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Seismic to Simulation, an integrated approach to explore in a mature field – A case study from Jambusar Field, Cambay Basin.

Abstract

The GS-6 (JS-1) sands of Hazad member of Ankleshwar formation in Jambusar area of Cambay Basin is deposited in deltaic environment. The main depositional features are channel sands and over bank deposits. Earlier attempts have also been made by other workers to characterize these sands for exploration and development. Newly drilled wells gave surprising results in both exploratory and developments wells and indicates that the delineation is still a challenge in this area. Issues were faced both in static and dynamic modeling in this field.

The main challenge in delineating these sands using seismic is to calibrate the reservoir interval. After calibrating the top and base of the reservoir, the reservoir sand geometry was delineated using spectral decomposition and average amplitude attributes. The seismic attribute was calibrated with the thickness of reservoir facies encountered in drilled wells in the study area.

A robust facies model using multi-point facies simulation method was prepared by capturing the heterogeneity based upon the new delineated sand geometry. The effective porosity was populated in the model guided by seismic amplitude attribute. A good history match was achieved at well level and field level with the static model. Most of the issues faced in static and dynamic modeling had been addressed.

New area for exploration was identified based on delineated geometry. One development and one exploratory well were drilled to test the new envisaged model. . The thickness of reservoir facies at both the drilled wells was as per model prediction and on testing objects in GS-6 sand, both the wells flowed hydrocarbon, adding incremental gain and additional reserve in this mature Jambusar field.

Introduction

The study area falls in the south western part of Jambusar field of Cambay basin, Gujarat (**Figure1**). GS-6 sand is most prominent and spread all over Jambusar field. Hydrocarbon accumulation in this sand is distributed in five different blocks. In GS-6 sand, Block of *Well F, P* currently the main producing area (**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 variation of reservoir facies and 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.

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) However new drilled wells gave surprising results in both exploratory and developments wells and indicates that the delineation is still a challenge in this area.

Further the 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*.

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 20m. To properly delineate the reservoir sand using seismic, calibrating the top and base of the reservoir is utmost important. The total pack thickness of GS-6 is below /4 resolution limit of seismic except near *well-H* where thickness is ~ 20m. This typical disposition of GS-6 sand poses a challenge in delineation of GS-6 sands.

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.

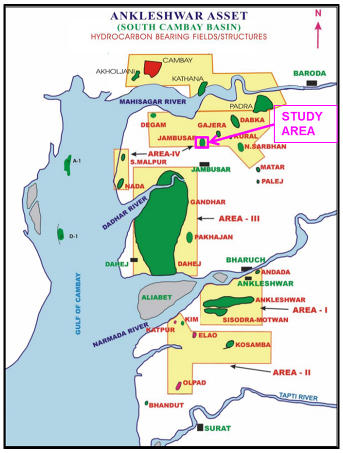


Figure 1. Study Area

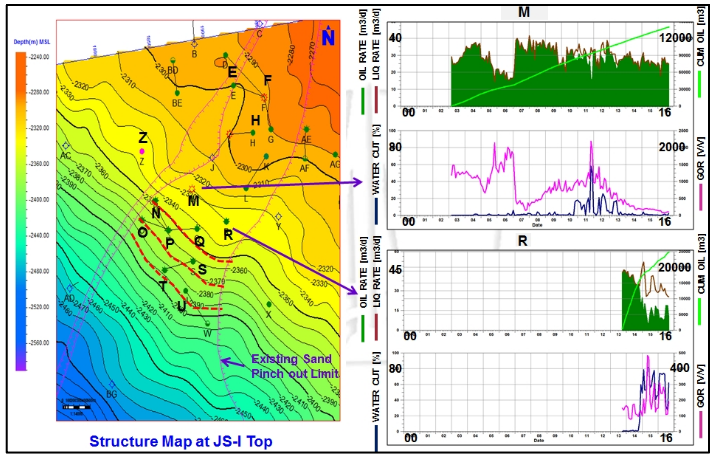


Figure 2. Water Breakthrough Behavior in *F*, *P* Block wells & Production Performance of *well M* & *R*

Methodology

Seismic Attribute Analysis and Spectral Decomposition study

As shown in frequency spectrum in **Figure 4,** peak frequency in the zone of interest is 32Hz and /4 is ~22m (V_{int} = 2850m/s).The effective sand thickness of GS-6 sand varies between 2-22m in study area. Seismically the individual sand units are below resolution except near *well-H* where the sand thickness of GS-6 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 studies by generating average amplitude attribute maps & using spectral decomposition method.

As per polarity convention used in ONGC an increase in acoustic impedance has been recorded as negative amplitude (plotted as trough). It has been observed that Hazad Top (increase in acoustic impedance) corresponds to trough in seismic data. The pay sands within Hazad are the main target from Hydrocarbon point of view however the thickness of individual sand are below seismic resolution limit except near *well-H* where the sand thickness of GS-6 sand is ~22m. Synthetic seismograms were prepared for key wells. A representative synthetic seismogram of *well-T* is shown in **Figure 5a**. The top of the Hazad Member and GS-6 sand bottom are calibrated and mapped with good confidence (**Figure 5b**).

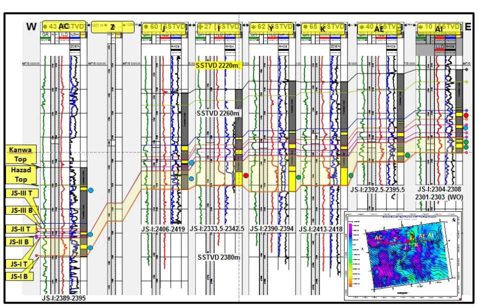


Figure 3. EW Log Correlation along *Wells AC, Z, J, I, Y, K, AE & AI*

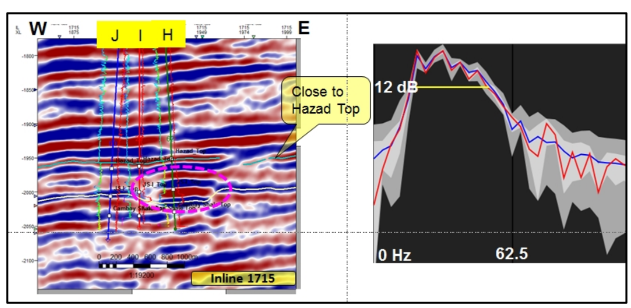


Figure 4. Frequency Spectrum of Seismic Data in Zone of Interest

Since the confidence level in mapping the reflector close to Hazad Top is very good, the area is gently dipping towards S-W (dip <5°) and there is no much structural variation at Hazad Top & GS-6, hence seismic cube is flattened using horizon close to Hazad Top to study the horizon slices within GS-6 pack. It helped in study the seismic response of GS-6 sand also the construction of horizon slice amount to reconstruction of a depositional surface (Alistair Brown, 2011). Study of horizon slices and *well-H* is used to calibrate the top and bottom of GS-6 reservoir pack.

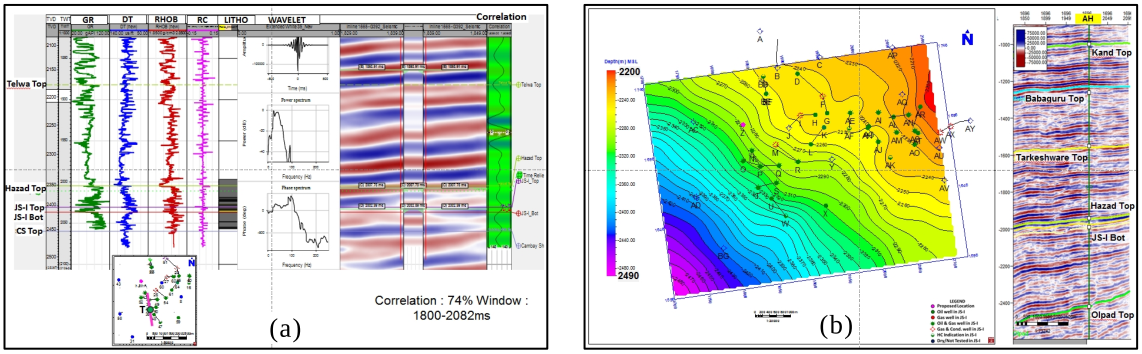


Figure 5. **(a)** Synthetic Seismogram of *Well-T* **(b)** Depth Map at Hazad Top

Horizon slices from the flattened seismic cube were studied for seismic response of GS-6 sand within GS-6 pack. One such horizon slice within GS-6 pack @2060ms (**Figure 6a**) clearly shows the impression of distributary channel in the central part of the study area within GS-6 pack as seen in variance cube also (**Figure 6b**). It indicates that the horizon slice is from within GS-6 pack as the same distributary channel has been interpreted in log response of wells drilled in the central part of the area as shown in the log correlation profile (**Figure 3)**.

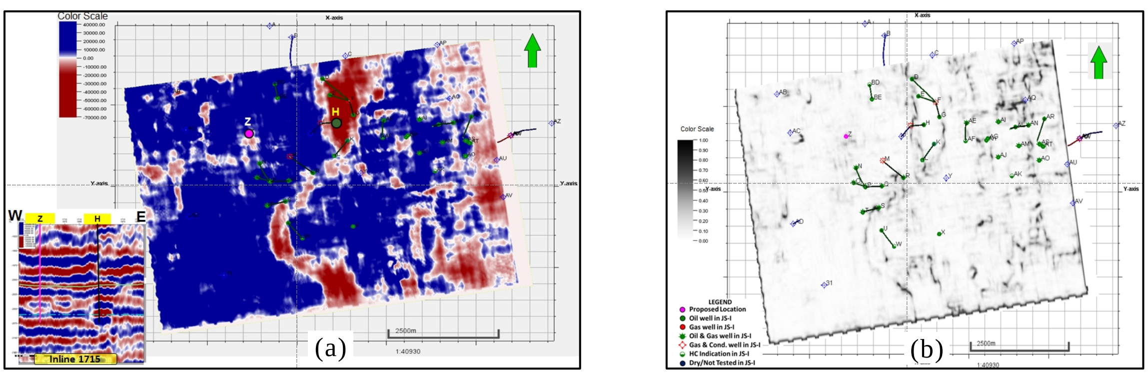


Figure 6. Horizon Slice @2060ms (within GS-6 Pack) from **(a)** Seismic Cube and from **(b)** Variance Cube (Flatten close to Hazad Top)

Spectral decomposition and RGB blending is also used to study the response of thin sand bodies and to bring out the GS-6 sand geometry in the study area. Three iso frequency cubes (20, 30 & 40Hz) have been used for RGB blending in Horizon probe prepared close to GS-6 top horizon. A distributary channel is seen in the central part of the study area and other reservoir facies like bar/crevasse splay & point bar could also be interpreted by integrating with log response of drilled wells in these areas. The log signature of wells located in main distributary channel (*well-H*), in crevasse splay part (*well-N*) and in point bar (*well-W*) also corroborate with the interpreted reservoir facies from spectral decomposition study (**Figure 7a & b**).

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 has been extracted in a window of 10ms from horizon close to bottom of GS-6 sand and the low amplitude ranges (plotted in hot colors) brings out the geometry of GS-6 sand in the study area (**Figure 8**). **Figure 9** shows the sand isolith map prepared taking into account the wells drilled in the area.

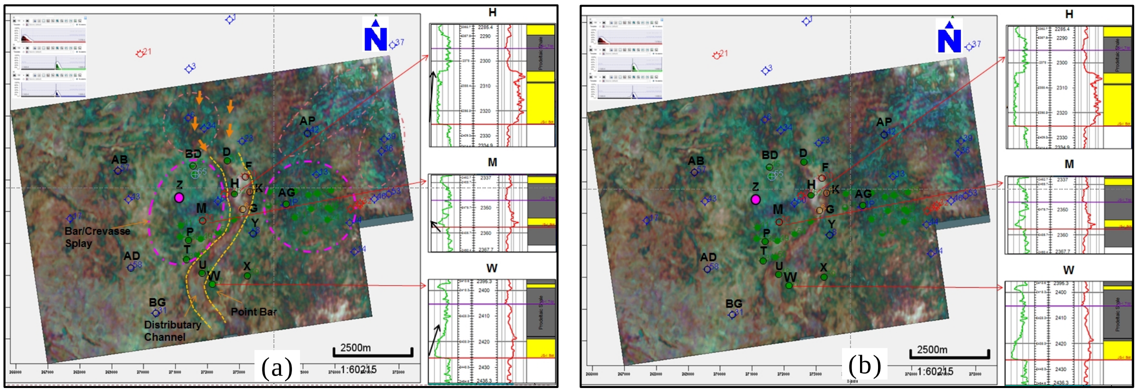


Figure 7. Spectral Decomposition with RGB Blending (20, 30 & 40 Hz) **(a)** Interpreted and **(b)** un-interpreted

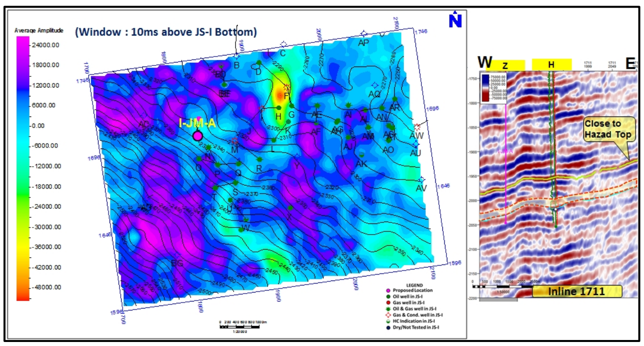


Figure 8. Average Amplitude Attribute Map with Depth Contour at GS-6 Top

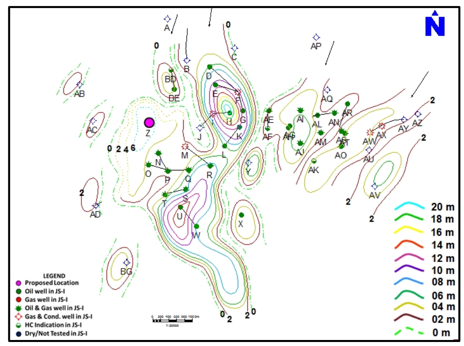


Figure 9. Sand Isolith Map of GS-6 Sand in Jambusar Field

Calibration of Seismic Attribute

To calibrate the sand geometry sand/shale percentage map 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 (**Figure 11**).

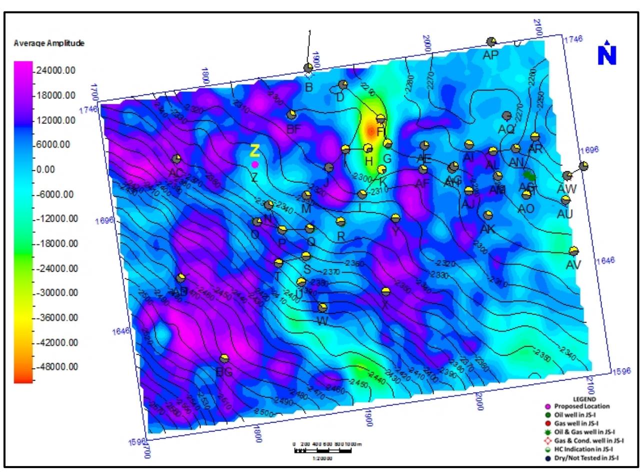


Figure 10. Sand-Shale Percentage Map of GS-6 Pack Superimposed on Attribute Map

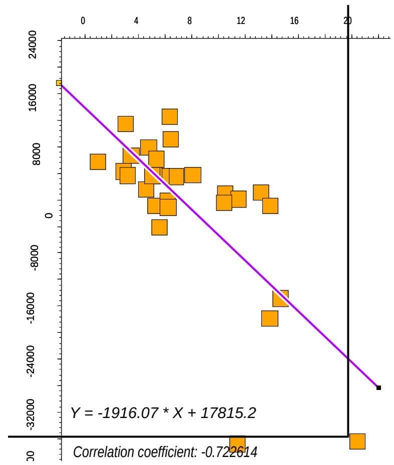
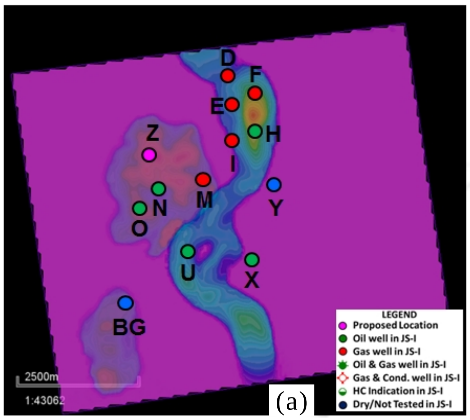


Figure 11. Cross plot between Reservoir Sand Gross Thickness vs Average Seismic Amplitude

Geocellular Modeling & History Match

For seismic consistent facies modeling multipoint statistical (MPS) simulation method (Colin Daly et al. 2010, Laetitia Macé, 2015) was used to prepare geologic conceptual model. Seismic average amplitude attribute was used as probability trend (**Figure 12a**) and a training image was prepared from average amplitude attribute map for use in MPS simulation method (**Figure 12b**). A goodcorrelation was observed between effective porosity and average amplitude attribute from seismic. The porosity was populated using seismic amplitude as secondary variable in collocated co-kriging.



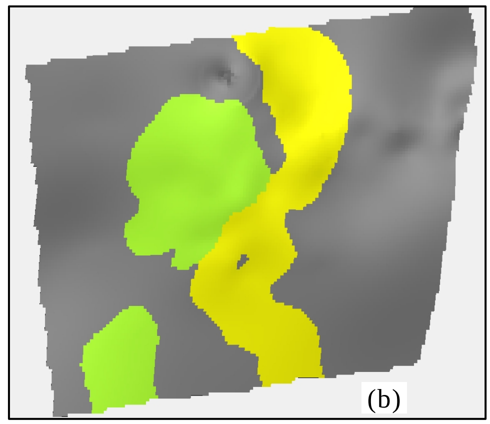
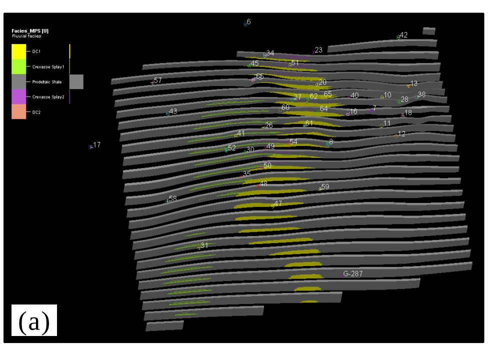


Figure 12. **(a)** Sand Probability Map prepared from Average Amplitude Attribute **(b)** Training Image Prepared from Average Amplitude Attribute Map

The Geocellular model prepared for GS-6 sand is shown in **figure 13 a**. A good history match (**Figure 13b**) had been achieved for this block and most of the static and dynamic modeling issues had been addressed. The production behavior of *well-M* with respect to *well-R* and water breakthrough behavior in well situated at structurally same level was also explained (**Figure 2**).

Additional area towards north-west of *well-M* outside existing sand pinch-out limit of GS-6 sand was identified for exploration. One exploratory *well-Z* and one development *well-E* was drilled to test the new model. The thickness of reservoir facies at both the drilled wells was as per model prediction and on testing objects in GS-6 sand, both the wells flowed hydrocarbon.



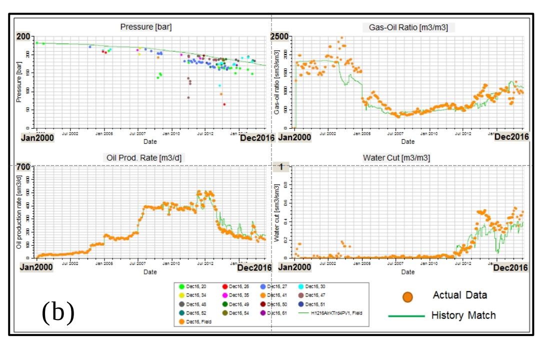


Figure 13. **(a)** Geocellular Model Prepared using Multi Point Simulation Method **(b)** History Match at Field Level for *Well F, P* Block with Delineated Sand Geometry of GS-6 Sand

Conclusion

In the present study calibrating the reservoir top and base while carrying out the reservoir characterization and then correlating the production performance of wells help significantly to further delineate the sand geometry. Spectral decomposition and average amplitude attribute study from seismic study brought out the GS-6 sand geometry in the study area.

This helps in preparing a robust geologically realistic Geocellular model using Multipoint statistical point simulation method of facies modeling. A robust Geocellular model in turn helps in achieving good history match. Through this study additional area for exploratory/appraisal location was identified. A development *well-E* and an exploratory *well-Z* were drilled to test the new envisaged model. The reservoir facies thickness encountered in both the wells validated the predictability of model. On testing object in GS-6 sand both the wells flowed hydrocarbon and further validate both the static and dynamic model.

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