Seismic-to-simulation an integrated approach to explore in a brownfield: A case study from Cambay Basin, India

Anoop Singh, Raman K. Singh, Ashok Arya & B. V. Bhushan
Oil and Natural Gas Corporation Limited, India

ABSTRACT

The GS-6 sand of Hazad member of Ankleshwar formation of Eocene age in Jambusar area of South Cambay Basin is deposited in lower delta plain environment. The main depositional features are channel sands and over bank deposits. Newly drilled exploratory & development wells gave surprising results in terms of reservoir sand thickness, indicating that the reservoir sand delineation is still a challenge in this area. Challenges were faced both in static and dynamic modeling in this field. While capturing the lateral heterogeneity of geological setup was main problem in static modeling, the water differential breakthrough behavior was posing a problem in dynamic modeling.

The thickness of GS-6 pack varies from 10 to 37 m in study area while GS-6 net sand thickness varies between 2 to 22m. The thicknesses of these sands are below resolution of available seismic data. The top and bottom of the sand is not distinguishable on seismic section, however its response is registered in seismic. The reservoir interval was calibrated on seismic through analysis of horizon slices & well to seismic tie. The sand geometry was delineated using average amplitude attributes & spectral decomposition analysis.

A seismic driven robust facies model was prepared by capturing the heterogeneity based upon the delineated sand geometry. The effective porosity was populated in the model taking guidance from seismic amplitude attribute. A good history match was achieved at well level and field level with new static model. Most of the issues faced in static and dynamic modeling were addressed.

Based on delineated GS-6 sand geometry, additional area beyond existing sand pinch-out limit was identified for further delineation. One development and one delineation well was drilled to test the new envisaged model. The thickness of reservoir facies at both the drilled wells was close to model prediction. On testing objects in GS-6 sand, both the wells flowed hydrocarbon, resulting in incremental hydrocarbon gain and additional reserve in this brown field.

INTRODUCTION

Jambusar field is located in northern part of Jambusar-Broach tectonic block of South Cambay basin, Gujarat. The study area falls in the south western part of Jambusar field (Figure 1). GS-6 sand

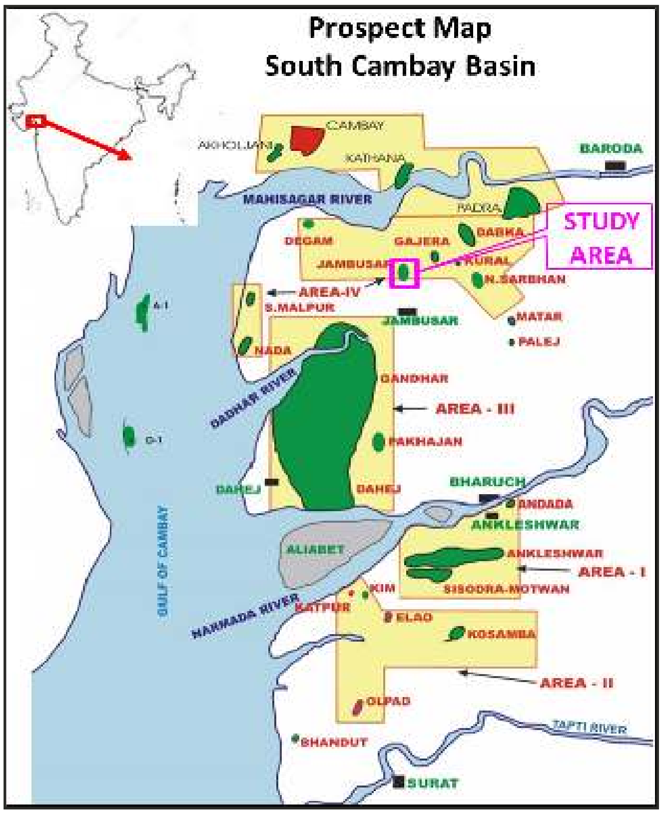

Fig. 1: Study Area

is most prominent and spread all over Jambusar field. Hydrocarbon accumulation in this sand is distributed in five different blocks. Block of Well F-P is currently the main producing areain GS-6 sand (Figure 2).

The GS-6 sand is deposited in a deltaic environment within Hazad member of Ankleshwar formation as distributary channel and over bank deposits. The EW profile showed in Figure 3 shows the structural disposition and variation of reservoir facies & thickness variation in E-W direction. Wells drilled in channel part are having thick development of GS-6 sand while wells drilled in splay/ bar area shows less thickness for GS-6 sand.

In the past, attempts have been made to delineate these sand bodies through seismic attribute analysis, seismic inversion studies and geo cellular modeling to understand the heterogeneity of complex geological setup (Bisht B.S. et al., 2013, Rath J. B. et al., 2013, Singh S.K. et al., 2013). Newly drilled wells gave surprising results in both exploratory and developments wells in terms of reservoir thickness. It indicates that the delineation of sand is still a challenge in this area for placement of development and delineation wells.

The differential water breakthrough behavior in wells at structurally same level ie U & T, S & O and Q & N (Figure 2) could not be explained with existing sand geometry, Water breakthrough was early in wells U, S & Q situated towards eastern side at same structural level compare to well-T, O & N. The better production performance of well-M compared to R (Figure 2) also suggests that there may be more GS-6 pay sand area beyond existing GS-6 sand pinch-out limit towards north-west of well-M supporting the production from this well.

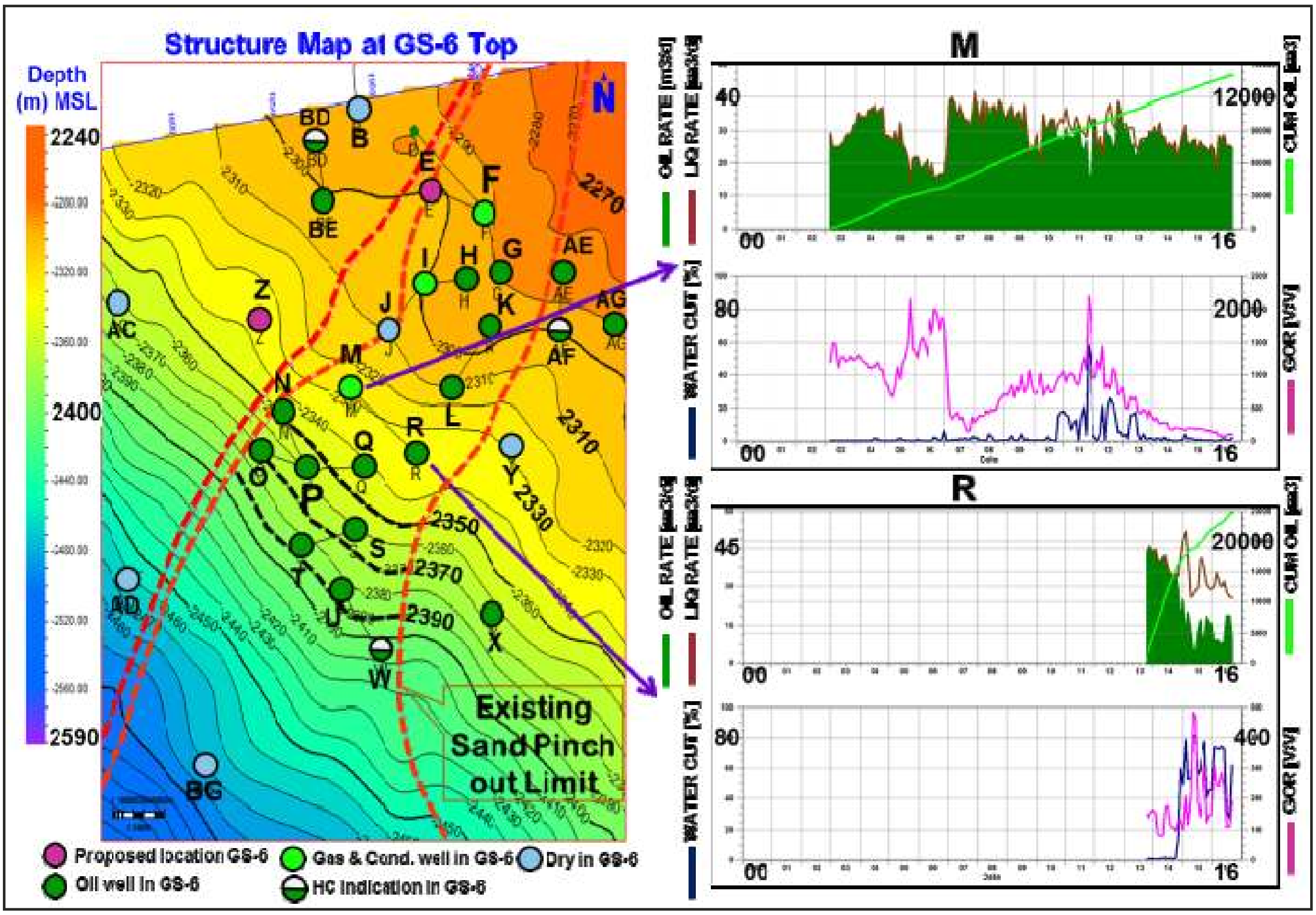

Fig. 2: Water Breakthrough Behavior in F, P Block wells & Production Performance of well M&R

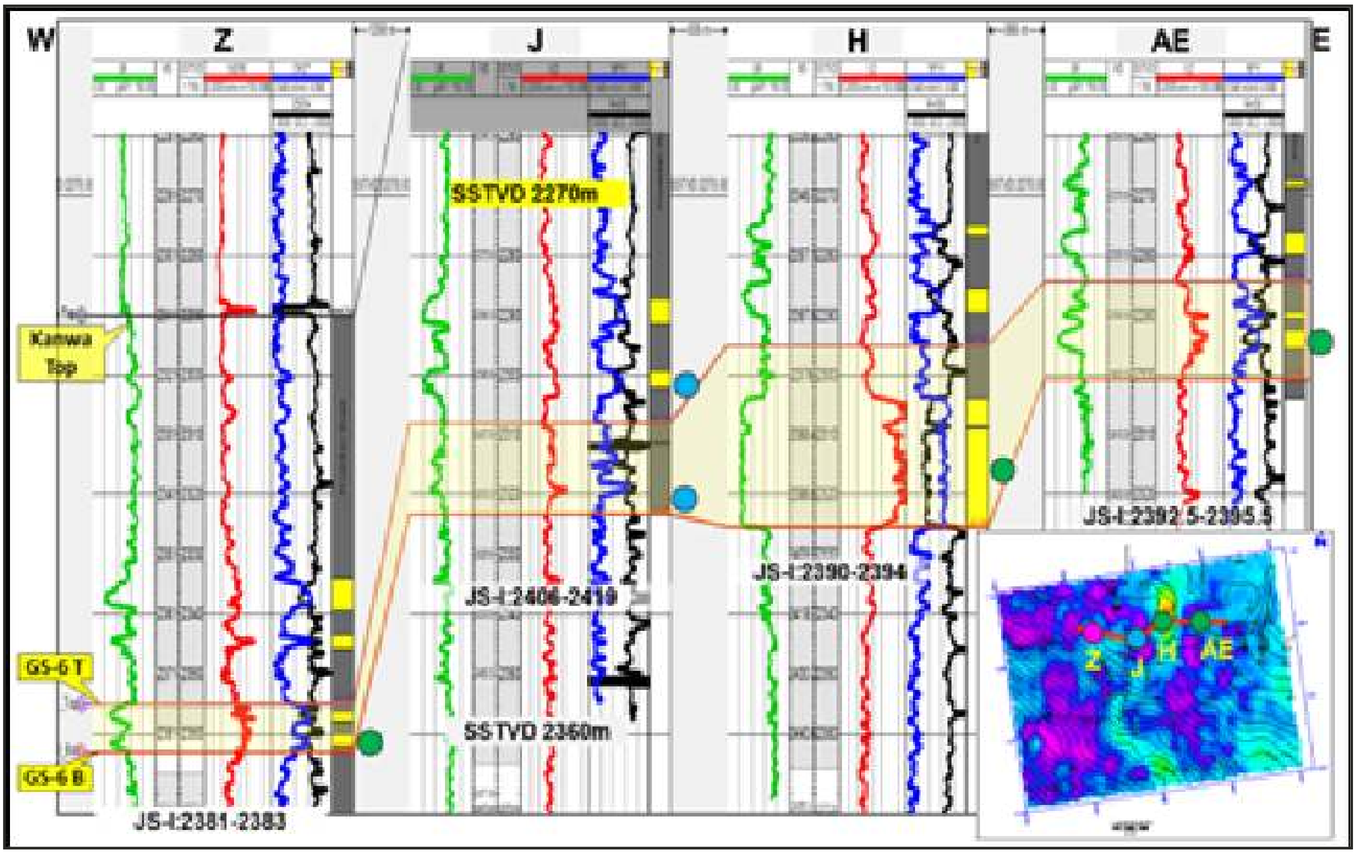

Fig. 3: EW Log Correlation along Wells Z, J, H & AE

The thickness of GS-6 pack varies from 10 to 37 m in study area while GS-6 net sand thickness varies between 2 to 22m. This sub seismic resolution thickness of GS-6 sand poses a challenge in delineation of GS-6 sands in this area. Even though the top and bottom of reservoir is not distinguishable on seismic section, effort has been made to captured the response of these sands in seismic through attribute study.

In view of the above observation an integrated study approach from seismic to simulation was taken up to delineate the GS-6 sand geometry to address the issues faced in static and dynamic modeling.

METHODOLOGY

Seismic Attribute Analysis and Spectral Decomposition study

As per polarity convention of seismic data used for study an increase in acoustic impedance has been recorded as negative amplitude and plotted as trough on seismic section whereas decrease in impedance is recorded as positive number and plotted as peak in seismic section. It has been observed that Hazad Top (increase in acoustic impedance) corresponds to trough in seismic data.

Synthetic seismograms were prepared for key wells. A representative synthetic seismogram of well-T is shown in Figure 4 showing the calibration with seismic data. The top of the Hazad Member is calibrated and mapped with good confidence. The depth map at Hazad top is shown in Figure 5. Taking reference from Hazad Top reflector the reflector close to GS-6 pack bottom is also mapped.

As shown in frequency spectrum in Figure 6, peak frequency in the zone of interest is 32Hz $\lambda/4$ is ~22m (V_{int} = 2850m/s). The thickness of GS-6 pack varies from 10 to 37 m in study area while the effective sand thickness of GS-6 sand varies between 2-22m in study area. Top and bottom of the

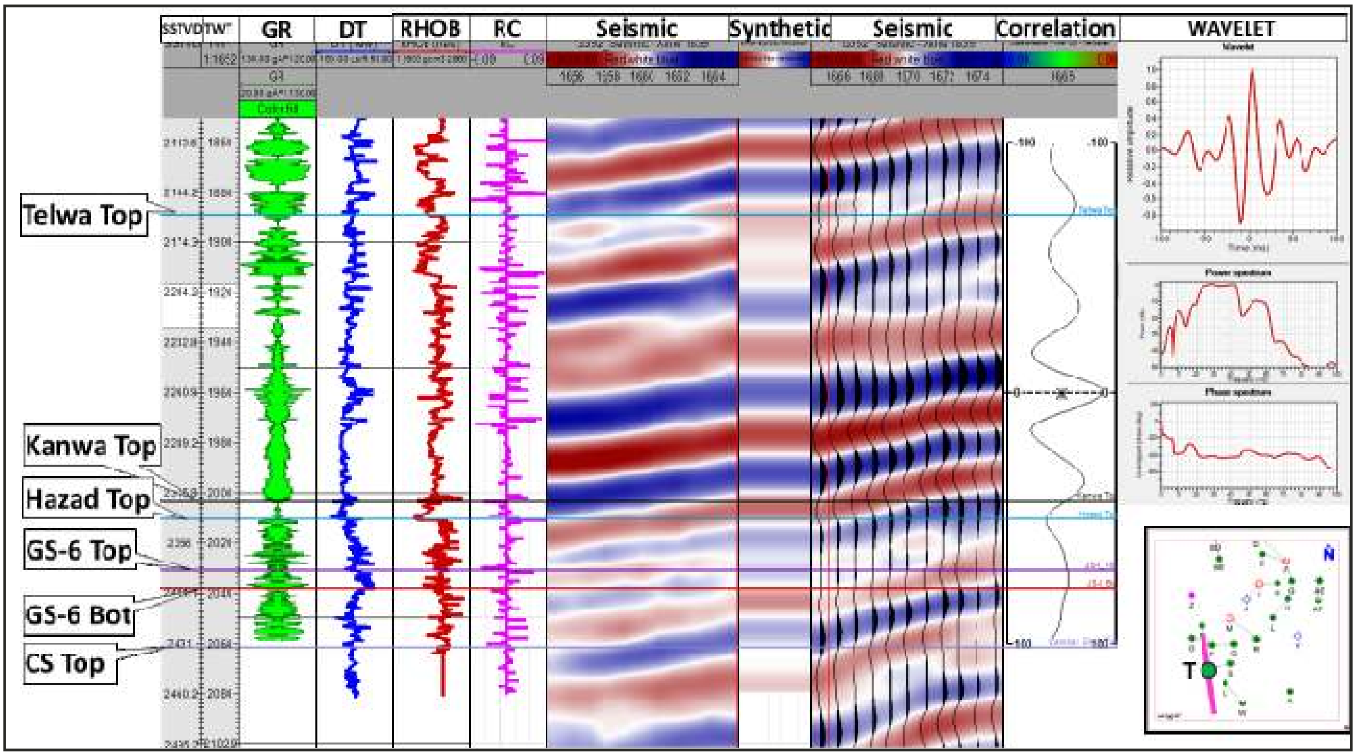

Fig. 4: Synthetic Seismogram of Well-T

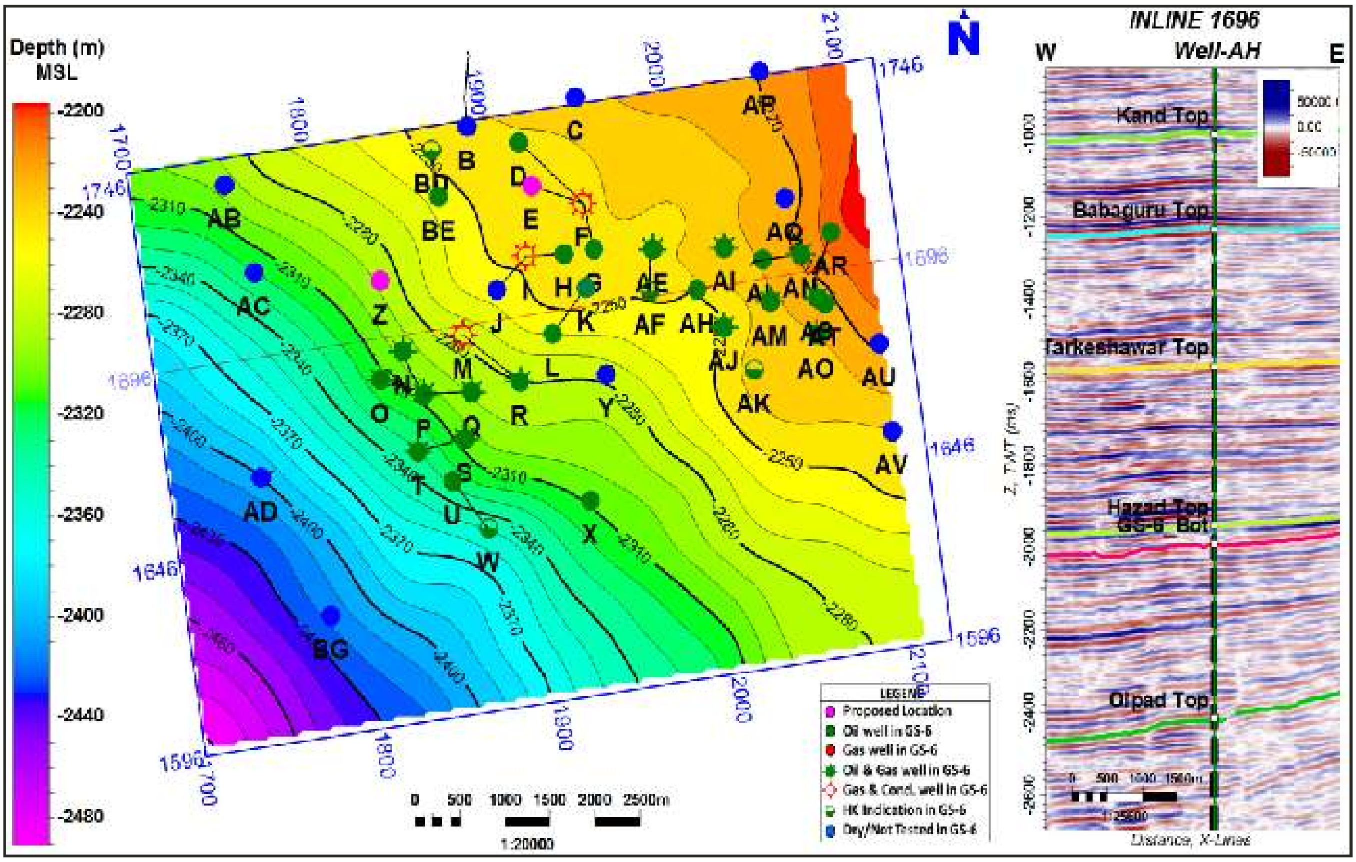

Fig. 5: Depth Map at Hazad Top

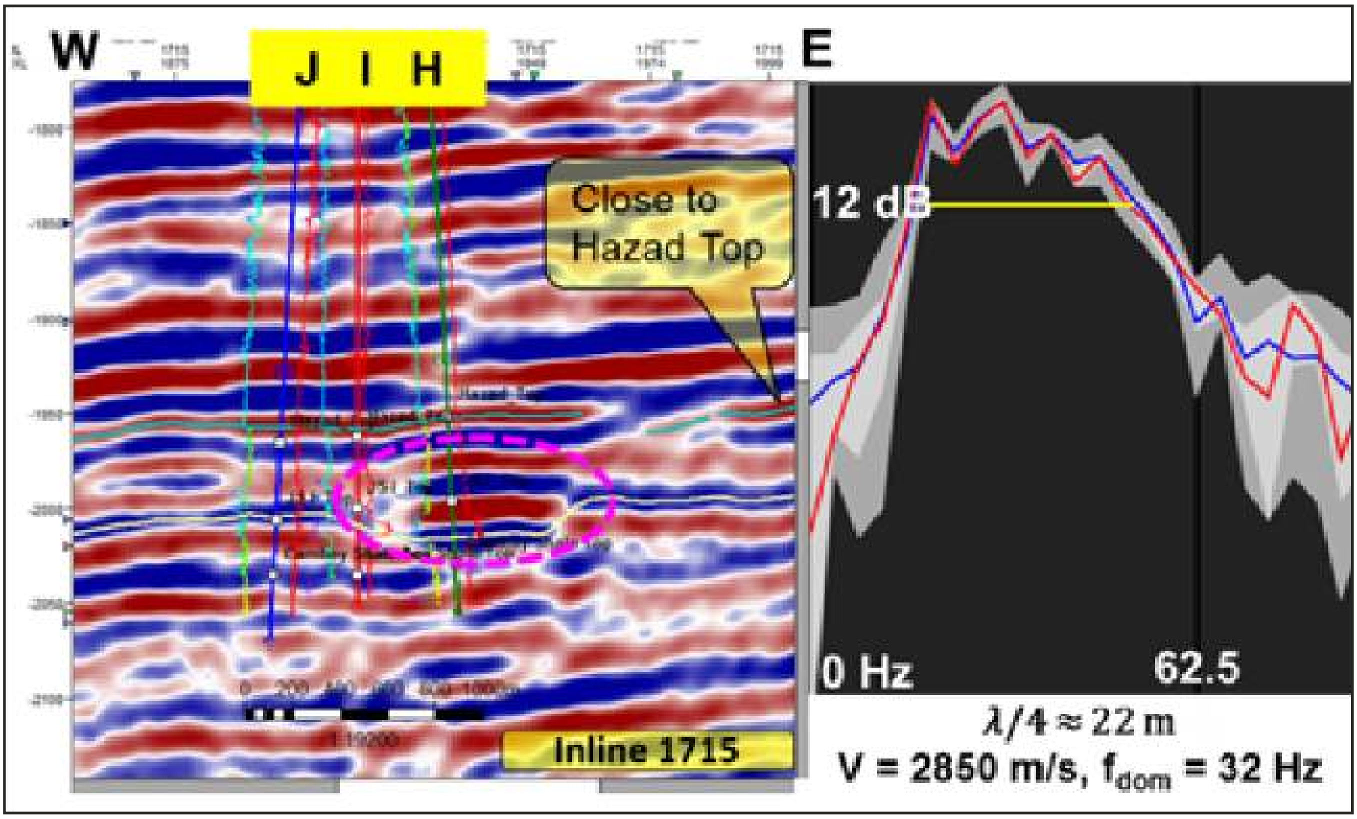

Fig. 6: Frequency Spectrum of Seismic Data in Zone of Interest

reservoir is not resolved by available seismic data except near well-H where the thickness of GS-6 sand is ~22 m. However response of these sands is registered in composite seismic reflection, studying the response may help in delineating such sand bodies (Anoop Singh et al., 2015). In study area the effect of development of these sand units in seismic has been studied by generating average amplitude attribute maps & using spectral decomposition method.

The confidence level in mapping the reflector close to Hazad Top is very good and the structural setup of GS-6 Top is similar to Hazad Top (the area is gently dipping towards S-W with dip <5°), hence seismic cube was flattened using horizon close to Hazad Top. As the construction of horizon slice amount to reconstruction of a depositional surface (Alistair Brown, 2011), the study of horizon slices within GS-6 pack, flattened close to Hazad Top was analyzed for GS-6 pack. One such horizon slice from within GS-6 pack (50ms below Hazad Top) is shown in Figure 7a, clearly showing the impression of distributary channel in the central part of the study area. Horizon slice from variance cube (50ms below Hazad Top) also brings out the edges of distributary channel as shown in Figure 7b. It indicates that the horizon slice is from within GS-6 pack as the same distributary channel has been interpreted in log response of well-H drilled in this area as shown in the log correlation profile in Figure 3.

Spectral decomposition and RGB color blending was used to study and interpret the response of thin sand bodies to bring out the GS-6 sand geometry in the study area. Three iso frequency cubes (20, 30 & 40Hz) had been used for RGB blending in Horizon probe prepared close to GS-6 top horizon. A distributary channel in the central part and other facies like bar/crevasse splay & point bar had been interpreted by integrating with log response of drilled wells as shown in Figure 8. The log signature of wells located in main distributary channel (well-H), in crevasse splay part (well-M)

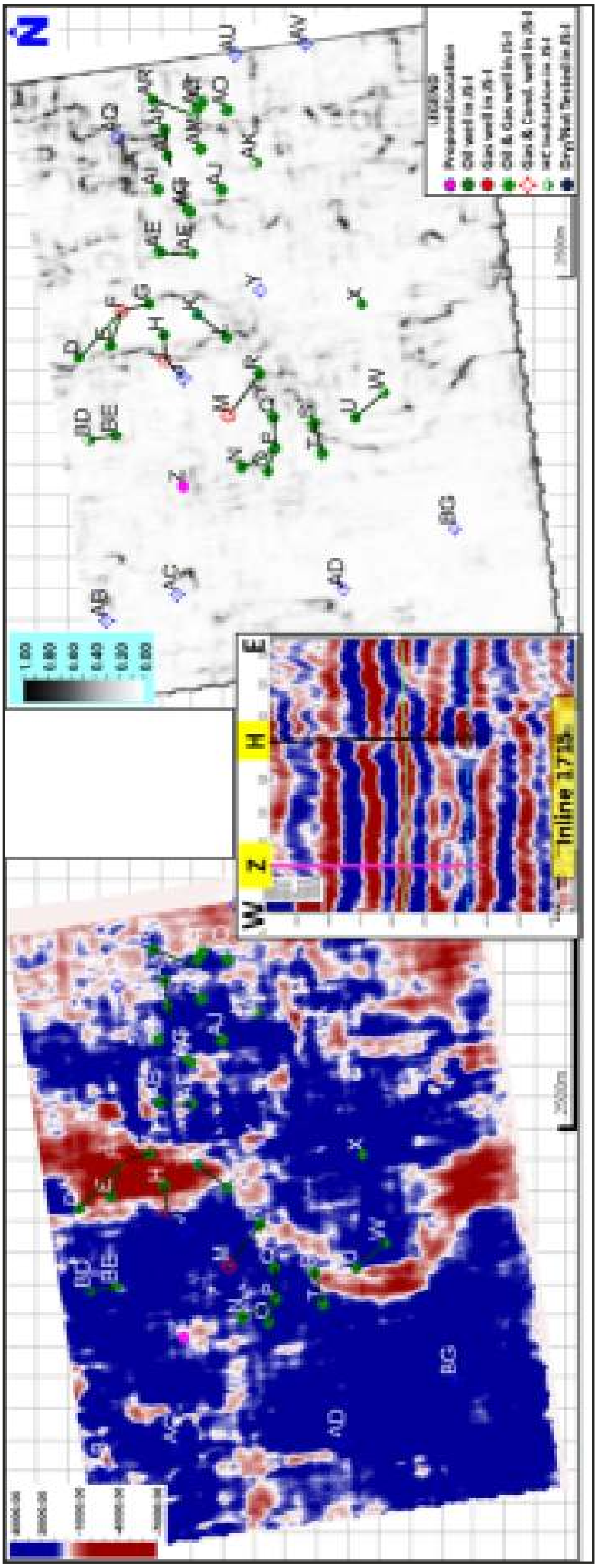

Fig. 7: Horizon Slice 50ms below Hazad Top (within GS-6 Pack) from **(a)**Seismic Cube and from **(b)** Variance Cube (Flatten close to Hazad Top)

and in point bar (well-W) corroborate with the interpreted reservoir facies from spectral decomposition study.

For window based attribute analysis, a window of 10ms above GS-6 pack bottom was optimized to capture the seismic response of GS-6 sand in seismic attribute analysis. Average amplitude had been extracted in a window of 10ms above GS-6 pack bottom reflector is shown in Figure 9. The low amplitude ranges (plotted in hot colors) brings out the geometry of GS-6 sand in the study area.

Calibration of Seismic Attribute

To calibrate the sand geometry sand/shale percentage map at drilled well locations was prepared for GS-6 pack and superimposed on envisaged sand geometry from attribute study. As shown in figure 10 it corroborates the envisaged sand geometry. The reservoir thickness encountered in drilled wells plotted against seismic attribute amplitude also shows a very good correlation (~72%) as shown in Figure 11 with some outlier, which were ignored to prepare a representative probability map. Using this correlation, the average amplitude map had been converted to 2-D sand probability map to prepare a trend for facies population during facies modeling. This map was further cross checked and calibrated with the thickness of GS-6 encountered in drilled wells. Sand isolith map of GS-6 pack had been prepared using sand probability map and the thickness of GS-6 sand encountered in wells drilled in study area as shown in figure 12.

Geocellular Modeling & History Match

To validate the delineated GS-6 sand geometry through history match, geocellular model was prepared. To prepare geologic conceptual

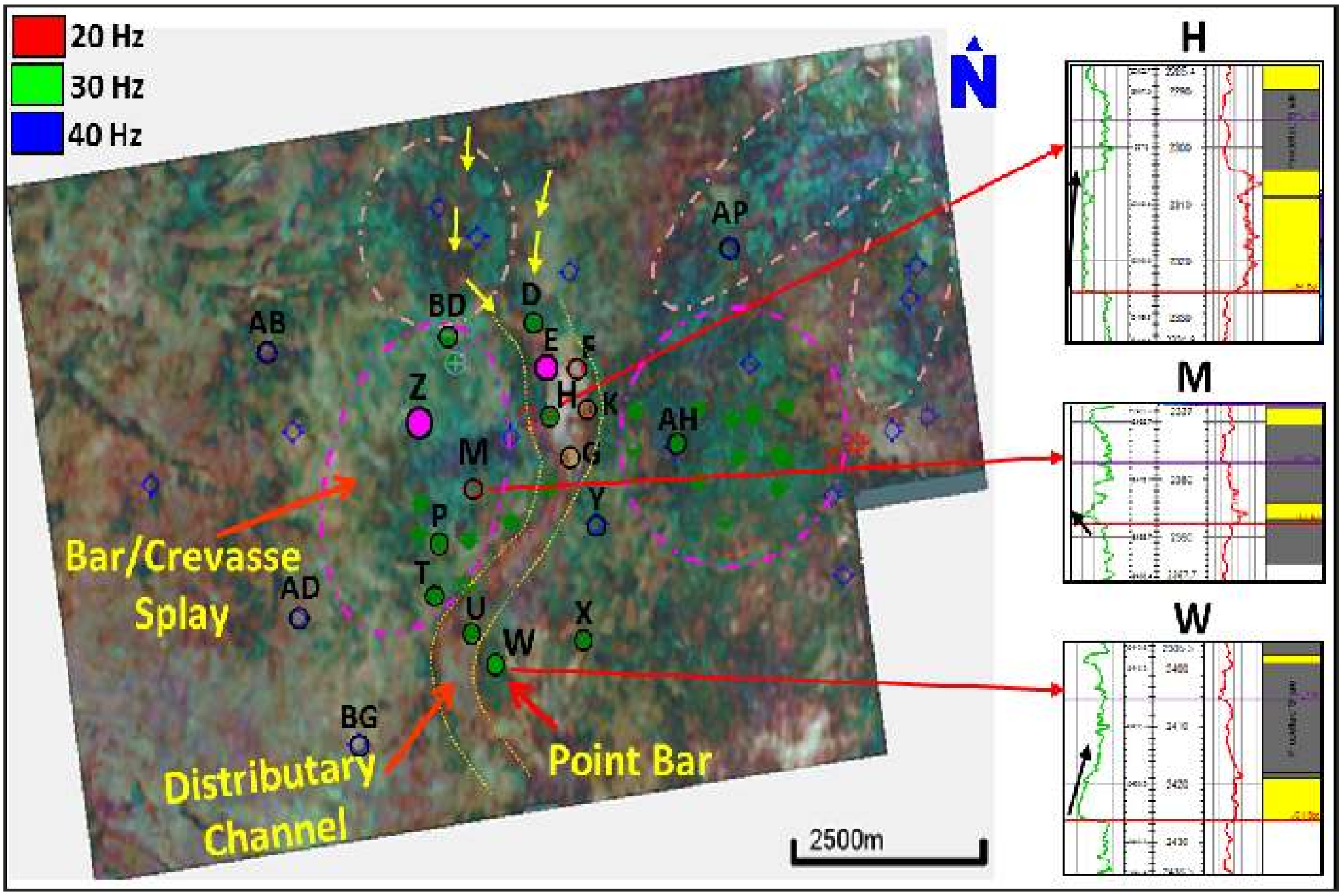

Fig. 8: Spectral Decomposition with RGB Blending (20, 30 & 40 Hz)

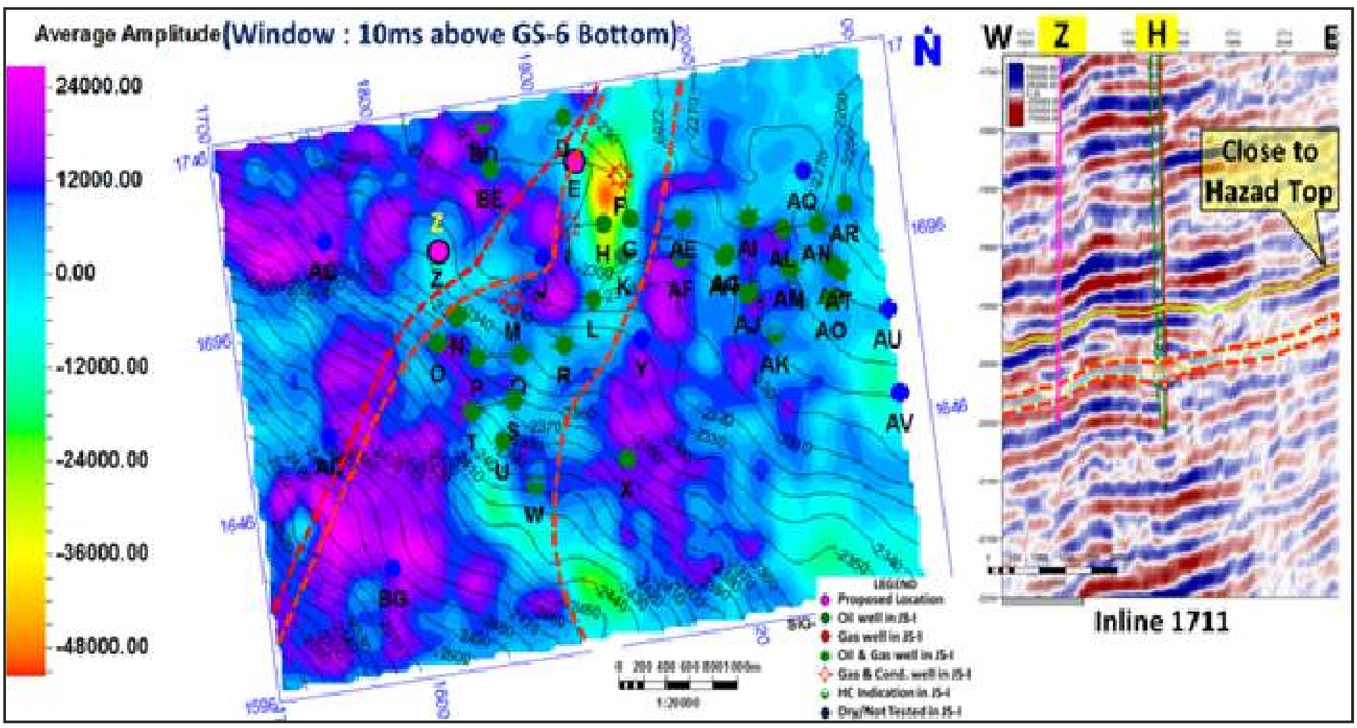

Fig. 9: Average Amplitude Attribute Map with Depth Contour at GS-6 Top

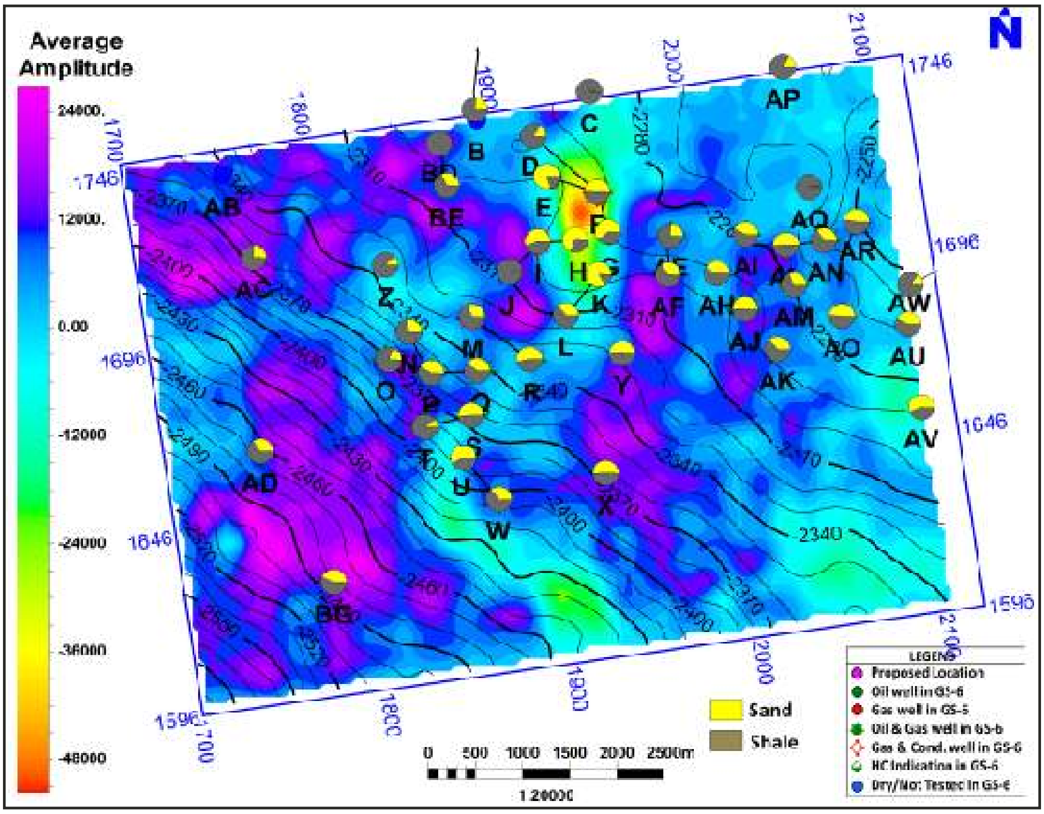

Fig. 10: Sand-Shale Percentage Map of GS-6 at Drilled Well Locations Pack Superimposed on Attribute Map

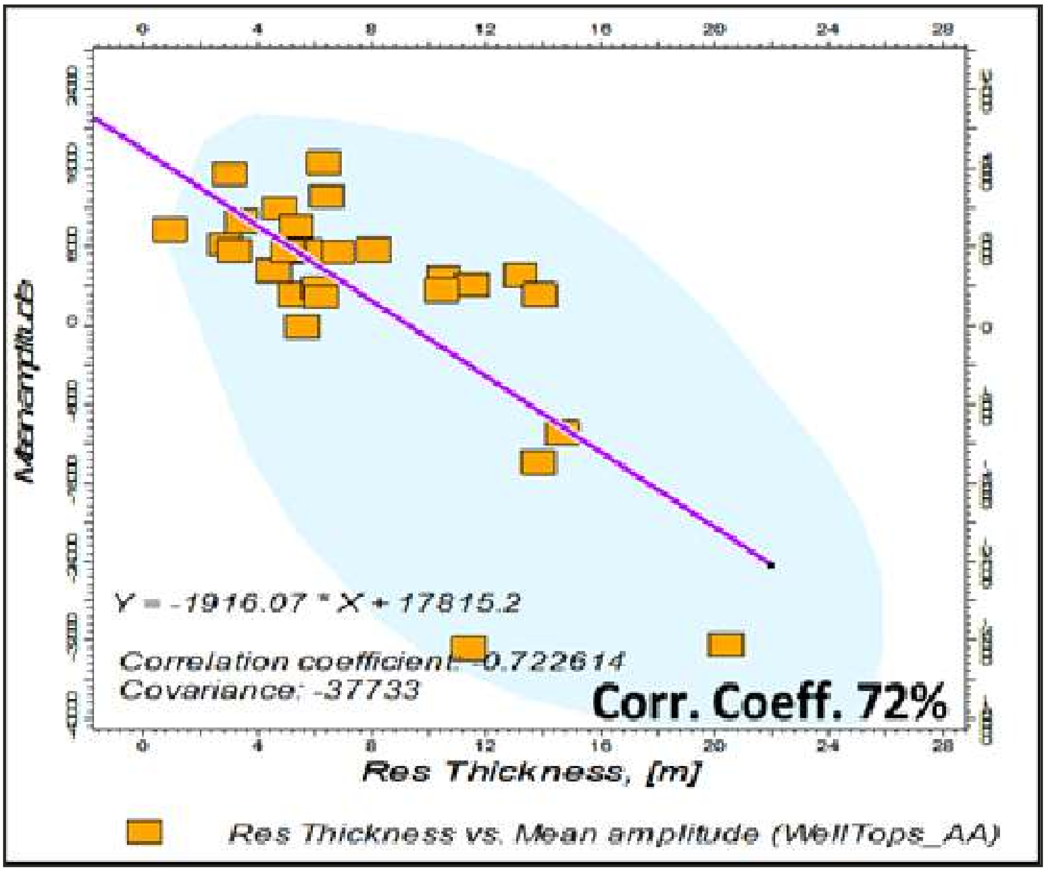

Fig. 11: Cross plot between Reservoir Sand Gross Thickness vs. Average SeismicAmplitude

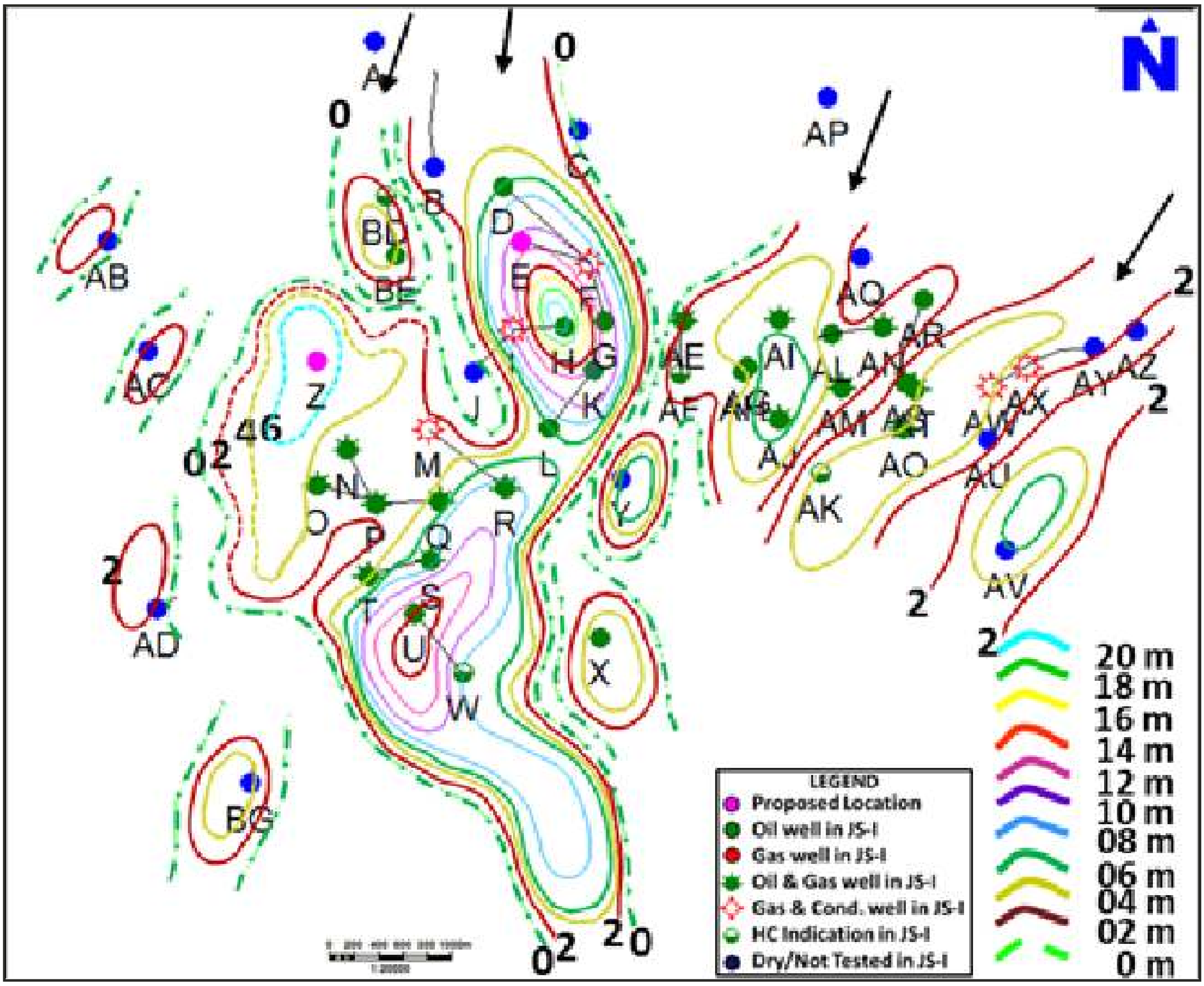

Fig. 12: Sand Isolith Map of GS-6 Sand in Jambusar Field

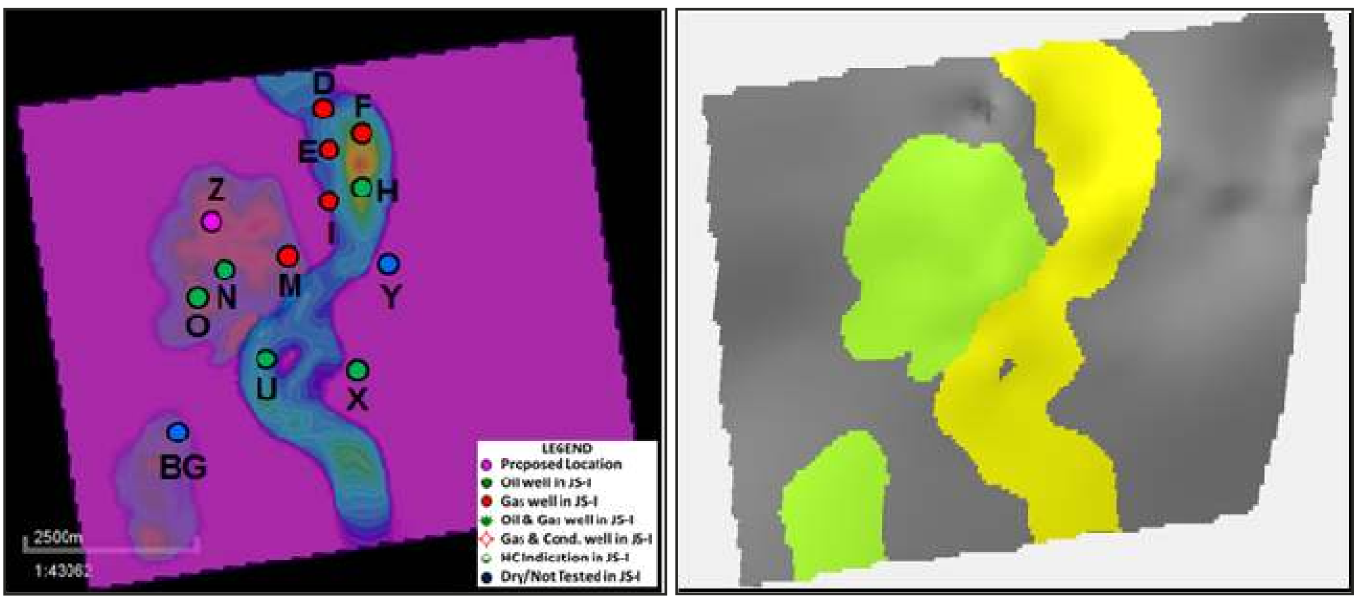

Fig. 13: **(a)** Sand Probability Map prepared from Average Amplitude Attribute **(b)** Training Image Prepared from Average Amplitude Attribute Map

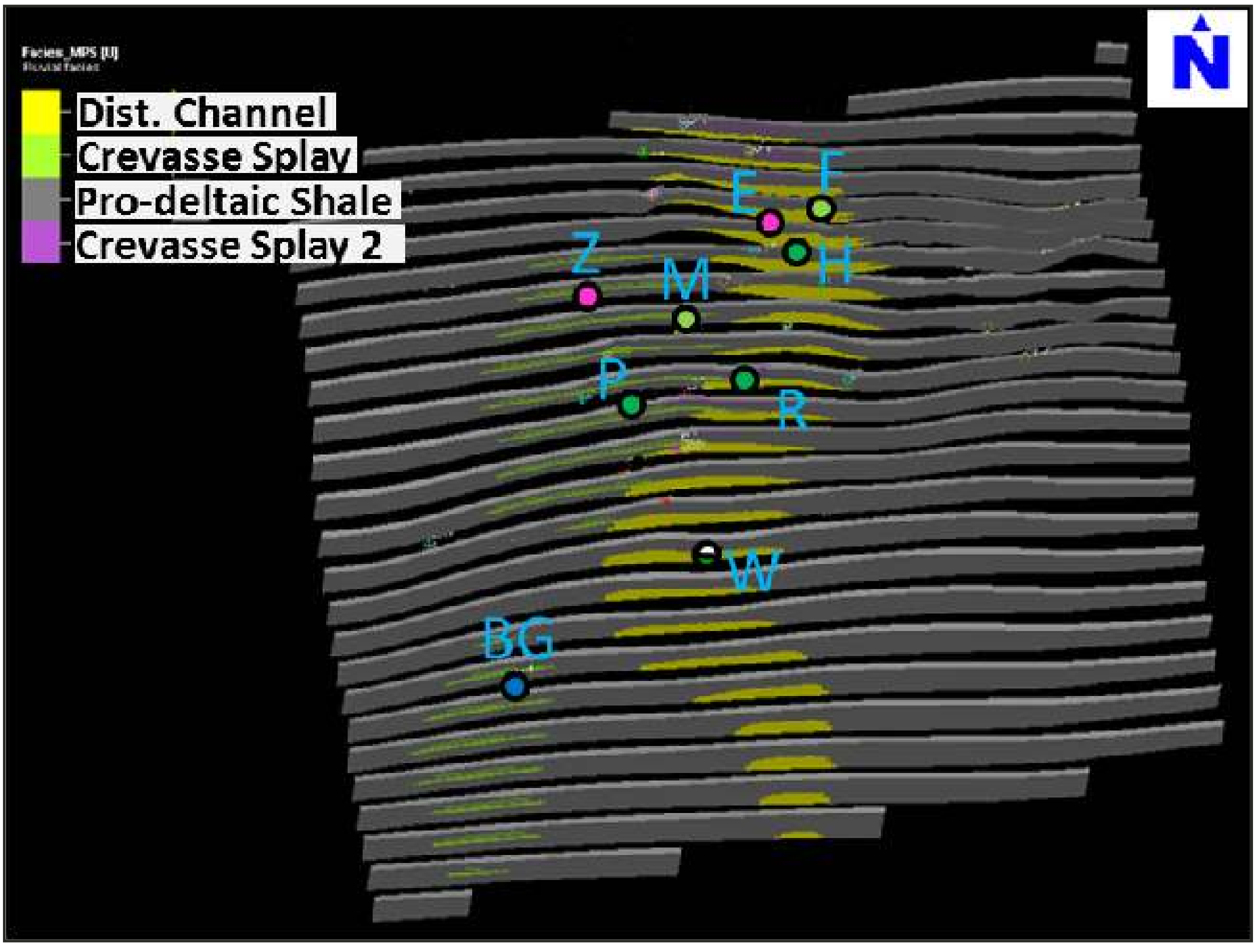

Fig. 14: Geocellular Model Prepared using Multi Point Simulation Method

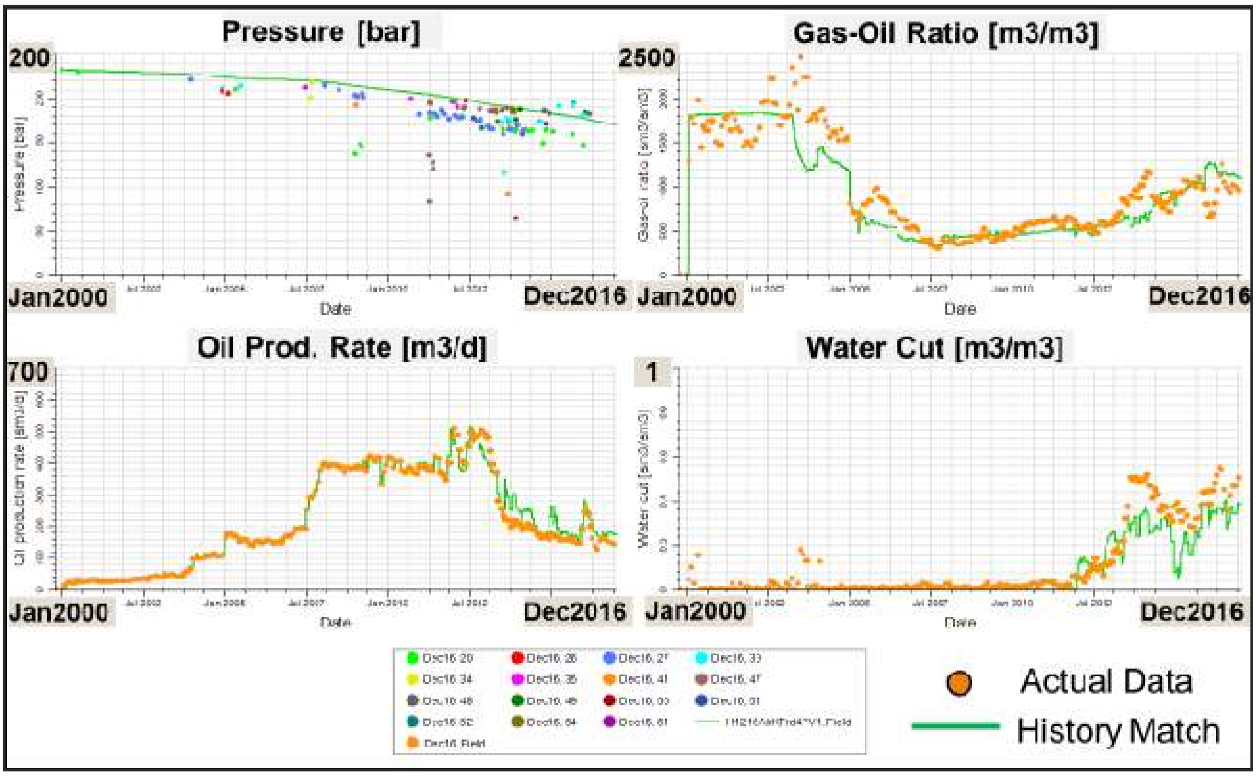

Fig. 15: History Match at Field Level for Well F, P Block with Delineated Sand Geometry of GS-6 Sand

model consistent with seismic and log data multipoint statistical (MPS) simulation method (Colin Daly et al., 2010, Laetitia Macé, 2015) of facies modeling was used. 2-D seismic average amplitude attribute along with vertical proportion curve from well data was used to generate 3-D probability trend (Figure 13a) and a training image was prepared from average amplitude attribute map for use in MPS simulation method (Figure 13b). A good correlation was observed between effective porosity and average amplitude attribute from seismic. The porosity was populated using 3-D probability trend generated using seismic amplitude attribute.

The geocellular model prepared for GS-6 sand is shown in figure 14. With the updated sand geometry the GOC, OWC & aquifer direction was updated and agood history match (Figure 15) was achieved for this block. The production behavior of well-M with respect to well-R is explained as addition area towards NW of this well is supporting the production of this wells. The water breakthrough in wells towards eastern part drilled in the distributary channel is early compared to wells drilled at same structural level in crevasse-splay/bar towards western part. (Figure 2).

CONCLUSION

The seismic to simulation approach through integration & interpretation of multi-disciplinary data helped in delineation of the GS-6 sand geometry. The differential water breakthrough in wells towards eastern part drilled in the distributary channel is early compared to wells drilled at same structural level but in crevasse-splay/bar towards western part. One delineation Well-Z was drilled to probe the additional area mapped towards north-west of well-M, outside existing sand pinch-out limit of GS-6 sand. One development well-E was also drilled based on the reservoir simulation study. The thickness of reservoir facies at both the drilled wells was close to model prediction which proved the predictability of the geocellular model. On testing objects in GS-6 sand, both the wells flowed hydrocarbon.

The integration of static and dynamic modeling in this study leads to better understanding the sub-surface. It helped in addressing the challenges in static and dynamic modeling challenges and resulted in incremental hydrocarbon gain and additional reserve in this brownfield.

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