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Reservoir Characterization of a heavy oil bearing structure in Bikaner Nagaur Basin, Rajasthan, India

S.K. Basha, Anup Kumar, *Oil India Limited,*
Anubrati Mukherjee*, Mukesh Gupta, *Schlumberger Asia Services Ltd.*

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Introduction

The study area is in the Bikaner Nagaur Basin in Rajasthan which essentially is a lower Paleozoic basin with a thin young sediment cover. Heavy oil has been discovered in the sandstone and carbonate intervals in the Paleozoic section. The sandstone interval is the most prolific hydrocarbon interval and is characterized by interbedded sandstone, siltstone and shaly layers having good porosity. The objective of the study was to carry out detailed reservoir characterization of a 50 sq km area surrounding one of the recent discovery wells and also comprising some of the interesting structural prospects.

Theory and Method

The key challenge when dealing with heavy oil is the lack of fluid sensitivity to the AVO attributes. It is usually seen that density can be used with some degree of success to discriminate between brine and hydrocarbon bearing intervals. This aspect is investigated in details using synthetic modeling of the well log data. The study area covered 50 sq km of 3D vibroseis land seismic data. The seismic bin size is 25 m by 25 m. There is only 1 well with good quality logs, which was used for the inversion study. The pre-stack simultaneous inversion algorithm used in this study uses the Aki-Richards AVO approximation as its forward modeling engine. A global multi-trace optimization based on simulated annealing is used for the inversion. This type of minimization is usually less sensitive to noise and is more accurate than local optimization as it can avoid getting trapped in local minima. To capture the effects of attenuation in the data, a depth varying wavelet was used. Angles are updated, using the estimated P-wave velocity iteratively. A separate wavelet is used for each angle stack. A schematic diagram illustrating the simultaneous inversion workflow is given in Fig 1. As is well known the seismic data is usually devoid of the low frequencies and needs to be compensated using the available well data and other apriori information. We used the available well logs, interpreted horizons and the PSTM velocity files to generate a low frequency model up to 10 Hz, as was deemed necessary from the spectral analysis of the seismic data. However, one needs to be very cautious when the extrapolation is dependent on only one well. We have used a robust workflow to reduce the uncertainty of extrapolation of information to fill up the null space. The low frequency models are used as apriori starting models for the pre-stack inversion. The pre-stack data is appropriately pre-conditioned to extract the best results out of the inversion.

Seismic Data Conditioning

The objective of seismic data conditioning was to prepare the post migration CRP gathers for AVO inversion. Improve the signal to noise ratio by applying AVO friendly noise attenuation procedures

- Anomalous Amplitude Attenuation
- Residual Anomalous Amplitude Compensation
- Weighted least squares radon residual de-multiple
- Flatten the gathers by residual velocity adjustments
- Remove remnant multiple energy and noise
- Angle stacks generation

AAA (Anomalous Amplitude Attenuation) is used to remove anomalous amplitudes and noise bursts of different frequencies present in the data. The RAAC (Residual Anomalous Amplitude Compensation) process uses statistical means to retain anomalous amplitude information, such as bright spots, while allowing the data

Schlumberger Asia Services Ltd., D105 TTC Industrial Estate, MIDC Nerul, Nerul (E), Navi Mumbai, 400706, India
Amukherjee2@slb.com

to be scaled. Weighted Least Squares Radon transforms seek to improve the focusing of events in the Radon domain over that provided by conventional transforms. Improved focusing in the Radon domain improves identification and separation of signal and noise trends, which reduces artefact levels. In a complex geological setting, velocity analyses at discrete locations (such as a grid of analyses every 250x250m can only guarantee optimum stack response at those locations. To optimize stack response, and therefore frequency content, for the whole section, a velocity analysis for each CMP is desirable. This can be achieved using an automatic velocity picker and model builder, such as SCVA (Surface consistent Velocity Analysis). AVO modeling and inversion for elastic parameters such as Poisson's ratio and density are very sensitive to flattening or alignment of events from near to the far offsets. NRM (Non Rigid Matching) has been used for the alignment of event from near stack to far stack. It is a 3D process which compares the input dataset with a reference data to produce a smooth displacement field. The principle of non-rigid matching is similar to that used in digital photography to 'stitch' several photographs into a panorama. It relies on the images being similar and there being a locally smooth deformation (or displacement) field to match them.

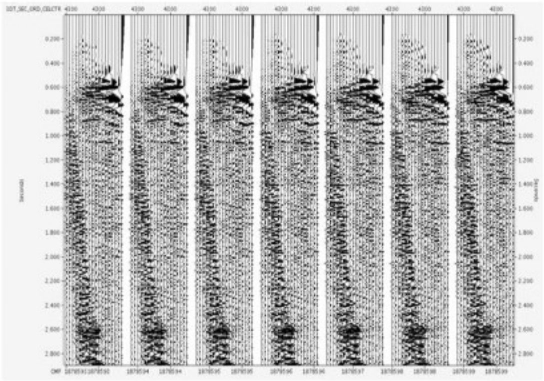

Figure 1: Raw Migration gathers

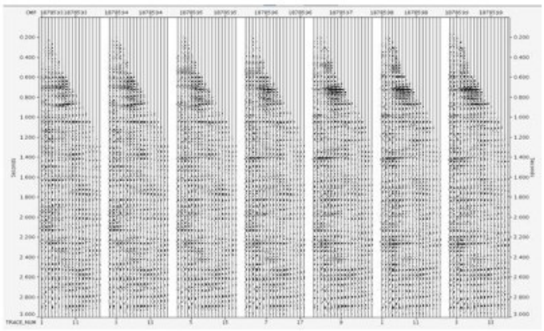

Figure 2: Migrated gathers after conditioning.

Two wells – one inside and one outside the study area were available for rock physics analysis. Both wells had measured P and S sonic and also RHOB logs. Borehole condition was generally stable and not much editing was necessary for the well log data. Key objective of the analysis was the behavior of the sandstone interval with respect to acoustic and elastic properties. It was observed that poor reservoir facies have porosities less than 10%, moderate reservoirs have porosities between 10 to 20% and good reservoirs have porosities more than 20%. Fluid sensitivity of these reservoir facies is also low to high. Table 1 shows the change in elastic properties between brine to heavy oil. The hydrocarbon bearing zone has low acoustic impedance and high Vp/Vs. Probability density functions built from a Bayesian classification scheme divided the rock classes into 3 types based on porosity as described above. While the high porosity class can be easily discriminated, there is significant overlap between the porosity classes 0-10 % and 10 to 20 %. Most of the good reservoir facies bearing hydrocarbon is observed in the high porosity intervals of > 20 % pu. Fluid substitution was carried out to further understand the reservoir interval. Large variation of porosity within the sandstone interval indicated presence of rocks with poor reservoir quality. Lack of core data and many wells adds some uncertainty into the Petrophysical estimations and also to the understanding of heterogeneity within the field.

Elastic Property	Bulk Density	Bulk Modulus	Shear Modulus
Variation	2%	9%	27%

Table 1: Change in elastic properties due to heavy oil.

Low Frequency Modeling, Wavelet Estimation and Simultaneous Inversion

As the study area consists of only 1 well, in order to avoid biasing the whole area with a singular data point, a combination of seismic velocities and relative inversion was used to guide the extrapolation. The seismic velocity provides a deterministic estimation of the very low frequency band. Velocity modeling is a key step of inversion. Typical seismic processing velocities are available in a 500 by 500 m grid. A structurally constrained interpolation of the velocities is necessary for it to be suitable for seismic inversion work. QC of velocity with respect to available well log data is also carried out to make sure the very low frequency trend is suitably captured. (Figure 6) Relative inversion results provide a trace to trace relative variation in properties which can calculate suitable and geologically relevant extrapolation parameters. For QC, maps of seismic amplitudes and relative inversions can be checked against the Low Frequency Model maps (Figure 7) to make sure that data from one point has not created bull's eye effect and special heterogeneity observed in in other forms of hard data has been captured in the model. (Figure 5) The next step of an inversion process is to estimate suitable wavelets. For a simultaneous inversion a separate wavelet needs to be estimated for each angle stack. As is very commonly observed due to positioning errors and seismic data imaging errors, well to seismic tie is better estimated by running a scan around the well location. The log data is available over a very short interval. Hence traditional long window estimation cannot be obtained. Hence some assumptions regarding the phase of the data need to be made in order to reduce uncertainty in a short window extraction. Source wavelet phase was referred from data processing reports and the wavelet extraction was mostly used to extract the amplitude spectrum of the reservoir interval. A scan revealed that much improved matches in the key sandstone and the carbonate interval above could be obtained at a location 115 m away from the original well location. The seismic horizons for the sandstone top and the basement had to be refined after the relative inversion is run so that the targets are clearly constrained. Fine tuning of horizons not only impacts the quality of the low frequency model but also improves QC and generation of property maps derived from inversion. Generation of angle stacks requires rigorous testing. Default angle stacks as near, mid and far provided by seismic processing shops are usually not usable for any serious inversion work. First step for angle back testing with respect to AVO is to understand the maximum usable angle. 32 degrees was the maximum recoverable angle. 6, 8 and 10 degree bands are tested. Near angles are contaminated with noise and hence the final bands used for simultaneous inversion are 8-16, 16-24 and 24-32 degrees. After further testing, it was observed using 12-18 and 20-26 degree stacks along with the 8 degree stacks, aided in improving in the match at the well location by further constraining the AVO with more number of central angles.

Results

Comparison between the raw and the conditioned gather data is presented in figure 1 & 2. Significant improvement in the coherency of the events and signal to noise was achieved through a rigorous workflow. Surface consistent Velocity Analysis resulted in a better constrained input from seismic velocities. As shown in figure 3 a generic simultaneous inversion workflow illustrates the need for separate wavelets and prior models as input into the inversion kernel. Even though the estimation window is short a good well to seismic tie is achieved after conditioning of the pre-stack data (Figure 4). After scanning and re-positioning of the well remarkable improvement in the match between well log and inverted trace is observed (Figures 8 and 9). Getting a good match is critical as it can be seen that the reservoir interval has low Vp/Vs overlying a zone of high Vp/Vs. Getting a match of this variation is critical as the hydrocarbon bearing interval lies in the zone of high Vp/Vs. Without a match the prediction of facies from the Bayesian process will result in incorrect facies results. Figures 11 to 14 show the crossplots, probablility density functions and the facies and probability of good reservoir facies maps.

Conclusions

An extensive seismic and well driven reservoir characterization process for a heavy oil field aids in characterization and distribution of good reservoir facies within the study area. The study is limited by only one well. However some innovative workflows were used to use limit the bias of one well point over the entire study area. The characterization of good facies is driven primarily by porosity based discrimination. The good reservoir facies are not necessarily hydrocarbon bearing. However in integration with geology and basin modeling significant drilling uncertainties can be reduced using these results. In the presentation these workflows will be discussed in further details and the fluid sensitivity issue will be address through AVO modeling examples.

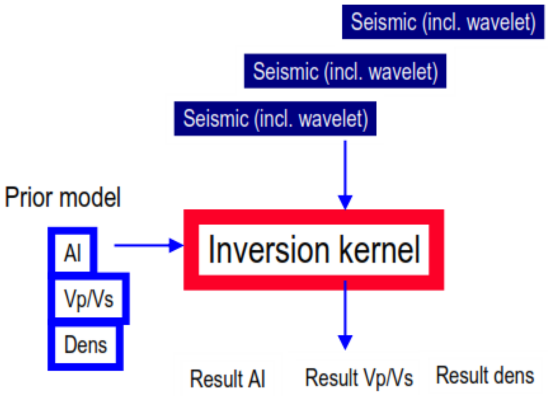

Figure 3: Simultaneous AVO inversion workflow

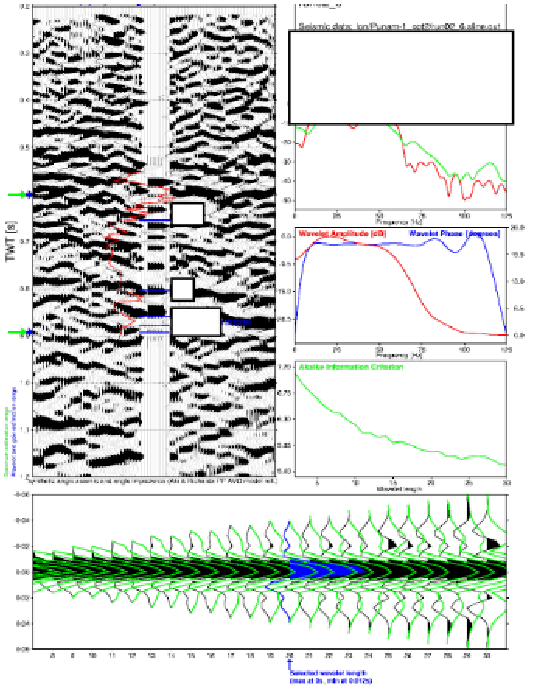

Figure 4: Wavelet and well to seismic tie for Well-1 for the 16-24 angle stack.

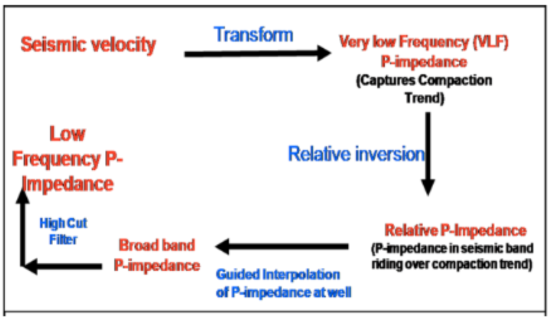

Figure 5: Low Frequency Modeling workflow

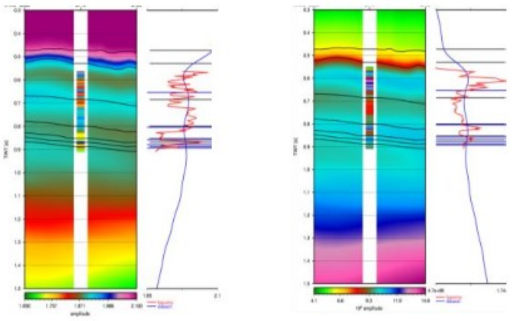

Figure 6: Seismic velocity derived AI and Vp/Vs trends overlain on the well logs from well-1.

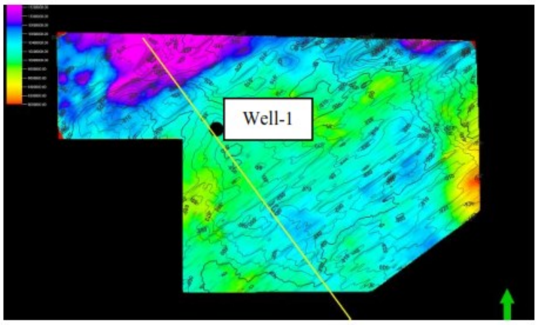

Figure 7: Map of Acoustic Impedance LFM showing the geologic heterogeneity derived from relative inversion.

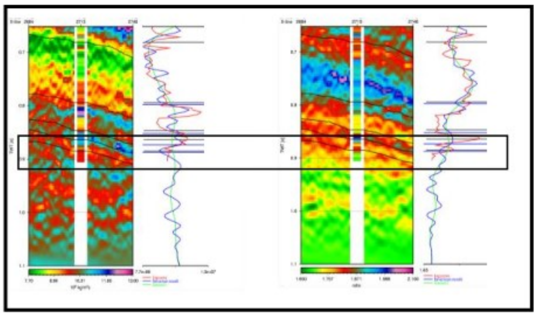

Figure 8: Seismic Inversion results at original well location. Left panel - AI, right panel – Vp/Vs. Red curve represents well log data and the blue curve represents the inverted properties. Reservoir interval is highlighted in the box.

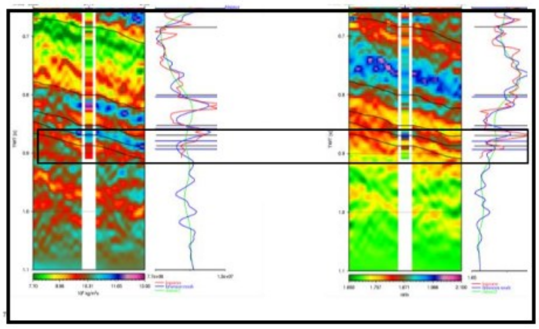

Figure 9: Seismic Inversion results at shifted well location. Left panel - AI, right panel – Vp/Vs. Red curve represents well log data and the blue curve represents the inverted properties. Reservoir interval is highlighted in the box.

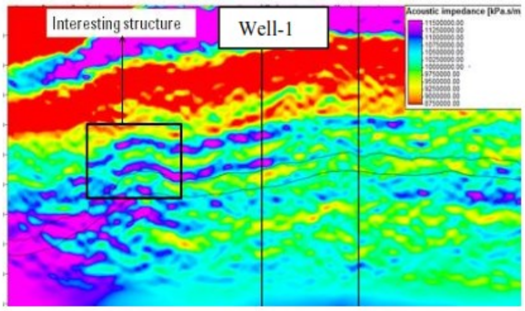

Figure 10: Acoustic Impedance section through the well location. To the right is a planned prospect and the left (north of the well) is a very interesting structure.

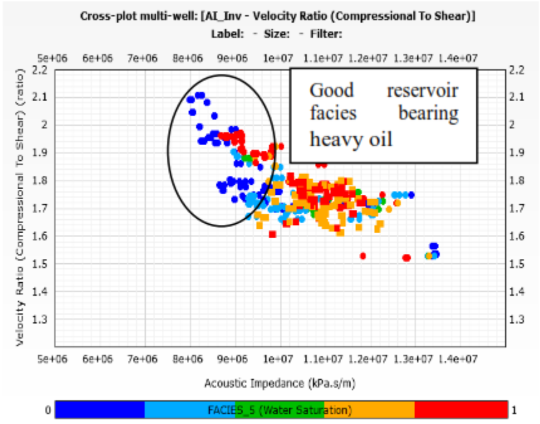

Figure 11: Crossplot of AI (x-axis) and VpVs (y-axis) color-coded using the defined classes.

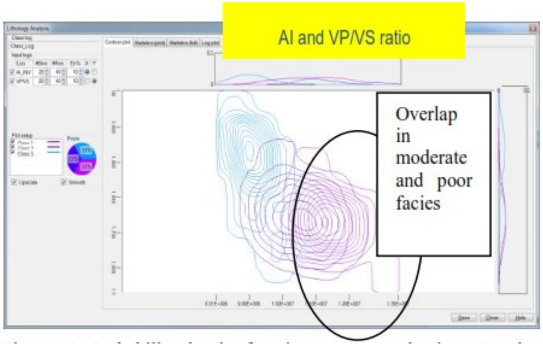

Figure 12: Probability density functions constructed using AI and Vp/Vs from well logs. Good reservoir facies are well discriminated. However the overlap between poor and moderate facies is significant.

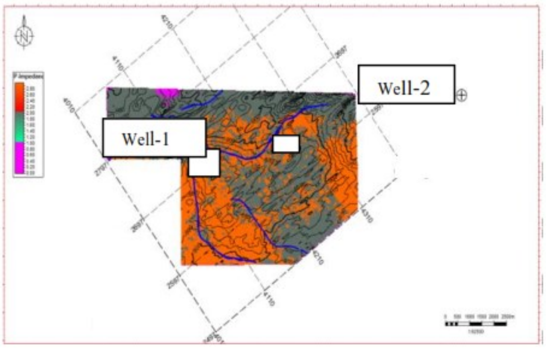

Figure 13: Facies map extracted for the reservoir interval. The good reservoir facies in Orange.

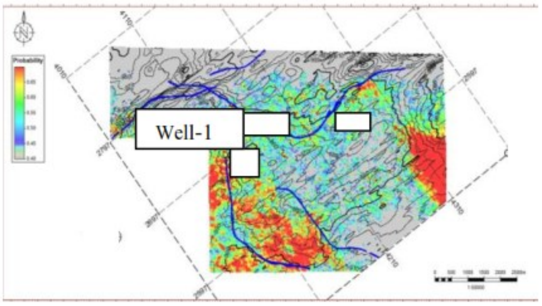

Figure 14: Map of probability of good reservoir facies within thesandstone interval. Area indicated in red are showing highprobability and should be considered for detailed evaluation.

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