligocene) is a well preserved, low density (API Gravity 47.74), low pore point (-15^{o}C), low wax crude, more like a condensate. The gases from GG-1 (Eocene), IP-1 (Oligocene), M-1 (Miocene), B-2 (Miocene), J-1 (Eocene) and GP-1 (Eocene) differ slightly in isotopic and chemical compositions but all are thermogenic in nature.

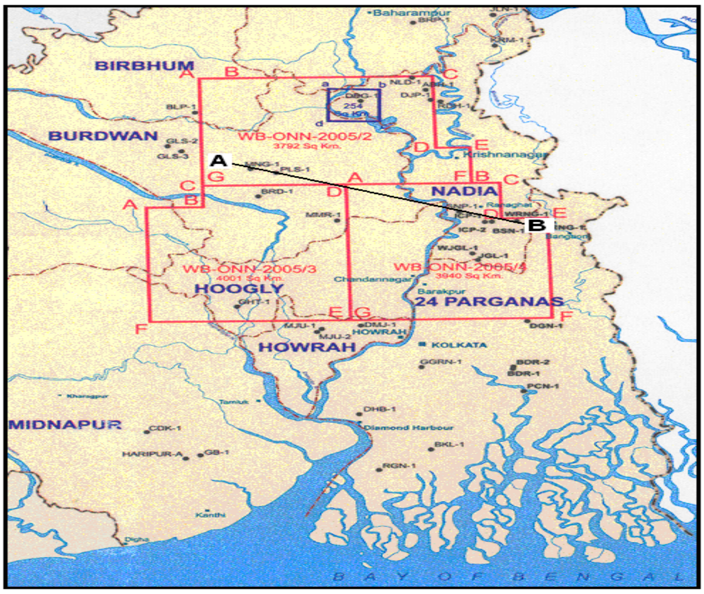

Figure-1: Location Map of Study Area (NELP-VII blocks WB-ONN-2005/2 and 4 with modeled cross section AB

Regional Source Rock Evaluation: A review of all available source rock data indicates that the sequences with fair to good source rock potential exist within Miocene (Pandua/ Malta), Oligocene (Memary/ Burdwan), Eocene (Kopili/ Sylhat) and Paleocene (Jalangi) formations. In Lower Gondwana, the excellent organic richness and source potential exist due to significant number of coal layers (Barakar coals) which may act as potential source rocks for gaseous hydrocarbons. In Lower Gondwana thick potential source rock sections are observed in drilled wells P-1, M-1 and C-1. The Hydrogen Index (HI) values in the potential source rock sections are consistently less than 150 mg/g TOC signifying terrestrial input with type-III kerogen. However in wells C-1 and GG-1 few sections in Kopili/ Sylhat and in well P-1 few sections in Jalangi formation show HI in the range of 200-300 indicating minor contribution of type-II kerogen. High S1 and PI values, mostly in Miocene (Pandua/ Malta) in few wells indicate the possible presence of free hydrocarbons signifying a migration channel or an accumulation horizon. Source rock log for the wells P-1 and M-1 is shown in Figure-2.

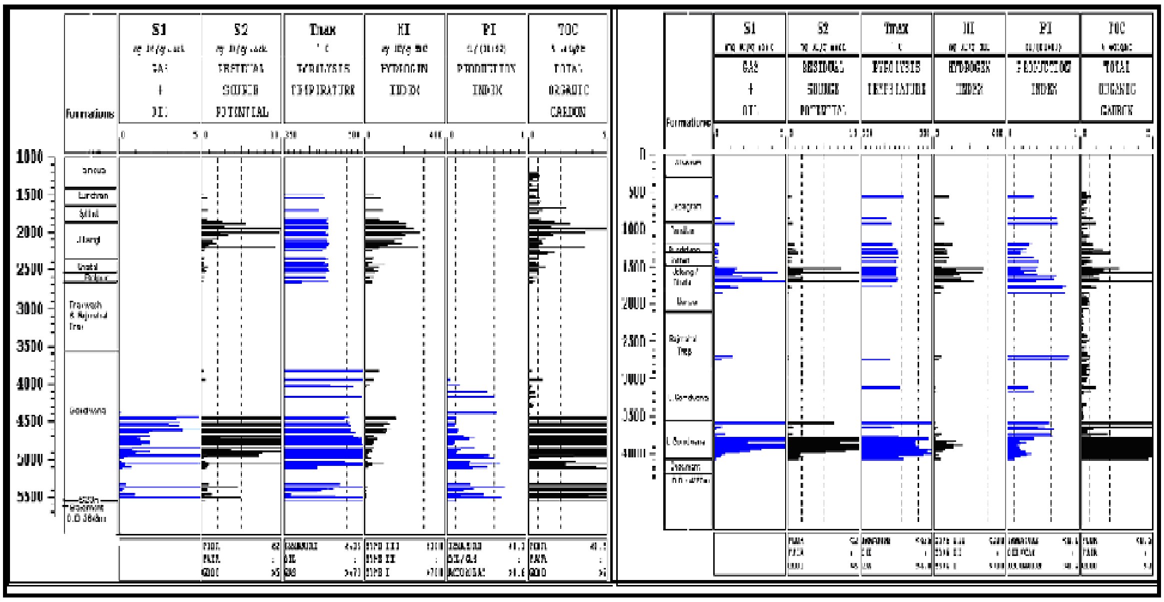

Figure-2: Source rock log of well P-1 and M-1 located at shelf part of the basin

Petroleum System Modeling (PSM): A multi dimensional, deterministic dynamic basin model of the study area was constructed on integrated 3D-Petroleum System Modeling software Petromod from M/s IES, Germany.

Input data, calibration and simulation: 2D- Petroleum systems modeling study along one seismo-geological cross section was carried out to model paleohistory reconstruction and to assess hydrocarbon generation and migration. 2D- modeling handles mass and energy transfer, both in vertical and lateral directions, hence leads to better understanding of hydrocarbon generation, expulsion, migration and accumulation/loss through geologic time (Hantschel T. and Kauerauf A.I.,2009) Input data consist of initial physical and thermal properties of sediments, paleobathymetric estimates, heat flux and amount and type of organic matter. The modeled section A-B **(**Figure-1A) covers the entire geological domain and passes through drilled wells G-2, M-1, P-1, S-1, I-1 and two synthetic locations. Source rock sections were identified based on the data obtained from drilled wells in west of Hinge zone. A generic type III kinetic model has been assigned to keep the model simple. The kinetic model is based upon Burnham (1989)-T III, where activation energy range is 46-68 K cal/mole with maxima at 52 K cal/mole and HI is 160. A good correlation of present day BHT and modeled temperatures was observed by setting the present day heat flow to 56mW/m^2 at P-1 and 52mW/m^2 at I-1. Only constant heat flow scenario was taken for modeling. Each formation/layer was assigned with its pertinent lithologies and Petroleum system elements. Assigned facies and petroleum system elements for all layers are listed in Table-1. Facies assignment along the cross section A-B is shown in Figure-3. Table-2 summarizes the source rock layers with source rock parameters used in this study:

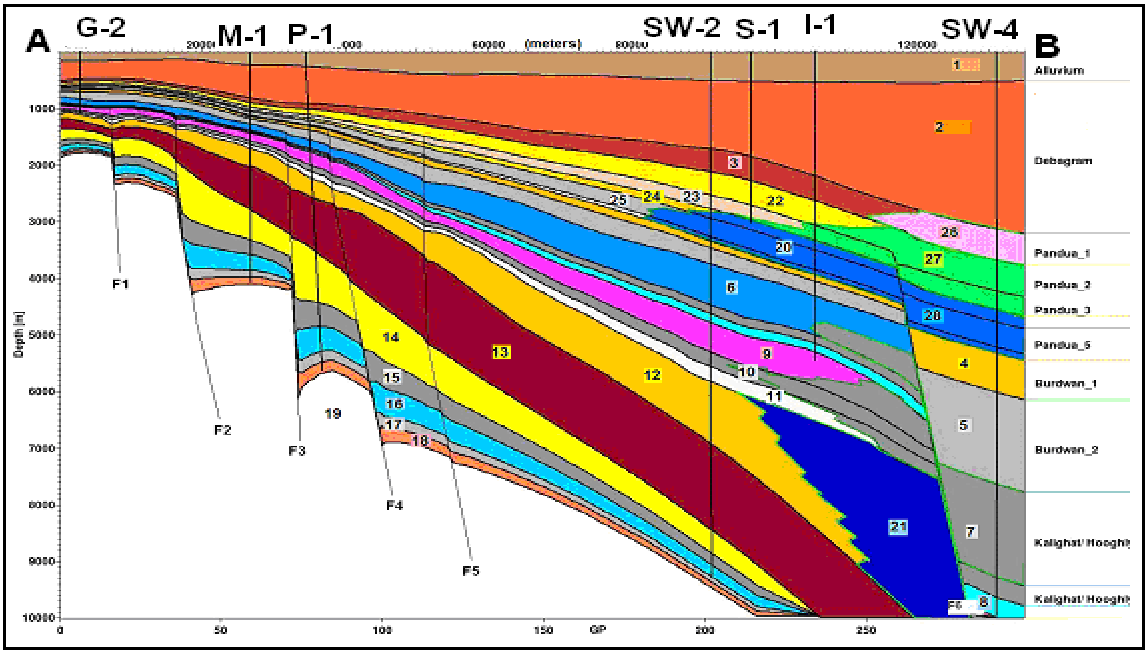

Figure-3: Facies assignment along the cross section AB showing faults (F1 to F6) and drilled/synthetic locations

Facies No.	Name	Petroleum System Element	Facies No.	Name	Petroleum System Element
1	Alluvium	Overburden Rock	15	Gondwana-2	Source Rock
2	Debagram	Overburden Rock	16	Gondwana-3	Reservoir Rock
3	Pandua-1	Seal Rock	17	Gondwana-4	Source Rock
4	Burdwan-1	Reservoir Rock	18	Gondwana-5	Reservoir Rock
5	Burdwan-2	Source Rock	19	Basement	Underburden Rock
6	Kalighat/ Hooghly1	Reservoir Rock	20	Pandua- 5 SR	Source Rock
7	Kalighat/ Hooghly 2	Source Rock	21	Bolpur Basinward	Source Rock
8	Kalighat/ Hooghly 3	Seal Rock	22	Pandua -2	Reservoir Rock
9	Jalangi-1	Reservoir Rock	23	Pandua-3	Overburden Rock
10	Jalangi-2	Source Rock	24	Pandua-4	Reservoir Rock
11	Jalangi-3	Source Rock	25	Pandua-6	Overburden Rock
12	Ghatal / Bolpur	Reservoir Rock	26	Pandua 1 BW	Seal Rock
13	Rajmahal Trap	Seal Rock	27	Pandua 2 BW	Reservoir Rock
14	Gondwana-1	Reservoir Rock	28	Pandua 5 SR BW	Source Rock

Table-1: Facies and assigned Petroleum System Elements

S.No.	Facies No.	Facies	Age	TOC (%)	HI	Kinetics
1	20	Pandua 5 SR	Mid to Late Miocene	1	100	Burnham(1989)-TIII
2	28	Pandua 5 SR BW	Mid to Late Miocene	1.5	120	Burnham(1989)-TIII
3	5	Burdwan-2	Oligocene	1	130	Burnham(1989)-TIII
4	7	Kalighat/ Hooghly- 2	Eocene	1.5	150	Burnham(1989)-TIII
5	10	Jalangi-2	Paleocene	2	160	Burnham(1989)-TIII
6	11	Jalangi-3	Paleocene	1	100	Burnham(1989)-TIII
7	21	Bolpur Basinward	L. Cretaceous	1	100	Burnham(1989)-TIII
8	15	Gondwana-2	E to L. Permian	20	120	Burnham(1989)-TIII
9	17	Gondwana-4	E to L. Permian	40	90	Burnham(1989)-TIII

Table-2: Source rock layers with source rock parameters used in this study:

Results and Discussion: The results from 2D-modeling show that both Gondwana source rock (G-4 and G-2) layers are presently in dry gas maturity to over mature (Figure-6). The G-4 layer has attained the critical time at 228 Ma and critical moment at 122 Ma whereas the G-2 has attained the critical time at 92 Ma and critical moment at 58 Ma. If faults are open then most of hydrocarbons expelled by Gondwana source rocks might have escaped during long unconformity of 228-145 Ma. After the deposition of Rajmahal trap between 145-112 Ma, it is more likely that if suitable traps are available**,** hydrocarbons might have accumulated in Gondwana reservoirs itself for which trap volcanics as seal resulting in conventional/ unconventional accumulations similar to coal bed methane.

The L. Cretaceous Bolpur basinwards source facies presently is in dry gas generation stage to over mature. The critical time and critical moment for this layer is 68 and 62 Ma respectively. The Paleocene Jalangi-3 source rock facies presently it is in dry gas generation maturity towards west and over mature towards east of Hinge zone with critical time and critical moment of 42 and 31 Ma respectively. The Jalangi-2 source rock facies is also in dry gas generation maturity towards west and over mature towards east of Hinge zone with critical time 41Ma and critical moment 28 Ma. The modeled Eocene Kalighat/Hoogly-2 source facies is in wet to dry gas generation maturity towards western side and dry gas generation to over mature towards east to Hinge zone. The critical time and critical moment for this layer is 32 and 28 Ma respectively. The modeled Oligocene source facies Burdwan-2 is presently is in main oil to wet gas maturity towards west and wet to dry gas generation maturity towards east with critical time 21 Ma in and critical moment 15 Ma in east. All the effective source rock facies show transformation ratio of more than 90% towards east of Hinge zone (Figure-7).

Mid to Late Miocene Pandua Source rock layer is in main oil to wet gas window towards basinwards, east of hinge zone. This layer has achieved maximum transformation ratio of 75% and modeled critical time and critical moment is 4 and 2 Ma respectively**.** Reservoir facies with suitable entrapment conditions within Mio-Pliocene section near the hinge zone area may be favorable for exploration.

Hydrocarbon generation and expulsion has taken place by Cretaceous and Tertiary source rocks towards basinal side (east of hinge zone). Arenaceous facies within these layers can act as reservoirs and argillaceous facies overlying sequence can act as seal. Any suitable trap in the vicinity of source rocks may be favorable for accumulation of hydrocarbons. Three hydrocarbon accumulations, all at the top of L. Cretaceous Bolpur formation, are envisaged. (Figure-8). The contribution mainly from basinward Cretaceous and Tertiary source rock facies is inferred suggesting relatively long distance migration from east of hinge zone towards basinal highs on western side. These accumulations may contain hydrocarbons provided suitable structure/entrapments exist. As per the modeled paleohistory reconstructions following three petroleum systems are speculated in study area: Gondwana (.) Petroleum system, Cretaceous (.) Petroleum system and Tertiary (.) Petroleum system. The formation fluids encountered in the Oligocene sequence of well IP-1 might be locally generated by Oligocene (Burdwan-2) source rocks and accumulated in overlying Burdwan-1 reservoir layer. Alternatively, this fluid may be sourced from more mature Paleocene source rocks (Jalangi-2,3) and reservoired in nearest Burdwan-1 reservoir layer.

Conclusion: Gondwana source rocks at the shelfal area are presently in dry gas generation maturity, if suitable traps are available, hydrocarbons might have accumulated in Gondwana reservoirs itself for which trap volcanics might have provided the seal resulting in conventional/ unconventional accumulations similar to coal bed methane. Effective source rocks in late Cretaceous Bolpur Formation, Paleocene Jalangi Formation, Eocene Kalighat-Hoogly Formation and Oligocene Burdwan Formation are presently in wet to dry gas to over mature stage and Mid to Late Miocene Pandua Source rock layer is in main oil to wet gas window towards basinwards, east of hinge zone where significant hydrocarbon generation and expulsion has taken place. Reservoir facies with suitable entrapment conditions within Mio-Pliocene section near the hinge zone area may be favorable for exploration.
Three modeled hydrocarbon accumulations at the top of L. Cretaceous are contributed mainly from basinward Cretaceous and Tertiary source rock facies suggesting relatively long distance migration. As per the modeled paleohistory reconstruction in the studied section following three petroleum systems are anticipated in study area: Gondwana (.) Petroleum system, Cretaceous (.) Petroleum system and Tertiary (.) Petroleum system. If suitable traps and seals are available then Gondwana and Cretaceous petroleum system may be operative in shelf area while Tertiary Petroleum system may be operative towards basinal part.

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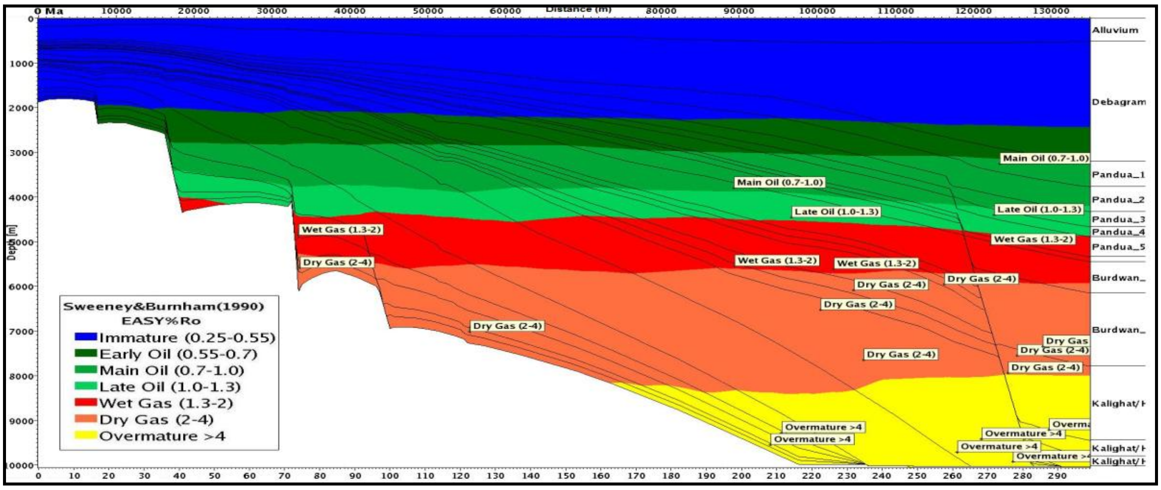

Figure-6: Modeled Maturity (% VRo) at 0 Ma (present day)

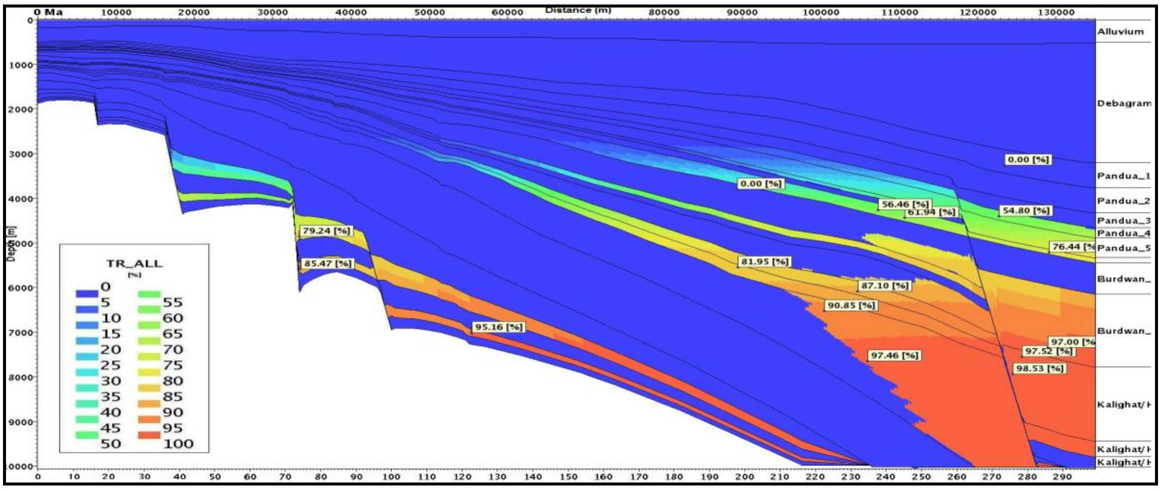

Figure-7: Modeled Transformation Ratio (%TR) at 0 Ma (present day)

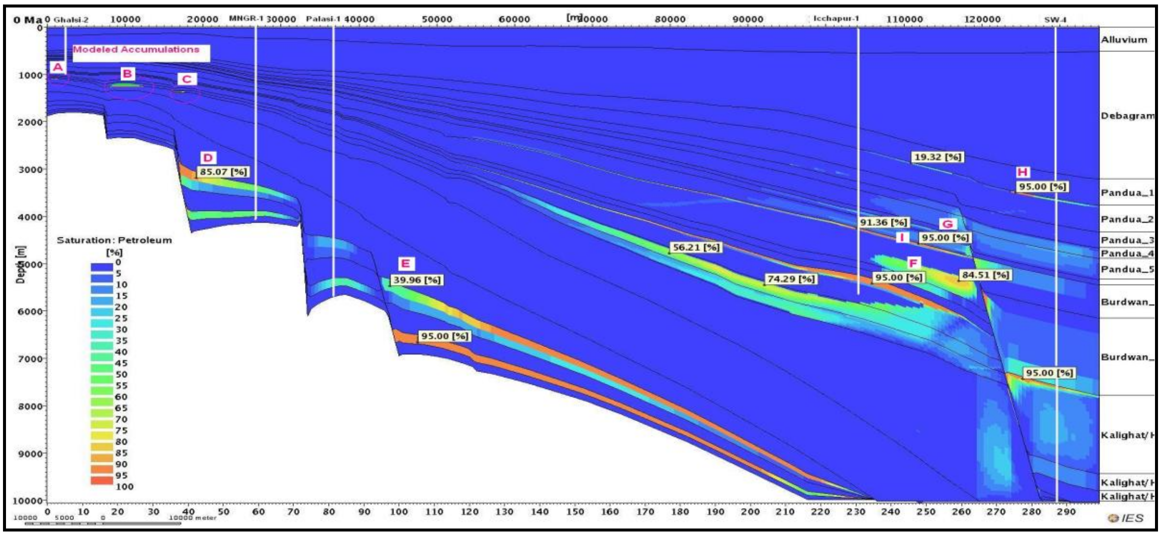

Figure-8: Three modeled hydrocarbon accumulations at the top of L. Cretaceous Bolpur formation with modeled hydrocarbon saturation.

A, B and C: Modeled Hydrocarbon Accumulation

Modeled hydrocarbon saturation- D and E: in Gondwana layers, F: in Paleocene Jalangi layer, G: in Oligocene Burdwan layer, H: Miocene Pandua, I: in Eocene Kalighat-Hoogly