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A Simplistic Channel/Facies Based Model for Hydrocarbon Accumulation Environment in an Upper Assam Field, Through Integrated Geological Modelling, Seismic and Petrophysical Approach

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Summary

Inconsistent hydrocarbon distribution trends within small oil fields are commonly sought to be explained by small scale sealing faults, often resulting in a network of faults in a small area. Generally these faults are not apparent on the seismic section and interpreted differently by different interpreters. A similar trend has been witnessed in a small but highly prospective Miocene oil field in Upper Assam, where different interpreters have interpreted various faults to explain the mounting tally of dry wells falling within the prospective area.

The present work is an attempt to offer an alternate and simple geologically consistent model derived from the same input data but interpreted differently.

This field has producing reservoir sands in Tipam sands TS-IV and TS-V of Miocene age and is developed in two separate blocks- of well#1 and well#9- located to SW and NE of a major NNE-SSW trending fault. The TS-VA reservoir in the former block poses the biggest challenge for evolving a satisfactory oil entrapment model and hence has been exclusively considered in the present study. The TS-VA surface while gently sloping to north also forms a gentle antiform, in the most prospective area (about 2.5 km2), where the earlier oil wells were located. A few wells of this block have a gross pay thickness of up to 60m while other nearby wells are having a thin oil column or are dry- which goes against the prevalent model envisaging a uniform oil column with OWC at -2570m. The prevalent view of structural traps as the main hydrocarbon entrapping mechanism does not seem likely as no significant structural closure or sealing fault has been mapped in the prospective area that can justify the oil columns. Furthermore, the faults are more likely to be non-sealing being formed in an extension regime. Another grey area in this block has been log evaluation (estimation of nature of fluid and determination of OWC) as the resistivity of both oil and water fall in same range The development program of this field in block of well#1 has been put on hold pending a suitable geological model.

The present study proposes a channel/levee sands based hydrocarbon entrapment system to explain the narrow linear trends formed by producing/ non-producing wells and the variable pay thickness of oil bearing wells.

The pattern and thickness of oil columns and lateral facies variation indicate that the traps are stratigraphic and role of structure/faults is secondary. A prominent 10-15m thick clay section at TS-VA top appears to have acted as a regional seal. Ineffective sealing of the Tipam sands or its breaching by faults/fractures resulted in dryness of a number of wells, structurally positioned within the established oil limits.

The model is supplemented with leads provided by bottom hole reservoir pressure studies, mineralogical studies and pattern of anomalies (geobodies) interpreted from seismic attributes study (RMS amplitude and Spectral decomposition time slices).The phenomenon of low resistivity oil is attributed to certain clay minerals of smectite group in the matrix, which are prevalent with in the Tipam sands, particularly in the upper oil bearing TS-VA section.

The present study recommends a channel pay sand delineation based approach for effective exploitation of the field. This study can also be applied for delineating prospective geobodies in analogous deposition environments.

Keywords*: Upper Assam Miocene oil field, Channel based simplistic model*

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Introduction

The field under study, located in Upper Assam, has significant hydrocarbon accumulations in Tipam sands of Miocene age, deposited in a fluvial environment. Structurally, the field is developed in two separate blocks – block of well #1 located in the south western part of the field and block of well #9 in the north eastern part (Fig.1). The two blocks are separated by a major NNE-SSW trending fault hading to SSE with a throw of upto 250m(Fig.1&5).The Tipam section is further subdivided from TS-VI at the base to TSI at the top. The oil bearing TS-IV and TS-V are further subdivided into 2-3 sublayers considering their separation by prominent argillaceous interbeds. The TS-IV is overlain by the LCM (Lower clay marker) which is a pervasive flooding surface comprising 5-20m of argillaceous sediments with sandy lenses.

The remarkable feature of this field is pattern of hydrocarbon accumulation. In the block of well #1, hydrocarbons are confined to TS-VA while in the block of well #9, oil gas occurs in most of the sub layers of TSV and TS-IV. The present study has been restricted to the block of well #1 where the pattern of hydrocarbon entrapment, thickness of oil column or even the presence/absence of hydrocarbons in adjacent wells is still not satisfactorily explained. After the initial success of wells #1 & #14- with gross pay up to 60 m thick- a 2.5 km2 a prospective area around these wells was identified and a development plan comprising both development wells and water injectors was firmed up. However, a number of development wells have gone dry in the area, despite structurally conforming to the level of oil bearing zones of wells #1, 14 & 15. Often the wells are dry within 200m of the producing oil wells. Another problem has been the estimation of oil zones from well logs as there is not much to distinguish in the resistivity of the oil and water zones. This feature is highly pronounced in sub layer TS-VA of the block of well #1.

The present study attempts to improve the understanding of the field through a basic depositional model approach. The phenomenon of low resistivity oil, that matches water resistivity, has also been addressed by inputs from petro physical analysis and mineralogical analysis of core data.

The study has presently been restricted to the block of well #1 owing to its complex nature but the concept is also applicable to the other block of well #9 where a similar deposition regime existed and also has some dry wells within the prospective area.

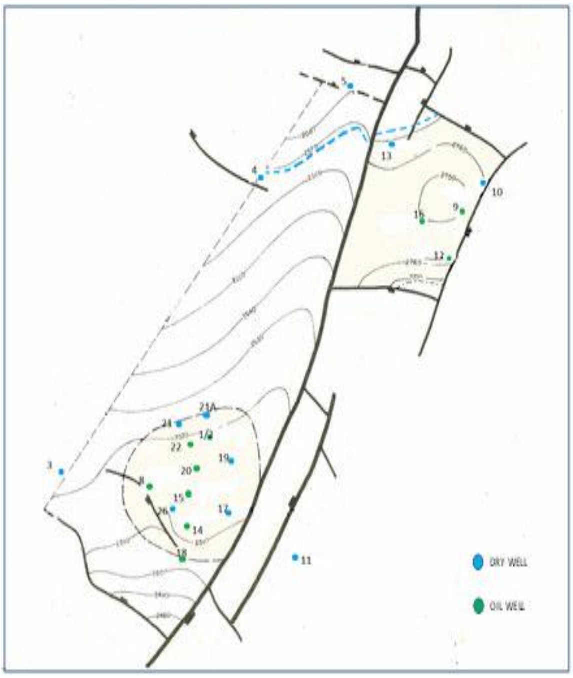

Fig 1. Structure Map of the field at TS-VA level with well locations (Map not to scale, North towards Top)

Pattern of Hydrocarbon distribution in block of well #1

Structurally, the TS-VA surface of this block shows a gradual slope from SSW to NNE with a nosing trend. The TSVA surface forms a gentle antiformal flexure in the estimated oil bearing area with reserves under Proved Category. Oil was established in this block through wells #1, 14&15. From the interpreted TSVA top at -2514m, oil column was estimated down to a depth of -2569m through a combination of well testing log evaluation and core/cuttings data (Fig1, 2&3). Subsequently a development plan for TS-VA was implemented and a number of wells to the north, east and south of these wells were drilled. However most of these wells located towards the periphery of the proved area turned out to be dry. In some of the wells there were only oil shows (#17, #19) or feeble oil flow only in its uppermost part (#8, #18) while certain others were dry such as #21,#21A,#25 & #26. The inconsistent oil distribution pattern within a small area of the estimated oil zone is well documented by the two well log correlation profiles drawn along and across the structural trend (Fig.3&4) and also shows the lithofacies variation between nearby wells. These results disproved the assumption of a uniform OWC and reservoir continuity forcing a rethink on the geological model and log evaluation techniques. However the oil accumulation model is still a matter of much debate and further development plan for the field has been put on hold.

Sedimentological model/Deposition environment of Tipam sands

It is well established that the Tipams have been deposited in a fluvial environment. The sand layers are extensive with silty/clay interbeds indicatingdeposition under a fluctuating environment .The broadly coarsening up log pattern observed in TS-VA section eg. wells #14, 17&18 is indicative of the anastomosing nature of the fluvial channels. Under this system there is a stable channel pattern that bifurcates and anastomoses into a series of multiple channels with small values of sinuosity (Klein, G.D, 1982). The individual channel sands range in thickness from 5-15m (Smith, D.G, 1983). It is also further observed that broadly the individual sands as well as the intervening clays/shale are maintaining pack thickness and are laterally correlatable with a well ordered three dimensional arrangement of associated facies (Fig2&3). These features indicate that the channel/levee system was stable during the deposition of TS-VA. These channels are confined and stabilized primarily by fine grained silt and clay of older levee / flood plain deposits. During late stage of TS-VA, the fluvial energy diminished resulting in progressively more deposition of finer sediments. The end of TS-VA was marked by a pervasive flooding environment resulting in deposition of a 5-10m clay section that prevented further upward migration of hydrocarbons.

Vertical sequence/ Log motifs of Anastomosing Channels

As anastomosing channels do not migrate, very little sorting is anticipated and no clear cut vertical trend in grain size exists. However, in a series of vertically stacked anastomosing streams, a coarsening upwards trend reflecting good discharge and sediment yield is expected. There is also preservation of adjoining channel facies such as levees, crevasse splays and vegetated, peaty interchannel areas. Such features are commonly observed in this field in the lower Tipam section. The log motifs are trendless to coarsening upwards and the sands are fine to coarse grained, subangular with poor sorting with a fair sprinkling of clay fragments. Clayey /silty interbeds corresponding to levee, splays and occasional coaly interbeds are also seen. The log patterns of some wells can be seen in Fig2&3.

Input from Petrophysical studies

The inputs from petrophysical studies primarily aim to establish a link between low resistivity of oil bearing sands to the clay content in the matrix and grains. Additionally, mineral and petrophysical data of conventional cores in TS-VA of wells #1&#14 was considered as follows.

Mineralogical Analysis

The mineral studies indicate that quartz is the dominant mineral followed by albite, muscovite. The clay minerals are mainly of smectite group. The sand porosity has been reduced due to the presence of smectite clay coating, pore filling and pore bridging. The irreducible water has been estimated around 50% in some of the TSVA core samples of wells #1& #14 by laboratory studies.

Determination of hydrocarbon saturation

Determination of hydrocarbon saturation of various zones, particularly TS-VA, based on standard log reprocessing techniques has been mostly unreliable due to low resistivity and dirty nature of sands as discussed earlier. Zones interpreted as hydrocarbon bearing have often been tested to be water bearing. This complexity is compounded by the variable the highly variable thickness of oil column in nearby wells estimated by repeated testing and workover jobs.

However, hydrocarbon indications such as GYF, observed in well cuttings has been found to be very reliable and along with core and well testing data has been used to estimate the thickness of oil column in various wells considered in the sections (Fig2&3).

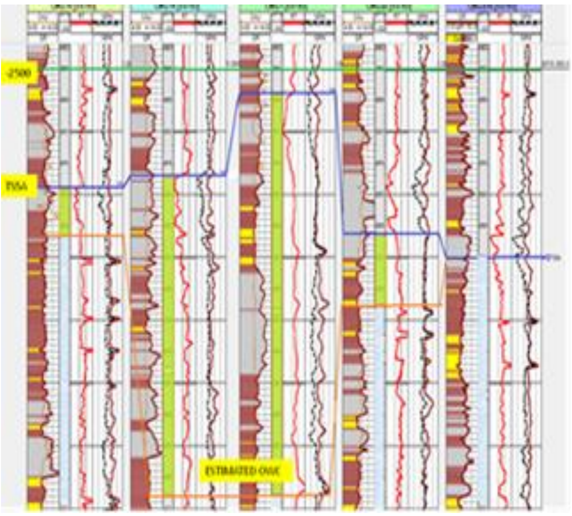

Fig.2 S-N Log section between Wells #18-21A showing variable oil column (Likely to be independent channels)

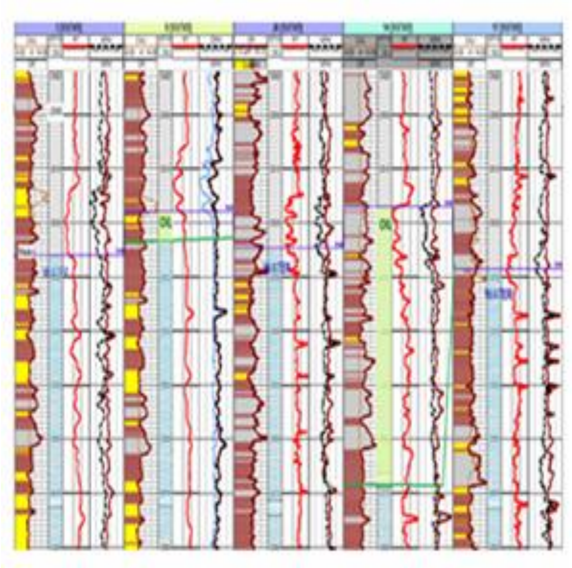

Fig.3 W-E Log Section between Wells #3-17 showing variable oil column (Likely to be independent channels)

Input from reservoir studies

The pressure performance history of various wells in the block gives lead on different pressure regimes that may be linked to discrete channels. As per Fig.4 showing normalized bottom hole pressures of different wells, independent reservoir bodies are indicated for wells #14,15 and wells #1,20,#22. Another discrete channel is inferred comprising linearly aligned wells dry wells #17, #19 having similarity in bottom hole pressures. Absence of oil in these wells may be due to leaking of charge though minor faults/fractures as feeble oil/ gas shows were observed during initial testing. Well #8 appears to be located in a separate channel with poor facies as indicated by its poor build up pressures and intermittent oil production from only its top 4m of TS-VA pay. The intermittent production may be due to the lateral charge leakage from the adjoining main hydrocarbon producing channel of wells #1 &#14 where pay thickness is estimated upto 40m thick. Separate channels/reservoir discontinuity in the upper part of TS-VA are also indicated for wells #21 & #26 which are dry and having different bottom hole pressures. Oil shows during their initial testing may be remnant of the escaped charge due to reservoir breaching.

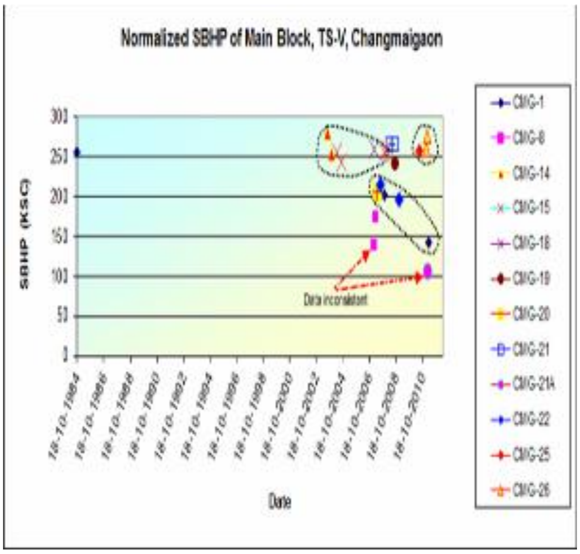

Fig.4 Clusters indicating different pressure regime

Aggradational channels which are partly in communication are indicated by well performances of nearby wells #14 & #18. Well #14 is an oil producer while #18, located 300m to its SW and with a slight structural advantage at TS-VA level, has a very shallow oil column (approx. 10m as compared to 50 m oil column proved in well #14. This phenomenon may be due to two separate aggradation channels with only partial reservoir communication in the the uppermost oil bearing section (likely due to clay facies). However, the broadly same reservoir pressures indicate reservoir communication in the lower acquifer part.

The huge variation in oil column thickness or its absence in certain wells can be explained by applying the concepts of numerous stacked aggradational channels that may be sealed, partly sealed or breached at the level of TS-VA top. A prominent 10-15m thick clay section at TS-VA top appears to have acted as a selective seal due to its breaching by tectonic disturbances at many locations.

Input from 3-D seismic studies

Various seismic attributes were derived from the 3-D seismic data (PSTM) of the area such as structure cube, RMS amplitude and Spectral decomposition slices at various frequencies. Fig 6 shows the pattern of artefacts and lineaments at 2168ms (near TS-VA top) and the sinuous features may be related to channels and the linear strong trends to the faults/fracture traces. The RMS amplitude slice near Tipam TS-VA top (Fig.7) and the spectral decomposition slice near TS-VA top at 28 Hz (Fig.8) shows some linear and sinuous, high amplitude features- geobodies that may be interpreted as sandy facies, likely to be channel/levy features with reservoir potential under proper sealing conditions. As no clear cut channel features could be seen in cross sections (Fig2), it can be inferred that the individual channel are not of sufficient depth to be resolved.

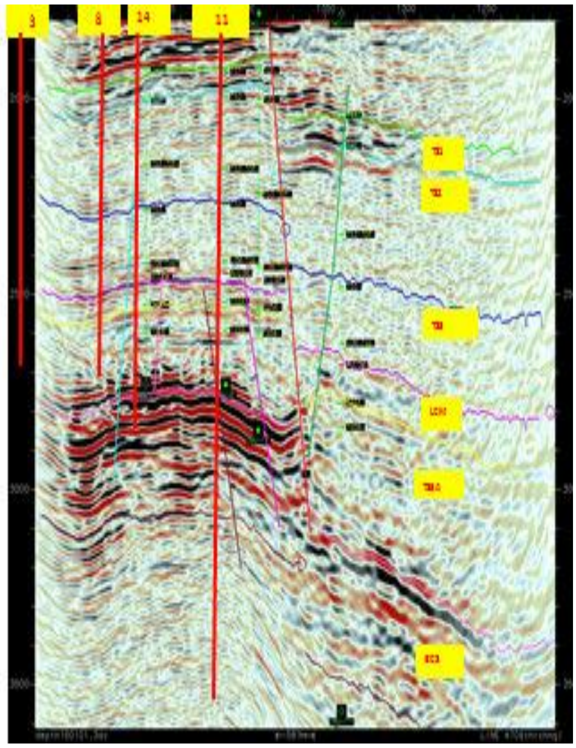

Fig.5 Seismic section across the structure showing major fault and correlated horizons.

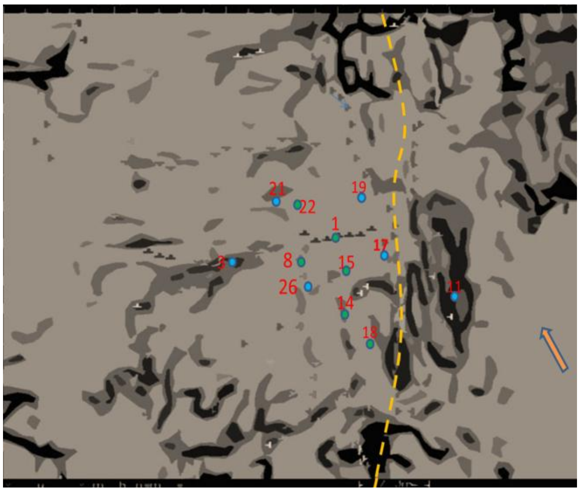

Fig.6 Structure cube near TS-VA top indicating channel/ lineament artefacts.

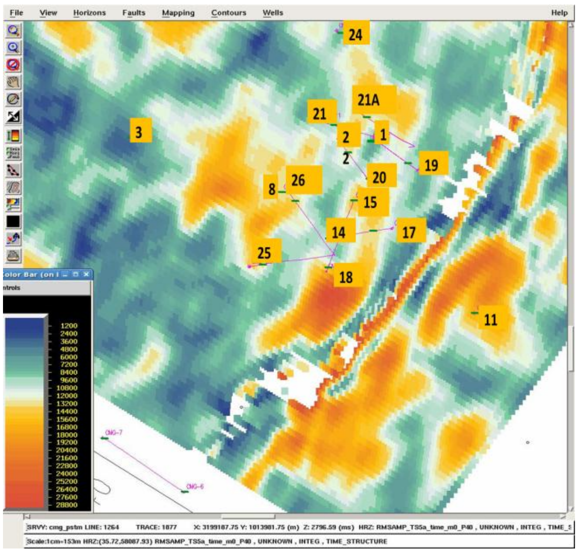

Fig.7 RMS amplitude for TS-VA in the window 0-40 ms showing independent geobodies.

Main Observations/ Findings of the Study

1. The lower Tipam sands were deposited in anastomosing channel/levy system as inferred from its channel geometry, type of sediments and its standard deposition environment.

2. The TS-VA sediments are more argillaceous towards the top due to cyclical decrease in fluvial energy and interference/erosional inputs from adjoining levees and flood plains.

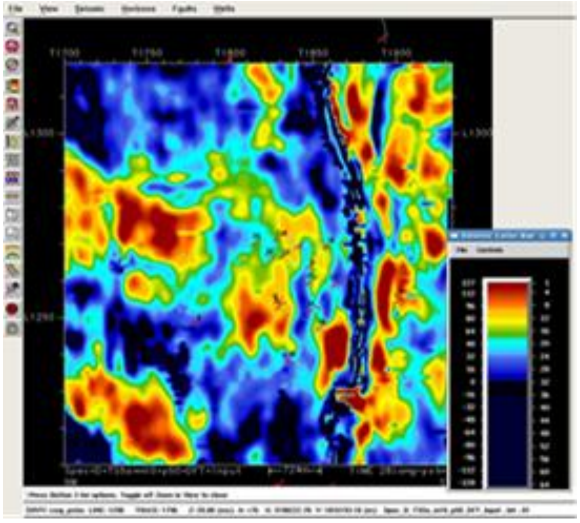

Fig.8 Spec-D near TS-VA top in the window -10ms to +50 ms at 28 Hrtz.,with Scale colorbar (inset)

3. A number of minor sealing faults have been interpreted by different workers to explain the pattern of oil accumulation. However, most of them are not conclusive and may not have any impact on hydrocarbon entrapment. Rather they may have leaked the charged reservoirs as they are normal faults formed under an extension phase of deformation. An evidence to this is inferred by the testing results of well #11 located in the downthrown block, east of the block of well#1.The TS-VA section shows Rt upto 10ohm/m/m interpreted as oil bearing on well logs, but flowed only water. Its TS-VI sand flowed a little oil followed by water. Being located near the major fault, the charge is likely to have fully leaked.
4. The top of TS-VA section is characterized by a persistent 5-10m thick clay layer that has acted as a strong seal for localization of upward migrating hydrocarbons within this section. There is no oil accumulation above TSVA in Block of well #1, apart from some minor deposits in TS-2 in few wells due to later fractures.
5. TS-VA sand porosity has been reduced due to the presence of smectite clay coating, pore filling and pore bridging. The higher clay content has lowered the oil saturation and resistivity of oil bearing sands which is often indistinguishable from the water bearing layers
6. A prominent 10-15m thick clay section at TS-VA top appears to have acted as a regional seal. Selective charging of the channel/levee sands has given a narrow and elongated hydrocarbon distribution pattern to the field. Charging has been dependent on the availability of conduit for charging, further lateral/vertical communication between channels and the quality of encasing argillaceous sediments.
7. The pattern and thickness of oil columns and lateral facies variation indicate that the traps are stratigraphic and role of structure is secondary. Ineffective sealing of the Tipam sands due to less thickness of the seal or its breaching by faults/fractures resulted in dry nature of a number of wells, structurally positioned within the established oil limits.
8. Hydrocarbon charging in selective channels is likely due to deep seated faults. It may be noted that oil accumulation is present in both the blocks of the field in the vicinity of the major NNE-SSW fault. This fault, along with its splays is the likely conduit for charging of channel sands.
9. Bottom hole reservoir pressure studies also indicate some well clusters of different pressure regimes implying closely spaced, linear independent bodies.
10. Independent linear to sinuous geobodies have been brought out by seismic attribute studies and may be related to multiple channel/levy complexes.

Conclusions

The existing reservoir, petrophysical and 3-D seismic data of the field under consideration have been relooked to suggest an alternate, logical hydrocarbon accumulation model for this field. Existing views on hydrocarbon entrapping mechanism are inclined towards a sealing fault system which appears to be inadequate as discussed earlier. Based on the present study, a sedimentary structure based entrapping mechanism formed under an anastomosing channel regime appears more likely.

It is suggested that further exploratory/development efforts in this field should be aligned along the identified unexplored trends that are present to the north of main oil bearing channel of wells 1,15 & 14 and to the south east of well 18.Another prospective area with structural advantage is indicated south west of well 8.

The geological concepts proposed in the model can be also applied to similar situations in other fields.

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