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Application of Pre-Stack Seismic Inversion in a Heavy Oil Field- A Case Study from Bikaner-Nagaur Basin, Rajasthan, India

Abstract

Forward Modeling derives the seismic trace from the impedance contrasts encountered at earth's interfaces during data recording, whereas Inversion is the process of deriving earth properties from the recorded seismic trace. The paper presents a Pre-Stack Seismic Inversion case study from a heavy oil field of Bikaner-Nagaur Basin of Rajasthan, India (Figure 1). On the basis of this study a couple of proposed locations have been verified and the extent of target reservoirs could be mapped successfully. The study also identifies probable leads in the area for future development of the field.

Introduction

The case study has been prepared on Pre-Stack Seismic Inversion for a heavy oil field at Baghewala in Bikaner Nagaur Basin subsequent to the discovery of heavy oil found in Jodhpur sandstone of Infra-Cambrian-Paleozoic Basin underlain by Malani volcanics of Precambrian rocks. Jodhpur formation consists of pinkish coarse grain sandstone with a thickness of about 25 to 50m over the area and is overlaid by Bilara dolostone, Hanseran Evaporite Group, Nagaur clastics and the Upper Carbonate super group.

The present Inversion method makes use of well logs to construct a low frequency model which is important for deriving absolute properties of the output volumes (Model Based Inversion) & constraining the inversion results. Pre-Stack Simultaneous Inversion outputs Vp, Vs & density volumes making use of reflectivity of the earth recorded in seismic traces at different angles. Of the few hydrocarbon tested and dry wells drilled in the area, 6 wells (Well1, Well3 & Well4, Well5, Well7, Well8) have been selected for the Inversion study, out of which Well1, Well4 &Well8 have been tested for Heavy Oil. Cut-off values of P-Impedance (Zp) & Vp/Vs ratio were selected from these tested wells to discriminate sand zones in the Jodhpur formation (target horizon for the study) from the background. Further, based on these cut-off values the inverted volumes were marked with probable zones of sand development, however, the heavy oil bearing reservoir could not be identified distinctly on the basis of Vp/Vs ratio. A porosity volume has been derived from the inversion result which gives a clearer picture of the hydrocarbon bearing sand reservoirs. The identified zones could be successfully verified at the well positions as well as the proposed locations on the basis of P-Impedance and Porosity zones (Loc1 & Loc2). (See Figure 2)

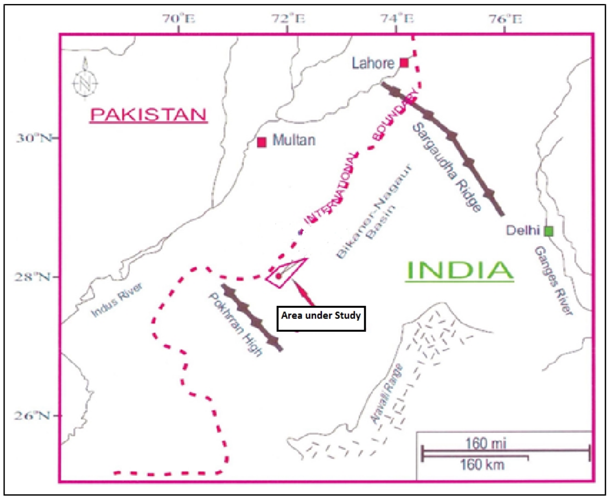

Figure 1: Location of the Study Field in Bikaner Nagaur Basin

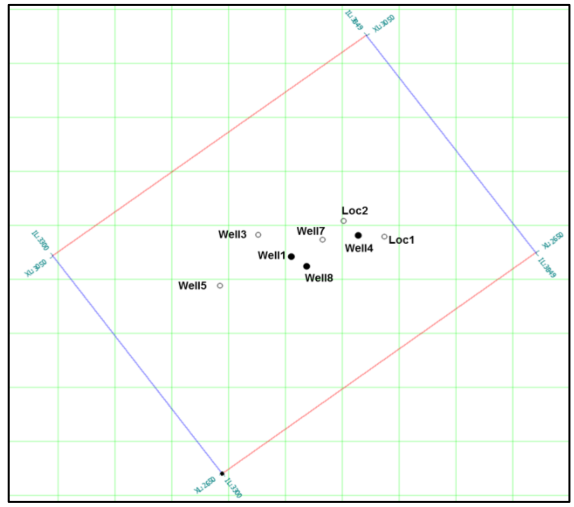

Figure 2: Base Map with wells & proposed locations

1. Data Preparation

All available data were collected and conditioned as required to conduct feasibility study. The datasets used for the study are as follows-

-Seismic Data

- **RMS Velocities**
- **CMP gathers**- Conditioned to improve S/N ratio, formed super-gathers, applied Radon filtering, trim statics and converted to angle gathers with RMS velocities
- **Seismic Horizons-** The horizons Upper carbonate, Nagaur, Intra HEG, Intra Bilara, Jodhpur and Basement(Malani) were interpolated and smoothed
- **Limitations-** Data with extremely low S/N ratio, limited bandwidth (Figure3a) low fold of coverage and limited offset & angle range (Figure 3b),

- Well Data from 6 selected wells

- **Full Waveform Sonic Log** (available for only 2 wells)- Manually edited & median filtered to remove spikes
- **Synthetic S-Wave** sonic generated for the zone of interest (for 4 wells) from existing P-Wave sonic & Density Logs
- **Density Log** (available for all 6 wells used in the study)
- **Well Tops**

- Log Transforms

As characteristics of Seismic amplitudes depend on Impedances (P-Impedance & S-Impedance) and Poisson's Ratio (or Vp/Vs), with the available P-wave, S-wave & Density logs, Impedance Logs & Vp/Vs logs were created at well locations using the equations:

P-Impedance (Zp = Vp * Density)
S-Impedance (Zs = Vs * Density)
Vp/Vs (Vp/Vs = Vp/Vs)

-Porosity volume was generated using the relationship between Zp & Porosity from the inverted volumes.

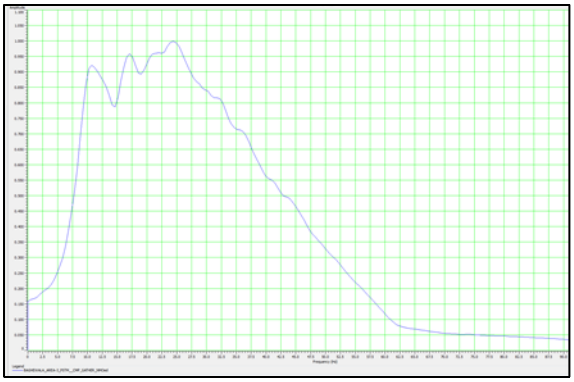

Figure 3a: Amplitude Spectrum within the Inversion Window

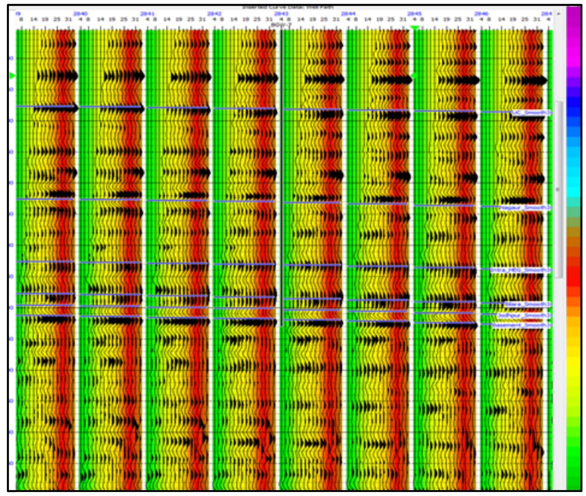

Figure 3b: Representative angle gathers

2. Feasibility Study

Feasibility study using well-log derived attributes is done to see whether these attributes are able to separate the reservoir-zone from the background and what is the cut-off range for the reservoir zone. A cross plot of Zp vs. Vp/Vs (Figure 4a&b) using the logs of all wells (within zone of interest) is created, and it is observed that this cross plot can discriminate between various lithologies viz. Sand, Shale & carbonates. The cross-plot can roughly distinguish the good & poor reservoir zones. A cross-plot of P-impedance vs porosity can successfully determine the hydrocarbon wells from the dry ones (Figure-4c&d) cut-off ranges for the reservoir zone fall mostly within-

Zp = 8500 -10300 ((m/s) (g/cc)

Porosity-8-18 %

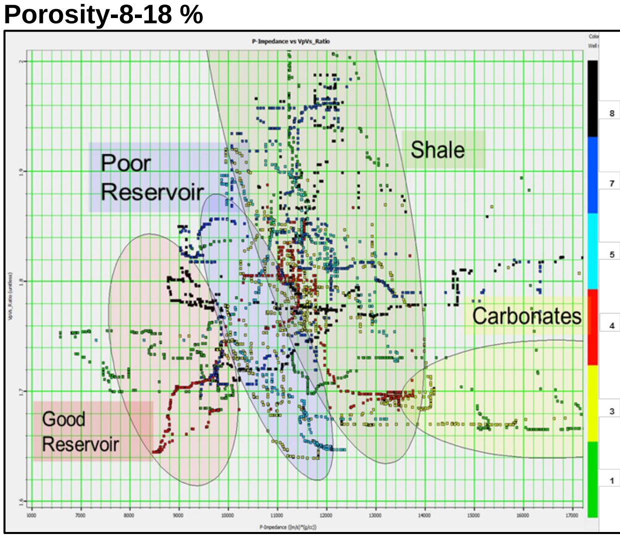

Figure 4a: Lithology types from Zp vs Vp/Vs cross-plot color coded by the well number (within Bilara &Jodhpur)

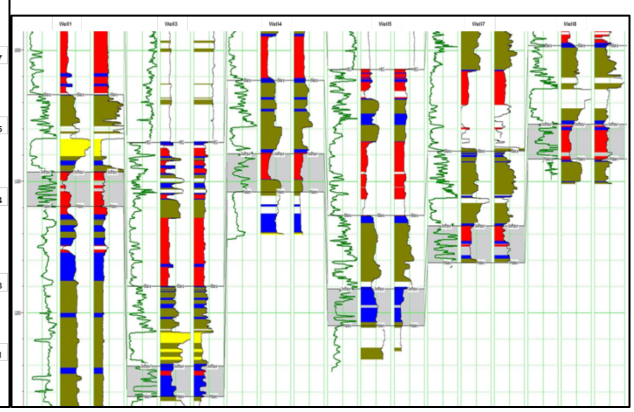

Figure 4b: Well Cross section to identify lithology type

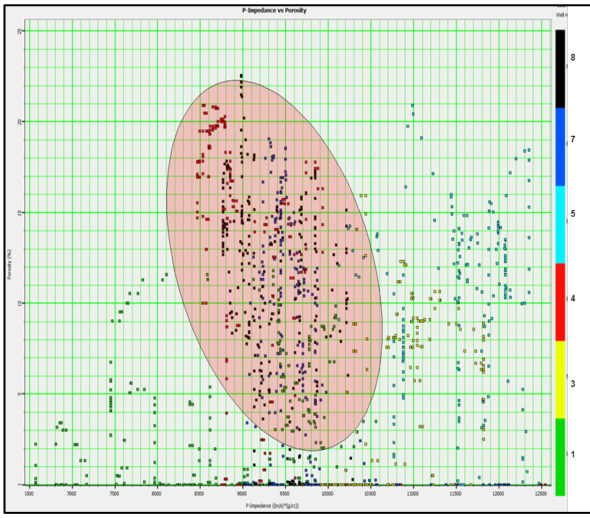

Figure 4c: Zp vs Porosity Cross plot color coded by the well number (within Jodhpur formation)

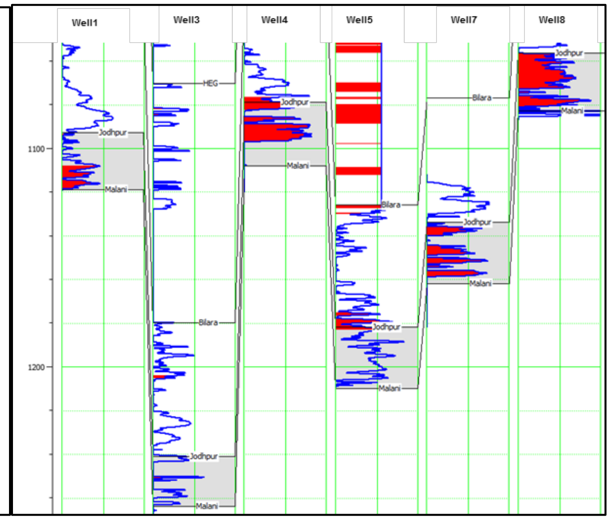

Figure 4d: Well Cross section to identify reservoir zones (plotted curves-Effective porosity)

3. Well-to-Seismic Tie & Wavelet Extraction

The amplitude spectra of angle gathers (for entire volume, within target formation, angle range = 5-34 degree) is generated. Amplitude spectra indicate that the dominant frequency in target formation is around 25 Hz. The wavelength of the extracted wavelet is kept 120 ms (25 ms taper length).

Wavelet extraction was done at all well locations, however, a statistical wavelet seemed more stable to be used for well to seismic tie at all the 6 wells. Well-to-seismic tie is done at each well location by comparing the observed seismic & synthetic seismic (derived by convolving the well impedances to extracted wavelet). A reasonably good correlation (in consideration of seismic quality) is achieved by performing a static shift and minor stretch & squeeze operation in P-wave logs. Well to seismic tie for Well7 is shown in Figure 5a.

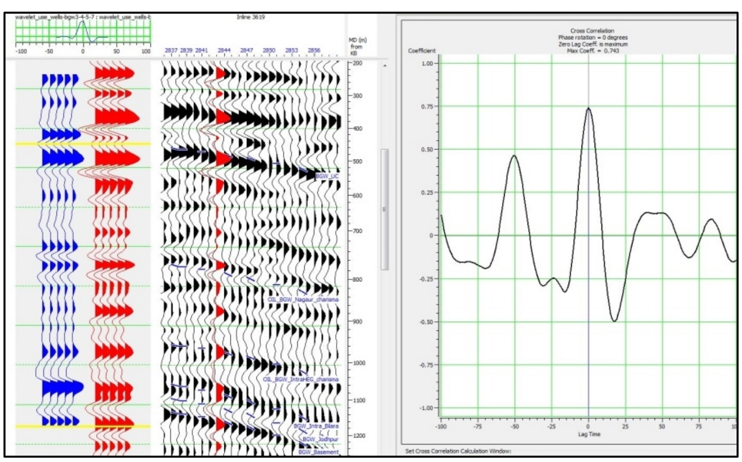

Figure 5a: Well-to-seismic tie for Well7

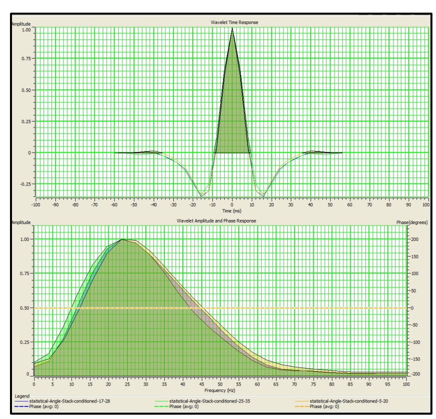

Figure 5b: Statistical wavelet extracted from horizon U. Carbonate+100 msec to Basement

4. Low Frequency Model Building

Low frequency priory model (or initial model) is essentially required in model- based-inversion, to constrain the inversion results. Low frequency model for P-Impedance & S-Impedance has been made using relevant logs of all the 6 wells used in the study. Interpolation between the wells has been done using Kriging method. Seismic horizons are used for layer interpolation during low frequency model building. The low frequency model is further smoothed by applying a high cut filter (corner frequencies 10-15 Hz) to preserve low frequency characteristics only. Low Frequency Model for Zp passing through all the wells is shown in Figure 8a.

5. Inversion Parameterization & QC

The simultaneous pre-stack inversion is performed by decomposing the angle gathers (5-34) into three (3) nos. of partial gathers i.e. 5-20, 17-28 & 25-34.
Probably because of poor quality of the seismic, low fold data and limited availability of incidence angles, the deterministic wavelets derived from the wells looked very unstable. The QC of inversion results suggests that a group of statistical wavelets (zero-phase) which is more of an average representation for all wells, gave better results. Hence 3 angle dependent statistical wavelets were derived from a window of the horizon Upper carbonate+100msec to basement and were used for carrying out the inversion (Figure 5b). The inversion is performed within the horizons Upper Carbonate and Basement+20 msec, this also includes the horizons- Nagaur, HEG, Bilara & Jodhpur).
After testing the inversion parameters, background value of Vs/Vp is selected as 0.55. Regression & Covariance Coefficients (relationship between Zp, Zs and density) defines the deviations from the modeled background trend. The log derived Zp, Zs and density (at all 6 well locations) within Jodhpur formation is plotted in logarithmic scale and Regression & Covariance Coefficients are derived by fitting the regression curves in Figure 6a. The final inversion QC at Well7 is shown in Figure 6b.

6. Validation of Results

Figure 7b shows the seismic section passing through all the wells and Figures 7c&d show the inverted results of Zp & Vp/Vs along the same line. The results show good match of Zp at the well locations. Although Vp/Vs shows a fair match at well locations, it is not able to discriminate between dry sands and hydrocarbon bearing sands of the Jodhpur formation. Figure 7e shows the RMS amplitude map at the Jodhpur formation showing the fault patterns and amplitude highs. The inverted results at the Jodhpur Formation are shown in Figures 7f&g. Low Zp values at the hydrocarbon bearing wells validate the inverted results at well locations. However, Vp/Vs ratio does not show a consistent signature for hydrocarbon bearing and dry sands (as analyzed earlier in the well feasibility study). A porosity volume has been extracted based on the inverted results and is shown in Figure 7h. The derived porosity showed a good match at the well locations. The cut-off values of Zp & Porosity are able to distinguish the reservoir-zone from the background, as indicated in the well logs.
Apart from the validation of two proposed locations Loc1 & Loc2, an attempt has been made to identify probable leads in the study area on the basis of inverted/derived attributes. An anomaly is observed in Figures 6e&g towards the south of Well1 and is marked with lower Zp & higher porosity values.

Conclusions

The study has been able to verify two proposed locations which are passing through the pay sands and are likely to be hydrocarbon bearing within Jodhpur formation. The inverted P-impedance & derived porosity map will be useful in reservoir modelling to reduce risk and uncertainty. The identified lead within Jodhpur sand can be further studied during reservoir modelling for future development of the field.

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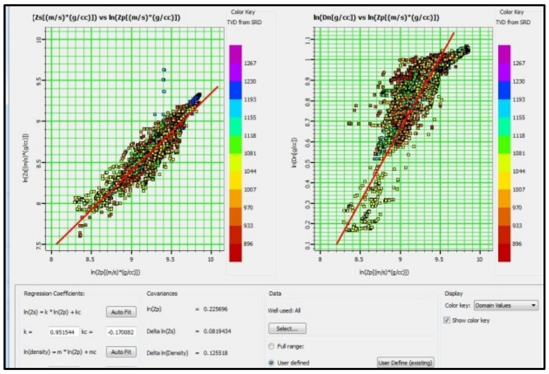

Figure 6a: Regression & co-variance co-efficients for Zp, Zs & density

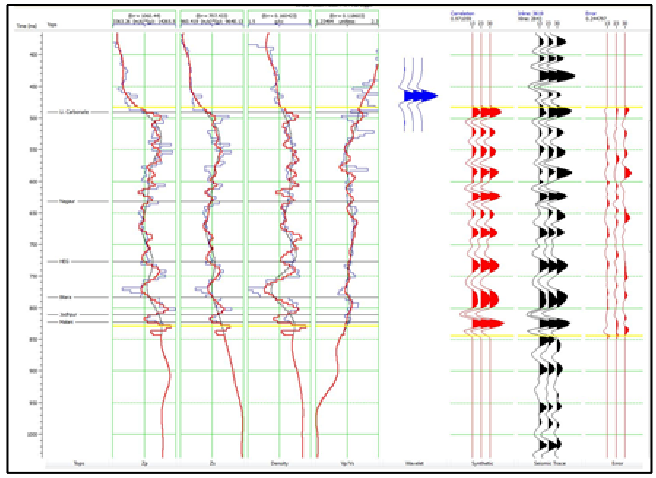

Figure 6b: Inversion Results QC at Well7

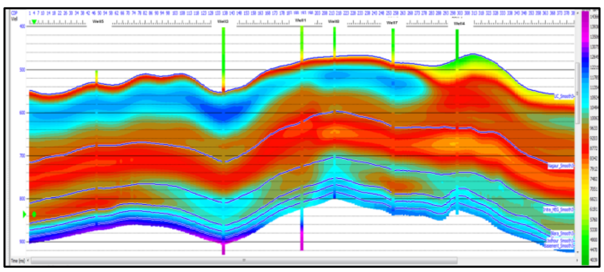

Figure 7a: Low frequency Model for Zp passing through all wells

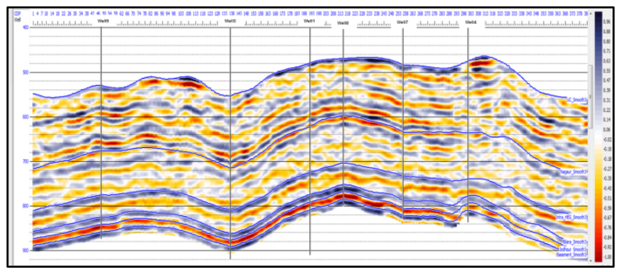

Figure 7b Seismic Section passing through all wells

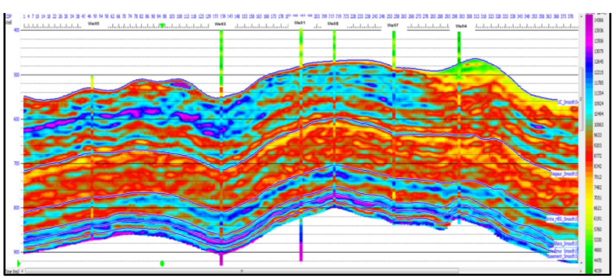

Figure 7c Inverted Result- Zp Section passing through all wells

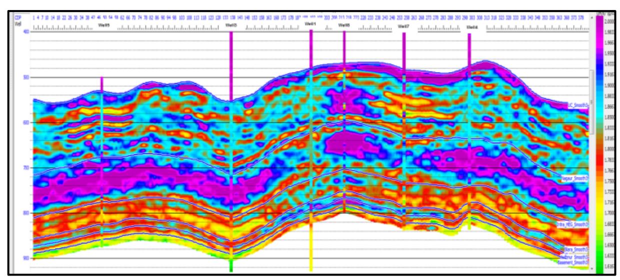

Figure 7d Inverted Result- Vp/Vs Section passing through all wells

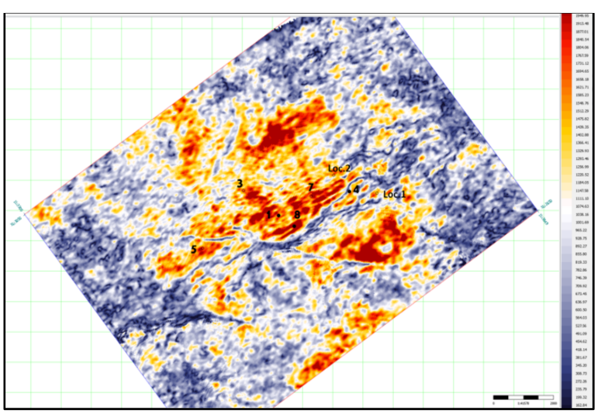

Figure 7e: RMS amplitude map at the Jodhpur horizon

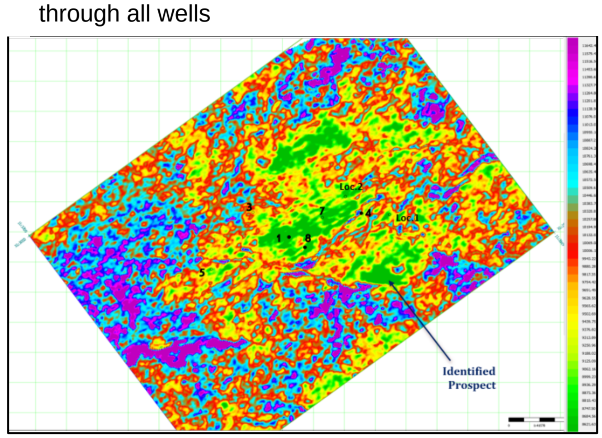

Figure 7f: Inversion result- Zp at the Jodhpur horizon

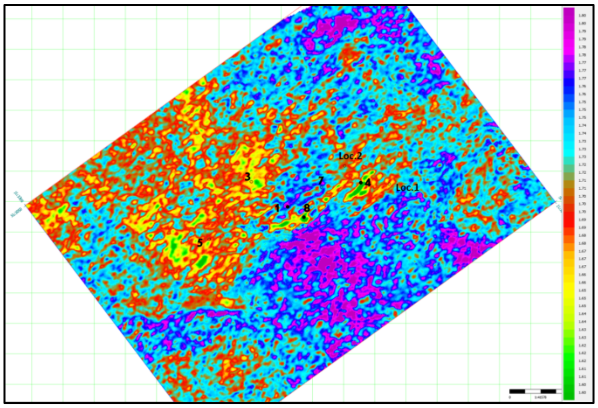

Figure 7g: Inversion result – Vp/Vs at the Jodhpur horizon

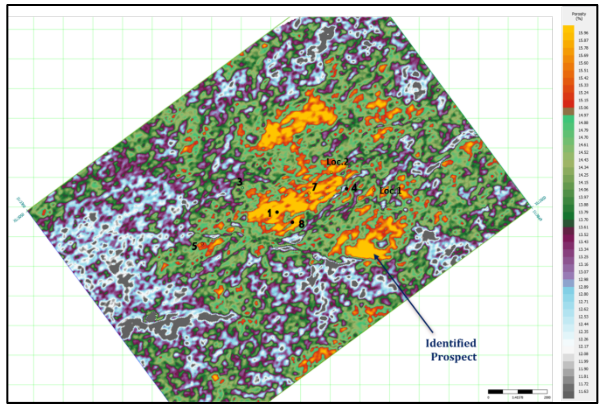

Figure 7h: Derived Porosity- at the Jodhpur horizon

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