Integrated Reservoir Characterisation study from core to Seismic for reservoirs of Sylhet Formation in Upper Assam Shelf South, A&AA Basin, India

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Summary
Reservoir characterization plays a fundamental role in the exploration and development of hydrocarbon field. In the present study, detailed geological and seismic studies have been carried out to understand the reservoir from core to seismic and from qualitative to quantitative and helped in reducing uncertainties. The main challenge in Upper Assam Shelf South, is the characterization, assessment of reservoir quality and delineation of sand units within Sylhet Formation. The Sylhet Formation is represented by one cycle of high amplitude seismic reflector putting the hindrance for detailed facies variation analysis of this formation in the seismic data. Present study was carried out for reservoir characterisation of the pay sands in Sylhet Formation for UAS in terms of facies and reservoir distribution. Higher order sequence stratigraphic analysis helped in better understanding of the depositional sequences along with reservoir characteristics. Rock Physics modeling aided Pre-stack inversion study was carried out for understanding reservoir distribution along with fluid behavior and likely anomalies for hydrocarbon bearing sands. Intensive attempts were made to understand and bring some analogy among amplitude, impedance and log responses for the pay sands encountered in the wells and to establish a meaningful relationship with hydrocarbon occurrences. Integrating all the studies, prospective areas have been identified. The results were validated with the known pay sands and in integration of other studies.

The study has helped in identifying prospective areas and optimizing available exploratory locations. Upside potential areas based on the integrated study have been delineated, which will accrete substantial amount of reserve and are future exploratory potential targets.

Introduction
Exploration in Upper Assam shelf South (UAS) of Assam & Assam-Arakan basin, north-east India was geared up after the discovery of Borholla-Changpang oil field in 1970 with multiple reservoirs of different age (Fig.1). In UAS, hydrocarbon pools are established and exploited from stratigraphic sequences ranging in age from Pre-Cambrian fractured basement to Mio-Pliocene sequences.

Fig.1: Base map of Study Area covering UAS showing different Fields, Seismic data Boundary, Surface expression of Naga thrust, areas of HC distribution for Sylhet Formation and position of reference wells A, B, C, D, X, Y.

Bokabil Formation of Mio-Pliocene age holds in-place volume (66%), while Sylhet (11%), Kopili (11%), Basement (9%), Tura (2%) & Barail (1%) are the other hydrocarbon bearing formations (Fig.2).

Fig.2: Play Assessment of Upper Assam Shelf South

The paper discusses about Sylhet Formation, which holds a good potential for future exploration. Hydrocarbons of commercial to sub-commercial...
order have been proved for Sylhet Formation in Borholla, Mekrang, East-Lakhibari, Dayalpur, Hazarigaon, Janatapathar, Babejia and Khoraghat, Nambar structures (Fig.1), which has given impetus for exploration of clastic reservoir of Sylhet Formation.

In the present study, detailed geological and seismic studies have been carried out to understand the reservoir from core to seismic and from qualitative to quantitative. Higher order sequence stratigraphic analysis helped in better understanding of the depositional sequences along with reservoir characteristics. Rock Physics modeling aided Pre-stack inversion study helped in understanding reservoir distribution along with fluid behavior and likely anomalies for hydrocarbon bearing sands. Intensive attempts were made to understand and bring some analogy among seismic signatures and log responses for the pay sands encountered in the wells and to establish a meaningful relationship with hydrocarbon occurrences. Integrating all the studies, prospective areas have been identified.

Geology, Tectonics and Stratigraphy

Fig. 4: Stratigraphy & Hydrocarbon Habitat of Upper Assam Shelf South

Granitic - gneissic complex constitutes the basement for sedimentary sequences of Tertiary age. The sedimentation started in Paleocene and continued till recent with an unconformity during Oligocene and Mio-Pliocene. In addition, Gondwana sediments have also been found in small localized grabens (Samal. et al, 2018).

Sylhet Reservoir: Characteristics, Distribution and Challenges

The Sylhet Formation of Middle Eocene age is composed of mixed silici-clastic and carbonates sediments and varies in thickness from 50 m to about 90m. This phase of carbonate dominated environment is stratigraphically represented by the shallow marine limestone with intercalations of shales and sandstones (mostly calcareous). The clastic intervals have been interpreted to be deposited during subtle regressive cycles within major transgressive cycle.

Hydrocarbon is generally restricted in clastic reservoirs of Sylhet Formation.
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Fig. 5: Reservoir Characteristics from core to log to Seismic in Sylhet Formation

Major challenge lies in the characterization, assessment of reservoir quality and delineation of sand units within Sylhet Formation. The Sylhet Formation is represented by one cycle of high amplitude seismic reflector putting the hindrance for detailed facies variation analysis of this formation in the seismic data (Fig. 5). To overcome the challenge, present study is an attempt to characterise the reservoirs integrating core, log, seismic (amplitude, impedance & VpVs) data to bring out a template.

Depositional Set up
After the deposition of the Tura Formation, the transgressive sea ensures a gentle south-easterly sloping platformal set-up that resulted deposition of Sylhet Formation. Sylhet Limestone has been broadly interpreted as deposition on a carbonate platform setting. Occurrences of sandstone-rich lithounits within Sylhet Formation have been explored and exploited as important hydrocarbon reservoir. The overall sedimentary facies architecture bears signatures of deposition in a tide affected near shore to inner shelf sedimentation with periodic delta building during progradational pulses (Shukla et.al, 2018).

High Resolution Sequence Stratigraphic Study
Present Study in high resolution sequence stratigraphic framework helped in better understanding of the depositional sequences along with reservoir characteristics. Sylhet Formation falls within TST of IInd order PM2 sequence. The deposition during TST is characterized by overall retrograding third order cycles and a band of two high amplitude reflectors characterizes seismic facies over the basement in most part of the basin.

Subdivision of TST into 3rd order sequences
In the present study, Sylhet Formation has been further subdivided into higher order sequences and two flooding surfaces i.e. FS-1 & FS-2 has been identified within Sylhet (Fig.6). These scheme divided Sylhet unit into three genetic sequences. FS-1 & FS-2 have been correlated across entire Upper Assam Shelf South (Fig.7). Log motif of the sequence clearly shows that higher order TR (Transgressive / Regressive) cycles within the TST and based on lithology, stratal package and electrolog signatures spatial heterogeneity of the formation was better understood.

Fig. 6: Identification of Sequence Boundaries on log in Sylhet Formation and dividing into different genetic sequences
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In Sylhet Formation, it has been observed that, the hydrocarbon distribution along Upper Assam Shelf South is within the zone Sylhet top to FS-1 surface (Fig.8). This FS1 surface coarsely matches with the +/- zero crossing within Sylhet formation (Fig.7). All the seismic attribute analyses have been carried out keeping this in mind.

Rock Physics Modelling

Rock physics Modelling (RPM) was carried out to estimate the shear wave velocity using processed data through multi-mineral modelling. The recorded P-impedence and VpVs log show a very scattered distribution of lithology which may be due to the borehole caving effect. After conditioning of logs, a linear relationship can be observed with a meaningful result (Fig.9). Cross-plot of model P-Impedence vs model VpVs on which limestone points are falling in the vicinity of 1.8 to 1.9 on VpVs axis for all the wells validates the model. The RPM log analysis shows the P-impedence versus VpVs having clear discrimination for lithology and pay sands (Fig.10). The cross-plot of model P-Impedence vs model VpVs indicates that the hydrocarbon points are well separated from those of water sand and shale points. Modelled RHOB, VP, VS and FLD log (Field Log depicting lithology) were used for pre stack inversion.

Pre-stack Inversion study

Pre-stack inversion study has been carried out for understanding of the likely anomalies for hydrocarbon bearing sands. RPM aided Pre-stack
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Inversion study generated meaningful P-impedance and Vp/Vs volumes, which would enable separation of reservoir and non-reservoir facies along with fluid anomalies. The resultant P-impedance and Vp/Vs were in reasonable conformance with the original P-impedance and Vp/Vs observed at the wells (Fig.11 & 12). Cross plots of inverted P-impedance and Vp/Vs coloured with litho log (filtered to seismic frequency) enabled identification of pay sands in major wells with reasonable certainty.

Sylhet Formation is characterized by relatively moderate impedance and low to moderate VpVs, which has been calibrated with the nearby producing and dry wells (Fig. 15). Inverted P-impedance and Vp/Vs at well indicating pay sand with P-impedance and Vp/Vs ratio in the order of 9500-10500 (m/s)*(g/cc) and 1.78-1.81 respectively. The calibrated results have increased the confidence level in bringing out seismic templates for pay sands in the area.

Fig.11: Cross plot between P-impedance and Vp/Vs at well scale. For Well-A, from Sylhet top to FS-1: Sylhet Sands characterised by relatively Moderate to High impedance, Low VpVs with some overlap.

Fig.12: Cross plot between Modelled P-impedance and Vp/Vs from Seismic.

Integrated Reservoir Characterization

Integrating core, log, seismic, impedance, VpVs data, the Sylhet reservoir has been characterized quantitatively and qualitatively in terms of P-impedance & VpVs (Figs. 13-15). The sands of

Fig.13: Pre-stack inversion result in terms of P-Impedance and VpVs.

Fig.14: Pre-stack inversion result of P-Impedance and corroboration with sequence boundaries for attribute analysis.

Fig.15: P-Impedance and calibration with nearby producing and dry wells. Applying the study output to new prospective areas.
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Seismic Attributes studies
Individual reservoir sand layers are below seismic resolution but they contribute in composite reflections. The trends observed in seismic attributes were used to bring out the sand geometries, wherever a trend could be inferred.

Since pre stack impedance volume has good correlation with interpreted lithology, attributes for different intervals using Impedance & Vp/Vs volume were generated to analyze facies. The calibration of these attributes w.r.t drilled wells with reference to known pays were carried out and results are satisfactorily matching with the reservoir characters (Fig. 16).

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Prospectivity Analysis
After integrating all the G & G studies, prospective areas have been identified for Sylhet in the study area (Fig.16). Intensive attempts were made to understand and bring some analogy among amplitude, impedance and VpVs for the pay sands encountered in the wells and to establish a meaningful relationship with hydrocarbon occurrences.

Conclusions
- Integrated study has brought out an analogy among log responses, amplitude, impedance and VpVs for the pay sands and to establish a meaningful relationship between the litho-responses with hydrocarbon occurrences in Upper Assam Shelf South. Integration of every piece of information from core to seismic helped in reducing uncertainties.
- RPM aided Pre-stack inversion study used to discriminate and delineate reservoir facies of Sylhet.
- Higher order Sequence Stratigraphic technique used for firming up the depositional model along with reservoir characterization.
- The study has helped in identifying exploratory prospects, optimizing exploratory and development locations.
- The results will be very much helpful for characterizing the reservoirs of other fields of A&AA basin.

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The views expressed in this paper are solely of the authors and not necessarily of the organization in which they are working.

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