Organofacies Characterization and Assessment of Timings & Extent of Hydrocarbon Generation of Source Rocks in Assam Shelf

Binita Mandal*, Neha Goel*, Sapna Sethi
*Suptdg. Chemist, Geochemistry Group,
Keshava Deva Malaviya Institute of Petroleum Exploration (KDMIPE), ONGC, Dehradun
Email: *mandal_binita @ongc.co.in*

Keywords: Organofacies characterization, early generating kinetics, liptinite macerals, petroleum system modeling

Abstract:

Upper Assam shelf is an important petroleum province with multiple reservoir rocks ranging from Upper Paleocene to Miocene. Most of the oil reservoirs are within Tipam sequences of Mio-Pliocene and Barail of Oligocene age. Prolific source rocks (SRs) occur within the Barail (Oligocene) & Kopili (Eocene). Established SRs in shelf area are immature to early mature while the oils have been generated at comparatively higher maturation stage. Hence, the present work has been taken up with an aim to characterize different source organofacies including custom kinetics and its variation within source sequences to evaluate timing and extent of hydrocarbon generation.

Barail sediments, one of the potential source rocks, show wide activation energy distribution, representing structural heterogeneity of kerogen that derived from mixed organic matter input (terrigenous and fresh water algal) as characterized by presence of biomarkers like Bisnorhopane, Oleanane, Oleanoid, unimodal distribution of tricyclic terpanes (TT), C29 >C27 & C28 regular steranes and absence of C30 24-n-propylcholestanes. Although early hydrocarbon generating kinetics (E_{max} 44-50kcal/mole and Frequency factor (A) e^{10-13} s^{-1}) have been determined in wells NRD-e, RD-b, RD-a, RD-c, RD-d, L-h, L-d, L-c, L-b and L-a, SN-b, G-e, G-d, G-b, D-b, K-a and MN-a for Barail SR. Presence of liptinite (2.7-17.9%), Resinite (3-4.6%), sporinites, suberinite, alginite, exsudatinite and bituminite embedded in vitrinite also indicate significant type II OM contribution.

Kinetics distribution for Kopili SR indicate mixed organic matter input (II+III). Well KH-a shows narrow Ea distribution, where E_{max} 50kcal/mole contributes >40% w.r.t. total Ea distribution. Similarly, early hydrocarbon generating kinetics are observed in wells L-d & e, G-c, NRD-e for Kopili SR, suggest the generation of early maturity oils.

Petroleum system modeling by applying custom kinetics in pseudo wells, demonstrates critical moment (50% kerogen transformation) at depth 7000m in Upper Assam North (UAN) and 4500m in Upper Assam South (UAS). However, the quality and organic richness of SRs in UAS is poor as compared to UAN. Early generating kinetics (E_{max}: 50kcal/mole, A: e^{13} s^{-1}), indicates that early oil window (VRo ~0.55%) commenced at the burial depth of ≥4km and attained significant kerogen transformation (upto 38%) of Kopili SR in Sonari low. It suggests that the source rocks encountered below 4km have contributed significantly towards hydrocarbon charging of adjacent structures viz. Lakwa, Geleki, Demulgaon, Kuargaon, Rudrasagar Sonari, Charali, Panidhing and Khoraghat with immature to low maturity oils (VRc <0.65 %).

Introduction:

Upper Assam shelf is an important petroleum province with multiple reservoir rocks ranging in age from Upper Paleocene to Miocene. Most of the oil reservoirs are within Tipam sequences of Mio-Pliocene age and Barail of Oligocene age. Oils of varying maturities have been established throughout the Assam shelf along with the presence of immature to low mature oils (VRc <0.65 %) in Rudrasagar, Demulgaon, Geleki, Lakwa, Sonari, Charali, Panidhing & Khoraghat areas. It is believed that prolific source rocks occur within the Barail (Oligocene) & Kopili Formation (Eocene), which are immature to early mature while the oils with comparatively higher maturity have also been reported. Hence, understanding of kerogen kinetics plays an important role to address the variation in oil maturity. The variation of kinetic parameters could be explained as a function of the molecular structure of kerogen (Tegelaar et al., 1994). The molecular structure of kerogen is related to types and mixture of biomacromolecules selectively preserved during diagenesis and provides the kinetic diversity as well as magnitude of kinetic parameters, resulting in a range of temperature for kerogen decomposition. The present work has been taken up with an aim to characterize different source organofacies using custom kinetics & biomarker study and to evaluate timing and extent of hydrocarbon generation towards hydrocarbon accumulations.

Geological settings:

The Assam and Assam-Arakan Basin evolved through several tectonic phases. During Early Cretaceous India started to drift towards the North and the Assam Shelf was being evolved in a passive margin tectonic setting with block faulting and a south easterly dipping shelf in the Assam province that lasted until Oligocene time. During Late Oligocene time uplift and erosion took place followed by the Miocene to recent extensive alluvial sedimentation in a foreland tectonic setting. The Oligocene unconformity marks the onset of the compressional tectonic regime in the Assam geologic province.

The Assam and Assam-Arakan Basin can be subdivided structurally into two parallel SW-NE trending features: the Assam Shelf and the Naga Schuppen zone (northwestern most part of the Assam-Akaran thrust belt). Presently the Assam Shelf is being subducted beneath the Eurasian plate to the north and the Burma plate to the southeast, while the overthrust belt (Naga Schuppen zone) is continually developing during shelf subduction. East-west trending wrench faults (Jorhat and Dauki Faults) subdivide the Assam Basin into three regions: the North Assam Shelf, the South Assam Shelf and the Surma Basin.

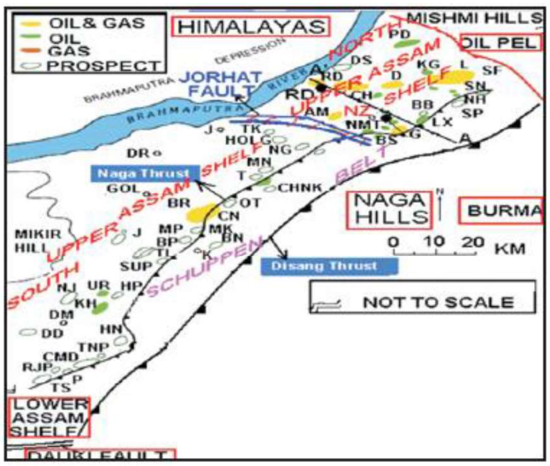

Figure 1: Location map of study area

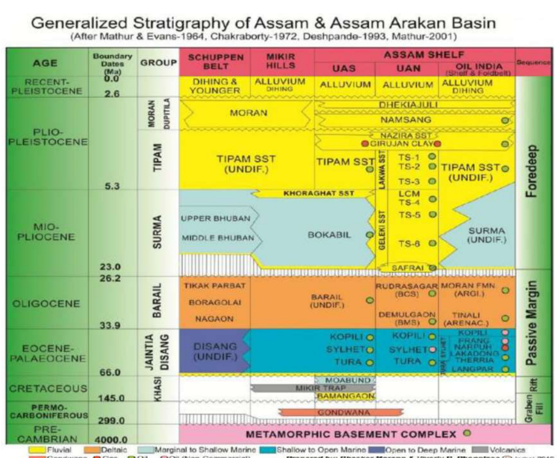

Figure 2: Generalized Stratigraphy of Assam shelf

Samples and Methodology:

Samples from 35 wells have been selected for the present study (Figure 1 & 2). Samples are further screened out based on their Rock Eval data for kinetic and molecular characterization study. The sediment samples were manually screened for any visible contaminants before subjecting to prolonged washing with hot distilled water and solvent extraction to remove traces of drilling fluid additives and migratory hydrocarbon. The samples were air dried at room temperature. The dried samples were ground to 60 mesh size and were homogenized before subjecting to any geochemical analysis.

Total organic carbon (TOC) content & Rock Eval analysis was performed with temperature programs 300°C for 3 min for thermal extraction of hydrocarbon present in sample then pyrolysed at 25°C /min to 650°C followed by oxidation at 300°C (for 1 min) heated at 20°C/min to 850°C (held for 5 min) in Rock Eval 6 (Turbo) instrument. Bulk kinetics parameters of the whole rock samples were obtained by non-isothermal open system pyrolysis at four different laboratory heating rates (2.0, 5.0, 10.0 and 20.0 °C/min) and some in quick kinetics module (at single heating rate of 25.0 °C/min) using Rock Eval 6 (Turbo). Results were exported to OPTKIN & GEOWORKS software for determination of kinetic parameters consisting of an activation energy distribution and a single frequency factor (A) through best fit optimization method. Leica 6000 DM microscope was used for measuring Vitrinite reflectance (VRo) and maceral studies.

Extractable Organic Matter (EOM) was recovered by Soxtherm Extraction of the sediment samples for 12-16 hours using Dichloromethane and Methanol mixture in the ratio 93:7 using Soxtherm. The EOM (~10 mg or more) components were separated by Column Chromatography on an activated alumina Silica dual column into Saturates, Aromatics and NSO's by elution with 75ml petroleum ether (40-60°C), 75 ml benzene and 75 ml methanol, respectively.

Saturate fraction of the EOM were analyzed for normal and isoprenoid alkane distribution on (PerkinElmer Clarus 680) using 30 m x 0.25 mm x 0.25 µm fused silica capillary column (DB-1) programmed as follows: 80°C (1 minute hold), increased @ 3°C/min upto 300°C and final hold time of 20 minutes and nitrogen as carrier gas.

Selective Ion Recording (SIR) for Hopanes (m/z 191) and Steranes (m/z 217) on GCMS (Shimadzu QP2020) using fused silica capillary column RTx-1MS (30m x 0.25mm x 0.25µm) and Helium as carrier gas. Initial oven temperature was kept at 80°C with 2 minutes hold time, increased @ 3°C/min up to 300°C with final hold time of 15 minutes. Steranes were further analyzed on Triple Quadrupole Mass Spectrometer (GC-MS/MS Shimadzu TQ8040) using fused silica capillary column RTx-1MS (30m x 0.25mm x 0.25µm) and helium as carrier gas and argon as collision gas. Initial oven temperature was kept at 80°C with 2 minutes hold time, increased @ 3°C/min up to 300°C with final hold time of 30 minutes.

Result and Discussion:

Samples for kinetics study have been selected based on the Rock Eval (RE) parameter having negligible S1 value, S2 >2.5mgHC/g rock, HI> 100mgHC/gTOC, TOC>1% and Tmax<435°C. To assess generation behavior of Barail source rocks kinetics study has been performed on a huge number of sediment samples (Table-1, Figure-3). Barail Formation in Safrai, Sonari, Demulgaon, Geleki, Kuargaon, Lakwa, Nazira, Rudrasagar fields in UAN and Khoraghat, Dayalpur, Rajaphe, Tenyiphe fields in UAS, are showing wide activation energy distribution ranging from 46 to 70 kcal/mole, that are interpreted as resulting from kerogen with a high diversity of bond types and structural configurations. Principal activation energies (E_{max}) for shale units of source rock are mostly in the range of 53-56 kcal/mole with a frequency factor of $e^{13 \text{ to } 14}$ s^{-1}, these clearly indicate predominance of type III organic matter input. Although kinetics of some coaly/ carbonaceous source facies are denoting significant contribution of type II organic matter (ΣEa 40-52 kcal/mol: 50- 65%).

SR no.	Well	Depth (m)	Formation/Age	Ea max (Kcal/mole)	Ea Range	Frequency factor (A, sec-1)	% Ea ≤ 48 cal/mole
1	D-b	3545	BARAIL_OLIGOCENE	48	44-66	4.86*E12	54
2	G-d	3595	BARAIL_COAL	48	44-66	5.47*E12	50
3	K-a	2635	BARAIL_COAL	48	42-66	4.92*E12	19
4	L-g	3940	BARAIL_OLIGOCENE	52	46-70	7.94*E13	2.16
5	L-h	3750	BARAIL_COAL	50	48-68	2.16*E13	2.3
6	L-d	3800	BARAIL_OLIGOCENE	46	40-60	1.1*E12	77.85
7	NRD-e	3065	BARAIL_OLIGOCENE	48	40-66	6.34*E12	55.6
8	NRD-e	3200	BARAIL_OLIGOCENE	46	42-62	9.77*E11	80.1
9	RD-b	3200	BARAIL_OLIGOCENE	46	38-56	4.97*E10	93.5
10	RD-c	3058	BARAIL_OLIGOCENE	46	40-60	5.08*E11	77.2
11	RD-d	3035	BARAIL_OLIGOCENE	44	38-56	4.03*E10	95.11
12	SN-b	4365	BARAIL_OLIGOCENE	48	46-64	3.78*E12	50.64
13	L-a	4255	KOPILI_LATE EOCENE	46	40-56	6.29*E11	90.33
14	L-h	4040	KOPILI_LATE EOCENE	48	44-66	4.67*E12	53.5
15	NRD-e	3445	KOPILI_LATE EOCENE	48	42-64	3.46*E12	57.2
16	RD-a	3015	BARAIL_OLIGOCENE	50	46-70	3.45*E13	24.79
17	L-f	3939	BARAIL_OLIGOCENE	60	52-82	2.206*E16	0
18	G-b	3880	BARAIL_COAL	50	44-68	1.60*E13	13.6
19	G-c	4150	BARAIL_OLIGOCENE	54	48-76	3.279*E14	1.9
20	L-b	3570	BARAIL_COAL	50	44-68	7.02*E13	16.4
21	L-c	3612	BARAIL_COAL	48	42-64	3.11*E12	42.9
22	MN-a	3320	BARAIL_OLIGOCENE	48	44-66	5.37*E12	59
23	SF-a	3815	BARAIL_OLIGOCENE	52	43-65	5.46E+13	2.2
24	SN-a	4140	BARAIL_OLIGOCENE	53	46-66	1.04E+14	1.2
25	D-a	3705	BARAIL_OLIGOCENE	52	45-59	6.9E+13	1
26	D-c	3320	BARAIL_OLIGOCENE	52	44-58	9.76E+13	2.8
27	G-a	3900	BARAIL_OLIGOCENE	55	45-68	4.24E+14	0.7
28	KG-a	3925	BARAIL_OLIGOCENE	54	43-59	9.78E+13	3.5
29	KG-b	3940	BARAIL_OLIGOCENE	54	44-60	7.27E+13	3.2
30	L-e	3370	BARAIL_OLIGOCENE	53	44-65	5.55E+13	3.4
31	NZ-a	4580	BARAIL_OLIGOCENE	52	44-66	8.19E+13	11.4
32	NZ-b	4150	KOPILI_LATE EOCENE	54	45-62	1.48E+14	2.7
33	SUP-a	2565	BARAIL_OLIGOCENE	53	43-63	5.64E+13	9.3
34	RJP-a	3060	BARAIL_OLIGOCENE	55	45-63	1.81E+14	1.8
35	TNP-a	3365	BARAIL_OLIGOCENE	53	43-61	6E+13	4.4
36	KH-a	2695	KOPILI_LATE EOCENE	51	42-55	2.38E+13	13.4
37	KH-a	2725	KOPILI_LATE EOCENE	51	43-58	3.5E+13	11.3
38	SUP-a	2665	KOPILI_LATE EOCENE	54	44-63	8.08E+13	10.5

Table 1: Kinetics parameters of studied sediment samples

Present study has also been focused on the identification of early generating Kinetics with maxima of activation energy (E_{max}) values 44-50 Kcal/mole. Early generating kinetics have been observed in Rudrasagar field with maxima of activation energy (Ea max) values 44-48 kcal/mole for Barail Formation in the wells NRD-a (3065-70m, 3200-05m), RD-b (3200-05m), RD-c (3058m), RD-a (3015-20m), RD-d (3035-40m). Hydrogen index (HI) transformation up to 95% at RD-d and ≥50% at RD-a, c, b, NRD-e has been observed in the lower Ea range 40-48kcal/mole. In the Lakwa field, early HC generating kinetics has been observed (E_{max} 46-50kcal/mole in wells L-h, d, c, b and a. BCS of SN-b also has been showing 50% HI transformation in very lower Ea range 40-48kcal/mole. Similarly in Geleki (G-e, d, b), D-b, K-a and MN-a, early generating kinetics have been observed which might contribute early hydrocarbon generation at lower thermal stress due to presence of sufficient labile source facies.

Kinetics distribution pattern for Kopili Source rock in Nazira, Dayalpur and Khoraghat fields indicate contribution of mixed organic matter input II+III as Σ Ea 40-52 (kcal/mol): 10-40% with E_{max} 53-54kcal/mole. Additionally narrow activation distribution is also observed for depth interval 2835-2845m in well KH-a with principal activation energy (E_{max}: 50-51 kcal/mol) contribution >40% w.r.t. total activation energy distribution. In UAN, well G-e, L-a, L-h and NRD-e also show early generating kinetics.

Maceral Composition study

Dominantly vitrinite is the main maceral component (78-96.5%), indicative of type III OM have been observed along with the presence of liptinite and its content varies 2.7-17.9% in BCS. Most of lipinite is in the form of resinite bodies. The entire groundmass in all the samples fluoresces indicating the presence of either submicroscopic resinite particles (colloresinite) and/or absorbed petroleum like molecules. 3-4.6% resinite has been observed in Barail Formation. Details of resinite content of different wells are described in Table-2, Figure-4. Along with resinite, pollen mass, sporinites, exsudatinite and bituminite embedded in vitrinite have also been visible in well D-b (3545-3550m), L-h (3750-55m), G-d (3595-3600m) and SN-b (4365-70m). In the well L-x (3804m, CC-4), D-b (3545-3550m) and RD-d (3035-3040m) early hydrocarbon generating maceral suberinite have been observed in Barail Coal shale. Suberinite is the preserved suberin layer of the cell walls in the typical cork tissues of tertiary brown coals which can generate HC at 0.4% VRo. Alginite, the signature maceral in type I kerogen, is also identified in barail sediments of wells D-b (3545-3550m) and K-a (263

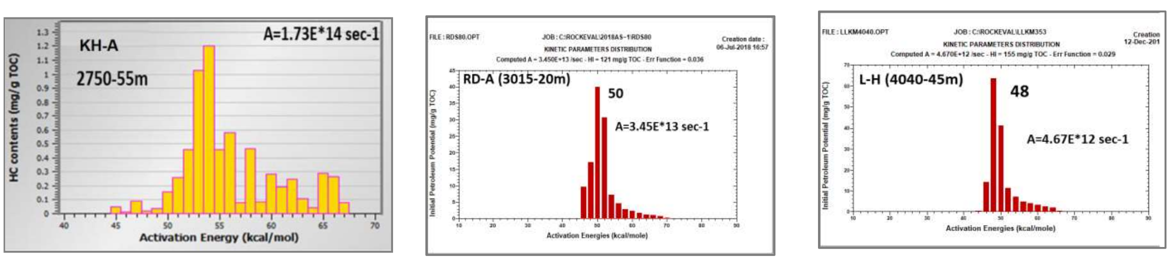

Figure 3: Kinetic distribution for Barail and Kopili source rocks

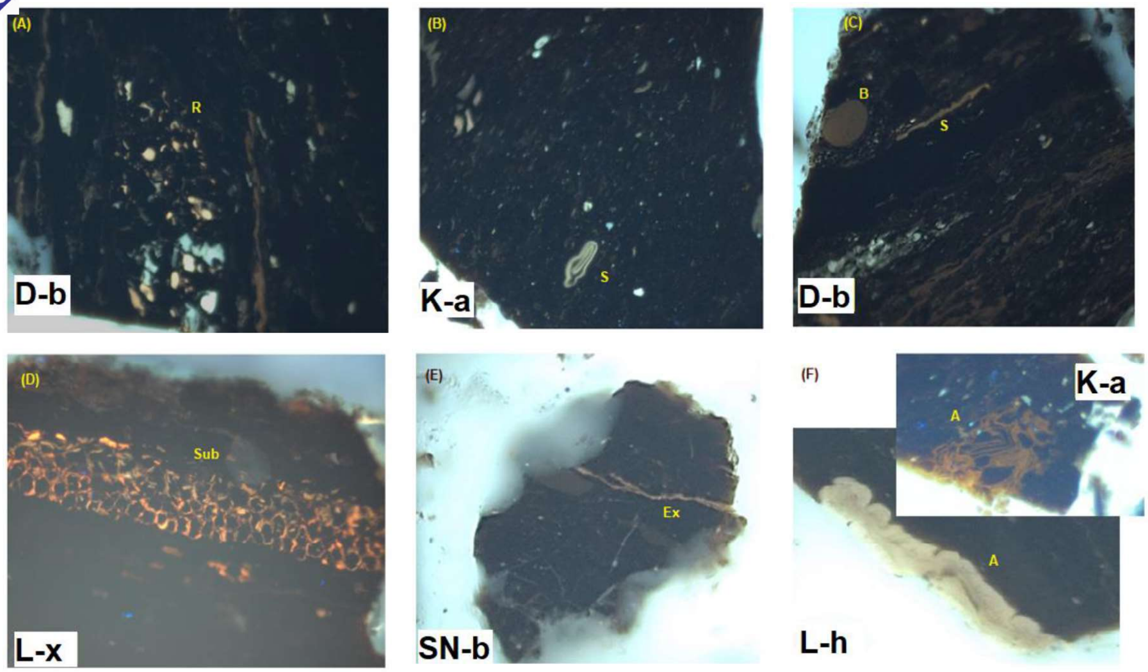

Figure 4: Liptinite macerals under Fluroscence mode: (A) Resinite , (B) Sporinite, (C) bituminite, (D) Suberinite, (E) Exsudatinite, (F) Alginite

Well Name	Sample Depth	Mineral free maceral composition			
		Vitrinite %	Liptinite %	Resinite %	Inertinite %
RD-d	3035	96	2.7		1.4
RD-f	3092	90.2	9.7		0.1
RD-g	3073	88.2	11.7		0.2
NRD-e	3050	96.5	2.4		1.2
D-b	3545	91.5	4.8*	3.2	0.5
G-e	3745	86.2	12.1		1.7
G-d	3595	91.2	5.8*	3	
SN-c	3950	89.5	9.2		1.3
SN-b	4365	88.3	7.8*	4	
L-x	3804	78	11		11
L-f	3939	87.1	8.6		4.3
L-h	4040	96.5	2.4*	1.2	
L-h	3750	91.3	5.8*	3	
L-y	3530	90.4	7.9		1.7
L-z	3795	94.1	3.28		2.62
K-a	2625	82.3	13.3*	4.6	

*Percentage of Liptinite excluding Resinite

Table 2: Maceral Composition of selected sediment samples

GC and GCMS studies

Based on the Rock-Eval data and kinetics study, samples from Demulgaon, Geleki, Kalyanpur, Sonari, Lakwa, Kuargaon, Nazira of UAN and Khoraghat, Dayalpur, Tenyiphe fields of UAS corresponding to Barail, Kopili were selected for detailed geochemical and molecular level studies. Bulk, GC and GCMS based molecular data of source rock extracts are shown in Table 3, Figure 5 & 6.

For the Barail Source rock, bimodal aliphatic distribution with significant presence of n-alkanes in C18 –C24 range suggests generation from algal precursors while the presence of significant quantity of higher alkanes suggests terrestrial input to the organic matter. High Pr/Ph ratio indicates oxic environment and high Pr/nC17 ratio indicates terrestrial organic matter deposited in peat swampy environment.

The m/z 191 mass fragmentograms also show the presence of Bisnorhopane, 18α-30-norneohopane (C29Ts), 17α-Diahopane (C30*), Oleanane, Oleanoid. In addition to pentacyclic triterpanes, unimodal distribution of tricyclic terpanes (TT) and tetracyclic terpanes (TeT) were also observed. Sterane mass chromatograms (m/z 217) are characterized by dominance of C29 regular steranes over their C27 and C28 homologues and absence of C30 24-n- propylcholestanes.

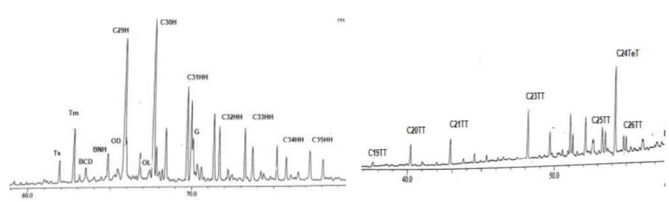

Figure 5: GCMS chromatograms of well KH-a of Barail SR

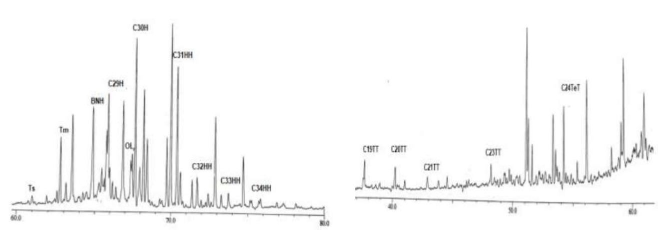

Figure 6: GCMS chromatograms of well NZ-a of Kopili SR

All these biomarkers reveal that it is a shaly source rock deposited in sub oxic conditions in near shore/ coastal/ deltaic environment having contribution from both terrestrial and fresh water algal matter. However, excellent preservation condition prevails in Khoraghat area (well KH-a & KH-b) for lower Barail formation as indicated by presence of well-preserved Homomhopanes C31-C35, Gammacerane, Bisnorhopane and significant presence of C25 & C26 tricyclic terpanes. These shaly source rocks deposited in anoxic condition in marginal marine to shallow marine environment having contribution from both mixed algal and terrestrial OM matter.

Sample Details	Pr/ Ph	Pr/ nC17	C19TT/ C23TT	Ts/ (Ts+Tm)	C29H/ C30H	Oleanoid /C30H	BNH/ C30H	C35S/ C34S	C30 Diah /C30H	ΣC31-C35/ C30H	%C27 st	%C28 st	%C29 st	C29 Sterane aaS/(S+R)	C29 Sterane ββ/(αα+ ββ)
D-a, 3805-10M(Barail)	3.10	1.04	1.42	0.03	0.71	0.08	0.33	0.37	0.08	2.16	9.70	16.96	73.33	0.21	0.34
D-a, 3455-60M(Barail)	3.43	0.71		0.06	0.19	0.00	0.21	0.63	0.09	2.09	14.78	18.32	66.89	0.21	0.46
G-a, 4080-95M(Barail)	2.44	0.50	0.39	0.12	0.59	0.16	0.45	0.00	0.22	1.53	17.35	18.29	64.36	0.23	0.39
KG-a, 3900-05 (Barail)	4.51	2.74	1.32	0.05	0.74	0.00	0.18	0.56	0.07	2.16	11.44	18.79	69.78	0.18	0.41
L-e, 3780M(Barail)	4.28	1.39	0.46	0.07	0.56	0.00	0.52	0.63	0.13	1.70	8.94	15.89	75.17	0.14	0.34
NZ-a, 4755-65M(Barail)	4.92	6.13	0.48	0.09	2.05	0.54	1.30	0.61	0.24	3.53	13.64	18.07	68.28	0.28	0.33
SN-a, 3905-10 (Barail)	6.26	5.25	3.36	0.00	0.83	0.00	0.00	0.38	0.06	2.40	7.12	20.48	72.40	0.12	0.36
SN-a, 4010-15(Barail)	8.06	9.73	4.81	0.00	1.04	0.00	0.20	0.44	0.10	3.13	6.15	17.46	76.39	0.17	0.32
SN-a, 4130-35 (Barail)	4.94	7.93	0.58	0.07	0.77	0.12	0.25	0.64	0.08	1.49	11.14	22.34	66.53	0.29	0.34
SN-b, 3900-20(Barail)	5.71	3.33		0.00	0.94	0.00	0.13	0.43	0.09	2.91	7.96	20.52	71.52	0.14	0.37
SN-b, 4080-90 (Barail)	7.89	8.13		0.00	1.02	0.00	0.35	0.52	0.00	2.85	13.01	27.15	59.85	0.37	0.47
SN-b, 4360-65(Barail)	6.45	7.13	1.26	0.08	0.88	0.14	0.24	0.54	0.09	1.67	11.83	18.29	69.88	0.37	0.32
SN-b, 4470-80 (Barail)	4.47	7.68	0.90	0.07	0.88	0.11	0.25	0.59	0.08	1.63	9.54	16.99	73.46	0.34	0.30
SUP-a,2560-70M(Barail)	3.93	1.92	0.19	0.12	4.11	0.00	0.40		0.00	2.15	12.23	16.17	71.59	0.11	0.41
KH-b, 2580-95 (Barail)	3.14	2.18	0.63	0.33	0.64	0.00	0.79	0.95	0.06	2.19	8.25	49.79	41.96	0.22	0.37
TNP-a, 3365-70M(Barail)	5.60	6.47	0.77	0.09	0.66	0.32	1.14	0.71	0.15	1.60	12.79	17.01	70.20	0.17	0.37
KH-a,2730-40M(Barail)	2.09	1.51	0.11	0.32	0.87	0.07	0.17	0.85	0.00	2.97	12.71	31.77	55.51	0.24	0.34
KH-a, 2750-90M(Barail)	2.24	1.11	0.21	0.23	0.76	0.07	0.22	0.93	0.00	1.81	9.43	30.11	60.46	0.21	0.34
KH-a, 2835-45M(Kopili)	3.27	3.15	0.21	0.09	0.58	0.21	0.61	0.85	0.08	1.28	14.75	23.34	61.91	0.15	0.36
NZ-b, 4135-4150M(Kopili)	3.69	4.81	1.27	0.12	0.36	0.14	0.55	0.81	0.07	2.15	12.50	20.50	67.00	0.18	0.33
SUP-a, 2700-2710M(Kopili)	3.63	2.11	0.33	0.00	2.05	0.00	0.76		0.00	1.63	12.36	16.35	71.29	0.14	0.38

Table 3: GC & GCMS-based geochemical data of the EOM of selected whole rock sediments

Kopili Formation also shows similar organofacies characterization in GC and GCMS, indicating mixed (terrestrial and fresh water algal) source input.

Petroleum system modeling

A 2D-Petroleum system modeling (PSM) study along a seismic sections (approx. 37.5km) has been undertaken to model paleo-history reconstruction and to access hydrocarbon generation and migration from the source rocks and also validate the possibility of early mature oil accumulations in Assam Shelf. This 2D section passes through drilled wells MH-a, KG-a, L-r, L-s, L-t, L-u and SL-a (profile -1, Figure 7). Geological age of deposition, lateral variation of facies and relevant lithologies across the section (Figure-8) was assigned based on the drilled wells data and seismo-geological interpretations. TOC_o and HI_o along with custom kinetics have been assigned for Barail and Kopili source rocks as per Rock-Eval data. The properties of the faults were defined in the model by carrying out sequential restoration of the profiles through Structural Modelling, from basement level to present day. A good calibration of BHT and modeled temperatures was observed by setting the present day heat flow to $38mW/m^2$ and VRo values for calibrating temperature and thermal history. The sediment-water interface temperatures (SWIT) are assigned based on Wygrala (1989) Auto SWIT in Petromod (Version 16.2) from M/s Schlumberger. Applied kinetics and their corresponding transformation ratio are shown in Table 4. This infers that early oil maturity window falls below 4000m approximately, while main oil maturity window is below 4800m in Sonari-Safrai low (Figure-9). Maximum transformation of kerogen is observed for the Kopili source (Late Eocene) sequences in Charaideo and Sonari area (~ 38% TR, Figure-10).

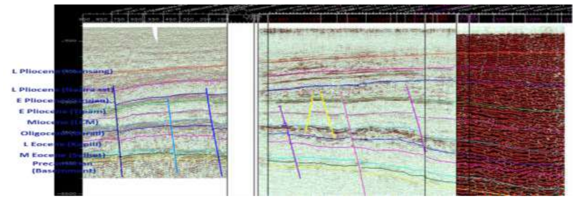

Figure 7: Seismic sections with the interpreted horizons and faults

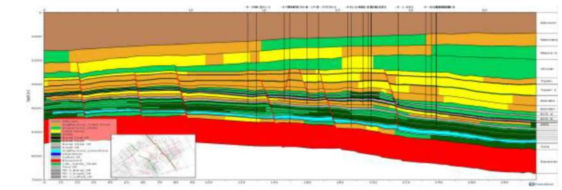

Figure 8: Lateral Facies variation through Profile-1

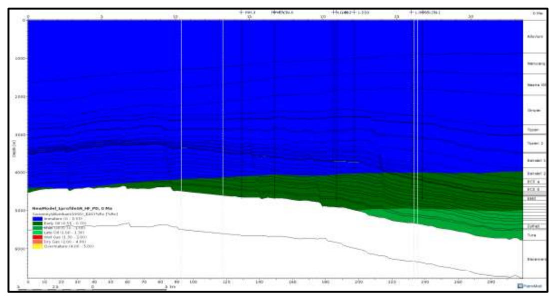

Figure 9: Maturity overlay of the source rocks

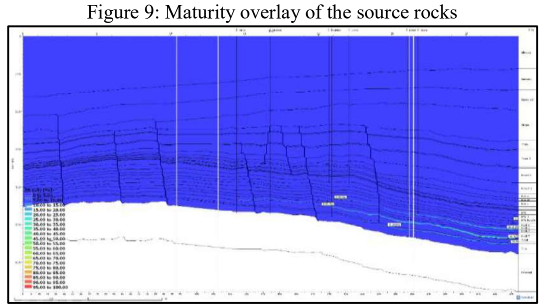

Figure 10: Transformation Ratio of the source rocks

Kinetics Applied	Transformation Ratio
L-H (Ea max: 50Kcal/mole, Ea range 48-68 Kcal/mole) for Oligocene SR	Barail SR: 0 to 5% TR
L-H (Ea max: 50Kcal/mole, Ea range 44-66 Kcal/mole) for Late Eocene SR	Kopili SR: 0 to 38% TR

Table 4: Applied kinetics and their corresponding transformation ratio of respective source rocks.

1D modeling of different well locations indicates that source rocks present in the shelf area do not exhibit adequate kerogen transformations (upto 4.22% at 4250m in UAN & 4.83% at 2700m in UAS) to generate any significant volumes of hydrocarbon. Applying the kinetics generated for organic matter in pseudo wells, it has been observed that source rocks need to be buried deeper than

7000m in UAN and 4500m in UAS to attain critical moment (TR~50%). 50% Kerogen transformation observed at much shallower depth in UAS as compared to UAN is due to high heat flow in UAS. However, the quality and organic richness of source rocks in UAS is poor as compared to UAN.

Conclusion

Kinetic study of Barail source rock shows wide activation distribution indicating heterogeneity in kerogen structure. Coaly/ carbonaceous source facies have significant contribution of Type II (saprophelic) organic matter (ΣEa 40-52 kcal/mol: 50-65%). Additionally, early generating kinetics with E_{max} 44-50 kcal/mol have also been observed in wells NRD-e, RD-b, RD-a, RD-c, RD-d, L-h, L-d, L-c, L-b and L-a, SN-b, G-e, G-d, G-b, D-b, K-a and MN-a, which has capability to generate hydrocarbon at lower thermal stress due to presence of sufficient labile source facies. Organic petrography of Barail source also suggests the significant presence of liptinite (2.7-17.9%), Resinite (3-4.6%), sporinites, exsudatinite and bituminite embedded in vitrinite. Early hydrocarbon generating maceral suberinite have been observed in well L-x, D-b, R-d and Alginite in well D-b, K-a. Biomarker study reveals that Barail source rock deposited in sub oxic conditions in near shore/ coastal/ deltaic environment having contribution from both terrestrial and fresh water algal matter.

Kopili Formation also exhibits similar organofacies characterization in Kinetics and biomarker study, indicating mixed (terrestrial and fresh water algal) source input.

Petroleum system modeling demonstrates critical moment (50% kerogen transformation) at depth 7000m in UAN and 4500m in UAS in pseudo wells. However, the quality and organic richness of SRs in UAS is poor as compared to UAN. Similarly, early generating kinetics (E_{max}: 50kcal/mole, A: e^{13} s^{-1}), indicates that early oil window (VRo ~0.55%) commenced at the burial depth of ≥4km and attained 26-38% kerogen transformation in Kopili SRs in Sonari lows.

The study suggests that the source rocks encountered below 4km have contributed significantly towards hydrocarbon charging of adjacent structures viz. Lakwa, Geleki, Demulgaon, Kuargaon, Rudrasagar Sonari, Charali, Panidhing and Khoraghat with immature to low maturity oils (VRc <0.65 %).

References

Pahari, S. et al., 2018, Organofacies Characterization of Early Generating Source Rocks in Eocene /Oligocene Sediments of East Coast Basins Including A&AA Basin; Unpublished report.

Stout, S. A., 1996, Resin- Derived hydrocarbons in fresh and fossil dammar resins and Miocene rocks and oils in Mahakam delta, Indonesia; ACS Symposium Series, 617, 43–75.

Abdullah et al., 1997, Evidence of early generation of liquid hydrocarbon from suberinite as visible under microscope; Organic geochemistry, 27, 591-596.

Prasad, IVSV. et al., 2009, Fluorescence studies of maceral of Tertiary and pre tertiary coals of upper Assam and Jharia-Raniganj Field; Unpublished report.

Banerjee, A. et al., 2002, Petroleum Geochemistry of Upper Assam; Unpublished report.

Peters, K. E.; Walters, C. C., Moldowan, J. M., 2007, The Biomarker Guide Volume 2 Biomarkers and Isotopes in Petroleum Exploration and Earth History.

Phaye, D. K. et al., 2016, 3-D Petroleum system modeling of Assam Shelf; Unpublished report.

Anand, R. et al., 2020, Petroleum Geochemistry of Assam Shelf; Unpublished report.

Tegelaar E. W. and Noble R. A., 1994, Kinetics of Hydrocarbon generation as a function of molecular structure of kerogen as revealed by PYGC; Organic geochemistry; 22, 543-557.

Acknowledgements

The authors express their deep gratitude to ONGC management for providing the opportunity to present this paper and to Shri Nandan Verma, GGM-HoI KDMIPE and Ms. Kusumlata Pangtey, CGM-Head Geochemistry for their constant encouragement and guidance. A sincere thanks to Shri S. Pahari (Ex-ONGCian), BRG group, Biomarker lab, technical assistants of Source rock lab of Geochemistry division for their help and support.

The views expressed are solely those of authors and not necessarily of the organization where they are working.