3D Reservoir Modeling of Saldanadi Gas Field Integrating Seismic and Wire-line Log Data

Md Zonaed Hossain Sazal¹, A. S. M Woobaidullah², Chowdhury Quamruzzaman³, Md Jamilur Rahman⁴, Rajib Chandra Chowdhury⁵, Hasan Ali⁶

¹,⁵,⁶Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh
²,³Professor, Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh
⁴Geophysicist, Chevron Bangladesh

Abstract— Saldanadi Gas Field, a part of greater Rukhia Structure located at northeastern part of Bangladesh, is one of the producing gas fields of the country. Integrating seismic and wire line log data this structure has been modeled by the Petrel software. Structural model, facies model, property model including porosity, permeability models have been generated using various algorithms present in the software. For the purpose of these modelings all the 12 seismic lines (SD-01, SD-02-RESI, SD-03-RESI, SD-04-RESI, SD-05-RESI, SD-06-RESI, SD-07-RESI, SD-08-RESI, SD-10-RESI, SD-10-mig, SD-12-RESI, SD-14-RESI) were interpreted and time map was generated. T-Z curve was used for time to depth conversion and depth map was also created. Three gas sands identified by BAPEX are Upper Gas Sand (UGS), Middle Gas Sand (MGS) and Lower Gas Sand (LGS). Among these three gas sands Upper Gas Sand (UGS) and Lower Gas Sand (LGS) are the study zones of this research work. Wire-line log data was used to correlate Gas Sand Zones between wells Saldanadi-1 and Saldanadi-2. Fault modeling was not performed as no fault was identified in any of the seismic sections.

Keywords—3D Cells, Depth Map, Facies, LGS, UGS.

I. INTRODUCTION

Natural gas is one of the vital natural resources to meet the demand of energy supply. Natural gas is one of the cleanest, safest and useful energy sources of the world. In Bangladesh natural gas is the main source of energy that accounts for 75% of the commercial energy of the country.

As most of the structures of eastern part of Bangladesh had already been discovered, development of new technologies and new methods are more important to enhance and re-evaluate the recovery of gas prospects for gas fields. Saldanadi Gas Field, a part of greater Rukhia Structure located at northeastern part of Bangladesh, is one of the producing gas fields of the country. Three wells have so far been drilled at Saldanadi structure. Saldanadi well # 1 was the first exploratory well (SD # 1) drilled on Rukhia Anticline in 1996 by Bangladesh Petroleum Exploration and Production Co. Ltd. (BAPEX) under Kashba Upazilla of Brahmanbaria District. It is located at 91º 10’ 19.73˝ E and 23º 40´ 29.73˝ N and drilled a depth of 2511m. SD # 1 first started production on 28 March 1998. Saldanadi well # 2 (SD # 2) is located at 91º 10’ 19.73˝ E and 23º 40´ 29.70˝ N at surface and 91º 10’ 35.73˝ E and 23º 40´ 29.70˝ N at subsurface. Drilled depth is 2458m and started production on 03 March 2001. Saldanadi well # 3 (SD # 3) is a development well located at 91º 10’ 19.73˝ E and 23º 40´ 29.70˝ N in surface and 91º 10’ 55.96˝ E and 23º 40´ 59.20˝ N at subsurface. Drilled depth is 2860m and started production very recently, 31 January, 2012.

The present work has been carried out for subsurface 3D structural and property modeling of Upper Gas Sand (UGS) and Lower Gas Sand (LGS) Zones identified at Saldanadi well#1 and Saldanadi well#2. Depth interval for UGS and LGS are about 2170-2215m and 2405-2430m with an area of 2.61 sq. km and 4.283 sq. km (proven + probable) respectively. (BAPEX, Well Completion Report on Saldanadi, 2004).
II. REGIONAL SETTINGS

Saldanadi Gas Field on the Rukhia anticline is occupying the major part of the Tripura Basin. Tripura Basin covering an area about 90,000sq.km has mainly two parts known as Agartola Dome and Rukhia Anticline located in the northeastern part of India. It forms a part of Arakan-Assam Frontal Belt, characterized by a number of N-S trending long narrow elongated anticlines and broad flat intervening synclines, occurring in en-echelon fashion. The general trend of the major anticlines of this basin is NNW-SSE with slight convexity towards the west. The intensity of folding increases towards east with progressively older rocks being exposed in the core of the anticline. Each anticline is generally bounded by longitudinal reverse faults on one or both flanks (D.K. Ghosh and Narayan, 2003).

This area lies between the Indian plate in the west and Burmese plate in the east. In the northwest, it abuts against the Shillong plateau and in the northeast, it wedges towards Himalayan arc. It is filled mainly by orogenic sediments derived from the eastern Himalayas to the north and the Indo-Burman Ranges to the east (Kumar and Prasad, 2008).

Oldest sediments exposed in the basin are the Tipam Group of sediments, comprising alternating argillaceous and arenaceous beds. Four litho units have been identified.

The bottom three units are the part of the Tipam group, whereas the uppermost unit is the part of Dupi Tila formation. The core of the northern culmination is occupied by the older arenaceous sequence whereas the core of southern culmination is occupied by relatively younger argillaceous sequence of Tipam Group.

The exploration activity in Tripura Basin was started in 1986. As on date, 23 wells have been drilled at Agartola Dome out of which 10 wells is gas bearing. In Rukhia 45 wells have been drilled out of which 30 wells gas bearing. Seven gas bearing sands have been established in Bokabil, Upper and Middle Bhurban formation of Miocene age in Agartola Dome of Tripura Basin. 12 pay sands in Manikyanagar and 5 in Konaban field have been established in Rukhia structure. (Madan Rajesh and Kandpal, 2008).

III. DATA AND METHOD

All relevant data are collected from Bangladesh Petroleum Exploration (BAPEX) in computer supported form (softcopy). 2D seismic data and well log data are used for this thesis work. The workflow of the research work is given in figure 2.

IV. T-Z CURVE

Velocity data of Saldanadi # 1 well was created for this thesis work. Average velocity of the well was used to convert the two way travel time (TWT) into depth using the following equation:
\[ Z_i = Z_{i-1} + V^* (t_i - t_{i-1})/2 \]

With all these data a time depth (T-Z) curve was made.

Figure 3: T-Z curve of Saldanadi well#1

V. SEISMIC LINE INTERPRETATION

A project was created in Petrel Software to interpret all the seismic lines and to prepare the time contour map and depth contour map of Saldanadi gas field. 2D seismic data were used to interpret the structure of the gas field. SEG-Y files were imported into single seismic survey with co-ordinates and shot point scaling action. Well data was imported by inserting new wells and importing wire-line log data in each well with well tops import in ASCII format. Deviation data were also loaded for Saldanadi well#2. Top UGS, Base UGS, Top LGS and Base LGS horizons are picked by manually for different seismic sections.

Figure 4: Picking horizon

VI. INTERPRETATION OF STRUCTURAL MAP

Time structural maps were first created by selecting the contour tab on grid map and selecting the smoothening level which were then further converted to depth structural map. These time and depth structural map interpretations are given below:

A. Time Contour Map along the Top of Upper Gas Sand (UGS):

The time contour map along the Top of Upper Gas Sand surface has been made using the following parameters.

- Contour interval- 10 ms.
- Minimum contour value- 770 ms.
- Maximum contour value- 1050 ms.
- Resolution- high.
A peak is found at the northern part of the area and another near the central part. The contour lines of northeast side are more closely spaced than that of the southwest. And contour line of outer part is more closely spaced than the central part. The structure is gentler in the western side than the eastern side. The structure is more or less NNW-SSE trending.

**B. Time Contour Map along the Base of Upper Gas Sand (UGS):**

The time contour map along the Base of Upper Gas Sand surface has been made using the following parameters.

- Contour interval- 10 ms.
- Minimum contour value- 780 ms.
- Maximum contour value- 1060 ms.
- Resolution- high.

A peak is found at northwestern part of the structure and another peak at near the central part. Contour lines between two peaks are very gentle whereas contour lines are gradually steeper outside from the peak. Contour lines of northeastern part are steeper than the other part of the structure.

**C. Time Contour Map along the Top of Lower Gas Sand (LGS):**

The time contour map along the Top of Lower Gas Sand surface has been made using the following parameters.

- Contour interval- 10 ms.
- Minimum contour value- 800 ms.
- Maximum contour value- 1090 ms.
- Resolution- high.

A peak is found at northwestern part of the structure and another peak near the central part. Contour lines are gradual towards the outer part of the structure and more or less homogeneous. Contour lines of central are very gentle and widely spaced whereas outer parts are closely spaced.

**D. Time Contour Map along the Base of Lower Gas Sand (LGS):**

The time contour map along the Base of Lower Gas Sand surface has been made using the following parameters.

- Contour interval- 10 ms.
- Minimum contour value- 810 ms.
- Maximum contour value- 1100 ms.
- Resolution- high.
A peak is found at northwestern part of the structure. Contour lines are gradual towards the outer part of the structure. Contour lines of central are very gentle and widely spaced.

Peak is found at the northern part of the area and another near the central part. The contour lines of northeast side are more closely spaced than that of the southwest. And contour line of outer part is more closely spaced than the central part. The structure is gentler in the western side than the eastern side. The structure is more or less NNW-SSE trending.

E. Depth Contour Map along the Top of Upper Gas Sand (UGS):

The depth contour map along the Top of Upper Gas Sand surface has been made using the following parameters.

- Contour interval- 10m.
- Minimum contour value- 1420m.
- Maximum contour value- 1990m.
- Resolution- high

F. Depth Contour Map along the Base of Upper Gas Sand (UGS):

The depth contour map along the Base of Upper Gas Sand surface has been made using the following parameters.

- Contour interval- 10m.
- Minimum contour value- 1470m.
- Maximum contour value- 2040m.
- Resolution- high

A peak is found at northwestern part of the structure and another peak near the central part. Contour lines between two peaks are very gentle whereas contour lines are gradually steeper outside from the peak. Contour lines of northeastern part are steeper than the other part of the structure.
G. Depth Contour Map along the Top of Lower Gas Sand (LGS):
The depth contour map along the Top of Lower Gas Sand surface has been made using the following parameters.
- Contour interval- 10m.
- Minimum contour value- 1540m.
- Maximum contour value- 2070m.
- Resolution- high.

Peak is found at the northern part of the area and another near the central part. The contour lines of northeast side are more closely spaced than that of the southwest. And contour line of outer part is more closely spaced than the central part. The structure is gentler in the western side than the eastern side. The structure is more or less NNW-SSE trending.

H. Depth Contour Map along the Base of Lower Gas Sand (LGS):
The depth contour map along the Base of Lower Gas Sand surface has been made using the following parameters.
- Contour interval- 20m.
- Minimum contour value- 1570m.
- Maximum contour value- 2100m.
- Resolution- high

A peak is found at northwestern part of the structure and another peak near the central part. Contour lines between two peaks are very gentle whereas contour lines are gradually steeper outside from the peak. Contour lines of northeastern part are steeper than the other part of the structure.

VII. WELL CORRELATION
Saldanadi # 1 well is located in the axial part of the structure whereas Saldanadi # 2 and Saldanadi # 3 are deviated wells at the same location. Well correlation has been made from available log data displayed in the Well Section Windows. Gamma Ray log is the main tool to identify the lithology.

In addition, Resistivity (deep, shallow, micro) log are used to integrate with gamma ray log. Newtron Porosity log, Sonic log also have been used to validate the correlation. From the Well Correlation, it is seen that two gas bearing zones UGS and LGS are present at Saldanadi # 1 well and only one gas bearing zone UGS is present at Saldanadi # 2 well.
The average thickness of UGS and LGS is about 120m and 50m respectively as seen from the well correlation log and the thickness of both UGS and LGS is more or less uniform towards the down dip location from Saldanadi # 1 to Saldanadi # 2 wells.

Figure 13: Well log correlation between Saldanadi well#1 and Saldanadi well#2.

VIII. 3D GRID MODELING

As fault has not been identified in the seismic sections in this structure, “Make Simple Grid” in the Utility process is used for gridding. It produces three skeletons of the structure named Top, Middle and Base skeleton.

The dimension of the grid is 100m by 100m resulting total number of 3D cells are 31110 and 3D nodes are 42312. Number of 2D cells and nodes are 10370 and 10578. The limit of the grid from top to bottom is from 3162m SSTVD to 3709m SSTVD. This gridding represents the skeleton of the model as shown in the figure 14.

Figure 14: 3D Grid Skeletal Modeling

IX. MAKING HORIZON

The Seismic grid/depth maps imported in Petrel have been converted into surfaces using make/edit surface option in the “Make Horizon Process”. Created horizons are Top and Base of UGS and LGS. Top and base horizons have been created by taking the tops and bases respectively of the respective gas sands from the wells.

Figure 15: Making Horizons
X. MAKING ZONE

Make zone process has been used for zone making. Depth maps along the tops and bases are converted into surfaces and have been used as input for zone making. The zones have been built from Top Horizon along stratigraphic thickness where tops and bases lie as conformable in the model. The zones are shown in figure 16.

![Figure 16: Making Zone](image16)

XI. MAKING LAYER

Artificial layers have been created using proportional thickness for UGS and LGS that have been corrected later according to the vertical range of the facies (Figure 17). The UGS has been subdivided into 12 artificial layers with average thickness of 10.2m. The LGS on the other hand has been subdivided into 7 to 10 layers with average thickness of 9.5m. This layering results the grid dimension into (122X85X3) cells.

![Figure 17: Make Layering](image17)

XII. SCALE UP WELL LOGS

Scale up means averaging log values in a cell. Log value is distributed by considering cell value through the model. In this step both discrete (facies) and continuous properties (porosity, permeability etc.) are averaged in each grid cell along the well path. For each grid cell, all log values that fall within the cell are averaged according to the selected algorithm to produce one log value for that cell (figure 18).

![Figure 18: Scale up Well Logs of Saldanadi#1 well](image18)

XIII. FACIES MODELING

A facies log has been created comprising Shale, Silt and Sandstone based on Effective Porosity. The porosity ranges against each facies are shown in table I.

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Effective Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale</td>
<td>≤ 10%</td>
</tr>
<tr>
<td>Siltstone</td>
<td>10-15%</td>
</tr>
<tr>
<td>Sandstone</td>
<td>≥ 15%</td>
</tr>
</tbody>
</table>

![Table I: Porosity Range with Lithology for Facies Modeling](image1)

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The log has been upscaled later in “Scale up well log” process. Sequential Indicator Simulation (SIS) algorithm has been used for facies modeling. Variogram have been used as input for facies modeling and making anisotropy of facies distribution. The major and minor ranges of variogram have been set as 5000 and 3000 respectively with azimuth -45 as there are two wells penetrating the structure. The resulting facies model for Zone-1, Zone-2 and Zone-3 are shown in figure 19 to 22.

XIV. POROSITY MODELING

At first data has been transformed using “Gaussian Random Function Simulation”. Under normal score transformation maximum and minimum values are estimated from upscale logs. Porosity model has been created based on the porosity value from upscaled neutron log. Then distribution curves for each facies have been set in the data analysis process and later used as inputs for petrophysical distribution. Porosity ranges 18%-27% at Zone-1, 16%-29% at Zone-2 and 16%-35% at Zone-3.
This model of each zone suggests that the porosity of all zones ranges from 18% to 30%.

XV. PERMEABILITY MODELING

Like porosity, variograms have also been made using the same method. Then distribution curve has been used and data analysis process is done for each zone. Permeability model has been created from upscaled permeability log (K-log) data.

This model of each zone suggests that the permeability ranges from 55-150mD at Zone-1, at 40-180mD Zone-2 and 30-410mD at Zone-3 (Figure 26 to 28).

XVI. DISCUSSION

The Saldanadi Gas Field, part of greater Rukhia structure of Tripura State of India lies in the Eastern folded belt of the Bengal basin. Saldanadi is an elongated anticline. The structural configuration of the Saldanadi anticline as interpreted from the seismic data is smooth and uniform throughout the area. The contour shape is elongated in NNW-SSE direction. (K. U. Reimann, 1993).

Three wells have been drilled in Saldanadi gas field named SD # 1, SD # 2 and SD # 3. Among these wells, SD # 1 has stopped producing gas and SD # 2 is still a producing well. SD # 3 well is under development. Seismic data interpretation shows no major fault in the study area (BAPEX, 2001).

In general the sediments of Rukhia structure are poorly fossiliferous to barren and consist of alternate shale, sandstone and siltstone in varying proportion. The area faced several uplift and erosion during basin history but the major uplift and erosion took place in the most recent times.
Saldanadi # 1 is drilled into an anticlinal structure and the surface is presently located 11m above mean sea level (MSL). From the seismic cross sections and the regional stratigraphy it is evident that the Dupi Tila formation is completely and Tipam is partly eroded (S. Ganguly, 1997).

XVII. CONCLUSION

Reservoir models (porosity, facies modes etc.) have been generated for this area using Petrel software subdividing the area into three zones. All the models were made by maintaining these zonings.

Facies model has been created using up-scaled gamma ray log. This model shows sand facies domination throughout the studied area with some silt and shale facies. 

Porosity model has been created based on the porosity value from upscaled neutron log. Porosity ranges 18%-27% at Zone-1, 16%-29% at Zone-2 and 16%-35% at Zone-3. This model of each zone suggests that the average porosity of all zones ranges from 18% to 30%. Permeability model has been created from upscaled permeability log (K-log) data. Permeability ranges from 55-150mD at Zone-1, at 40-180mD Zone-2 and 30-410mD at Zone-3.

XVIII. RECOMMENDATION

It is recommended to carry out 3D seismic survey before attempting any further drilling campaign over Saldanadi field. According to the industry standard 3D seismic data is a requirement in order to better image the subsurface structurally and stratigraphically. The 3D seismic dataset should definitely give a better image of the structure if properly acquired and processed.

If any other well is planned to drill in Saldanadi Gas field, it should be located in the northern part from the well No. 1, because the probability of finding the gas sand is high in that area.

REFERENCES