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Generation of synthetic shear wave logs for multicomponent seismic interpretation

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Summary

Interpretation of Multicomponent Seismic requires an integrated study of PP and PS seismic data. Shear wave log data is essential for tie up of well and PS seismic information. In the absence of shear wave log in a few wells, an attempt has been made to generate synthetic shear wave log using multivariate statistical analysis of different basic log parameters to generate shear wave logs, which is validated with recorded Dipole Sonic log. The procedure is then extended to wells having no shear wave data. Finally, the generated shear wave is used for further multicomponent interpretation.

Keywords: *Shear Wave logs, Multilinear Regression*

Introduction

The increasing demand for energy discovery and recovery has compelled scientists to venture into hitherto unknown pastures. One such venture involves exploring the use of elastic waves and their properties to get an increasingly accurate insight into the subsurface geology. In situations where conventional 3D seismic interpretation pauses to answer, multicomponent seismic technology has come to the fore. In the Indian hydrocarbon scenario, ONGC has very aggressively pioneered in assimilation of this new technology, andthe ONGC 3D-3C Interpretation team had indigenously taken up a pilot project for interpretation of multicomponent data in a part of Padra field in Cambay Basin.

Overview

Multicomponent seismic interpretation requires petrophysical well log analysis and correlation, integration of well database with seismic at various stages of interpretation, calculation of Vp/Vs ratios, and joint inversion of PP and PS data for P-impedance, S-impedance and density. The presence of shear wave logs (Dipole Shear Sonic Imager, or DSI log) in the study area is an essential prerequisite for the study. However, the absence of recorded shear-wave data in most cases imposes severe limitations in interpretation. S-wave velocity can be estimated using P-wave velocity logs. The three commonly used techniqueswere explored, viz.Castagna's equation, Fluid Replacement Modeling (FRM) and multilinear regression analysis.

The Castagnaet. al. (1985) "mudrock line" gives

$$\mathbf{V_S=C_1*V_P+C_2,}$$

where C_1 and C_2 are local constants, for which different values were derived by various workers (viz. Han, 1986; Mavko et. al., 1998; Castagna et.al., 1993) for differing lithologies and geological set-ups. The method has been reported to be useful in clastic sequences, especially wet sands. FRM requires inputs like a) consistent and high quality density and porosity information, b) saturation data, c) rock matrix information and d) fluid properties, besides assuming that there is no water in the reservoir. The process, though more accurate, enhances the chances of error due to possible incomplete or inaccurate data.

Multilinear regression analysis, on the other hand, uses multiple well log data combinations, to predict certain reservoir parameter of interest through multilinear regression. The user has the choice to select either a single attribute or multiple attributes to achieve the goal. The present study has made use ofEMERGE module from Hampson-Russel software suite for generating the S-wave log.

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Padra field is situated on the rising flank of the eastern basin margin of south Cambay basin, and is one of few fields producing from the Basement/Trap section in India. The present study was aimed at prediction of shear wave velocities for wells where S-wave velocity data is not available in the field. Shear wave log is available in three wells in the study area (Wells P-A, P-B and P-C, Fig. 1). Of these, a well having good quality S-wave velocity log was chosen to test the viability of the process. The generated S-wave velocity log was then compared with the recorded log.

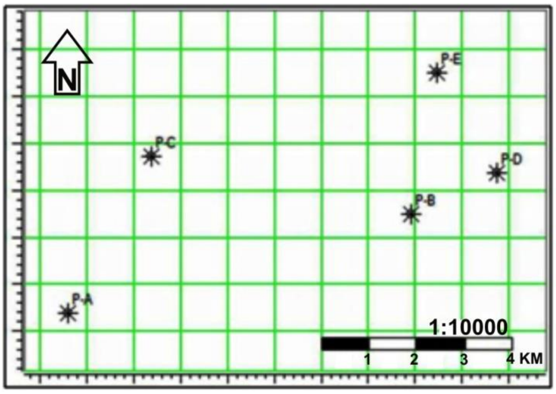


Figure 1: Map of Padra field displaying the well locations.

AGE	FORMATION	LITHOLOGY
LOWER TO MIDDLE MIOCENE	KAND	Sand &Shale in alternations
LOWER MIOCENE	BABAGURU	Sand with interbedded shale
UPPER MIOCENE TO UPPER OLIGOCENE	TARKESHWAR	Mainly shaly faceis with minor sand
LATE EOCENE TO EARLY OLIGOCENE	DADHAR	Sandstone with Shale, Claystone
MIDDLE TO UPPER EOCENE	ANKLESHWAR	Sand with shaly faceis
PALEOCENE	OLPAD	Trap conglomerate, Claystone&trapwash
UPPER CRETACEOUS	DECCAN TRAP	Weathered&fresh basalt

Table 1: Generalised Stratigraphy of Padra Field

Methodology

A suite of standard logs (Fig. 2) available in the selected well was chosen as input. The depth range can be selected for either the entire well or for a specified range. In the present study, the range was confined between the top of Dadhar Formation (Late Eocene–Early Oligocene) and top of Deccan trap (Upper Cretaceous) (Table-1).

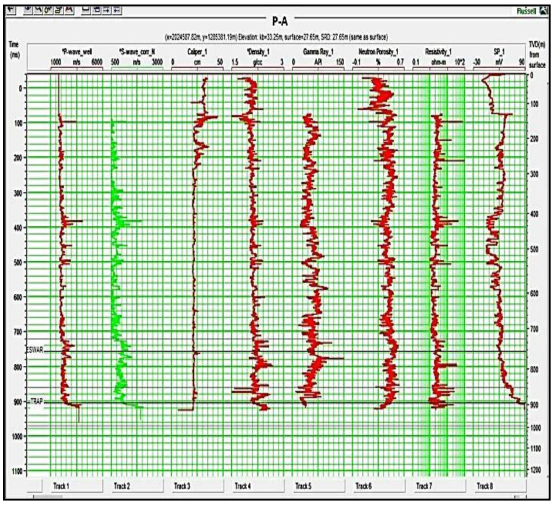
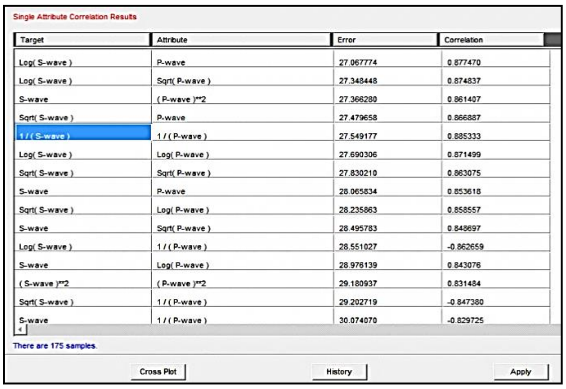


Figure 2: Log Display window

The system accordingly generates a list of attributes with different degrees of correlation (Fig. 3) to generate the target log (S-velocity, in this case). The attribute giving the highest percentage of correlation is taken for analysis.The simplest procedure for deriving at the desired relationship between the attributes is to crossplot the two.



Single Attribute Correlation Results

Target	Attribute	Error	Correlation
Log(S-wave)	P-wave	27.067774	0.877470
Log(S-wave)	Sqrt(P-wave)	27.348448	0.874837
S-wave	(P-wave)**2	27.366280	0.861407
Sqrt(S-wave)	P-wave	27.479658	0.866887
1 / (S-wave)	1 / (P-wave)	27.549177	0.885333
Log(S-wave)	Log(P-wave)	27.690306	0.871499
Sqrt(S-wave)	Sqrt(P-wave)	27.830210	0.863075
S-wave	P-wave	28.065834	0.853618
Sqrt(S-wave)	Log(P-wave)	28.235863	0.858557
S-wave	Sqrt(P-wave)	28.495783	0.848697
Log(S-wave)	1 / (P-wave)	28.551027	-0.862659
S-wave	Log(P-wave)	28.976139	0.843076
(S-wave)**2	(P-wave)**2	29.180937	0.831484
Sqrt(S-wave)	1 / (P-wave)	29.202719	-0.847380
S-wave	1 / (P-wave)	30.074070	-0.829725

There are 175 samples.

Figure 3: Single Attribute parameters

A conventional crossplot (Fig. 4) of the selected attribute is generated, which shows the variation of the points from line of best fit. The output of the analysis was compared with the recorded S-velocity log (Fig. 5), showing a high percentage of correlation within the analysis window.

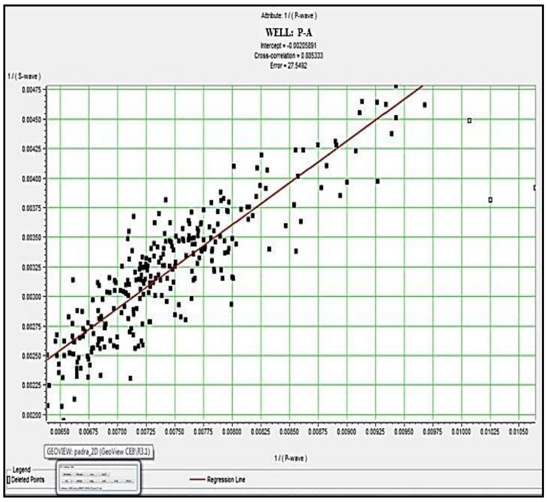


Figure 4: Single Attribute cross plot: Correlation 88.5%

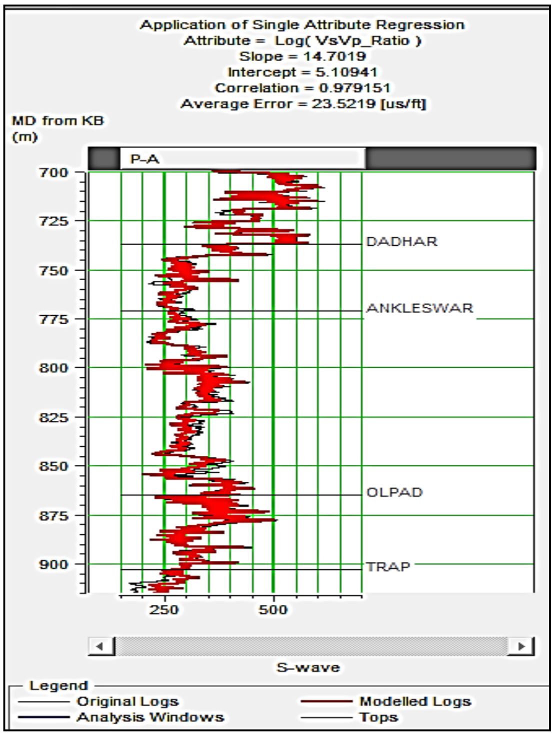
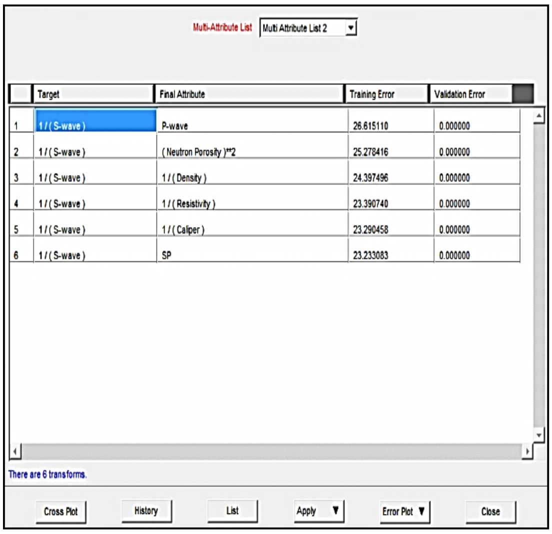


Figure 5: Application of single attribute regression, with 98% correlation:original log (black) with modeled one (red)

Next, the same data is used for multi-attribute analysis, in the same analysis window as above. Again, a list of attributes is generated (Fig. 6).



	Target	Final Attribute	Training Error	Validation Error
1	1 / (S-wave)	P-wave	26.615110	0.000000
2	1 / (S-wave)	(Neutron Porosity)**2	25.278416	0.000000
3	1 / (S-wave)	1 / (Density)	24.397496	0.000000
4	1 / (S-wave)	1 / (Resistivity)	23.390740	0.000000
5	1 / (S-wave)	1 / (Caliper)	23.290458	0.000000
6	1 / (S-wave)	SP	23.233083	0.000000

There are 6 transforms.

Figure 6: Multi Attribute correlation list

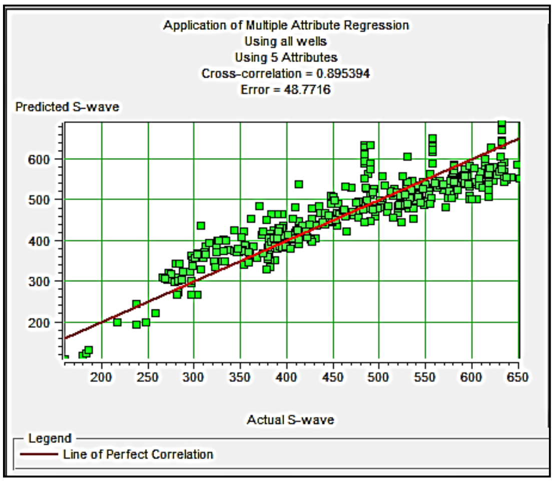


Figure 7: Multi Attribute crossplot: Predicted vs Actual S-wave: Correlation 89.5%

It was observed that the combination of all the 5 attributes generated (Fig. 7) gives the highest correlation. The analysis outputs using different numbers of attributes, on comparison with the recorded S-velocity log showed high degree of correlations within the analysis window, the maximum being 99.8%, with 5 attributes (Fig.8).

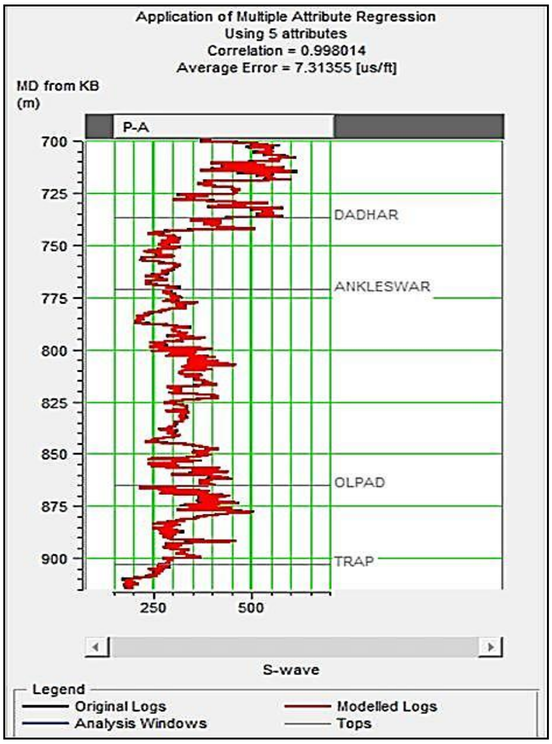


Figure 8: Application of multi attribute regression, using 5 attributes, with 99.8% correlation

The comparison of the actual and the synthetic S-wave log shows a quite perfect fit (Fig. 9), thereby authenticating the procedure of generating the synthetic shear wave log.

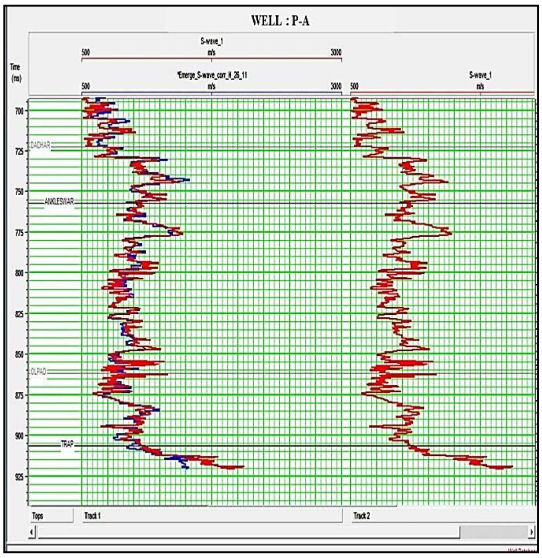


Figure 9: Comparison of synthetic (blue) vs actual (red) S-wave log

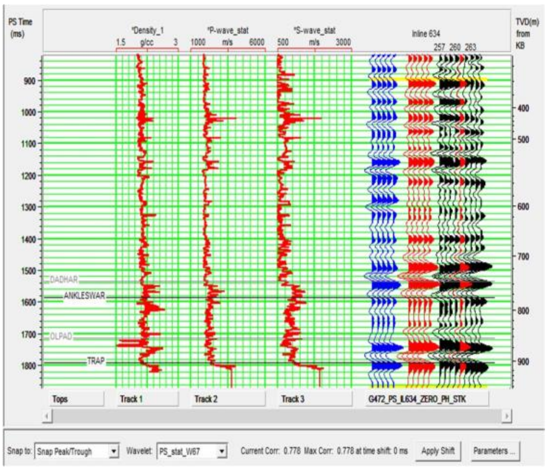


Figure 10: Synthetic seismogram of well P # A

The synthetic S-wave data from the well is then tied to the seismic, and a good correlation is obtained (Fig. 10).Following the same procedure, the synthetic S-wave velocity logs are again generated for the two other wells in the field where actual S-wave velocity logs were available. In all the cases, the synthetic log matches quite well when compared with the actual.

Now, synthetic shear wave logs are generated for some wells (wells P-D and P-E, Fig. 1) where there was no recorded shear wave log available (Fig. 11). When the respective wells were tied to the seismic, they showed fairly good correlation (Figs. 12& 13).

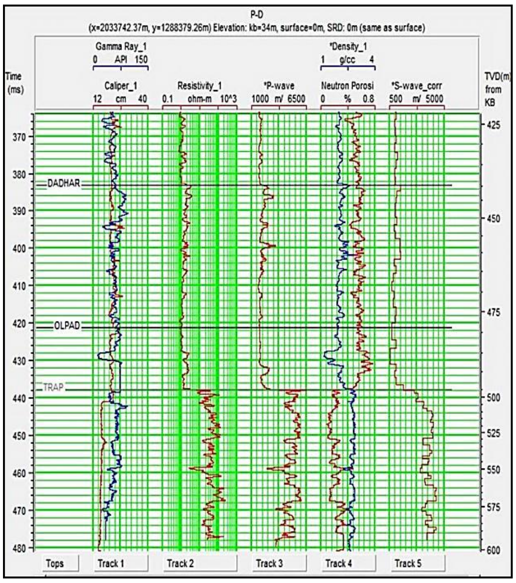
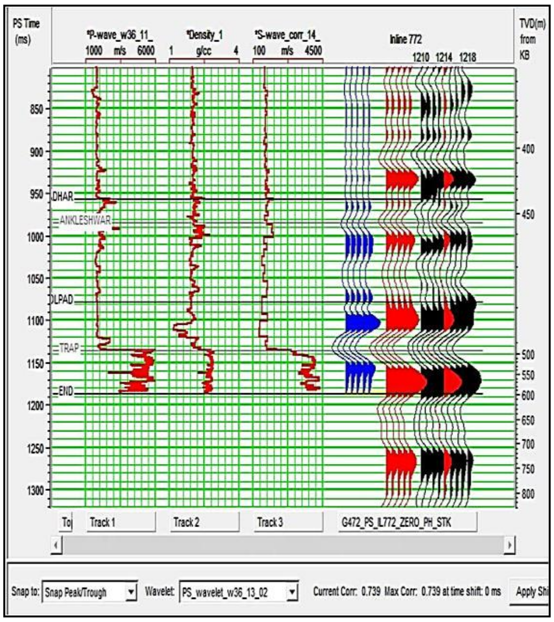
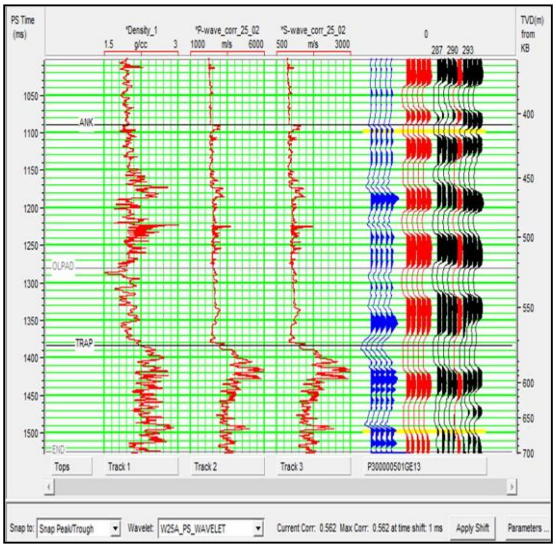


Figure 11: Generation of synthetic S-wave log in well P # D



Snap to: Snap Peak/Trough Wavelet: PS_wavelet_w36_13_02 Current Corr: 0.739 Max Corr: 0.739 at time shift: 0 ms

Figure 12: Correlation of synthetic S-wave log with seismic: Well P#D



Snap to: Snap Peak/Trough Wavelet: W25A_PS_WAVELET Current Corr: 0.562 Max Corr: 0.562 at time shift: 1 ms

Figure 13: Correlation of synthetic S-wave log with seismic: Well P # E

Finally, joint inversion studies were carried out and parameters like Zp, Zs, Density and Vp/Vs ratios were obtained.

Discussion

An integrated interpretation of conventional seismic data (PP wave) with converted wave (PS) data plays an important role in the geophysical study of a reservoir towards objectives such as lithology, pore fluid type and geophysical interpretation. There are different methodologies for generation of synthetic shear wave velocity data, in the absence of recorded shear wave logs. However, most of these are empirical mathematical models using limited petrophysical inputs, having been developed mostly for sandstone reservoirs and are not studied for all lithologies. Therefore, to predict Vs utilizing a fast and robust system from well log data is considered more efficient and useful.In the present study, a statistical method was used to establish a correlation among effective petrophysical properties and shear wave velocities, giving a very high correlation of 98% for single attribute analysis and over 99% for multi-attribute analysis.

Conclusion

It can be concluded that the use of multilinear regression method gives a satisfactory result for generating shear wave velocity logs in the present field. This method may help interpretation of multicomponent data recorded in different basins in Indiawith diverse geological set-ups. However, the process needs to be further validated through application in other basins.

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N.B.: The views expressed in this paper are those of the authors only, and not necessarily of the organization they represent.

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