Reservoir Characterisation in Complex Geological Set-up of Fold Thrust Belt: Case study from Manikyanagar Field of Rokhia Structure in Tripura Fold belt, India

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Summary
The first hydrocarbon lead in Rokhia Structure in Western Tripura Fold belt was obtained in 1983 and thereafter Gaseous hydrocarbon has been discovered in various pay sands viz. MP-20, MP-21, MP-30, MP-33, MP-34, MP-35 in Manikyanagar area and SP-29, SP-34, SP-38 and SP-39 pays in the southern Sonamura area within the Upper Bhuban formation, while MP-50 & MP-51A pays are within the Middle Bhuban formation in Manikyanagar area. These pay sands are limited in their extension and discrete in nature. All the pay sands cannot be correlated with confidence having similar amplitude characters and levels over the whole area, though at times some of them occur at correlatable depths with different log signatures.

The main challenge in the area is to ascertain the reservoir facies and their extent. Lithology interpretation imposes challenges due to lot of gradational variations within individual stratigraphic sequences. Present study was carried out for reservoir characterisation of the pay sands of Manikyanagar - Sonamura fields in terms of facies and reservoir distribution. Comprehensive study was made to understand and bring analogy between seismic amplitude, impedance and log responses for the pay sands encountered in the wells and to establish a meaningful relationship between the litho-responses with hydrocarbon occurrences. The paper discusses characterization of one of the pay sand, MP-21 in Manikyanagar field.

The cross plot between P-impedance and GR log indicates that the pay sand is having lower P-impedance values than the enclosed shales overlying and underlying the reservoir. Inverted P-Impedance and well log P-Impedance (filtered at seismic bandwidth) show good match. Post-stack inversion study has helped in delineating the likely anomalies for gas bearing sands. The pay sands in the area are characterized by bright amplitude and relatively lower impedance surrounded by higher impedance layers. The results were validated with the known pay sands and in integration of other studies. Different maps from seismic and impedance volumes for pay sands show the pay extents. The study has helped in optimizing exploratory and development locations. Upside potential areas based on the integrated study have been delineated, which will accrete substantial reserve and are potential exploratory targets in the future.

Introduction
The study area covers Manikyanagar-Sonamura Field, which is southern part of the Rokhia Structure in Western Tripura, a part of the Assam-Arakan Fold Belt (AAFB), India (Figs. 1 & 2). Commercial production in Rokhia anticline started in 1989. Since then, a total of 35 wells have so far been drilled in the study area of Manikyanagar-Sonamura Field, out of which 18 wells have proved to be gas bearing. Till date, the well data have established presence of 12 pay sands within Upper and Middle Bhuban Formations. As on date, MP-21 and MP-30 pays within Upper Bhuban holds the bulk of the reserve base of the total Manikyanagar Field. These pay sands are limited in their extension and discrete in nature. Hence, the characterisation of these pays are critical and challenging for success of exploration and development. Very few works related to reservoir characterization have been carried out in the area earlier. Present study is an attempt to characterize the pay sands, calibrate with the drilled wells and to identify future prospective areas.

Regional Tectonics
The dynamic nature of the Tripura Fold Belt can be attributed to the interaction of the Indian, Tibetan (Eurasian) and Burmese Plates. The intensity and pattern of plate-to-plate interaction varied with time, affecting the basin architecture and sedimentation style throughout the basin.
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Tectonically, the northern boundary of Tripura-Cachar Fold Belt with the Shillong Massif and the Assam Shelf is marked by the extension of the east-west trending Dauki Fault and further to the east is the Naga-Haflong-Disang thrust which separates the Fold belt from the Schuppen belt and subsequently intersects with the Dauki Fault. The western boundary with the Bengal Basin is represented by the Chittagong-Coastal Fault (CCF) which is considered to be the outermost major thrust of the Tripura-Cachar Fold belt. Further to the east, the north south Kaladan thrust divides the fold belt into two structural provinces- Chittagong-Tripura Fold Belt (CTFB) to the west and to the east, as far as the Kabaw Fault, the area is known as the Indo-Burma Range (IBA), extending outside the basin. Also a prominent NE-SW trending structural lineament namely the Hail-Hakalula Lineament delimits the fold belt towards the northwest, where this lineament joins with the Dauki Fault whereas, southwards, it passes over the Barisal-Chandpur Subsurface Gravity High which is considered to be the manifestation of the continent–ocean crust boundary (Fig.1).

Geology and Stratigraphy

Tripura-Cachar fold belt comprises a series of sub-parallel elongated en-echelon anticlines trending NNW-SSE with slight convexity towards west (Fig-2a). The anticlines are, in general, bounded by longitudinal reverse faults on one or either limbs. Geologically, Rokhia anticline, in the same trend is the outermost frontal structure of the fold belt. It is an elongated gently folded doubly plunging, flat topped, near symmetrical anticline (Fig-2b).

Fig.1: Regional Tectonic Elements of Tripura Fold Belt and adjoining areas on Digital Elevation Model (DEM).

Fig.2: (a) Study area on Geological map of Tripura (after Dotiwala et.al, 2000). (b) Enlarged Geological Map showing Rokhia Structure with drilled wells.

Fig.3: Generalized stratigraphy with tectonic history of Tripura-Cachar Fold Belt.

The oldest stratigraphic unit in Tripura-Cachar region is Barail Group of sediments of Oligocene age, unconformably overlain by the Surma Group of Mio-Pliocene age (Fig-3). The older Surma sediments are
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exposed in central and eastern part of Tripura and younger Tipam Group is exposed in western part i.e. Rokhia anticline. Based on litho-assamblage, the Surma Group is divided into two sub-groups, viz. Bhuban and Bokabil Formations. The Bhuban Formation is further divided into three units, Upper Middle and Lower Bhuban. The Bhuban Formation is mainly argillaceous in the middle part while it is relatively arenaceous in the upper and lower parts. The limited grain size analysis of sediments exposed in the folds of Tripura-Cachar area has indicated that Tripura area was located in front of a prograding delta with marine transgression during the deposition of Surma Group sediments and earlier times. Gradually the depositional environment changed to fluvial conditions during deposition of Tipam Formation.

In Rokhia area mainly upper and middle Bhuban is explored in different wells. The oldest sediments exposed in the core of the Rokhia anticline are Tipam and Bokabil sediments (Fig-2), comprising of alternating dominantly arenaceous and moderate to thin argillaceous beds. The core of the northern culmination is occupied by older arenaceous sequence of Bokabil whereas, the core of southern culmination is occupied by comparatively younger sequence of Tipam Group.

Depositional Environment
Various studies indicate that deposition of sediments in the Upper Bhuban in the Manikyanagar area have taken place in marginal marine environment in a paleo-bathymetry ranging up to 40m under fluctuating relative sea levels in an overall transgressive system. The Upper Bhuban is overlain by the Bokabil Formation followed by the fluvial sediments of Tipam Group.

Reservoir Sand Distribution
Gaseous hydrocarbon has been discovered in various pay sands viz. MP-20, MP-21, MP-30, MP-33, MP-34, MP-35 in the northern Manikyanagar area and SP-29, SP-34, SP-38 and SP-39 pays in the southern Sonamura area, within the Upper Bhuban formation while MP-50 & MP-51A in the Manikyanagar area are within Middle Bhuban formation. These pay sands are limited in their extent and discrete in nature (Fig-4). All these pay sands cannot be correlated with confidence having similar amplitude characters and levels over the whole area (Figs-5 & 6), though at times some of them occur at correlatable depths with different log signatures.

Till date, most of the wells have been drilled on the crest of the structure (Fig-2 & 4), but during the recent years the focus has shifted to explore flank areas of the structure. The main producing pays in the study area are MP-20, MP-21 and MP-30 (Fig-4, 5 & 6). MP-21 and MP-30 pays together constitute about 70% of the estimated reserve. MP-21 and MP-30 pays are present in the northern sector near the axial part of the structure. Other pays which have been encountered in isolated wells, are MP-33, MP-35, MP-50, MP-51A, SP-29, SP-34, SP-38 and SP-39.

Log correlation profile (Fig.-5) and seismic section (Fig.-6) in north-south direction shows the distribution of pay sands in the field.

Fig.4: Pay sand distribution in Manikyanagar-Sonamura field.

Fig.5: Electrolog Correlation from North to south showing disposition of different pay sands with discrete nature
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Major Challenges
The main challenge is to ascertain the sand distribution pattern in the study area and characterize the reservoir sands. Lithology interpretation is also very challenging in the study area as lot of gradational variations in the lithology exist within the stratigraphic sequence. Lithology grades from fine Clay – Clay-Silt - Fine to coarse sand.

Present Study
The detailed integrated study has been carried out for characterization of all the pay sands. However, present paper discusses characterization of one pay sand (MP-21) of Manikyanagar Field. 3D Post-Stack Time Migrated seismic data was used for the study. The two main sequence stratigraphic surfaces which have been correlated throughout the study area are- MFS (close to top of Upper Bhuban) and SU_3 (close to top of Middle Bhuban). MFS (Maximum Flooding Surface) is the final culmination of the entire transgressive sequence whereas SU-3 is an Unconformity surface.

Electro-log correlation along the structure indicates discrete nature of most of the sand layers and their lateral variation of facies (Fig-5). Sands developed within Upper Bhuban are predominantly silty/shaly sands and the effective porosities show wide range of variations depending upon the degree of compaction and association of varied quantities of porosity reducing clay minerals within rocks.

Reservoir Characterization
Post stack inversion study has brought out a good understanding of the likely anomalies for gas bearing sands. Inverted P-Impedance and well log P-Impedance (filtered at seismic bandwidth) show good match (Fig-7).

Impedance response of pay sands on log
Impedance response of pay sand MP-21 on log is characterized by low impedance. (Fig-8).

Fig.6: 3D Seismic Section in depth domain showing distribution of pay sands in the field

Fig.7: Cross plot of well log P-impedance and inverted P-impedance for all the wells

Fig.8: Impedance response on log for MP-21 Pay sand in well RO#A
Pay Level Cross plot analysis
The cross plots indicate reasonable separation of sand and shale in terms of P-impedance. In such cases sand appears to have lower impedance than shale. Cross-plots of P-imp Vs GR coloured with Sw as third axis for MP-21 in the wells, RO#A, clearly show that the H/C saturated pay sand has lower P-Imp. compared to the encompassing layers (Fig-9).

Analysis of inverted Volume
P-impedance volume generated through post-stack inversion is able to discriminate sand from encompassing shale facies for most of the pay sands which are having relatively lower impedance as compared to encompassing shales. Figure-10 shows low impedance nature of MP-21 sand on seismic.

Calibration with gas bearing and dry wells
The MP-21 sand is characterized by bright amplitude and low impedance, which has been calibrated with the nearby producing and dry wells (Figs-11 & 12). The pay sand MP-21 has produced gas from six wells including RO#A and RO#B. Calibration of bright amplitude and low impedance with lithology is well depicted in Figures 11 and 12. The calibrated results have increased the confidence level in bringing out seismic templates for pay sands in the area.

Fig.9: Cross-plot of GR vs P-Imp logs colored with Sw for MP-21 pay sand in well RO#A

Fig.10: Seismic impedance response for MP-21 Pay in the well RO#A

Fig.11: Calibration of bright amplitude corresponding to MP-21 Pay in wells RO#A, RO#B and other producing wells with lithology.

Fig.12: Calibration MP-21 Pay sand corresponding to Low Impedance on inverted volume in the wells RO#A, RO#B and other producing wells with lithology.
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Analysis

Maximum Negative amplitude, Spec-D and Minimum Impedance maps for different intervals using seismic volume and impedance volumes have brought out the reservoir extent (Figs-13 & 14) and future prospective areas. The calibration of these attributes w.r.t. known pays is satisfactorily matching with the reservoir body characters.

Conclusions

- Integrated study has brought out an analogy among amplitude, impedance and log responses for the pay sands encountered in the wells and to establish a meaningful relationship between the litho-responses with hydrocarbon occurrences in Manikyanagar-Sonamura Field.
- Cross-plots of Pimp Vs GR coloured with Sw, log response and seismic response of impedance for MP-21 pay shows that the H/C saturated pay sand has lower P-imp and GR values compared to the encompassing layers. The bright amplitude and low impedance character is well corroborated with the lithology of reservoir.
- The output of the study clearly brings out the extent of the pay sands in vertical and lateral direction. The results were validated with the known pay sands and in integration of other studies, the output has been used in identification of future prospective areas (Fig-14).
- The study has helped in optimizing exploratory and development locations.
- The results will be very much helpful for characterizing the reservoirs of other fields of Tripura Fold belt.

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