Abstract

Introduction

Barmer Basin is one of the most prolific hydrocarbon basins of India having more than 30 discoveries to date. The Raageshwari Deep Gas (RDG) Field, situated in the southern Barmer Basin, was discovered in 2003 by exploration well Raageshwari-1 and is a part of RJ-ON-90/1 contract area operated by Cairn India. This field is characterized by tight gas-condensate reservoirs with excellent gas quality of approximately 80% methane, low CO₂ and no H₂S. Subsequent to discovery, the field was further appraised by six more wells and is being developed by 27 wells from 4 well-pads. The main objective of the initial development plan was to meet internal gas demand; however, based on years of encouraging well performance and additional data acquired, a revised FDP focusing on commercial gas sales in addition to internal gas consumption was submitted to and approved by the Management Committee in 2014. The field is currently being developed using deviated wells with multi-stage hydraulic fracturing to allow substantial production at economic rates.

Regional Geology

The RDG Field is located at the northern end of the Central Basin High (CBH) which is a 40km long composite structural high with N-S oriented fault terraces, arranged en-echelon within the southern Barmer Basin. The field is contained within a horst block controlled by the confluence of N-S and NW-SE trending bounding faults. A brief summary of key depositional and tectonic events is summarized as below, extending from Late Cretaceous to Early Paleocene age:

- Eruption and deposition of basic and acidic lava flows with associated sediments
- Tilting and erosion of volcanic deposits driven by ENE-WSW trending faults
- Onlap of Fatehgarh fluvial and lacustrine sediments onto the volcanic high during syn-rift faulting dominantly in N-S direction
- Silts and muds of Barmer Hill and Dharvi Dungar create a regional seal
Stratigraphically, the reservoir is composed of clastic Fatehgarh Formation overlying the volcanic complex comprising basic lava flows (basalts) and stacked silicic pyroclastic flows interbedded with basalts. Seismic data suggests the volcanic complex has a layered internal structure, presumably due to cyclic flows of basic and acidic lava during the Deccan volcanism. In RDG field, the volcanic reservoirs contribute approximately 70% of the total gas in-place with a thickness of around 700m in places.

**Challenges in RDG Volcanic Reservoirs**

Owing to the complex nature of volcanics, reservoir identification and predictability of reservoir trends away from wells pose a significant challenge. Variability in mineralogy, lithofacies, thickness of reservoir subunits and areal distributions of pores/vugs and fractures results in marked reservoir heterogeneity over a few meters. Moreover, their complex characteristic nature has resulted in a limited number of global analogues. It is therefore imperative, for effective reservoir management and optimum production performance, to devise a comprehensive facies characterization as a first step towards improving reservoir predictability and building a robust reservoir model. The facies classification is also integral to designing and execution of the multi-stage hydro-fracturing operations required in development of the field.

**Facies Characterization in RDG Volcanics**

Against these challenges, the facies characterization study integrates different datasets from conventional cores, mudlogs (gas shows and chromatographs), wireline logs and production data. Conventional (sand-shale) petrophysical workflow are not applicable to volcanics. A new unconventional work flow needed to be developed which would account for the complexity of the volcanic reservoirs and aid in hydraulic fracture optimization. A refined geological correlation of the volcanic sequences led to a robust sub-zonation based on chronological markers, which occur as two thin tuff-layers within the basalts. It was evident that the key parameter to address would be permeability given the tight nature of the formation (micro-pores). Core measured porosity and permeability data indicated the presence of complex pore size distributions resulting in different permeability for a given porosity. Hence, facies classification would be essential to characterize permeability and define pay zones in these tight rocks.

Winland approach was applied to identify different facies according to pore size criteria. Density log was found to be useful in discrimination of various facies as lowering of density was associated with relatively bigger pore size in the rock. Gamma ray log delineated felsic volcanics from the basalt volcanics. Very conductive mineralized zones present in basaltic rock were segregated from pay zones using resistivity log. It was observed that presence of higher
NMR bin porosity in rocks was associated with higher gas counts and resulted in higher productivity. The different NMR bins (as per T2 decay spectra) qualitatively reflected the pore size distribution in the rock with higher bin porosity indicative of larger pores. The available processed NMR bin porosity data was integrated along with density, gamma and resistivity logs to arrive at a robust facies model.

Results

The pay zones identified based on facies model were used for enhanced hydraulic fracturing of more than 100 zones as part of the current Hydro-frac campaign. The effectiveness of the reservoir units was matched with fracturing parameters and productivity was validated using permeability (derived from DFIT and pressure build up data) and production logs. Spatial distributions of these facies and reservoir properties were populated by geostatistical techniques in the revised reservoir model, incorporating available geometries and flow unit dimensions from well data and analogues. The approach also emphasizes the importance of integrating different datasets for facies characterization in unraveling reservoir complexity leading to increased confidence in effective reservoir management.

Conclusion

The tight volcanic reservoirs pose a huge technical challenge due to unusual geology and strong heterogeneities in terms of mineralogy, lithofacies, thickness, fracture presence and also reservoir properties like porosity and permeability. The high impact on production performance and reservoir management calls for continuous upgrading of the facies model aggregating the data from hydro-fracturing and newly drilled wells. This integrated reservoir characterization workflow adopted in RDG field is a good example of how detailed definition of facies has been deployed in challenging reservoirs to better understand uncertainties and increase performance predictability.