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Application of quantitative interpretation for development of challenging reservoir in limestone formation of Rajasthan Basin, India

Abstract

Quantitative interpretation is an advanced analytical approach for find out reservoir body in challenging geological environment. This study is an integrated study which is collaboration of seismic and well log data. Hydrocarbon exploration and further development of in carbonate sequence is a challenging task due to abrupt velocity changes. Limestone section in Rajasthan basin is tight and less porous. These are immense limitations for exploration in this type of formation. In current study seismic inversion analysis and rock physics template study was carried out using one well data. The study was produced presence of sweet spot in limestone section which is probable reservoir location for hydrocarbon exploration in carbonate section of Rajasthan basin.

Introduction

Rajasthan basin is consisting with 3 major sub-basins – i) Bikaner-Nagaur sub-basin ii) Barmer-Sanchor sub-basin and iii) Jaisalmer sub-basin. Current study was carried out in the Jaisalmer sub-basin region. This sub-basin can be categorized under precratonic division (information published by Director General of Hydrocarbon). Jaisalmer sub-basin is surrounded by Shahgarh depression, Kishangarh shelf and Miajlar depression. Altough current study area is fallen between Shahgarh depression and Kishangarh shelf. As per geological setting the ages of sedimentary rock is from late Proterozoic to recent (information published by Director General of Hydrocarbon). Limestone section under Jaisalmer formation was deposited mostly under Jurassic age. There one well A which was drilled earlier in the current study area. Both the well was turned to be undiscovered well where well A was dry well and well B was water bearing. Geological setting of Jaisalmer sub-basin and petrophysical analysis of drilled well data along with drill cutting result was established that bright chances for hydrocarbon exploration in Jaisalmer limestone section. The study was carried out in Jaisalmer sub-basin area in Rajasthan. Jaisalmer limestone formation was selected for study of interest. Apart from Jaisalmer formation Goru, Pariwar, Baisakhi-Bedisar these are few formation which were encountered during drilling of drilled well A. Few sections of these formations were containing good porosity for maturation of hydrocarbon but in view of water saturation quantity these section were feasible for water bearing formation. Drilling result from well A was shown few traces of oil based on drill cuttings analysis and mild fluorescence cut in side wall core data from Jaisalmer formation. But this result is not encouraging for further exploration in Jaisalmer limestone section. This study was carried out for findings of possibilities of hydrocarbon in limestone section based one quantitative analysis. Petroleum system has already been established in Jaisalmer sub-basin area and proper geoscientific analysis for limestone section may lead to discovery of hydrocarbon from limestone section. Petrophysical analysis was established that acoustic impedance (AI) decreases with volume of clay with increasing depth. Estimation of porosity was not same for throughout carbonate section. Apart from Jaisalmer limestone the full Jaisalmer formation was cumulating of thin bedded formations with different lithology such as sandstone, siltstone and shale. Full Jaisalmer formation may be classified into three category – i) before build-up of carbonate formation ii) major carbonate formation and iii) after build-up of carbonate formation. To get correlation between AI and porosity three different trends were established in there different zones. Although main focus for the study was in main carbonate zone for establishment of hydrocarbon prospectively in Jaisalmer limestone. In few places AI was looking low which was indicator of gas bearing zone. In current study post stack seismic data was used for analysis. Apart from post stack seismic data angle stack data was also available from 0 to 15^0 as near angle stack, 15^0 to 30^0 as mid angle stack and 30^0 to 45^0 as far angle stack data. In view of sub-optimal data quality angle stack data was not used for pre-stack inversion study. North eastern part of the drilling well is tectonically affected with two major fault blocks. In this faulted zone seismic interpretation was carried out with comparatively low confidence. Based on geological setting and structural interpretation approximately 15 sq.km area was selected for current study. The study was carried out through unconventional post stack seismic inversion study – i) coloured inversion and ii) genetic inversion

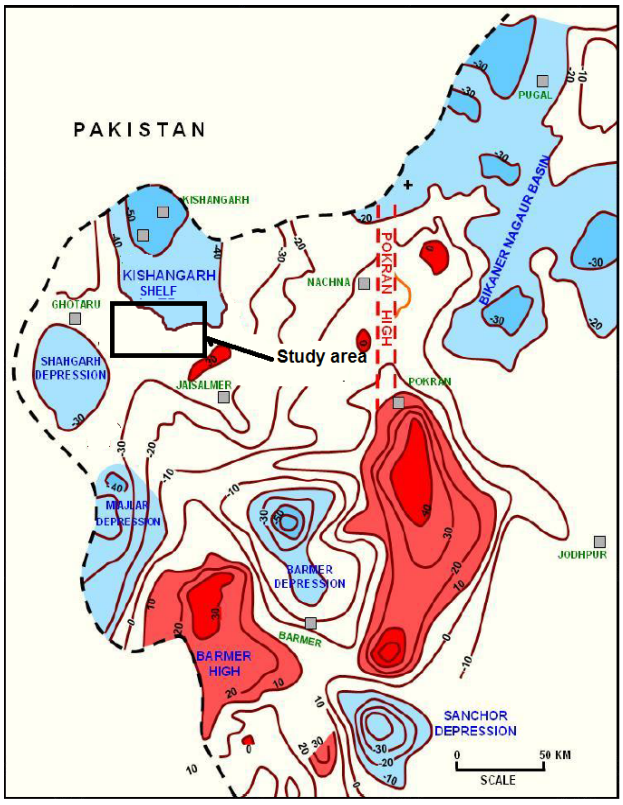
study. Both the study was supported each other through most likely result of limestone reservoir. Based on spectral analysis and AI log nature both the process was conducted. AI well log was generated during well to seismic tie of well A. Although the well A was dry but each information for dry well was used for comparative study for find out the new prospective location. Seismic volume and surface attribute analysis and rock physics template analysis at well level and away from the well was adopted for finding of sweet spot. Based on quantitative analysis one location was identified with probable hydrocarbon bearing lead.

Geoscientific Data Analysis

Petroleum system has been shown the potentiality of Jaisalmer sub-basin area. Bhuana formation under Permian age, Baisakhi-Bedisar formation under Jurassic age and Goru formation under Cretaceous age are the good source rocks. Shumarwali formation under Triassic age, Jaisalmer formation under Jurrasic age and Pariwar formation under Cretaceous age is major reservoir. The Jaisalmer sub-basin is a part Rajasthan basin and Rajasthan basin is continuation part of Indus basin which is a good source of hydrocarbon accumulation. Current study was concentrated on Jaisalmer formation as carbonate reservoir. The risk factor for drilled well was mentioned below:

Well A	Reservoir	Source	Accumulation	Trap	Total Risk
	0.5	0.3	0.3	0.8	0.036

Reservoir risk was judged through evaluation of formation, reservoir quality and well distance for study; source risk was evaluated based on maturity of the source rock; risk of accumulation was estimated based on migration and trap formation time; finally risk of seal was evaluated based on seismic data quality, structural trap, seal and well control. Total risk 0.036 may be considered as moderate risk category. In view of this risk analysis most of the cases well A was analysed. Figure 1 is showing tentative study area for current study over gravity anomaly data whereas figure 2 is showing the conventional well log data of the study well.



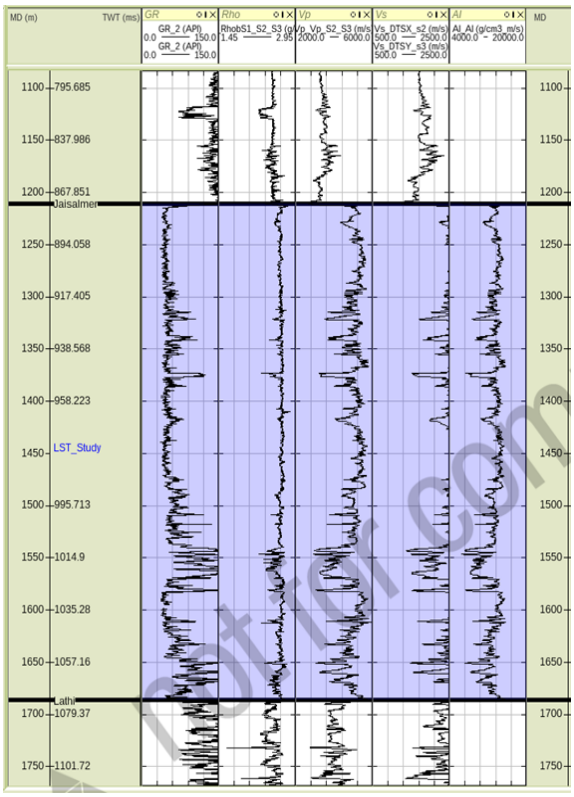


Figure 1: Tentative area for current study in Jaisalmer area

Figure 2: Study well with conventional well log data

Further study was conducted based on well to seismic tie of well A. Well to seismic tie was conducted based compressional velocity and density well log. Apart from time to depth calibration changes of seismic signature was captured during tie. The tie was mostly evaluated as quantitative well to seismic tie. Based on statistical wavelet in Jaisalmer limestone formation window well to seismic tie was conducted. The wavelet length window was 120 ms. Figure 3 is showing the result of tie.

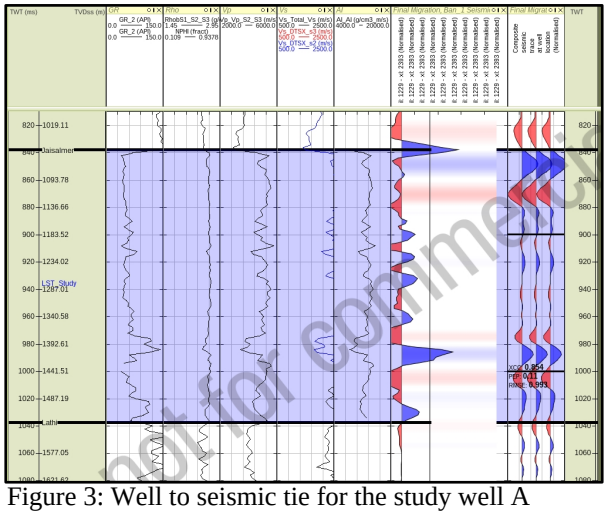


Figure 3: Well to seismic tie for the study well A

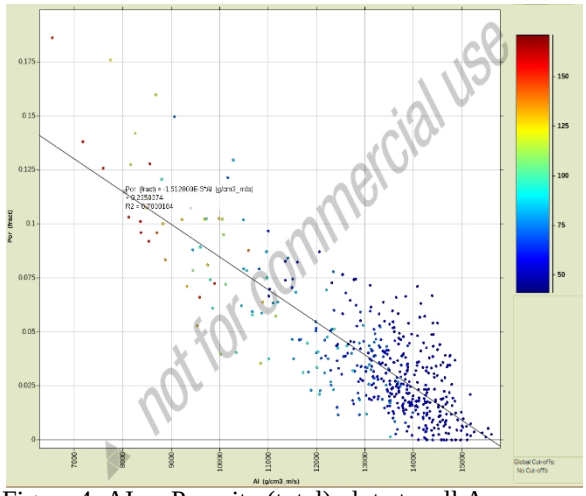


Figure 4: AI vs Porosity (total) plot at well A

The study has shown that good correlation between synthetic and seismic through interested amplitude build-up zones over seismic. Current study has been restricted to 1212m to 1580m in MD under Jaisalmer limestone section. Petrophysical model was prepared based on drilled well data for further study. Based encouraging drilled result 1212m to 1580m 9MD) was selected for petrophysical analysis, the working interval is known as LST study. Probabilistic approach was adopted for evaluation of petrophysical parameters such as water saturation, porosity and volume calculation. Figure 4 is showing the correlation between AI and total porosity at well A the cross plot has been coloured by GR log. The plot is showing typical regression trend with 70% correlation in limestone section. The correlation is showing good relation between rock physical and petrophysical parameter of limestone formation where porosity is decreasing with increasing of AI.

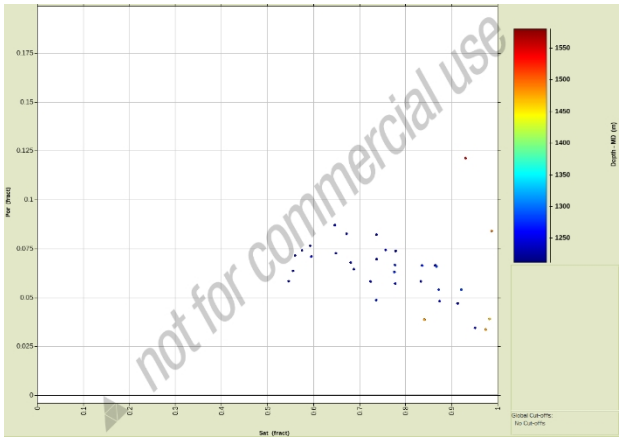


Figure 6: EEI well log correlation for well A

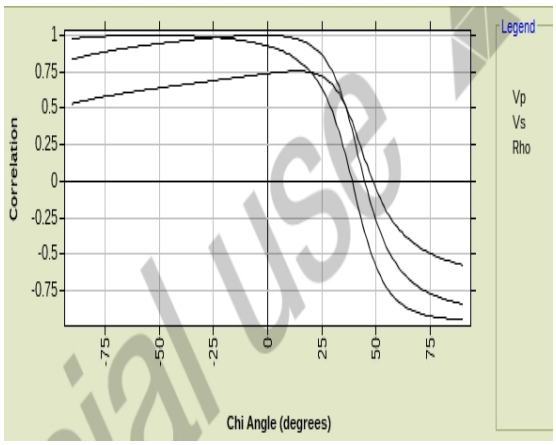


Figure 5: Porosity vs water saturation plot at well A

Well log analysis has shown relation between porosity and water saturation (figure 5). The relation has shown 50 to 65% water saturation in the lower side which may be considered as favourable condition for carbonate reservoir hydrocarbon accumulation. Water saturation was estimated based on Rw value 0.1 ohm-m on 130 ^{0} F reservoir temperature using picket plot. In well A porosity was estimated around 9 to 12% which is typical tight

limestone formation. Petroleum system has shown chances of hydrocarbon accumulation but for extensive discovery from limestone reservoir quantitative analysis for geoscientific data is required as pre-drill precaution. Figure 6 is showing extended elastic impedance well log generation at well level which is generated based on Vp, Vs and density set from well A data. EEI well log correlation has shown that high correlation for Vp log 98% at Chi angle 10^0 for Vs well log we have got high correlation 97% at Chi angle of 2^0 whereas for density log the correlation level is comparatively low 74% at Chi angle 25^0. The EEI estimated well log has been compared petrophysical log which was established a good statement in limestone reservoir. In current study coloured inversion and genetic inversion process was adopted for identification of good prospective away from dry drilled well A.

Coloured Inversion

In this phase spectrum was analysed of inverted seismic data with observed spectrum (Lancaster and Whitcombe, 2000). The coloured inversion is band limited inversion using convolution process the inversion result has been estimated. One operator was chosen for this inversion. Amplitude spectrum of the operator was correlated with mean values seismic spectrum and mean value of earth impedance. It was observed that there -90^0 phase differences between two spectrum. Mean value of the earth impedance was estimated from well log data (Maynard et. al., 2013). Absolute impedance was estimated from relative impedance data set the low frequency content was added from well log data. The encouraging result was evaluated based on migrated zero phase (Kemper, 2010) seismic data.

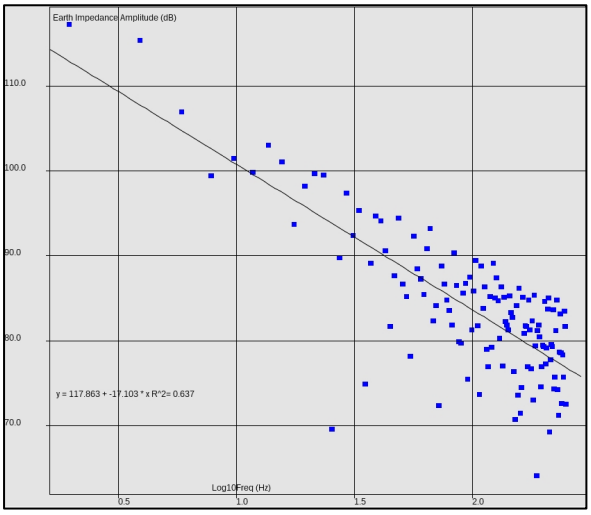


Figure 8: Comparison between inverted and well Frequency

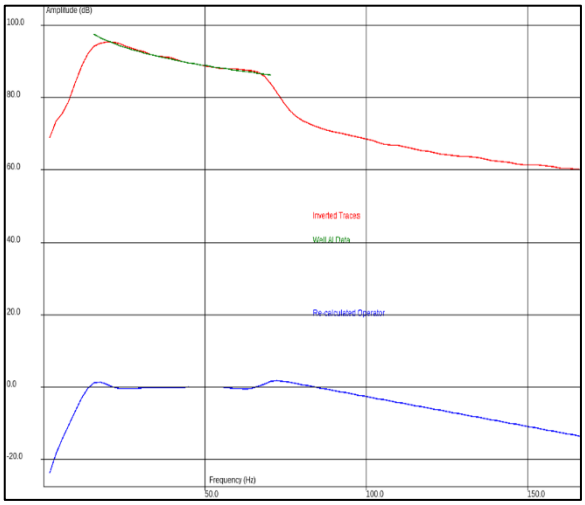


Figure 7: Coloured inversion for earth impedance and data

The operator mentioned above was applied for coloured inversion. Figure 7 is showing the relation between earth impedance and log frequency where the achieved correlation is 63.2% which is acceptable for further study. Inverted result and well result has shown in figure 8 with respect to operator variation.

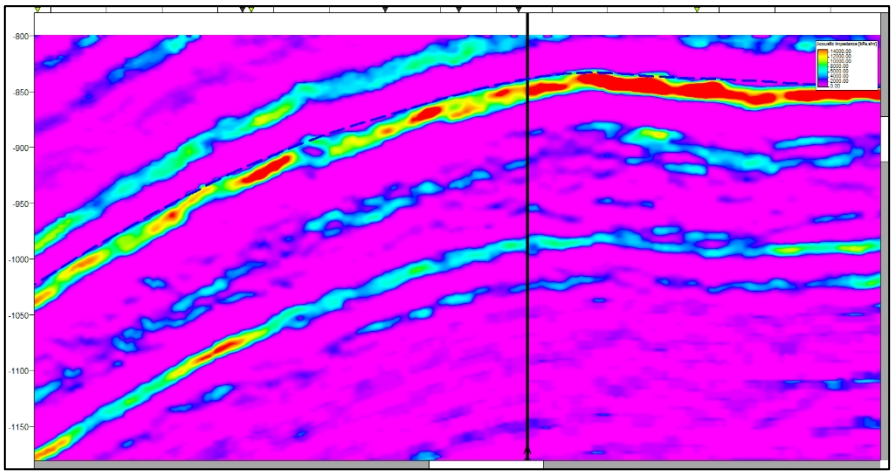


Figure 9: Coloured inverted impedance volume in time domain after applying of operator

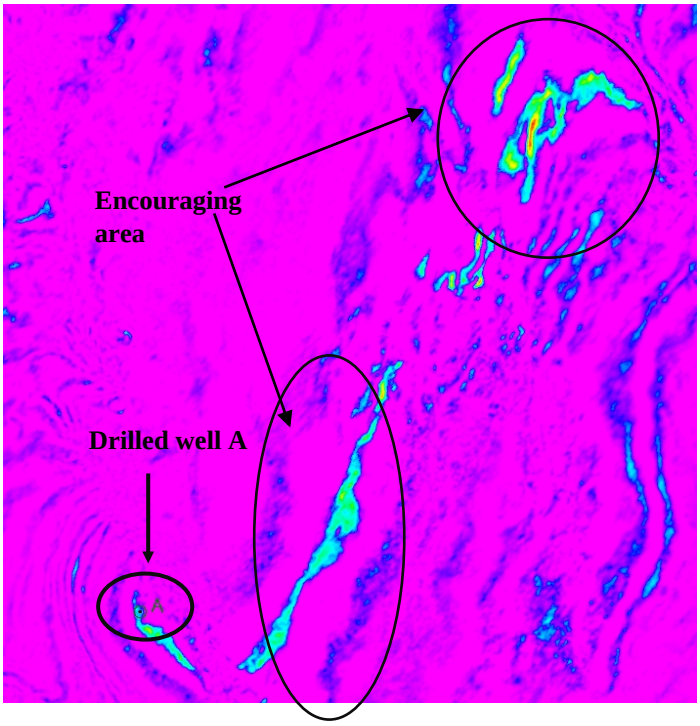


Figure 10: RMS attribute analysis in between encouraging zone in time window over coloured inversion

Figure 9 is the final product for coloured inversion which was used for attribute analysis. The petrophysical analysis was shown that 840ms to 853ms (1220m to 1236m in MD) is good limestone facies for hydrocarbon accumulation. Based on RMS (root mean square) analysis between time of 840ms to 850ms it was found that good limestone facies was not properly encountered in well A. Two good encouraging limestone facies distribution was found which is marked with dotted circle in figure 10. The result has shown in drilled well good facies was encountered edge of the target body.

Genetic Inversion

Genetic inversion (GI) is a neural networking process where nonlinear optimization problem has been taken care. Non-local optimization inclusion of global optimization technique was used for GI study for searching of possible solution with artificial intelligence method. The conversion was adopted through probabilistic approach with three operator such as selection of data, crossover and mutation of the data (Klinger et. al., 2008). Non-deterministic dynamical system with probabilistic nature of each population with random vector was the nature of the final product of GI study (information was taken from published document of Schlumberger).

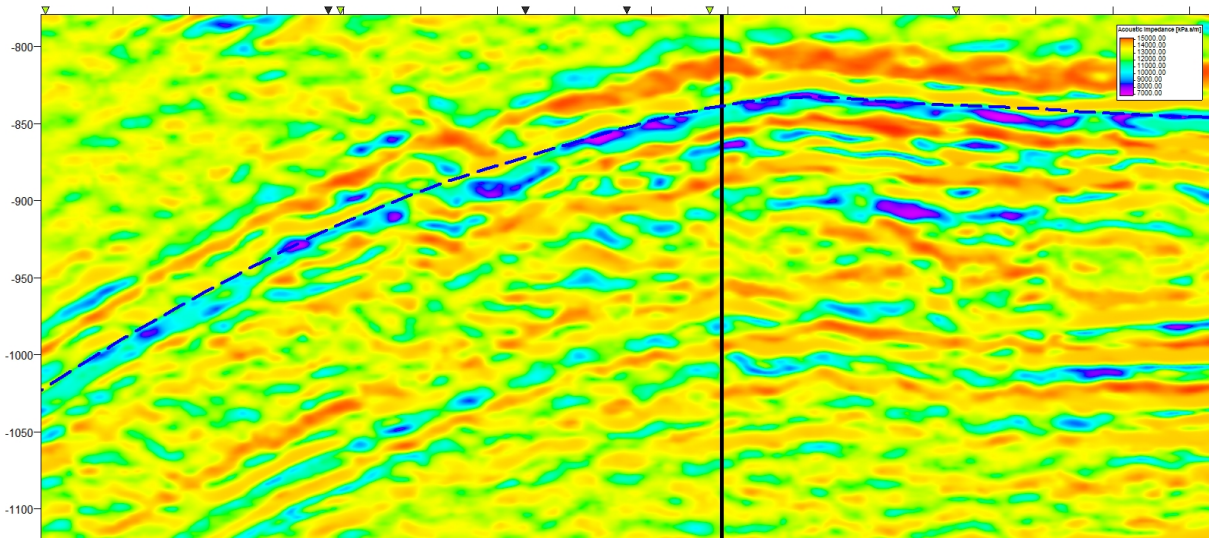


Figure 11: Genetic Inversion volume in time domain using AI well log section through well A

Figure 12: RMS attribute analysis in between encouraging zone in time window over genetic inversion

Acoustic impedance well log data was used for GI study (figure 11). Quantitative well to seismic was produced possible sweet spot through generation of acoustic impedance (AI) log data. This AI log data was used as global for developing genetically inverted volume. RMS attribute was analysed near Jaisalmer formation top through time window separation over genetically inverted volume (figure 12). Figure 10 and 12 both are showing drilled well was positioned edge of the targeted body and few prospective areas are identified away from drilled well based on this analysis with acceptable petrophysical and rock physical property.

Conclusion

One well was drilled in the study area of Jaisalmer sub-basin. The drilled well was dry and from drilled well data it has been analysed that the study area is under moderate risk category and satisfactory for hydrocarbon accumulation. Petrophysical analysis was shown that reservoir is fairly tight and water saturation also varying 50 to 60%. Available post stack seismic data is coming under moderate quality and angle stack data is not inspiring. In view of these limitations the study was carried out based on coloured inversion and genetic inversion algorithm under quantitative interpretation. Quantitative well to seismic tie cross plot was shown the possible encouraging zone in drilled well. This result was populated based on surface attribute analysis within restricted time window under limestone section of Jaisalmer formation. It was found that drilled well positioned edge of the body and few zones have been evaluated based on targeted body property for future prospect.

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