Reservoir Delineation & Characterisation of shallow gas pays in Agartala Dome, Western Tripura using 3D Seismic Data-A case study


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Summary
Exploration for hydrocarbons in Western Tripura, India began in 1972 with the very first well drilled in Baramura being the shallowest structure based on field geological map. Subsequently, the next phase of exploration activity was concentrated on the westernmost, less tectonically disturbed Rokhia structure with the belief that the broad syncline in between the Rokhia and Baramura could be less attractive area for exploration. Later, the study of remote sensing & photo-geological studies revealed the presence of a domal structure with a geomorphic high within the broad syncline caught the eyes of explorationists.

The quest for hydrocarbon in Agartala Dome began in 1987 with the very first well (AD-T) drilled, proved the presence of gas both in Upper and Middle Bhuban sands. Subsequent drilling activities (17 wells) resulted in discovery of number of pay sands within Bhubans. However, the biggest discovery of gas in Agartala Dome came from shallowest sand named AP-10B within Upper Bhuban with the drilling of 18th well (AD-A) in 1996-97. Subsequent drilling activities aimed at delineation of the reservoir led to the establishment of geological model integrated with the available seismic 2D data. This pay sand almost contributes 1/3rd of GIIP established for Agartala Dome field and currently one of the key layer for ONGC Tripura Power Company (OTPC) production commitments. However, two development wells drilled on north and south of the axis of the conceptualised channel met with few surprises revealing the deterioration of reservoir sands which forced the geo-scientists to relook at the depositional model afresh with the then available of newly acquired 3D seismic data in 2011-12.

All the petrophysical characters of the pay sands were re-evaluated along with mapping the top of pay sand in 3D seismic data based on the well to seismic tie. The cross plot analysis carried out between P-impedance and GR log indicates that the pay sand is having lower P-Impedance values (5500 to 6500 g/cc.m/s) than the enclosed shales lying above and below the reservoir. The RMS amplitude attribute extracted by mapping the exact top and bottom of the pay sand brought out the geometry and distribution of reservoir facies over the field. The post stack acoustic impedance volume helped in delineation of reservoir limit as gas bearing wells fall in the low impedance zone. The depositional environment predicted from the study of log motifs along with lab data integrated with property mapping of reservoir facies have revealed the coalescence of mouth bar along with distributary channel. The study has resulted in delineation and characterisation of shallowest gas reservoir pay sand of Agartala Dome Field resulting in implementation of a better suited development scheme for optimal exploitation of reservoir fulfilling the OTPC production commitment.

An upside potential area based on RMS attribute corresponding to time equivalent of AP-10B sand facies has been delineated which may open up a large chunk of reserve base may be looked in as future exploratory potential targets.

Introduction
The study area is located in the tectonically active geologic province of the Assam-Arakan Fold Belt (AAFB) in the western part of Tripura state in India (Fig.-1).
Agartala Dome field is a concealed structure located at a distance of about 15 km SE of Agartala town lying on a broad syncline between Rokhia anticline in the west and Baramura anticline in the east (Fig.-2). The structure is wide with a slight crestal shift towards south. The areal extent as well as closure increases with depth. Its eastern and western margins are faulted.

As on date, the field has a total of eleven pay sands, which are designated as AP-10B, AP-36, AP-38, AP-39, AP-40, AP-50, AP-53, AP-55A, AP-55B, AP-58 & AP-60 from top to bottom. As on date, the shallowest pool AP-10B within Upper Bhuban holds the 1/3rd of reserve base of the total Agartala Dome field. Hence, the delineation of this pay is critical for fulfilling the production commitment. Initially, as inputs for model building of reservoir pay sand AP-10B in 2007-08, fault bounded structures mapped from surface geology, study of well logs and 2D seismic data were considered. But the initial geological model of gas reservoir met with few surprises subsequently, mainly due to the absence/poor development of envisaged reservoir facies as proved after drilling of two development wells (AD-E & AD-F) in 2010-11.(Fig.-3)

Well log interpretations from newly drilled development wells (AD-E & AD-F) show sudden lateral facies change from clean sand to silt and then shale within a very short distance and thus indicating heterogeneous depositional patterns and spatio-temporal variation emphasizing a different geological model than the earlier envisaged distributary channel model.(Fig-3).

For mapping and delineation of reservoir facies and updating geological models, 3D seismic data were acquired in different seismic campaigns over various structures/fields within Tripura acreage holdings. To meet the objective, robust interpretation workflows consisting of sequence stratigraphic concepts, cross plots and 3D seismic attribute analyses were applied. Well logs and other geologic data were integrated for calibration, validation and seismic guided multi-attribute log property mapping for delineation of the gas reservoir.

Geology and Tectonics of the area:
The Tripura-Cachar region forms a part of the folded foredeep accretionary prism of the Assam Arakan orogenic belt. The area comprises a series of sub-parallel, long, narrow doubly plunging anticlines arranged in en echelon fashion (Fig.- 2). Degree of deformation increases due east with progressively older rocks exposed in the core. The sigmoidal shaped Assam-Arakan mountain belt belonging to the Indo-Burma ranges covers most of the northeastern states of India as well as Bangladesh and Myanmar. This province lies between the Indian plate in the west and the Burmese plate in the east. In the northwest, it abuts against Shillong Plateau (Fig. - 1). The northern margin of Tripura Fold belt with the Assam Shelf is marked by the extension of the east-west trending Daukani Fault which is an up thrust with right lateral displacement. Further to the east is the Naga-Haflong-Disang Thrust that separates the Tripura-Cachar fold belt from the Schuppen belt and subsequently intersects with the Daukani Fault. The western boundary with the Bengal Basin is represented by the Chittagong-Cox Bazar Fault (CCF) which is considered to be the outermost major thrust of the Tripura-Cachar Basin. A major north south thrust, the Kaladan Thrust divides the basin into two structural provinces to the west is the Chittagong-Tripura Fold Belt whereas to the east extending outside the basin as far as the Kabaw Fault the area is known as the Indo-Burma Range. Also a prominent NE-SW trending structural lineament namely the Haila-Hakalula Lineament delimits the fold belt towards the northwest. Southward, the basin extends up to Tripura. The basin extends beyond Nagaland, Manipur and Mizoram into the Arakan coast of Myanmar. The basin also extends south-westward under the alluvial cover of Bangladesh and is contiguous with Bengal Basin.

Stratigraphy:
The stratigraphy of Assam and Assam Arakan Fold Belt has been studied by a number of workers like Evans (1932), Mathur and Evans (1964), Dasgupta et al (1977). The first attempt to understand the sequence stratigraphy of the basin was made by Despande et al. (1993). The
Tripura Cachar Fold Belt exposes different sedimentary units mainly along the narrow linear ranges formed by the anticlines. The cores of the anticlines usually expose the Bokabil or Bhuban Formations flanked by Bokabil and Tipam/Post Tipam Formations exposures. A detail of the generalized stratigraphy is given above in Fig.-4

**Methodology:**
In the present study, 36 wells drilled over the Agartala Dome field were considered for correlation of logs. The basic framework of sequence stratigraphic concepts of C_H_100 (close to the top of Bokabil), MFS (close to the top of Upper Bhuban), SU_3 (close to the top of Middle Bhuban) were followed for electrologs correlation. Several log correlation profiles both east-west (B-B') (Fig.-5) as well as north-south (A-A') (Fig.-6) were constructed to observe the aerial extent and distribution of pay sands in the field.

**Seismic data interpretation**
Around 400 skm. of 3D seismic data was considered for interpretation. The quality of the present seismic data is variable in respect of standout, continuity, frequency contents and random noise, may be due to surface conditions and subsurface geological complexities. Spectral analysis in the zone of interest shows that, frequency content is low in the entire area. Peak frequency is found to be in the order of 13-15 Hz. with bandwidth 8-40 Hz.(Fig.-7).

The tuning thickness, 1/4th of wavelength is around 60m for the pay sand AP-10B .The reservoir thickness is observed to be varying within a range of 73m to 90m in wells and hence could be resolved through seismic studies.

A good well to seismic tie is attempted in four successful wells. Based on the well picks, the pay sand top and bottom surface was correlated within 3D PSTM data (Fig.-8 & 9).

For matching seismic markers and well picks, T/D functions generated by synthetic to seismic matching and VSP were considered. Synthetic Seismogram of well AD- A is shown in (Fig.-10).Statistically there is good match between synthetic and surface seismic. Character based matching between synthetic and seismic shows that shallower sand AP-10B is generating high amplitude trough.
velocity modelling the new sand relief map is prepared on top of pay sand AP-10B (Fig.-11).

Fig. - 9: RC Seismic section showing pay sand calibration with RMS attribute. Both seismic section and RMS attribute map indicates that AP-10B sand is not continuing in wells AD#S and AD#F.

Fig.- 10: Synthetic to seismic correlation of well AD-A, Well tie 90%, time 850 to 1350ms. Character based matching between synthetic and seismic shows that shallower sand AP-10B is generating high amplitude trough. It is a low impedance sand surrounded by high impedance shale.

Fig.- 21: New Sand Relief map of AP-10B sand, Agartala Dome after 3D seismic mapping.

Attribute Analysis:
Good quality seismic data is the major pre-requisite of any "qualitative seismic attribute study". Amplitudes being the most important seismic property, a number of window based amplitude attributes were generated along MFS close to Upper Bhuban top. Amplitude attributes studied are viz. RMS, Avg, or Mean, Max Peak, Avg Absolute, & reflection strength etc. It, however, turned out on scrutiny that most of these amplitude attributes contained nearly the same information.

The RC section showing Reflection strength at pay sand AP-10B level is shown in Fig.-12.

An attempt has been made to map both reservoir top as well as bottom surface which could be fairly established in the seismic data. The RMS amplitude attribute was extracted between these two horizons corresponding to top and bottom of reservoir. The RMS attribute map (Fig.-13) clearly brings out the geometry and distribution of sands and well calibrated with the drilled wells. Also this attribute map explains the non-development of reservoir facies in the two development wells (AD-E & AD-F) drilled in 2010-11 just north and south of the structure.

Fig.- 33: RMS amplitude attribute map extracted between AP-10B top & bottom. AP-10B is proved at centre of Agartala Dome. The upside potential is to be tested.

Acoustic impedance volume was generated through model-based post-stack inversion method in which the initial impedance model is prepared from actual impedance log and correlated horizons. The RC section passing through some of the gas bearing wells clearly indicates lower impedance range at the pay sand AP-10B level (Fig.-14).
Depositional Model of AP-10B sand:
The log motif of reservoir pay sand AP-10B developed in 4 gas bearing wells were analysed to understand the depositional environment (Fig.-18). The Upper Bhuban Formation is deposited in lower deltaic regime, where deltaic progradation was predominant due to huge influx of sediments from north and north-east in an overall marine transgression set up.

The thickness of these prograding sands and the associated potential reservoirs is a direct function of the accommodation space created by the difference between the culmination of the rate of relative sea-level rise and the total sediment input. Numerous present and ancient examples of similar facies are described in the north central portion of the Gulf of Mexico shelf (Galloway, 1981; Berryhill, 1986; Anderson et al., 1990; Bartek et al., 1990; Pacht et al., 1990; Abdullah and Anderson, 1991). They all converge to indicate that potential reservoirs in similar settings are generally poor unless the sands are reworked and their morphology altered into elongated sand bodies (Anderson et al., 1990; Saxena, 1990; Pattison and Walker, 1992; Reymond and Stampfli, 1994).

The deposition of AP-10B sand is believed to have taken place in a terminal distributary channel setup which is characterised by a fining upward sequence log motif separated by a thin shale streak observed in case of wells AD-D & AD-B which are lying in the downstream side. Channel migration is reported from Upper Bhuban Formation by Chakrabarti et al., 1992 from nearby Agartala Dome field.

Terminal distributary channels are formed within a delta at the very end of a distributive channel system. Terminal distributary channels start from the last sub aerial bifurcation and extend to the last channelized expression on the subaqueous delta front. Terminal distributary channels represent the most active part of the distributive channel network and are intimately associated with
mouth bars. Formation of terminal distributary channels is related to channel mouth processes. Mouth-bar deposits form as the flow condition at the channel mouth changes from confined to unconfined and velocity decreases (Albertson et al. 1950; Bates 1953; Wright 1977). The initial mouth bar forms close to the channel axis and bifurcates the channel flow (Figs. 19b, c, d & e). Several stages of evolution of terminal distributary channels have been differentiated and are closely related to mouth-bar evolution (Fig. 19). In phase one, new terminal distributary channels are formed by extension of subaqueous channel levees, widening of the channel, and bifurcation of the flows because of mouth-bar formation. In phase two, the growth and migration of a mouth bar (lateral and upstream accretion) forms terminal distributary channels at different scales. Mouth bar setup is represented by coarsening upward sequence log motif displayed in the upstream wells AD-C & AD-A. The extension of mouth bars and distributary channels are limited. The bar/channel coalescence seen on logs and seismic indicates good reservoir facies development in the area. Concomitantly with flow decrease in one terminal distributary channel, the flow is diverted toward another active terminal distributary channel or a new one is formed.

**Conclusion:**

- The shallowest AP-10B sand has been deposited in a lower deltaic plain below Upper Bhuban showing the characteristics of coalescence of terminal distributary channel and mouth bar. The mouth bar sand shows typical coarsening upward log motif and the terminal distributary channel deposited at the distal end of distributary shows fining upward sequence on log.
- Hydrocarbon is mainly restricted to topmost part of the reservoir i.e., within the channel body in all the four wells except in well AD-A, where the mouth bar is also charged with HCs additionally.
- The seismic 3D RMS attribute extracted corresponding to top and bottom of the reservoir has helped in exact delineation and characterisation of reservoir facies which would further expedite the development process for fulfilling the production commitment.
- The gas bearing sands are having lower acoustic impedance range of 5500-6500 g/cc.m/s as delineated both from cross plots as well as post stack acoustic impedance volume.
- An upside potential area based on RMS attribute corresponding to time equivalent of AP-10B sand facies has been delineated in northwest and eastern part of central Agartala Dome which may open up a large chunk of reserve base needs to be explored by exploratory efforts in future. (Fig.-13)

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