GCM Enabling Development Opportunities in a Mature Carbonate Gas Reservoir

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Keywords

GCM, Development, Seismic, Sweetness map, Compressor gain, MDT pressure, Carbonate

Abstract

Lately drilled exploratory well in B-55 area brought out southward extension of the field. Newly acquired seismic data provided an opportunity to relook into the entire area along with integration of all the pays in the field for holistic development. In view of this, a Seismic to Simulation study was taken up for preparation of an integrated geo-cellular model for all the pays of B-55 area with the help of geological, 3D-Seismic, well log and field reservoir data.

This is the first integrated geo-cellular model (GCM) for B-55 Area unlike previous individual prediction models. The study has brought out hydrodynamic connectivity between B-55 main and B-55 South block at aquifer level. The study also brings out possible upsides identified with the help of seismic attributes, well logs and production testing results in the existing wells in H and M pays which could be completed at an opportune time.

B-55 is a multi-layered carbonate gas reservoir located in the Western Offshore Basin. The field was has four major gas bearing pay zones identified, namely M, H, A and B zones. Also, the field is prone to H_2S environment. The field was put on production with 11 gas producers in 1999 and nearly 50% of gas in-place has been recovered from the field.

This paper is a case study, demonstrating classic example of holistic approach of developing an offshore mature gas field.

Introduction

B-55 field is located in the Western Offshore Basin, at about 110 km northwest of Mumbai city. The field was discovered in 1978. It is located at a water depth is about 30m. This field is a multi-layered carbonate offshore gas reservoir having four major gas bearing pay zones identified, namely M, H, A and B. However, A & B are considered as continuous pay zones on the basis of log correlations and for development strategy they are treated as a single reservoir. Also, the field is characterized as sour gas reservoir with H_2S ranging from 60-250 ppm.

Field Performance

The initial development of the field was planned with 12 gas producers from one well head platform. 11 wells were drilled and completed in A& B pays. Gas production from these wells started in 1999 and an average gas rate of around 0.25 MMSCMD/well was achieved till year 2002. However, in due course of time, increase in water production was observed affecting the gas production from wells.

In 2015, one additional well was drilled and completed in M pay. And, one another well was zone transferred to H pay as it was producing sub-optimally from A & B pays. Both the wells came up with nearly three times of the rates realized in rest of the wells all of which were completed in A & B pays.

In 2017, first development well in B-55 South culmination was put on production from A & B pays which also came up with gas rate of around 0.10 MMSCMD.

Currently, the field is producing with the gas rate of around 1.40 MMSCMD and has recovered nearly 50% of gas in-place through 13 wells. The field performance is shown in Figure 1.

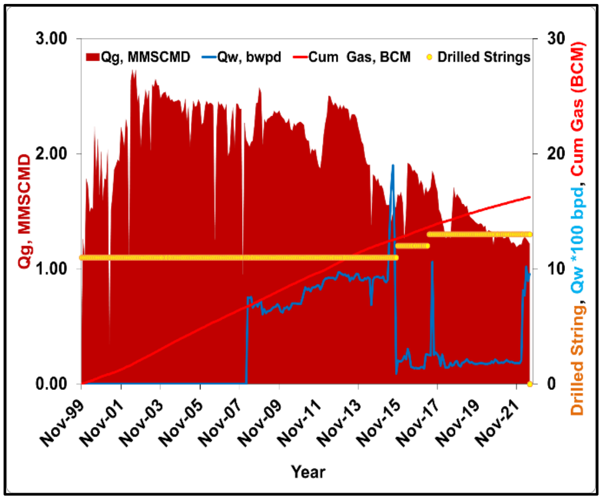


Figure 1: Field performance

Need for integrated geo-cellular model (GCM)

Initial development of the field was based on FORGAS model targeting A & B pays only. It is a tank based model which can deliver forecasting and development scheduling for oil and gas system. However, an exploratory well which was drilled in the year 2007, brought out southward extension of the field, also called B-55 South and produced gas from A pay. In addition, recently acquired seismic data was also available in the area enabling an opportunity to relook into entire B-55 area along with integration of A, B, M and H pays for holistic field development. In view of this, an integrated geo-cellular model for all pays of B-55 area was prepared with the help of 3D-Seismic, geological, well log and reservoir data.

Seismic study

Two seismic volumes covering entire B-55 field were used in the present study for mapping. Time shift between both seismic volumes were negligible. The line and trace intervals of both volumes are 25 m and 12.5 m, respectively. For proper understanding of the field, large area comprising structure of B-55 field was studied in detail. Seismic study was carried out in Landmark software.

Synthetic seismogram of exploratory wells were prepared. An example of one of the well as attached as Figure 2.

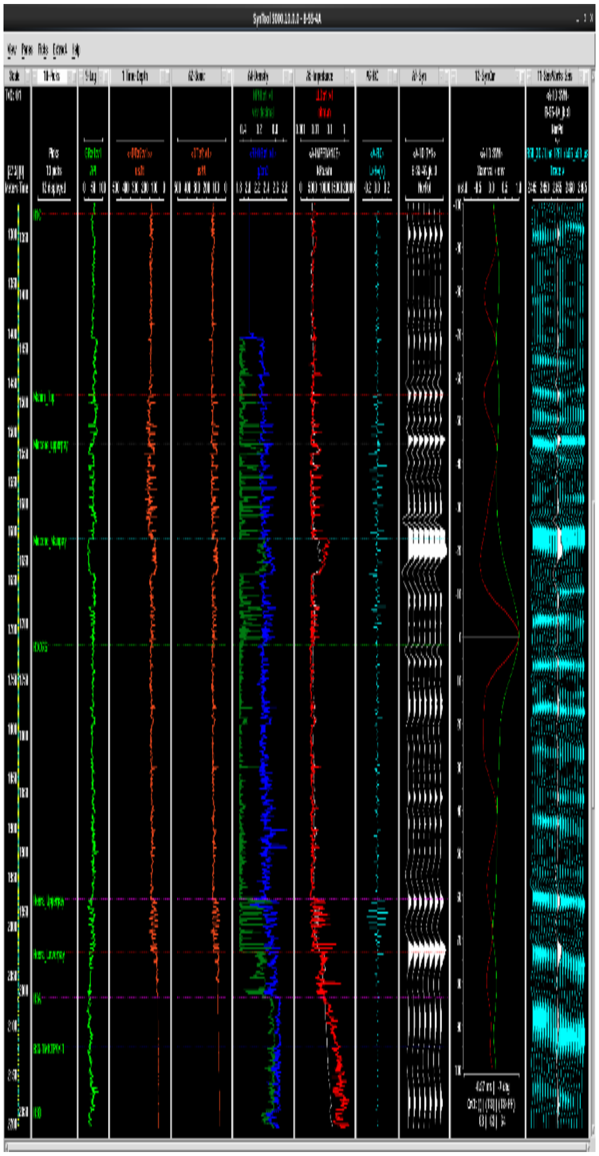
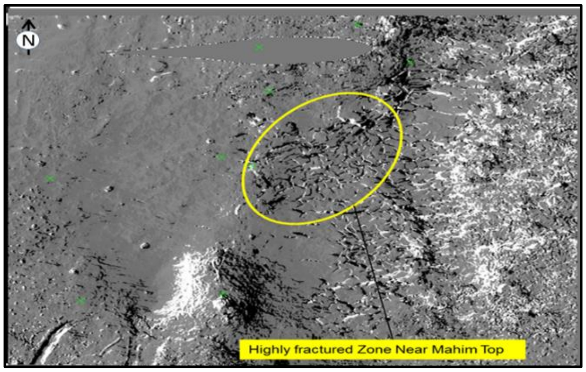


Figure 2: Synthetic Seismogram

Synthetic seismograms for 8 wells were prepared and the time depth relationship derived from these have gone into the velocity model building. The average correlation factor was 60%.

Horizons near M top, H top, A and B were tracked. In addition, horizon H1C and H4 were also mapped for velocity modelling. Standard loop closure and seed point auto track method were adopted for populating the reflection events corresponding to horizons. Horizons were tracked in both the volumes and were subsequently merged in time domain.

Faults were correlated at every 25th inline and 25th traces. Its alignment was carried out in the entire volume. Seismic attributes such as Dip, Dip-Azimuth and Event Similarity Prediction (ESP) were generated. These attributes corroborated with fault interpretation. At M level, fracturing were observed both in seismic section and in attributes. These fractures appear at shallow level (up to H3CGG marker) and do not continue up to A-B formations. The seismic section is shown as Figure 3.



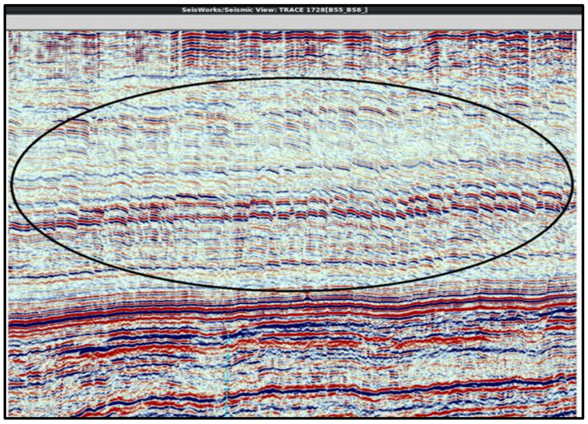


Figure 3: Seismic section

Well Logs

The geological facies, effective porosity (PIGN) and water saturation (SUWI) as estimated in the logs were up scaled using arithmetic average method. The departure of the up-scaled logs from the processed values was reasonably low within different stratigraphic zones. The scaled up properties were propagated from the well location to the grid cells geo-statistically by assigning a value of the property into every grid node. Appropriate variograms were constructed in major, minor and vertical directions for each of the stratigraphic zones giving a numerical description to the properties through methods of simulation (Monte Carlo Simulation). Hence the analysis was done for the up-scaled effective porosity (PIGN) and water saturation (SUWI) separately.

Petro-physical Modelling

Effective Porosity

Data analysis was carried out on the up scaled effective porosity (PIGN). An effect of transformations on the data population was studied as regards Normal Score on both the properties.

Before going for porosity population with Kriging method, impedance attribute was extracted from seismic. Several attempts were made to establish a good correlation between the well porosities and the seismic attribute but correlation were mostly poor. Thus, the seismic attribute could not be used for population of the porosities in the model.

Simple kriging method was used to populate the up scaled effective porosity (PIGN). While populating, co-kriging was also used wherein the population was given a trend using a probability function from maps generated from the depth-porosity cross-plots for each stratigraphic zone. The average effective porosity maps for M & H pays are shown in Figure 4 & 5. Red, yellow & green region in the map is showing porosity from 11 to 7%.

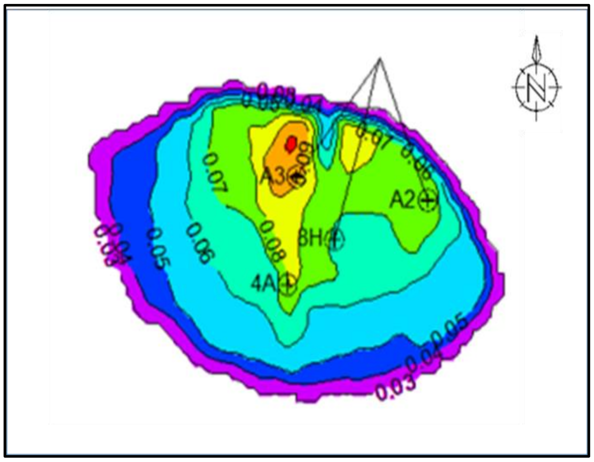


Figure 4: Average effective porosity map of M pay

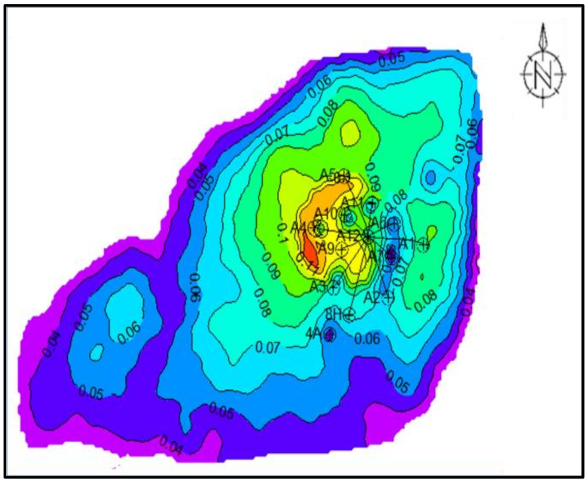


Figure 5: Average effective porosity map of H pay

Water Saturation

Water saturation modelling has been attempted through three approaches namely appropriate variogram/kriging, J-function & RQI (Rock Quality Index). The up-scaled water saturation has been populated from point data of all wells, through simple kriging. Thereafter, the saturation was also co-kriged using a trend of probability function that was generated from Saturation-Porosity cross plots for each stratigraphic zone. The saturation modelling with the kriging method was found to be satisfactory for M and H pays and was used as such for dynamic modelling. However, this method does not result in representative saturation modelling for A & B pays. RQI method was found to render a better population than other techniques. Saturation-RQI function was generated using capillary pressure curves derived from core samples of three different wells. RQI is defined as,

$$RQI = 0.0314 \operatorname{sqrt}(K/\Phi)$$

Where, K=permeability, mD and Φ=Porosity, fraction.

Using this equation, RQI was calculated for all the cores for which capillary pressure curve was available. Irreducible water saturation was available from capillary height functions of these cores. Thus, a relation between RQI and Irreducible water saturation was generated and best fitted trend-line was identified as the Water saturation Vs RQI function. Hereafter, this function was upscaled with log derived water saturation and RQI of well#1, #3 & #12. The water saturation vs. RQI function thus obtained is-

Sw= 0.3939*(RQI^(-0.267))

Primary porosity distribution as obtained in upscaled model is considered for dynamic modelling. Figure 6 shows the water saturation vs. RQI relationship derived using core, log and build-up data. The data points derived using core data correspond to tighter facies. Build-up data being representative of entire reservoir shows better facies. Hence to capture heterogeneity, best average fit power function is considered for saturation distribution in model.

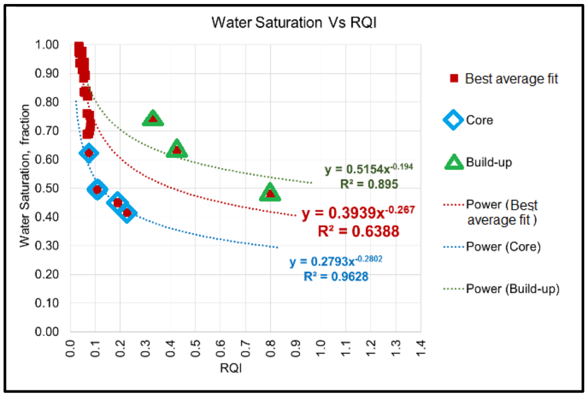


Figure 6: Sw vs RQI Relationship

Inferring Fluid Contact from MDT pressure plot

B-Zone is gas-bearing and no presence of oil is indicated on the logs. No gas-water contact is observed in most of the wells in B-55 main block. However, as the field has historically produced water, it was pertinent to decipher the source of water. It was found while analyzing MDT data that GWC can be considered at 2160m below MSL. The MDT pressure plot vs. depth is shown in Figure 7.

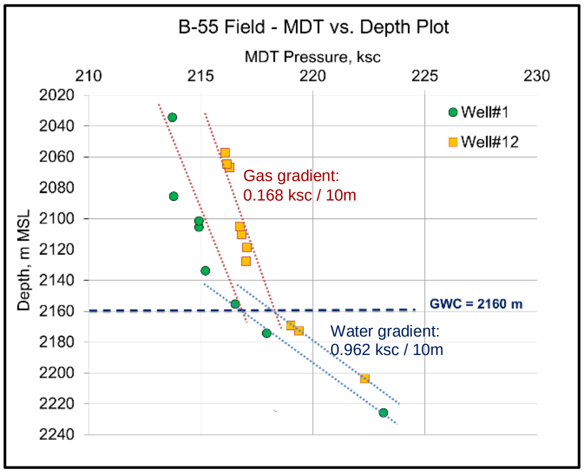


Figure 7: MDT pressure data versus Depth

Further, a permeability barrier is observed between B-55 and B-55 South blocks on property maps and a structural low is observed between these two blocks. Additionally, the log characteristics of exploratory well in B-55 south shows presence of water below the level of 2150 m below MSL.

Pressure recorded in exploratory well of B-55 South was ~210 ksc at datum in 2008 without any production, which is nearly 7 ksc lower than initial pressure recorded in B-55 main block. In 2017, while first development well was being drilled in the B-55 south block, the pressure was recorded to be ~200 ksc at datum. Thus, pressure drop of nearly 16 ksc is observed in 17 years without any production from B-55 South block. The pressure drop in B-55 South block is possibly due to communication with the B-55 main block at aquifer level, which has been on production since 1999. A vertical cross-section from model showing the communicating aquifer is shown as Figure 8.

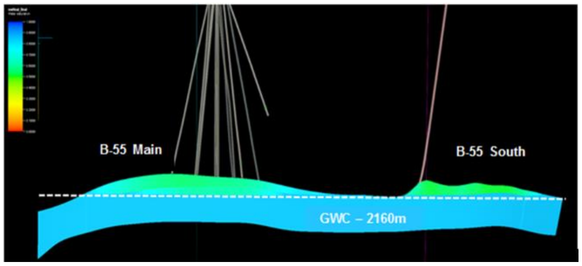


Figure 8: Vertical cross-section from model

Findings

The Geo-cellular model has been utilized to understand the field behavior and to examine the scope of further improvement in gas recovery.

Impact of Compressor on Production Performance

As field has matured with decline in reservoir pressure and corresponding well head pressure, one of the options to increase production could be lowering of back pressure through installation of compressor. Accordingly, this opportunity was evaluated in the integrated simulation model which yielded significant gas gain.

Opportunities for side-tracks and zone transfers

The sweetness seismic attribute is defined by the Instantaneous Amplitude (reflection strength) divided by the square root of Instantaneous Frequency. It is very useful for capturing lithological variations.

3D PSTM seismic data was used for generating the Sweetness attribute volume. Using M pay top and bottom horizons, mean of sweetness attribute was extracted for M pay. High sweetness zones (Figure 9) have the best facies development in well#4A and poorer wells are falling in low sweetness areas.

Sweetness attribute of M pay also indicates the locales for development opportunities (Figure 9). This could be achieved through sidetracking of one of the non-flowing wells i.e., well#2. Confidence in fixing the sub-surface locale was supplemented by the overwhelming production performance of well#8, completed in the same layer. The sweetness attribute with identified locale at M pay is shown in Figure 9. The attributes also indicate additional prospects A, B & C which can be assessed with an appraisal location and are shown in Figure 9.

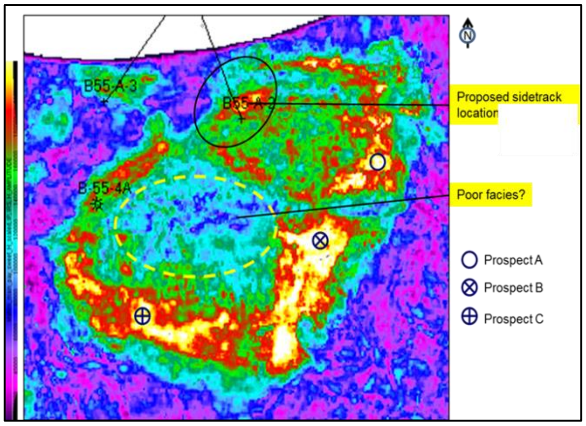


Figure 9: Sweetness map at M pay

Similarly, the study also looks at possibility of enhancing production through zone transfer to H pay in the other existing wells. Interesting development of H Pay is seen in around 6-7 wells having development of ~5-15 m as seen on logs. Zone transfer to H Pay might be taken up at an opportune time.

Conclusions

An integrated geo-cellular model is prepared for B-55 field including all the pays and southward extension of the field with the help of geological, 3D-Seismic, well log and field reservoir data. The study has brought out hydrodynamic connectivity between B-55 and B-55 South block at aquifer level.

The study also brings out possible upsides identified in H & M Pays in the existing wells with the help of seismic attributes like sweetness map coupled with well logs and production testing results.

As field has matured with decline in reservoir pressure and corresponding well head pressure, one of the options to increase production could be lowering of back pressure through installation of compressor. Accordingly, this opportunity was evaluated which yielded significant gas gain.

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Acknowledgements

The author would like to express their gratitude to the Oil and Natural Gas Corporation for granting permission to publish the paper. The Author is also indebted to Head-IRS, Institute of Reservoir study, ONGC who always motivates to print the ideas & wisdom. A very special thanks is due to all the colleagues who are directly or indirectly associated with the work reported in this paper.