Rock physics modeling and simultaneous inversion to map heavy-oil bearing sands in Baghewala area, Bikaner-Nagaur basin, India

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Introduction

The Bikaner-Nagaur basin is a Late Proterozoic-Cambrian basin in Rajasthan, India. The basement composed of Malini rhyolite and granite gneiss has a thin sedimentary cover (~ 1500m) of Lower Paleozoic sediments overlain by Mesozoic and Tertiary sediments (Dasgupta and Bulgauda, 1994). The Baghewala anticline provides conditions favorable for oil migrating from Bilara shales to be entrapped in shaly Jodhpur sand. Exploration in the Bikaner-Nagaur basin attracted attention with the discovery of heavy oil (~ 20 degree API gravity) in the clastic of early Cambrian Jodhpur formation Baghewala Well A1 (Figure 1).

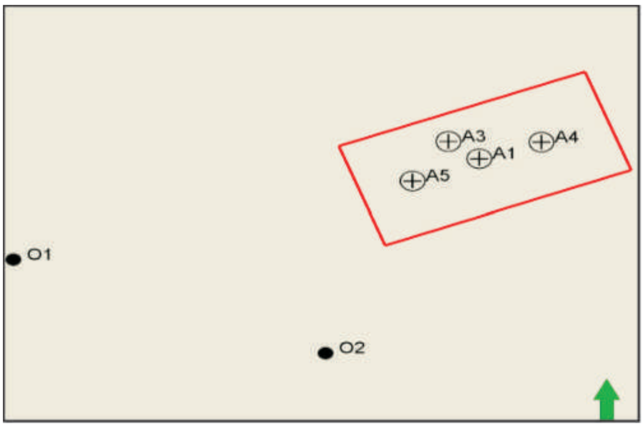

Fig. 1: Wells used in the study.

A few wells drilled on the Baghewala structural high produced oil from the Jodhpur shaly sand. The Jodhpur interval is established as the prime producing reservoir over the prospect area with top seal provided by Bilara carbonates or shale. Analyses of available petrophysical data from the Jodhpur formation in the study area show that heavy oil in the Baghewala area is encountered where the sand has a relatively high porosity. This observation gives rise to the hope that acoustic impedance (AI) will be sufficient to map the oil sand distribution. But overlapping values of AI for brine sands and heavy oil sands limits the use of AI alone to characterize these sands adequately. Thus, derivation of additional rock properties [shear impedance (SI) or ratio of compressional and shear velocity (V_p /V_s)] is essential to reduce the uncertainty in mapping oil sands and lateral heterogeneity of the reservoir.

The objectives of the present study are to map the Infra-Cambrian Jodhpur sandstone to assess the limits of heavy oil in the reservoir and to better understand the lateral heterogeneity of reservoir. Major challenges to achieve these objectives are posed by the complex habitat of hydrocarbons caused by poor porosity (<10%), significant vertical and lateral reservoir heterogeneity, and high viscosity of the fluid (specific gravity 14-18 degree API gravity) and by inadequate and inappropriate data (e.g. non-availability of measured shear velocity (V_s) in wells and suboptimal quality seismic data for quantitative interpretation). Rock physics modeling (Greenberg and Castagna, 1992) from two offset wells have been used to address the lack of shear sonic data in the area of interest. Amplitude-preserved seismic data conditioning was used to attenuate noise and improve the residual misalignment in reflections from the target for modeling amplitude variation with offset (AVO). AI and SI from simultaneous inversion of multiple angle stacks were used as inputs for derivation of litho-facies under a Bayesian framework. Good and poor reservoir facies with associated probabilities provided insight to understand lateral and vertical heterogeneity in the Jodhpur sandstone reservoir. The reservoir property maps derived from inverted seismic data delineated the boundary of heavy-oil bearing sands which conforms the Baghewala anticline.

Method

For quantitative reservoir characterization using simultaneous inversion, shear velocity logs in study area are used at two important stages: to estimate wavelets for multiple angle/offset stacks and to build low frequency shear impedance or V_p/V_s model to serve as a background model for inversion. One of the major technical challenges for simultaneous inversion in this area is absence of shear sonic data in wells penetrating the Jodhpur formation. We used the Greenberg-Castagna (1992) rock physics model to predict shear sonic data in the study area wells to meet the data requirement for simultaneous inversion.

Shear Prediction

The Greenberg-Castagna (1992) rock physics model predicts shear velocity in a sedimentary rock from measured compressional velocity and volume fractions of constituent lithologies using the following equation.

$$V_s = \frac{1}{2}\left\{\left[\sum_{i=1}^{L} X_i \sum_{j=0}^{N_i} a_{ij} V_p^j\right] + \frac{1}{\left[\sum_{i=1}^{L} X_i \left(\frac{1}{\sum_{j=0}^{N_i} a_{ij} V_p^j}\right)\right]}\right\}, \quad \ldots(1)$$

with the constraint that. $\sum_{i=1}^{L} X_i = 1$.

Here, L is the number of pure mono-mineralic lithology constituents. For the i^{th} constituent, the volume fraction is given by X_i and N_i represents the order of best-fitting polynomial. The corresponding regression coefficients are given by a_{ij}. V_p and V_s represent the P- and S-wave velocities (km/s), respectively, in composite brine-saturated multi-mineralic rock.

The following steps were used to map the good reservoir-quality Jodhpur sands. i) Build a rock physics model from offset well and use it to predict shear velocity in other wells for use with AVO modeling ii) Condition seismic data and perform AVO modeling iii) Perform simultaneous inversion to derive AI and SI iv) Define probability density functions for good and poor reservoir facies under Bayesian framework v) Derive reservoir facies and associated probability and vi) Map reservoir heterogeneity and limit of good reservoir facies.

Results

We used offset Well O1 having measured V_p and V_s logs to determine the regression co-efficients (Table 1) of the Greenberg-Castagna rock physics model. The match between the observed and modeled shear velocities in the Bilara and Jodhpur formations in Well O1 (Figure2a) shows that a first-order curve (i.e. $N_i = 1$ in Eq.1) best explains the observed shear velocity. Next, we used these parameters to predict shear velocity in Well O2. A very good match between the observed and predicted shear velocities in both Bilara and Jodhpur formations validates that the Greenberg-Castagna rock physics model is appropriate for prediction of shear velocity in this area (Figure 2b). Finally, we used the validated rock physics model to predict shear velocity in all the available wells in the study area for use with simultaneous inversion. Figure 2c shows the predicted shear velocity log in the Bilara and Jodhpur formations in Well A1.

Table 1 : Parameters for Greenberg-Castagana model.

Formation	Greenberg-Castagna Model Coefficients			
	Coefficient	Shale	Sand	Dolomite
Bilara	a_0	-1.00	-0.85588	-0.07775
	a_1	0.50	0.62000	0.60000
Jodhpur	a_0	-1.00	-0.85588	-0.07775
	a_1	0.56	0.62000	0.60000

The results of simultaneous inversion show a very good match between the observed and inverted AI and SI at all the wells. Figure 3 shows the match between observed and inverted AI and SI at Well A-1. The inverted data have been used to predict the disposition of good-quality sand over the Baghewala structure through a Bayesian framework (Sengupta and Bachrach, 2007). Figure 4 shows the inverted impedance and sand facies maps over the Jodhpur formation which is consistent with the geological setting of the area. The spatial extent of the hydrocarbon-bearing Jodhpur sand in the area could be delineated from the inversion results.

Conclusions

Rock physics modeling solved the problem of data inadequacy, lack of shear velocity in the wells for simultaneous inversion. Prediction of shear data also facilitated AVO modeling at these wells, which further enhanced the confidence in preconditioning of seismic data.

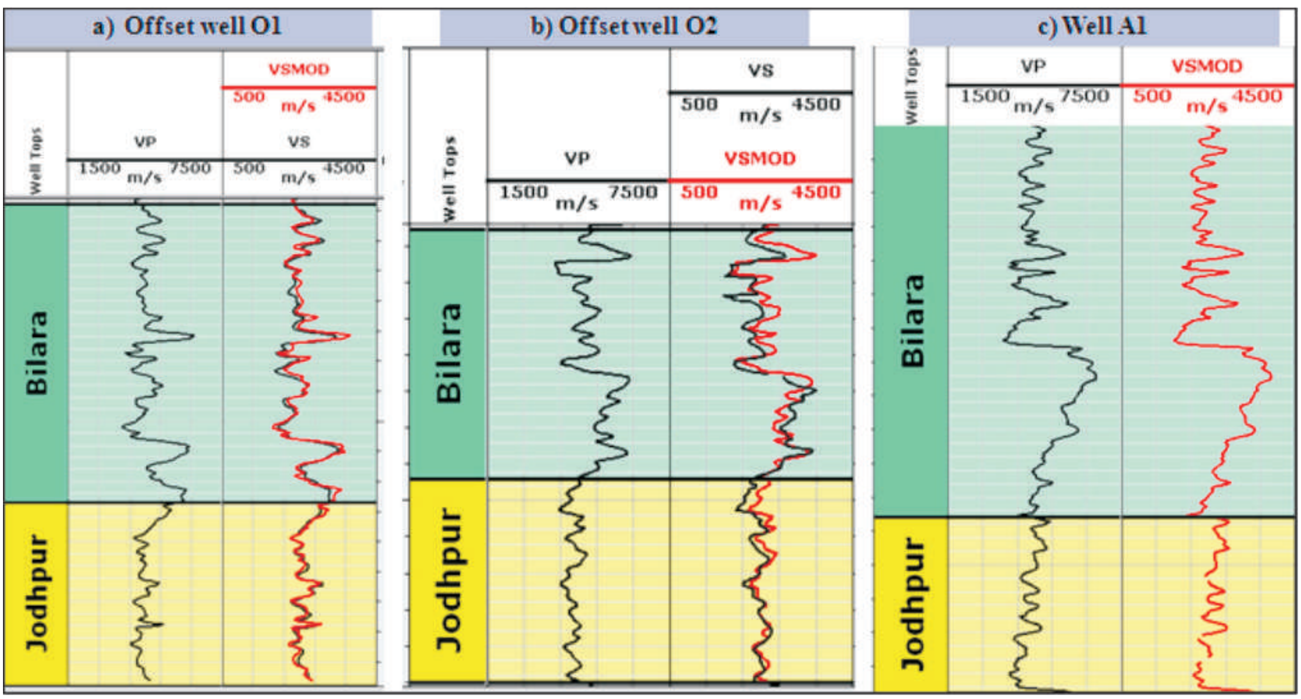

Fig. 2: Measured and predicted logs in a) offset Well O1 b) offset Well O2 and (c) Well A1. Left track shows compressional velocity and right track shows shear velocity. Red curve represents predicted values from rock physics model.

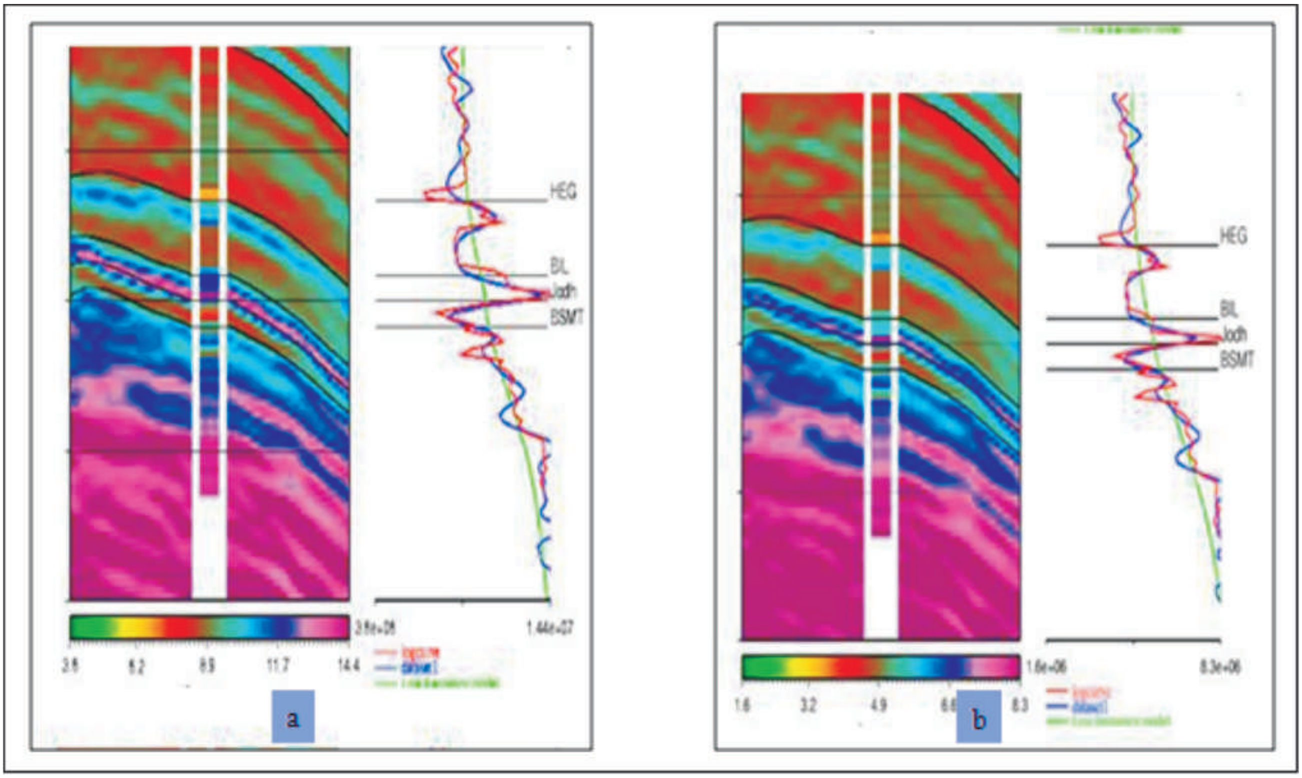

Fig. 3: (a) Inverted acoustic impedance and (b) shear impedance at Well A1. Red, blue and green curves show filtered log data, inverted rock property and low-frequency modeled data respectively. BSMT, basement; Jodh, Jodhpur; BL, Bilara; HEG, Hanseran Evaporite

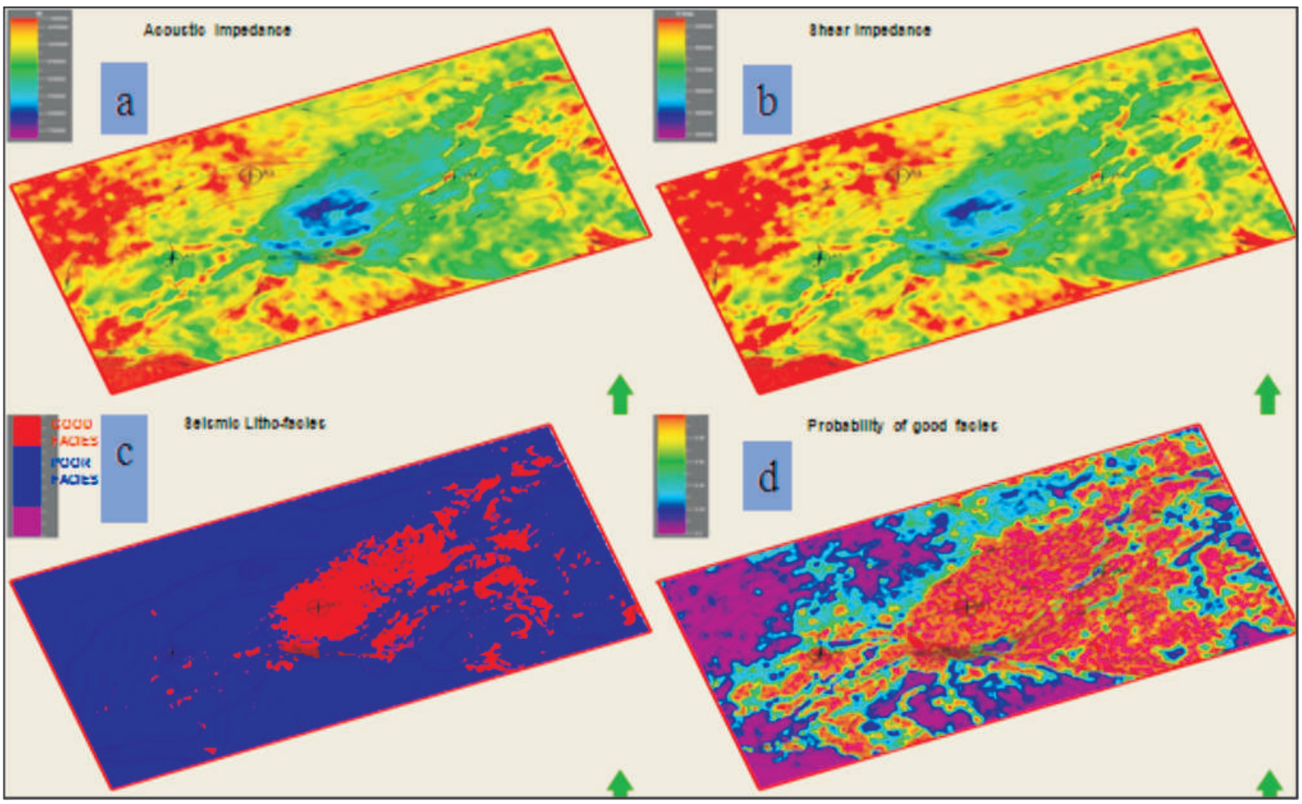

Fig. 4: In the Jodhpur sand, (a) minimum acoustic impedance, (b) minimum shear impedance, (c) seismic lithofacies and (d) associated probability of good reservoir facies over the study area.

Inversion-derived rock properties helped to create seismic reservoir facies maps as well as define associated uncertainties. A Major outcome of this study is that relatively good-quality reservoir facies favoring the occurrence of heavy oil in Jodhpur formation have been mapped over the Baghewala structure along with associated uncertainty. This will be used to locate (appraisal and development) wells in the area.

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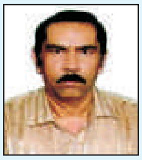
Author's Profile



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He has joined Oil India Limited (OIL) in the year 1982 after obtaining his Master of Technology (M.Tech) degree in Applied Geophysics from University of Roorkee. He has work experience of more than 30 years in Seismic API and G&M Surveys. He is a member of SEG, SPG, AEG & IGU and presented technical papers both in National and International Conferences/Workshops. He is presently holding the post of General Manager (Geo-services) in OIL and also the President of SPG, Duliajan Chapter, Assam.