Multidisciplinary Approach in Tight Oil Appraisal: A Case Study from Barmer Basin, India*

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Abstract

Despite a difficult era of low crude oil prices, production from tight oil and gas fields have gained importance to meet the ever-rising energy demands in developing nations. Barmer Basin, a 300 km intra-cratonic rift in NW India, has produced ~ 400 million barrels of oil since 2009. With the present production primarily from the multidarcy reservoirs on decline, prudent and cost-effective exploitation of tight oil and gas portfolio assumes utmost significance in order to maintain the reserve replacement ratio of this mature basin and augment the production shortfall. The exploration and appraisal activity within the basin is presently focused on tight rocks. The lacustrine porcellanites facies within the Barmer Hill (BH) Formation contribute significant shares of in-place resources. The reservoir rocks are thinly laminated siliceous units of medium to high porosity, low permeability, and require hydraulic fracturing to produce at commercial rates.

The Diatomite Play Field, discovered to the north of the giant multidarcy Mangala oil field, hosts such porcellanite reservoir rocks of BH Formation in a tilted fault closure. A downdip exploration well tested commercial oil flow on hydraulic fracturing. However, one of three updip appraisal wells drilled on the eastern edge of the field produced mostly water with only 5% oil cut. The ambiguous appraisal results warranted further studies.

Re-interpretation of petrophysics showed dissimilarities in saturation height trends in the exploration and appraisal wells which is also supported by reservoir pressure data acquired in these wells. These observations were integrated with the newly acquired 3D PSDM interpretation to infer faults, hitherto unidentifiable. Integrated interpretation showed the four wells drilled so far to be in separate fault compartments. On close observations, the water producing well is inferred to be connected to distal sands of deltaic facies towards the east. Alternatively, the porcellanites get connected to the underlying water bearing Fatehgarh Formation through a sub-seismic fault is also a distinct possibility. All observations are integrated in a stochastic model to optimize the future appraisal and development plans. A quick swab test conducted in one of the updip appraisal well confirmed presence of mobile oil.
The paper stresses the importance of innovative and pragmatic integrated multi-disciplinary approach for appraisal and subsequent monetization of such tight oil fields.

**References Cited**


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Outline

- Basin Introduction
  - Stratigraphy
  - Porcellanite Portfolio

- DP field: A Case Study from Barmer Basin, India
  - Introduction to DP Field
  - Depositional/Trap Model
  - Reservoir Characteristics
  - Uncertainty Estimation
  - Well Testing
  - Pressure Data & Depth – Saturation Trend
  - Interpretation of new 3D Seismic

- Technology Application

- Conclusion & Way forward
Barmer Basin: Introduction

- Located in NW India
- Failed intra-cratonic rift basin
- Sediment fill is dated Jurassic to present day overlying a Proterozoic basement
- Multiple phases of rifting followed by inversion and tilting during the Himalayan orogeny.
- Short exploration history of 16 years
- One of the biggest hydrocarbon provinces in India
- 38 discoveries declared by Cairn India & ONGC to date

After Dolson et al., 2015
Barmer Basin: Stratigraphy

- Structural upliftment in North of Barmer Basin; sediment thickness increases towards South
- Active rift process during Paleocene
- Transition from fluvial through shallow lacustrine to lacustrine environment
- Most prolific Source Rock: Barmer Hill Formation; Ultimate seal: Dharvi Dungar Formation
- Primary Reservoirs: Paleocene Fatehgarh and Barmer Hill Formations

~ 90% of syn-rift Barmer Hill reservoirs consists of tight sand and porcellanites
Porcellanite Portfolio

Aishwariya (~330)
Mangala (~600)
DP (~171)
NL (~27)

~1.1 Billion BOE in place
Porcellanite: How it looks?

- Diagenetically altered biogenic silica reservoirs; predominantly laminated porcellanites, analogous to the Diatomites of Monterey Formation, CA, USA.
- Laminated reservoirs of lacustrine origin with alternating silica, organic matter & clay.

Core Photograph

Porcellanite in thin section

Outcrop sample, Opal CT phase

Reservoir sample, porcellanite

XRD Whole Rock Mineralogy (wt%)

- Dolo. Tr
- Siderite 2
- Pyrite <1
- Chlor. 3
- Quartz 81
- Total Clay 15
- Kaol. 11
- Ill. 1
- S/1
DP Field
A Case Study from Barmer Basin, India
Introduction to DP Field

- D-P-1 was drilled (May 2014) in a structurally down-dip area; fracced, tested and flowed @ 50 BOPD (liquid rate 300 BPD) with N2 lifting; 27 degree API oil; poor cement behind casing was observed.
- Three more appraisal wells were drilled in an up-dip location of D-P-1.
- Four wells are located in different compartments.
- Current estimated STOIIP ~ 170 MMBOE.
**Reservoir Characteristics**

- **Lithology:** Diatomite & Claystone
- **Average NTG:** 60-70%
- **Reservoir porosity:** Average 28-30%
- **Matrix permeability:** 0.1 - 4 md
- **Reservoir pressure:** 1300-1400 psia
- **Reservoir temperature:** 65-70°C
- **Reservoir fluid:** Oil and water
- **Oil quality:** API-28°C; Viscosity-10-30 cP

Pay zones are in transition state with mobile water
Depositional / Trap Model

After Pander et al., 2016

Depositional model RMS amplitude at Top Barmer Hill based on 2D and 3D seismic

After Pander et al., 2016
Qualitative Assessment of Uncertainties

<table>
<thead>
<tr>
<th>Key Uncertainty</th>
<th>Plan to Address</th>
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| Reservoir behavior                          | 1. Acquire Core  
2. Short/long term production tests                                              |
| Volumetric Uncertainty/Contacts             | 1. 3D seismic acquisition to reduce uncertainties  
2. Pre-stack inversion  
3. MDT pressure on up-dip appraisal wells  
4. Static model building for resource estimate                                      |
| Seismic response: Reservoir or Fluid        | 1. Forward model to understand seismic response  
2. Pre-stack Inversion                                                              |
| Fluid Characterization                      | 1. PVT analysis on tested / MDT oil samples  
2. Oil and gas composition / undesirables                                              |
| Lateral Seal                                | 1. Appraisal wells to test the lateral seal  
2. Seismic study to understand lateral seal                                            |
| Fraccability                                | 1. Core data for geo-mechanical / brittleness study  
2. Image log interpretation                                                           |
| Possibility of gas cap                      | 1. Appraisal well to test GOC  
2. Retest N-C-West-1                                                                  |
| Optimal Well Design                         | 1. Appraisal well will test vertical, deviated and sub-horizontal well             |
Well Testing Summary

- Appraisal results proved that the amplitude anomaly was unrelated to reservoir or fluid type.
- DP-4 test results further increased the uncertainty.

Oil Sample:
- 50 BOPD for 19 Days
- Swabbing: 2.9 BBL oil

5-6% oil after 115% frac fluid recovery; Liquid rate 900 BOPD

* Cross section not to scale
Pressure Data & Depth Vs. Saturation

- Free water level could not be established with the help of available formation pressure data
- Most pressures against BH are of low confidence due to poor stabilization/ poor repeatability/ supercharging
- DP-3 pressures are very different from other wells suggesting possibility of compartmentalization
- Depth Vs. pressure plot suggests D-P-1 and D-P-2, D-P-4 might be in different compartments
Estimation of FWL from SHF
Interpretation of new 3D Seismic

- Seismic interpretation based on 2015 acquired 3D seismic
- Presence of fault up-dip of D-P-2 separating N-C-West-1
D-P-1 and D-P-2 are located in separate fault blocks.
D-P-2 and D-P-3 are also separated by faults
Interpretation of new 3D Seismic

- Hint of possible fault between D-P-2 and D-P-4 wells suggest a possible compartmentalization; throw against these faults are less
- Dip-Azimuth map generated on a limited auto-tracked area of the Top BH suggests possible presence of lineament/faults
Unlocking 1.1 Billion Barrels of Contingent and Proved STOIIP
Conclusion & Way forward

- Contrary to the previous concept, present study conclusively suggests that DP field comprises of multiple compartments
  - Geological processes controlling the deposits of porcellanite ensures similar reservoir properties across the compartments
  - Different compartments probably have different free water level (FWL)
  - Well deliverability in different compartments may vary due to presence/absence of natural fracture

- Developing this field would require different approach for different fault blocks
  - Extensive well testing has been planned for the drilled wells
  - Two more up-dip appraisal well has been planned in the D-P-1 fault block to be drilled in Q4 2018-19
Thank You

Mangala Processing Terminal, Barmer, Rajasthan, India