A Holistic Approach to Characterize the Reservoir, flow units and to deduce the Paleo Depositional Environment using Electro-logs: A case study of Gas pays of Sundulbari syncline of Tripura Fold belt

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Keyword

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Abstract

Initial exploration of hydrocarbons is limited to Anticlinal/High structures. But recent discoveries in the synclinal structures proved to be prospective hydrocarbon plays through strati-structural traps. In Tripura fold belt, Sundulbari structure lies in the northern plunge of Tichna anticline and is low structure. Relict pays have been identified through RMS attributes which are corroborated with elctrolog facies have been tested and yield enormous gas pools (1,60,000 m3/d gas) in Upper Bhuban formation of Miocene epoch, this accelerated the exploration activities. However, limited lateral extent, up dip pinch outs, and fault closures are throwing more uncertainty for its exploration. In view of the above complex reservoir configuration, exploitation of these gas plays is a challenging task, which needs an effective strategy for optimum completion & exploitation of this field. The objective of the present study is to understand the reservoirs in fold-belt Sundulbari syncline structures wholly for better exploration. Through this study it is concluded that, in relict gas pays, three major port (pore throat) systems/flow units are developed viz Megaport, Macroport & Mesoport. By comprehensive analysis of natural GR logs and XRD results, it is concluded that in the Upper Bhuban formation, matrix main frame work is quartz with occasional presence of feldspar and kaolinite & Chlorite are the main clay minerals. Integrated Structural and stratigraphic analysis of Resistivity image logs have yielded information about the paleo depositional environment that, it could be tidal bar/channel of tide dominated deltaic system. And also, could map the thrust/reverse faults on log scale along with many structural events. As a holistic approach, this study throws light on complete reservoir characterization and provides a strategy for future exploration and exploitation.

Introduction:

The Tripura-Cachar fold belt represents the frontal fold-belt of Assam and Assam Arakan (A & AA) Basin along the convergent Indo-Burmese plate margin. This area constitutes the Surma Sub-Basin of the A & AA basin. The Surma Group of sediments is further divided into Bhubans and Bokabil. The Bhuban is further subdivided into three litho-units viz. Lower, Middle and Upper Bhuban depending upon the relative abundance of coarser and finer clastics. Proven gas producing reservoirs are established mainly within the arenaceous facies of Bhuban formations.

Sundulbari is the northern plunge of Tichna anticline with comparatively gentle eastern flank. Sundulbari area is surrounded by major gas producing fields of west Tripura viz. Agartala Dome gas field to its north, Tichna gas field in the south and Manikyanagar-Sonamura Gas field to its west and Baramura Gas field to its east, shown in **FIG-1.**

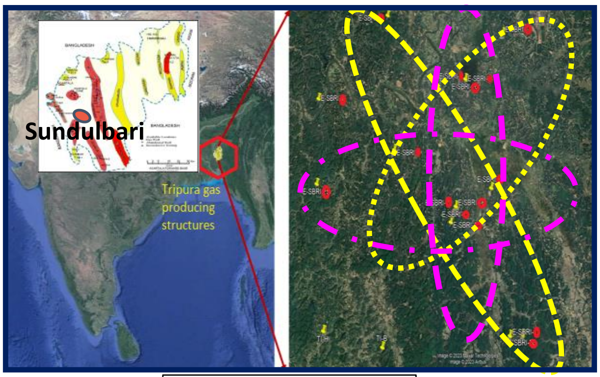

Fig1: Present study Area

Fault closures and up dip pitchouts in the limbs of anticline in the adjacent synclines are the anticipated main trapping mechanisms in this structure. Thin sand sections within thick shales in the formations with small culminations could also have trapped hydrocarbons.

So far, no discovery has been made from Bokabil & Lower Bhuban sequences in Sundulbari area. The structure gained its importance after the discovery of gas in well SD#XX from Upper Bhuban Formation and established pay sands UB_A and UB_B. The well SD#L was drilled on the eastern flank of the structure, in a separate fault block and it produced commercial gas from UB_W from a relict feature within Upper Bhuban Formation at shallow depths which opened flank exploration in all the structures of Tripura.

The objective of the present study is to characterize reservoir & to identify the potential flow units using pore throat radius cross-plots, identification of clay mineralogy and to identify the paleo-depositional environment using electro-conventional & image & acoustic logs which are corroborated with core data for better exploitation of Gas plays of Upper Bhuban formation (UBF) in Sundulbari syncline.

Methodology

In the present study, 14 wells of Sundulbari are considered and identified them as SD # A, B, C, D, E, F, G, H, I, J, K, L, M and N. In three wells SD#A, SD#H and SD#K conventional cores from Upper Bhuban formations are available and hence core-driven porosity and permeability are evaluated using RCA (Routine Core Analysis). In one well SD#K, NMR log is available. In recent two exploratory wells SD#M & SD#N, Resistivity image logs are available for Upper Bhuban section. In Sundulbari structure, 8 pays identified till now namely UB_W, UB_X, UB_Y, UB_Z, UB_A, UB-B, UB_C and UB_D pay sands. Among them UB_W and UB_Y are highly gas prolific sandstone reservoirs with mild intercalation of fine-grained siltstone. Core driven poro-perm parameters are available only for UB_Y pays. Study is carried out for UB_Y gas pays which belongs to Upper Bhuban formation (UBF) of Miocene epoch. For identification of strati-structural events UB_W & UB_Y of relict pays and UB_A and UB_B pay sands of Upper Bhuban section drilled in two wells SD#M & SD#N are considered. Four correlation profiles are carried out using 14 wells with the available logs, in N-S, E-W, NE-SW and NW-SE directions and among them consistent sand thickness is observed in South East/West direction in wells SD# F, SD#G, SD#J and SD# K (shown in **FIG-2**). These wells are considered for permeability evaluation after calibrating the Elemental Log Analysis parameters with core driven permeability values. SD#H and SD# K wells are considered to derive the clay mineralogy in corroboration with core data.

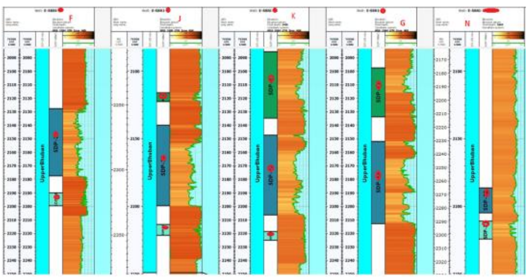

FIG-2: Log correlation

The UB_Y sands are mainly developed with coarsening upward sequence for gas bearing sands at the top and after GWC the down sands are developed with cylindrical shape or fining upward sequence occasionally. The average sand thickness of the UB_Y sand is 40-50 m and net pay sand thickness is around 10-12 m, which is shown in **FIG-2.**

Identification of Clay Mineralogy

Natural GR spectroscopy log can yield individual elements Uranium, Thorium, Potassium curves. Using these curves, cross-plots have been plotted to analyze the clays and find Kaolinite, Chlorite as the main clay minerals along with Feldspar in matrix, Biotite is also observed in one core-plug in UBF. The clay minerals are also well-matched with the XRD analysis of core-plugs in wells SD# H and SD#K. In well SD#K, the points have been shifted towards right side because of KCL-PHPA mud used in borehole, however the higher values of thorium still giving inferences of Kaolinite band in K vs TH plots. Similarly, TH/K vs Pe plots also gave the inferences of chlorite in well SD# H along with Biotite which also marked in XRD of core plug. (FIG-3).

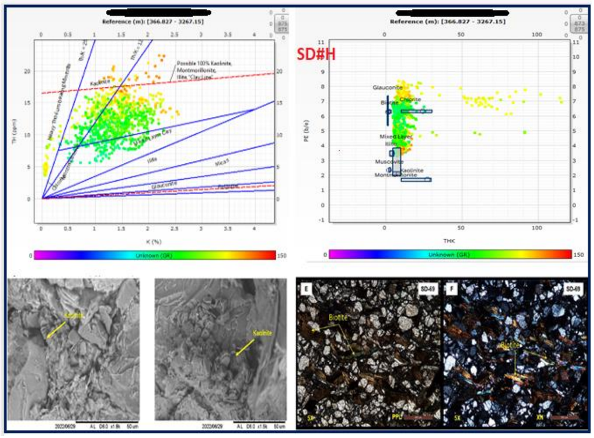

FIG-3: Identification of clay mineralogy-cross plots

Rock Characterization & Identification of Flow-units (FU)

Porosity is a parameter which determines the storage capacity and Permeability is an intrinsic property which controls the flow capacity. Porosity (poro) and Permeability (perm) play crucial role in identifying movable hydrocarbon and can be used to prevent early water cuts. Higher the pore throat radius, higher will be the inter-granular porosity & connectivity between pores there by greater will be ease of water to flow due to its high mobility. In this study for relict gas pays of UBF Core driven poro-perm parameters are taken into consideration and have been utilized to calibrate well logs and these calibrated results are propagated into wells, where conventional cores are not available to evaluate continuous Permeability. Poro-perm cross-plots have been plotted to identify the R35 pore throat radius using Winland plot to identify the flow units contributing to gas production and to find variances in the pore-throat radii of gas bearing sands, water producing clean sands and silty-sands.

In this study, an attempt is made to classify the rocks using R35 pore-throat radius and permeability is evaluated using Core-Calibrated Log elemental analysis in Techlog software and has showcased a strategic approach to optimize the intervals with optimum pore throat radius for completion of wells to produce water free gas.

Winland gave an empirical relationship between Porosity, Permeability and Pore throat radius at point of 35% mercury saturation in capillary pressure measurement. The equation is given by

$$\textbf{Log R35} = 0.732 + 0.588\,(\text{Log } K_{air}) - 0.864\,(\text{Log } \Phi)$$

R35: Pore throat radius at 35% mercury saturation

K_{air} : Air Permeability

Φ : Porosity in percentage

The above equation is valid in inter-granular, inter-particle and inter-crystalline porosity systems such as Sandstones where pore and pore throat geometry are closely related to rock texture. There is good coherence between porosity and permeability with pore throat radius with Core-driven values when they plotted using Winland equation. Based on the pore throat radius, three types of rock facies identified are, Mega-pore sands (clean), Macro-pore sands (silty) and Meso-pore sands (shaly) and these are shown in Fig-4.

In well SD#K, core derived poro-perm values are available for UB_Y pay along with NMR log, the conventional logs are processed and calibrated the elemental log analysis parameters for estimation of Permeability using Geochemical Algorithm available in Quantitative ELAN module of Techlog software, which was originally developed by Herron (Herron et.al SPWLA 1987).

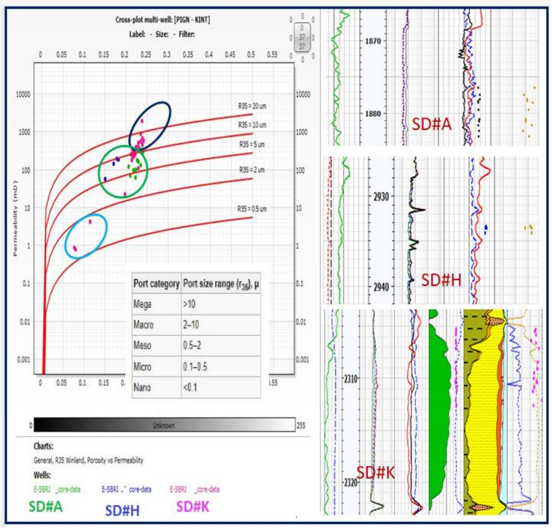

FIG-4: Winland plot with core derived poro-perm

ELAN derived porosity and permeability values are corroborated with core-derived values. NMR log derived permeability is under-estimated against the gas bearing sands shown in **FIG-5**, and in water bearing sands it is in coherence with the ELAN derived permeability Based on this algorithm permeability factors of silt and clay minerals are calibrated. The same values are propagated to other wells SD #F, SD #G and SD #J and evaluated Continuous Porosity & Permeability.

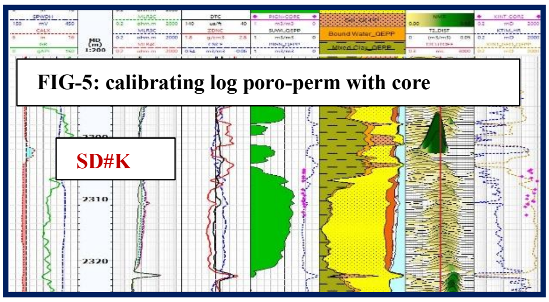

FIG-5: calibrating log poro-perm with core

The evaluated continuous permeability curve and Porosity curve are plotted on Winland cross-plot for other three wells SD#F, SD#G and SD#J for UB_Y pay sand (Shown in FIG-6). The results are very encouraging, 3 types of rock facies are identified with different R35 pore throat radii which are varying in the ranges of =>10 µm (Mega port), 2-5 µm (Macro port) and 2-0.5 µm (Meso port) which are corresponding to sandstone, silty sandstone and shaly silty sandstone facies respectively. As far as completions are concerned, UB_Y pay sand is tested in four wells, produced remarkable gas @ 2, 15, 487 m^3/d, @ 1,74, 378 m^3/d, @ 95, 725 m^3/d and @ 1,54,052 m^3/d from UB_Y pay sand from wells SD# F, SD# G, SD# J and SD# K respectively through 10 mm bean, from Mega port and Macro port flow units.

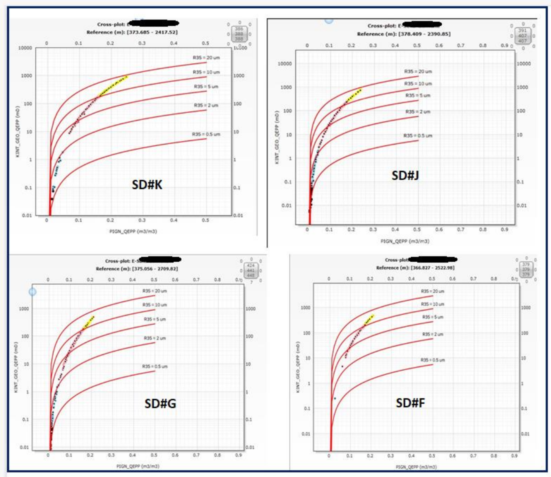

FIG-6: Winland plot with Log derived poro-perm in wells SD# K, J, G & F

A comparison table with core and log derived poro-perm values and R35 i.e pore throat radius is presented in **Table-1(core in UB_Y sand)** as annexure below references. It is found that, point to point depth wise accurate matching is not achieved, however same R-35 ranges are professed by both Core and Log results confirming Mega pore throat for clean gas bearing sand.

Deducing Paleo Depositional Environment

Tripura fold belt is resultant of compressional tectonics which are very active even today. Initial Paleontology and Palynology studies revealed that UBF is deposited under tide dominated deltaic systems. In the present study two wells SD# M and SD# N are considered to deduce the Paleo depositional environments of the gas pays of Sundulbari, in which Resistivity Micro imaging logs are available. The structural dip of thick shales deposited in UBF is found to be 5° in SW direction. So structural dip removal process is not carried out while analyzing structural or stratigraphic events.

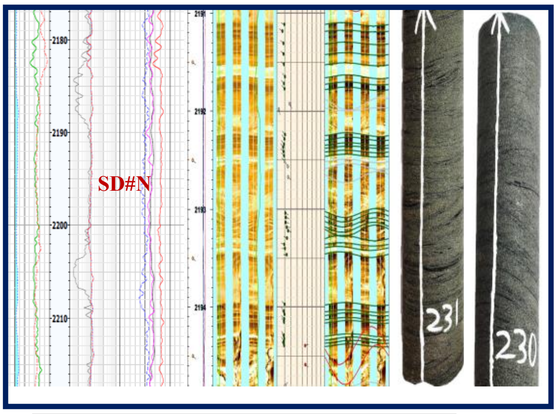

FIG-7: bi-flow cross-beddings in UBF

In UB-Y sand Herringbone cross-stratification is observed against the interval 2192-2194m and convolute bedding is observed at 2194-95m.The bi-flow cross-beddings in NW and SE confirms the tide dominance in UB_Y sand. (FIG-7)

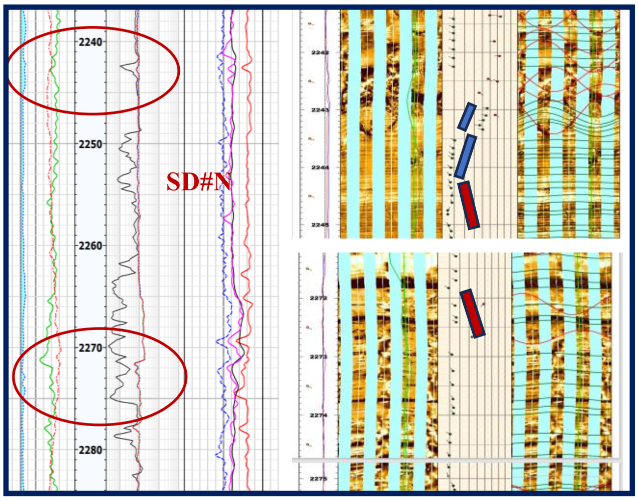

FIG-8: blue patterns conveying flow direction in NW for UB_Y

In UB-Y pay, silty sand with remarkable shaliness has been developed with alternated coarsening upward and serrated GR log signatures. Against the depth 2243-44m blue dips (in NW direction) are marked followed by one low dip red pattern (in NW direction), which represents the slope is in NW direction too. This confirms the tidal bar sand deposition. (FIG-8)

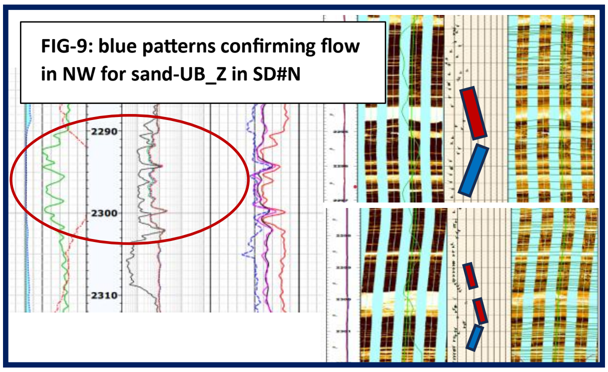

FIG-9: blue patterns confirming flow in NW for sand-UB_Z in SD#N

Similar tidal bar sand deposition is observed for UB_Z sand, which is shown in **FIG-9**. In the interval 2294-2296m the red pattern in NW direction is observed followed by blue pattern with in NW direction, the red pattern shows that the slope is in NW direction, blue dip is yielding paleo-flow direction, along with these inferences from image logs, coarsening upward GR is confirming the tidal bar environment. This pattern in repeatedly can also be observed in the interval 2299-2301m.This is shown in FIG-9.

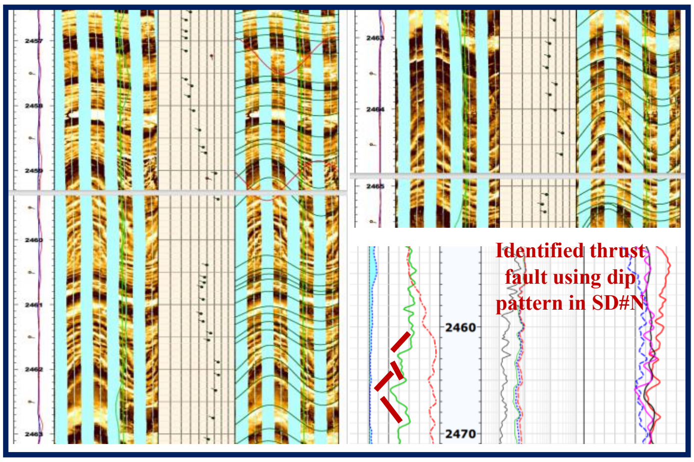

FIG-10: showing thrust fault in well SD#N

The paleo-flow direction is ascertained from sand body orientation of tidal bars and it is in NW direction for UB-Y Sand. SD# N well is placed in Western direction and whose image analysis gave inference of paleo-current flow in NW, then better reservoir facies are supposed to be deposited in SE direction. This is proved in wells drilled in SE direction w.r.t. SD#N, in wells SD# F, SD# G, SD# J and SD#K, which are potential gas wells with prospective gas pays. One log scale level micro thrust fault is observed in UB_A sand in well SD#N (FIG -10), which is identified using dips pattern and repeated log sections. Reverse/Thrust faults are common structural events in fold belt basins formed by compressional tectonic movements and such reverse faults can be mapped by imaging tool, which cannot be resolved by seismic interpreted sections.

Many more structural events are observed, like network of fractures on image logs, which are also calibrated with horizontal anisotropy on shear wave anisotropy analysis, conductive fractures and these are calibrated with Stoneley reflectivity analysis which can show only open fractures through reflectivity analysis. Similarly, the fracture orientation is also confirmed by azimuthal anisotropy analysis. Predominant fracture direction is NE-SW and at occasional depths it is observed to be in NNW-SSE due to fault closures. Sand Injection intervals also identified on Image logs.

Recommendations and Conclusions

- The gas pays of Upper Bhuban formation are studied to characterize the Reservoir and found clay mineralogy as Kaolinite-Chlorite rich clays with occasional presence of K-Feldspar in Quartz matrix.
- Upper Bhuban Relict gas pays are studied to identify the flow units and based on the core-data and continuous log data corroborated with core-data in non-cored wells, it is concluded that three Flow units with different pore throat radius are observed. They are Megaport (>10 µm), Macroport (2-10 µm) and Mesoport (0.5-2 µm). In four wells combination of Mega and Macro port flow units of relict pay SDP-Y has been tested and yielded 1,50,000-2,00,000 m3/d gas in each well along with mild water due to opening of Megaport. In future wells, critical analysis needs to be carried out diligently while completion of the well to perforate Macroport that to have sustainable liquid free gas production.
- Resistivity imaging tools are geological event mapping tools that help to identify the strati-structural events, and to deduce the environments including paleo flows. In this meticulous study, it is deciphered that, that sands developed in UBF are deposited in tidal bar sand environment in tide dominated deltaic regime. The paleo flow is ascertained as NW direction dominantly with minor azimuthal variances.
- Structural events fractures, network of fractures, conductive fractures, log scale micro reverse faults are mapped. Sand injection is observed in highly agitated multiple fractured zones. By knowing the fracture orientation, better planning of stabilized/healthy well can be done which can reduce the NPT during Drilling and Logging.

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"Views expressed in this paper are solely of authors, does not necessarily reflect the views of ONGC".

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Annexure: Table-I- Comparison Table of Core & Log derived Poro-perm & R35 values for UB_Y sand in well SD#K

Core-plug No	Depth(m)	KINT-core (mD)	PIGN-core(%)	R35-Core (µm)	KINT-Log (mD)	PIGN-Log(%)	R35-Log (µm)
X-1	2305.26	386.97	22.37	12.23	24.92	9.4	5.16
X-2	2305.46	296.94	22.09	10.58	21.66	9.1	4.88
X-3	2305.79	413.28	22.94	12.44	16.54	8.5	4.42
X-4	2306.35	111.18	22.97	5.74	93.67	13.72	8.10
X-5	2306.59	402.94	22.74	12.35	141.59	15.41	9.34
X-6	2307.11	872.77	23.52	18.89	443.75	20.93	14.04
X-7	2308.44	668.67	23.94	15.91	367.85	19.82	13.18
X-8	2309.08	584.36	24.16	14.58	587.71	22.38	15.63
X-9	2309.45	249.9	21.25	9.89	592.78	22.39	15.70
X-10	2309.98	224.36	21.84	9.06	613.66	22.7	15.84
X-11	2310.3	477.82	23.92	13.07	481.21	21.4	14.45
X-12	2310.4	556.72	23.51	14.51	393.58	20.35	13.41
X-13	2310.82	256.51	22.13	9.69	204.82	17.62	10.34
X-14	2311.24	177.13	21.38	8.03	472.79	21.23	14.40
X-15	2311.85	514.31	22.98	14.13	627.82	22.76	16.02
X-16	2312.1	1699.94	23.83	27.65	630.59	22.78	16.04
X-17	2312.6	210.21	21.58	8.81	645.36	22.93	16.17