Seismic to Simulation Approach for Improved Reservoir Management of AP-10B pay sand of Agartala Dome: A case study

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Summary
Agartala Dome is a concealed structure developed in the synclinal area between Rokhia and Baramura Anticline (Fig-1). Another exposed structure, Tichna anticline is in its southern side while towards north the structure merges with synclinal area of Bangladesh. It has gentle and oval shaped geomorphic expression on the surface. It was discovered by the discovery well AD-A in the year 1987 and so far 51 wells were drilled on the structure of which 21 are gas bearing. The field was put on production in 1998. The deepest well drilled in Agartala Dome is AD-L which was drilled down to 4513m which encounter Tipam, Bokabil, Upper Bhuban, Middle Bhuban and partly Lower Bhuban Formation.

This structure has a multi-layered reservoirs and so far 13 pay sands have been established out of which 5 are in Upper Bhuban and 8 in Middle Bhuban Formation. The shallowest pay sand AP-10B holds about 1/3\textsuperscript{rd} of the reserves estimated for the total field. The sand was put on regular production in 1998. Initially it was thought that this pay sand was producing under depletion drive and the material balance analysis (P/Z Vs Gp plot) indicated a higher volume than the booked volume for this pay sand. However Havalena-Odeh analysis and energy plot indicated presence of aquifer support which is further substantiated by rise in GWC observed in wells AD-G and AD-I. Hence Seismic to Simulation approach is adopted to capture adequate subsurface detail in order to characterize vertical and lateral heterogeneity of the pay sand AP-10B which in turn helps in formulating better exploitation strategy.

Introduction
Agartala Dome structure is located about 15 kms south-east of Agartala City. The shallowest pay sand AP-10B in Agartala Dome is discovered with the drilling of exploratory well AD-C in the year 1996-97. This pay sand is one of the major producing sands, developed in the eastern raising flank of the Agartala Dome. The sand was put on regular production from February 1998 through the well AD-C. Currently six wells AD-C, F, D, E, G and H are producing gas from this pay sand at an average rate of 0.93 MMSCMD. As on March 2017 the pay sand has cumulatively produced around 2 BCM of gas.

Due to subsequent gas production there is around 11m rise of free water level as evident form well-log of AD-G & AD-H which were drilled in the year 2015-16. Again a development well AD-I drilled to exploit gas from the northern block revealed deterioration of facies and the sand is also structurally down in this block. In view of these inconsistencies a fine scale geo-cellular model is prepared incorporating available 3D seismic data, petrophysical data, geological information and the pressure production data on which simulation study is carried out to develop a holistic reservoir development plan.
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Geology and Tectonics of the area

Tectonically, Tripura area comprises of north-south trending series of sub-parallel, elongated, en-echelon, double plunging tight anticlines separated broad flat syncline where turtle back structure have developed at many places. Intensity of folding increases eastwards and relatively older rocks are exposed in the core of anticline towards east. Anticlines are usually bounded by N-S longitudinal reverse faults on either side of limbs, which disappears towards the flanks and oblique faults of multiple alignments with strike-slip component off set to the longitudinal faults and fold axis. Tripura fold belt area is also characterised by discontinuous sand bodies, frequent lateral facies variations and preferential charging of sands. Absence of a regional marker and time transgressive natural of litho-facies unit make the area highly challenging from exploration and exploitation point of view.

The stratigraphy of Agartala Dome is known from the neighbouring exposed anticlines and particularly from the drilled wells. About 4500 m of Tertiary sediments ranging in age from Miocene to Pliocene have been encountered in the sub-surface during drilling. The drilled wells mostly penetrated up to Middle Bhuban Formation. However, few wells have partly penetrated into Lower Bhuban. The generalized stratigraphy of the area is given in Fig-2.

Methodology

Sand description and Well Log correlation

The AP-10B pay sand in Agartala Dome is a part of Upper Bhuban formation which is envisaged to have deposited in fluvial environment. The deposition of the pay sand AP-10B may have taken place as a terminal distributary channel characterised by a fining upward sequence (Das Soumitri S. et al. 2016). This sand is present just below the maximum flooding surface which is marked as top of Upper Bhuban formation. It also has a restricted development having maximum thickness near well AD-C. For regional stratigraphic correlation 36 wells are considered and two log markers (i.e Upper Bhuban top and Middle Bhuban top) are picked. The sand AP-10B top and bottom are also marked on well-logs where developed. N-S well correlation profile passing through well AD-I, D, H, C, E, G and F is shown in Fig-3.
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Resolvable in seismic data, the sand top and bottom are picked after the seismic data is inverted.

A good well to seismic tie is attempted in four successful wells. Well to seismic tie for one of the well AD-C is demonstrated in Fig-4. Based on the well picks, the pay sand top and bottom surface was correlated on inverted impedance volume. Sand top and bottom correlation in inline and xline passing through AD-C is shown in Fig-5 and Fig-6 respectively.

Again Acoustic impedance volume was also generated through model-based post-stack inversion method. The pay sand AP-10B is low impedance sand surrounded by high impedance shale as shown in AD-C well. The impedance slice and RAI attribute extracted between sand top and bottom very accurately delineated the sand extension. The pay sand pinch out line is taken from these attribute map as shown in Fig-7.

These seismic surfaces along with the faults interpreted in the time domain on 3D seismic data were converted to the depth domain using velocity model. Depth converted longitudinal and transverse faults were imported into Petrel™ software of M/s Schlumberger for structural modelling.

Seismic attribute analysis has been done to find the extension of this pay sand. RAI (Relative Acoustic Impedance) attribute map extracted between top and bottom surface clearly depicts the reservoir limit.

Structural Modelling

Fault framework is generated taking the depth converted faults from seismic interpretation. The top and bottom boundary of the model were defined by AP-10B top and AP-10B base seismic horizon and only these two surfaces were used in the make horizon process, thus generating only one zone. Further this zone is divided into layers having cell thickness of 1m. The pinch out limit for this sand is drawn on the basis of the seismic attribute study and also validated by well data. The structure map of AP-10B sand is given in Fig-8.
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Petro-physical Interpretation

The petro-physical evaluation has been used to derive the reservoir properties such as volume of shale, effective porosity (inter granular porosity) and Water saturation (uninvaded zone water saturation) which are the key input for quantifying the hydrocarbon in-place of the given sand interval. The Schlumberger’s Elemental Log analysis (ELAN Plus) module of Geoframe has been used for quantitative log evaluation. The model used for AP-10B pay sand considered sand, shale as main constituents and silt & Clay as other constituents along with Gas and water as constituent fluids.

The minimum value of shale volume computed from both GR and Neutron-Density methods has been used to correct for total porosity. The effective porosity has been computed from the Density-Neutron and Neutron-Sonic logs. The effective porosity of AP-10B sand ranges from 17-24 % with an average value of 20 %. The established formation water resistivity (Rw =0.5 ohm-m) has been used for AP-10B sand, which was obtained from Pickett plot (Rt/Phi crossplot) technique. The sand unit has a resistivity value varies from 15-25 ohm-m. The standard a, m, n parameters (a=0.62, m=2.15, n=2) were used to compute water saturation.

The water saturation was estimated using Indonesian shaly sand equation which ranges between 20-40 % with an average of 30%. From log data it has been observed that the upper portion of the AP-10B is clean as compared to bottom interval which slightly silty in nature.

Property Modelling & Volume Calculation

Porosity and saturation logs were up-scaled to 3D grid. Porosity for 7 wells were considered. Then variogram analysis was carried out and the vertical, major and minor ranges are set as 73m, 2100m and 1000m respectively. In case of porosity modeling the probability trend map generated from minimum impedance slice is taken as secondary input.

There is an upward movement of water contact as evident form the log data , saturation modeling was carried out after relationship between bulk volume of water (BVW) and height above free water level (FWL) was determined as shown in Fig-9. An intersection plane showing propagated porosity and saturation is given in Fig-10.

For volume calculation Net-to-Gross was calculated using porosity cut-off of 8% and GWC at -1711 m. The GIIP of sand AP-10B in present study is 6.9 BCM of gas.

Performance review of pay sand AP-10B

AP-10B pay sand was put on regular production from February 1998 and six wells are producing gas from this pay sand at average rate of 0.95 MMSCMD with 4 m3/d water. As on March 2017 the pay sand has cumulatively produced around 2 BCM of gas.

AD-I drilled towards north of the structure, did not show any activity during initial testing, however depleted pressure of 142 Kg/cm2 was recorded in the well. Pressure production data of wells indicate homogeneous nature of reservoir as the pressure communication among the producers is very good. The production performance of the sand indicates
that none of the wells are producing substantial amount of water. Production performance of pay sand AP-10B is given in Fig-11. Conventional plot between $P/z$ Vs Cumulative gas produced suggests GIIP of 9.2 BCM considering depletion drive as the principle drive mechanism as shown in Fig-12. However presence of water drive would potentially reduce the GIIP.

Fig-9: Relationship between bulk volume of water (BVW) and height above free water level (FWL)

![Fig-9](image)

Fig-10: Intersection plane showing propagated porosity and saturation

![Fig-10](image)

**Simulation study**

Static model for the pay sand was imported from PETREL through RESCUE format to IMEX black oil simulator. No up scaling has been carried out from static to dynamic modeling. Two-phase Gas-water system was considered for simulation.

![Porosity and cumulative gas](image)

Porosity and permeability data obtained from routine core analysis has been used to generate correlation. The distributed permeability is in the range of 10-140 md. In the absence of SCAL, the relative permeability tables for the rock were generated with established correlations. Porosity-permeability correlation is given in Fig-13.

Well wise production data up to February 2017 have been incorporated into dynamic model. In this pay sand GWC is at -1711 m and Water production during entire production history of each well is less than 1 m3/day. Gas production and pressure data was satisfactorily matched during production history. Static bottom hole pressure history match for pay sand AP-10B is shown in Fig-14. Keeping in view of the elevated GWC observed in AD-G and H the reservoir pressure was matched by providing aquifer support (aquifer strength re/frw = 6) wherein the rise in FWL could be adequately brought out in the model as 10 m.
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Conclusions

- Seismic attributes analysis brings out very accurate areal extent of the sand body which defined the pay sand limit. An upside potential for sand AP-10B is also seen, in the northwest and eastern direction, form the attribute maps which was also indicated by other authors who worked on this field previously.

- Using both geo-statistical modeling and trend modeling, better porosity propagation is being achieved.

- As some wells were drilled at a later stage after substantial gas production, saturating height function is used for saturation modeling.

- The static and dynamic reservoir modeling not only aided in estimating the representative gas inplace but also captured the movement of free water level by 10m as evident from the logs recorded in wells AD-G and H.

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References


