Identifying Exploration Target Area for Lower Barmer Hill Shale play in Kaameshwari graben, Barmer Basin

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Keywords

Shale gas play, Play based approach

Abstract

The Lower Barmer Hill (LBH) Member of the Barmer Hill Formation has significant unconventional resource potential. The paper focuses on assessing shale play prospectivity on a source kitchen, the Kaameshwari graben, in the central Barmer Basin and has complete 3D seismic coverage. Three wells drilled through the target LBH formation in the structural highs have quad-combo wireline logs. The zone of interest in the graben is at depths of 4000-5000m. Maturity in the graben is expected in the gas window. The potential target area is demarcated by combining gross thickness, organic richness, and thermal maturity maps. 76 sq km of gas play was identified with 300 – 600 m gross thickness. Integrating the lithofacies from the updip wells, seismic analysis and paleoenvironment reconstruction, we infer that the expected lithofacies in the target are organic-rich shale deposited in anoxic conditions during the LBH transgression event. Finally, an analogous shale play is identified which can be used for further characterization of the shale potential. This study provides the basis for further estimation of in-place resources and to identify the target locations for shale gas exploratory drilling in Kaameshwari graben.

Introduction

The primary source rock of Barmer Basin petroleum system, the Lower Barmer Hill (LBH) Member of the Barmer Hill Formation has significant unconventional resource potential (Kuila et al., 2020, Aastha et al., 2020, Dutta et al., 2019). Our previous work used a play-based approach to delineate prospective areas in the northern part of the basin (Kuila et al., 2020). We identified four grabens as exploration target areas and divided them into eight play segments (five oil and three gas segments) (Figure 1a). This paper focusses on a southern source kitchen, the Kaameshwari graben, east of the Kaameshwari field and north-west of the Raageshwari Deep Gas field in the central Barmer Basin. Figure 1b shows a W to E seismic section passing through the Kaam-1 well and the Kaameshwari graben, defined by the main bounding fault in the east, separating it from the Saraswati field. The zone of interest in the graben is at depths of 4000-5000m and defined by the top and base LBH surfaces. Maturity in the graben is expected in the gas window (Naidu et al., 2017). We present an assessment of shale gas potential of the Kaameshwari graben integrating all available data and finally delineating exploration target area.

Data and Methods

The Kaameshwari graben lies in central part of the Barmer Basin and has complete 3D seismic coverage. Three wells drilled through the target LBH formation in the structural highs have quad-combo wireline logs. All three wells have wireline logs including Gamma Two of these wells have nuclear magnetic resonance (NMR) log. The drill cuttings from one well underwent geochemical studies (Leco TOC, Rock-Eval Pyrolysis, Vitrinite reflectance, SCI) to characterize the source rocks. The results of these studies were used to create a predictive pseudo-3D basin model.

We identified shale resource play in the Kaameshwari graben using an integrated play-based exploration approach described in Figure 2 (Kuila et al., 2020). We defined the play boundaries by combining gross thickness, organic richness, and thermal maturity maps. We assigned a play-segment based on gross-depositional environment (GDE) map. The sub play-segment polygons demarcate the variation of fluid type within the play segment. We compared the play-segment characteristics with analog commercial N. America shale plays to assess the potential.

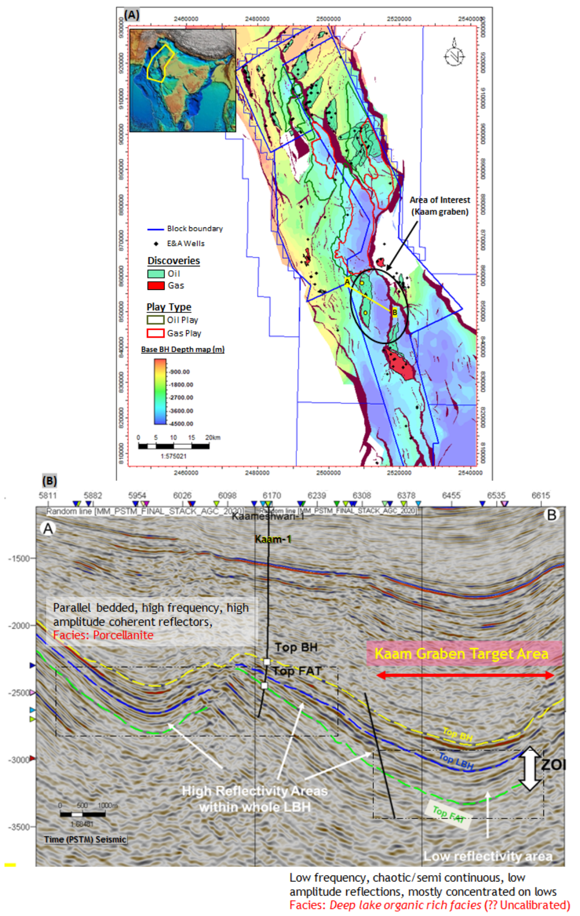

Figure 1(a) Map highlighting the shale oil and shale gas play segments identified in Barmer Basin along with the area of interest in the central part (Kaameshwari graben), (b) Seismic Inline along Kaam-1 well highlighting the downdip Kaameshwari graben

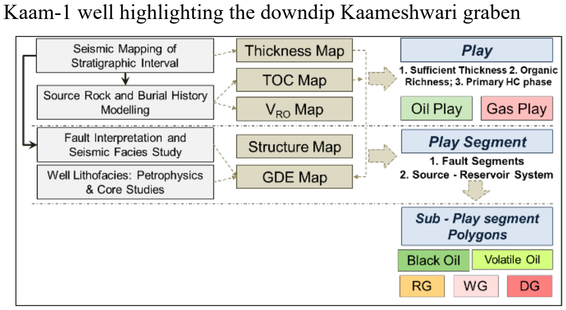

Figure 2: The play-based workflow used in this study (from Kuila et al., 2020).

Play and Play Segment Mapping

Structure and Thickness Maps: We mapped the Lower Barmer Hill top and base surfaces across the study area on PSTM 3D seismic volume after tying the LBH surfaces to the three updip wells. We used seismic stacking velocities for depth conversion of the time interpreted surfaces, after calibrating with an average scalar from the well measured velocities (Figures 3). The thickness map we obtained from the depth converted surfaces suggests that the thickness varies from 300m to more than 600m in the deeper downdip graben area (Figure 3b).

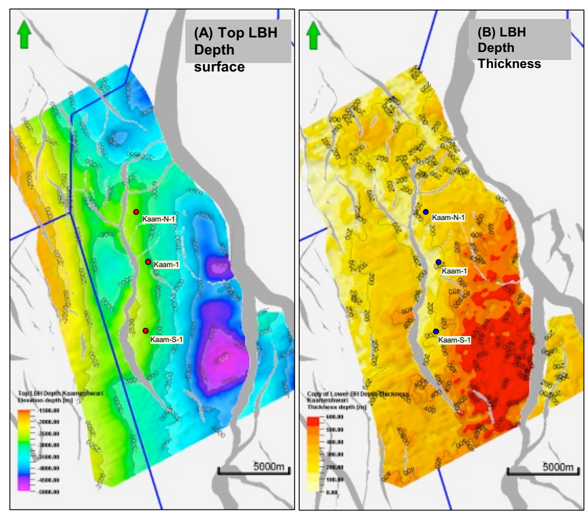

Figure 3: Depth structure map in Kaameshwari area at (a) Top LBH, and (b) Gross thickness map for the LBH interval.

Organic Richness and thermal maturity: Figure 4a show the TOC and Rock-eval pyrolysis data performed on the drill cuttings samples of Kaam-1 well against depth. The LBH section has moderate to good TOC (present day) content. The TOC is highest towards the lower part of LBH consistent with the maximum transgression and lake deepening event occurring at Fatehgarh-BH boundary. Visual kerogen analysis and the pseudo van-krevelen plot suggest a mixed type-I and type-III kerogen indicating higher depositional HI. (Figure 4b). The present-day HI values ranges between 150- 200 mg HC/g TOC reflect the effect of thermal maturity. Thermal maturity indicators (Tmax, Vitrinite Reflectance and Spore Coloration Index) confirm suggest late oil window at the well location (Figure 4b).

Along the crestal part, we observed an increase in log-derived TOC from north to south (Figure 5a). We extrapolated the results these crestal wells to predict organic richness and thermal maturity in the lows of the Kaameshwari half graben. We created a basin-wide TOC map by gridding this log-derived TOC and extrapolated it to areas with no well coverage by guiding it through our understanding of gross depositional environment (GDE) (Figure 5b). We modelled the thermal maturity thermal maturity by incorporating the burial history, heat flow and kerogen kinetics data into the basin model (as discussed in Naidu et al. 2017). The thermal maturity at the top and base of LBH vary significantly owing to large thicknesses (>600m) in graben. Therefore, we consider an intra-LBH iso-proportional surface (50% of thickness above and 50% below) to generate the VRo map for play segment demarcation (Figure 5c).

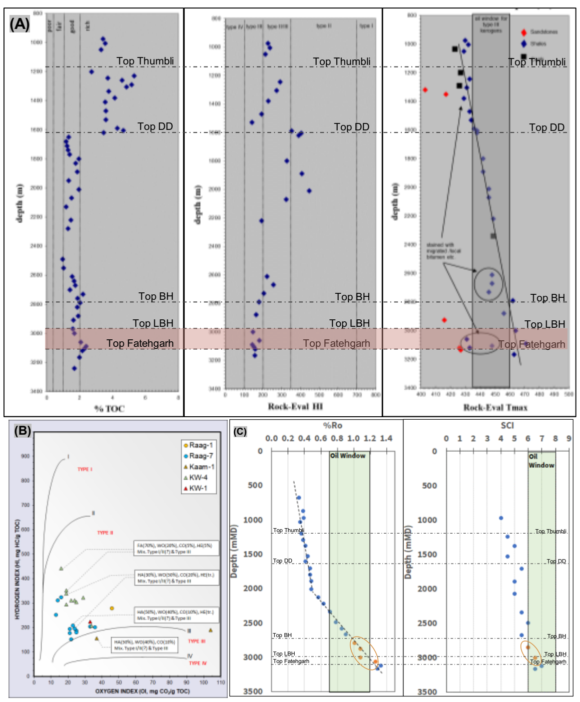

Figure 4: (a) Geochemical plots for Kaam-1 well drilled in the crestal part of Kaameshwari graben, (b) Pseudo Van-Krevelen plot for LBH samples from Kaam-1 well and other offset wells in the adjacent Kaameshwari West and RDG fields (FA: Fluoro-amorphous material; HA: Amorphous material; WO: Woody material-vitrinite precursor; CO: Coal and non-translucent materials; HE: Sporomorphs), (c) VRo and SCI plots against depth for Kaam-1.

Well facies, seismic facies analysis and updation of GDE:

We analyzed the lithofacies from petrophysical analysis of the three crestal wells. A comparison of similar log response for a cored well in the nearby Raageshwari Deep Gas (RDG) suggests that the main lithofacies in the Kaam wells alternate between biogenic silica dominated porcellanite facies and claystone facies. This indicates a shallow water lake environment during LBH deposition. We observed a decrease in net porcellanite thickness and an increase in shaliness and total organic carbon (TOC) from north to south (Figure 6), indicating a gradual deepening lake environment where the shale content and TOC are increasing.

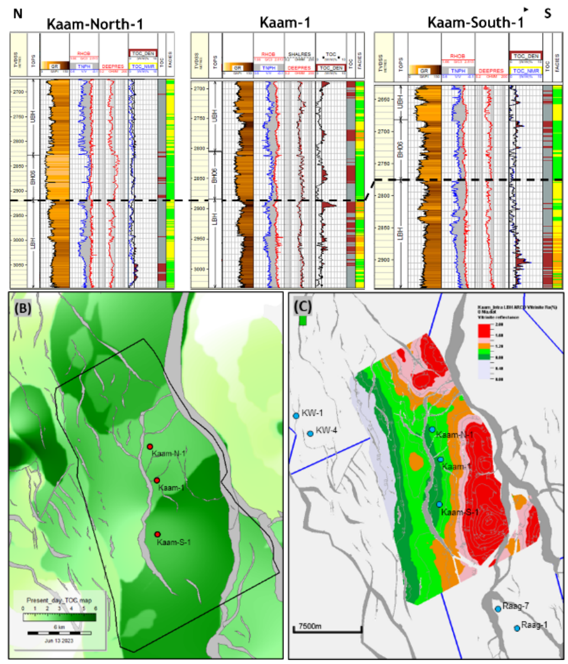

Figure 5: (a) Log-derived TOC estimation and lithofacies for the three crestal wells, last track shows lithofacies, porcellanite: green, lean shale: yellow, and Organic rich shale: orange (b) Present day TOC map for LBH interval focusing on the Kaam graben, (c) VRo maturity map for an intra-LBH depth surface.

The seismic facies vary across the half-graben. The crestal part toward the north shows parallel, continuous, high frequency, coherent reflectors. These amplitudes represent areas with porcellanite dominated facies calibrated with lithofacies of Kaam-North-1 and Kaam-1 (Figure 7). The downdip areas become progressively low amplitude, low frequency chaotic reflections, suggesting a different lithofacies compared to drilled crestal wells.

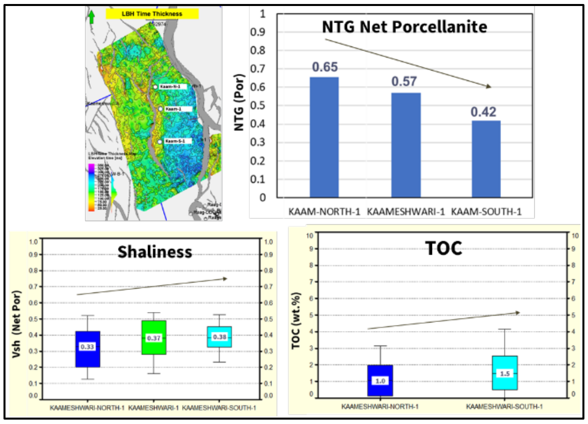

Figure 6: Comparison of Net porcellanite, Vshale and TOC in Kaameshwari wells moving from North to South.

The "normalized sum of magnitude" attribute map captures the seismic reflector continuity and amplitude (Figure 7a). This attribute provides a sum of all amplitudes between the top and base of LBH and normalizes to thickness. The red to yellow color on the map depicts areas with high amplitudes while the green to blue color represents comparatively lower or no concentration of amplitudes. This attribute map shows the variability and distribution of lithofacies in the half-graben structural unit. We observed similar facies variation in other seismic attribute maps (Figure 8) obtained by spectral decomposition. Frequency decomposition suggest that the 20Hz signal is most dominant in our zone of interest and correlates to the high reflective seismic facies (Figure 8a). Similar trends are observed in RGB color blend maps (10, 20 and 35Hz) for the entire lower LBH section.

Integrating all the attributes shown in Figures 7&8, we observed that the crestal area in the north is dominated by porcellanite facies deposited in a shallow lake environment. The lows towards the south with thicker LBH package (Figure 3b) possibly have completely different facies. Since the LBH is an early synrift deposit marked by a major transgression event, we postulate that the deeper grabens represent a deeper lake environment with possible anoxic conditions. We observe an increase in TOC in Kaam-South-1 consistently with the geological interpretation. The most likely lithofacies would be deep lacustrine organic-rich shale interval. We capture the geological understanding in Figure 9 as the revised Gross Depositional environment map of Kaameshwari graben. There might be few turbidite deposits or fan deltas deposited along the margin faults, however, their extent could not be resolved in the low frequency seismic data.

Play and Play Segment Demarcation: We demarcated the play area using the standard cutoffs for thickness, TOC and thermal maturity as shown is Figure 10. The total area of this play is 89 km^2 (13 km^2 for oil play and 76 km^2 for gas play). The entire play

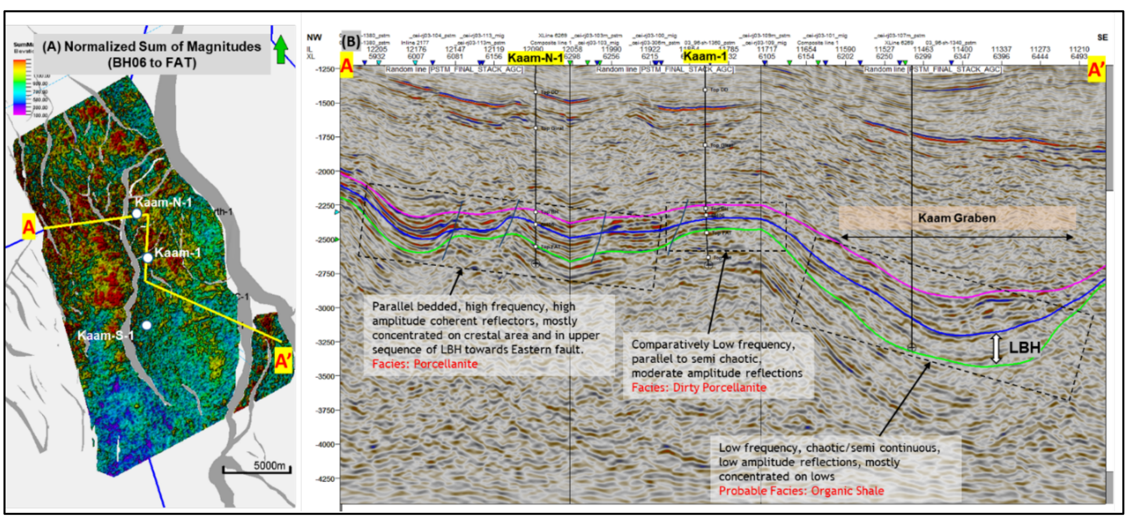

Figure 7: (a) Normalized Sum of Magnitudes map in the study area for the LBH interval, (b) Composite seismic section along A-A' showing the seismic facies variation in Kaameshwari area.

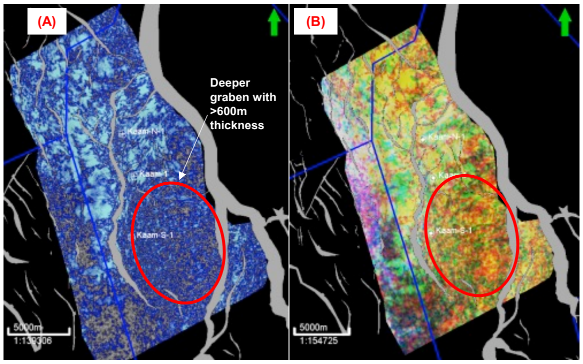

Figure 10: Amplitude of 20Hz frequency along a stratal slice in lower LBH, (b) RGB Spectral Blend in lower LBH

area is expected to be in a deep lake environment based on the seismic facies analysis and updated understanding of GDE in this study. During transgression, thick shale package deposited under anoxic conditions with organic-rich shale facies (ORS). Hence, the play area is subdivided into ORS-oil and ORS-gas play segments (Figure 11).

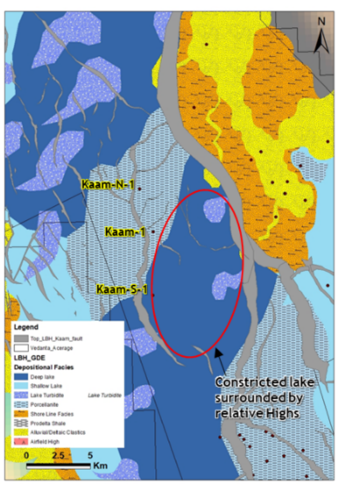

Figure 9: Gross Depositional Environment (GDE) map for LBH in the study area

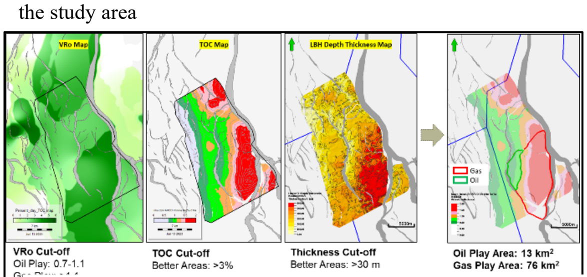

Figure 8: Play area demarcation using VRo, TOC and thickness maps.

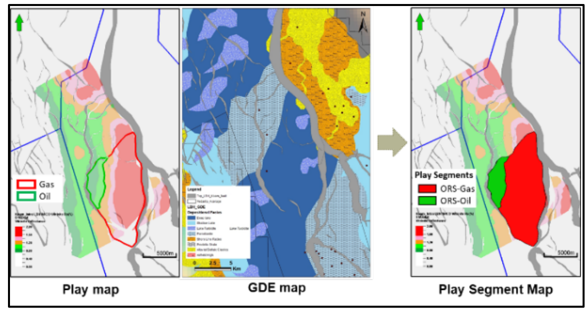

Figure 11: Play area subdivided into play segments based on GDE map.

Discussion: Target of Shale gas exploration

The Kaameshwari gas play segment is an attractive target for shale gas exploration. The source kitchen is close to the largest conventional gas discovery in the Barmer Basin, the Raageshwari Deep gas field. The source rock appears to have high source richness with thermal maturity in the wet to dry gas window. The play area has sufficient thickness but occurs at depths greater than 4000 m. The geological model suggests pure source rock organics rich shale. We need to identify global analogs for the target play segments to characterize and quantify the shale potential of LBH. Understanding from these analogs is important for predicting petrophysical parameters used in volumetric assessment, type curve analysis, well performance forecasting, and play development strategy. We have identified Haynesville shale as a valuable analog for pure source play occurring at similar depths (Table 1). The analog helps to fill the gap particularly due to the absence of direct well penetration; however, those potentials can only be derisked by drilling a pilot exploration well and data acquisition. This study helped define the play segment polygons that will provide the basis for volumetric assessment and finalizing pilot drilling locations for unconventional resource exploration in Kaameshwari graben. A discovery in the Kaameshwari graben would act as a play opener in the basin and would open opportunities for further shale gas exploration in the southern part of the Barmer Basin.

Conclusion

We used a play-based workflow integrating different geological, geophysical and petrophysical studies to delineate the prospective area for shale gas exploration in the Kaameshwari area. The main conclusions are

1. Kaameshwari graben have moderate to good source richness going into maturity of wet gas and dry gas window.
2. The expected lithofacies would be organic rich shale deposited in anoxic condition during the LBH transgression event.
3. Play and play segment mapping suggest a prospective area of 76 sq km of gas play, with 300 – 600 m gross thickness occurring at depth of 4000 – 5000 m

Table 1 Analog comparison table for the Kaam-ORS play ([1]Hammes et al. 2011; [2]Wang et al. 2013; [3]Spain and Anderson, 2010; [4]Stoneburner, 2010; [5]Klaver et al. 2015)

Parameters	Haynesville	Kaam LBH
Depth (m)	3000 - 4700 [1]	3500 - 5500
Thickness (m)	70 - 100 [1]	400 - 600
Reservoir Pressure (psi)	8000 - 17,000 [2]	*Expected High (as deep and hot)*
Pore Pressure gradient (psi/ft)	0.70 - 0.95 [2]	*High overpressure expected due to kerogen conversion and no uplift (increasing overpressure trend observed in updip wells with lower maturity)*
Temperature (°C)	127 - 221 [2]	185 - 220
Thermal Maturity (R_o)	1.25 - 2.30 [3]	*1.3- 2.4* (1.0 measured in Kaam - 1 at 3000 mSS)
TOC (wt.%)	3 (0.5 - 7) [4]	*3 (2 - 4)%*
Porosity (%)	11 (3 - 14) [4]	*Expected to be same as Haynesville (Analog based no direct offset data)*
Permeability (nD)	400 [4]	
Sw (%)	15 - 40 % [1,2]	
Depositional system	marine transgressive to highstand mudrocks within mixed carbonate-clastic depositional systems in a restricted basin [1]	Restricted deep anoxic lake, porcellanites in high
Lithology	Calcareous (near the carbonate platforms SW) to siliceous (near delta progrades. N and NE) organic-rich mudstone [1]	*Siliceous organic-rich mudstone (Sarl)*
Mineralogy	Carbonate, quartz and clay [1]	Quartz and clay
Pore (Storage) System	Mixed pore network with Organic hosted pores in solid bitumen to Interparticle clay-rich matrix pores [5]	*Organic hosted porosity*

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