Extended Elastic Impedance (EEI) in Class I Low Porosity Sands.

Sakunthala Devi Chada*, Dibyendu Guchhait, Ajai Bansal, Reliance Industries Ltd (E&P)

Sakunthala.chada@ril.com

Keywords

Cross Plots, EEI logs, FRM, Lithology, Fluid, AI, GI.

Summary

The objective of this study is to analyze whether fluid and lithology discrimination is possible using Extended Elastic Impedance (EEI) logs within a complex low porosity, low permeability Class I sands. The presence of compressible fluid (gas) in the pore space of rock is known to have considerable influence on elastic parameters like P-impedance and S-impedance but is not often observed in Class I reservoirs. In the East Coast of India wells have also targeted the Class I reservoirs sands. The Well 'A' drilled in offshore India has been used to test the lithology and fluid discrimination. The lithology discrimination is achieved with the use of well log data however the fluid discrimination could not be achieved.

Extended elastic impedance (EEI) as described by (Whitcombe et al, 2002) is a coordinate rotation in AI-GI(Acoustic Impedance – Gradient Impedance) space has been tested to separate the fluids in the well .The generation and analysis of EEI logs was carried out to distinguish the shales from sands and different reservoir fluids. Fluid Replacement Modeling (FRM) using Gassmann's equations is carried out to simulate various fluid scenarios and tried to see whether the same cross-plot technique can be used to distinguish between different reservoir fluids. The discrimination of sands from shales is achieved but fluid discrimination of hydrocarbon sands from water sands remains challenge in general in Class I low porosity sands. Similar results were obtained from the study carried out in other wells in the region.

Introduction

In the realm of reservoir characterization, it is vitally important to understand the ability to discriminate between different lithologies and fluids. Cross-plotting technique using well log data is a well-known technique in the evaluation of lithology and pore fluid variations. Cross-Plots were built using the insitu log data and the Fluid Replacement Modeling (FRM) log data for lithology and fluid discrimination. The Well 'A' drilled in the East Coast of India has been used in this study to analyze fluid and lithology discrimination using cross-plot technique between different elastic parameters (EEI logs). Both acoustic and elastic properties were analyzed.

Methodology

Extended elastic impedance (EEI) as described by (Whitcombe et al, 2002) is a coordinate rotation in AI-GI (Acoustic Impedance-Gradient Impedance) space (using log-log axes) as shown in Figure 1. An EEI curve is parameterized by the rotation angle 'Chi'. The rotation angle chi can be optimized to improve the correlation with the reservoir parameter such as Vshale or porosity with an elastic parameter such as bulk or shear modulus, Poisson's ratio or shear impedance, Compressional-wave to shear-wave velocity ratio (Vp/Vs). These benefits reduce the uncertainty in hydrocarbon exploration (Stewart et al., 1995, CREWES Report#7).

Bulk modulus and Lame's parameter tend to be very sensitive to changes in pore fluid. In AI-GI space they lie at angles somewhere between 10 to 30 deg. This suggests that at around this angle there's a projection that will optimally enhance fluid contacts. This is referred to as the fluid projection. Similarly shear modulus and shear impedance will be insensitive to changes in pore fluid but potentially sensitive to changes in lithology (and porosity). These parameters typically lie around (-30) to (-90) deg so a projection near to this angle is referred to as a lithology projection.

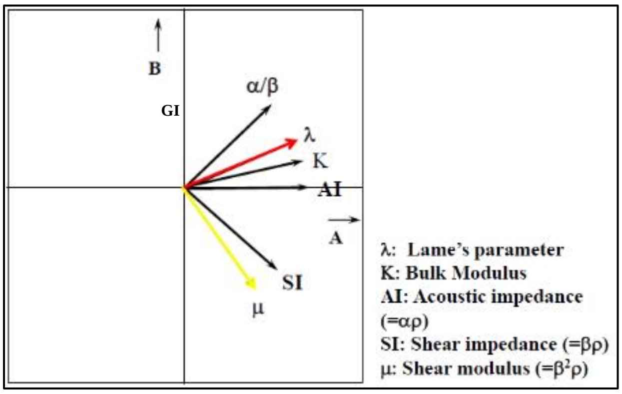

Figure 1.Elastic parameter projection in AI-GI space (Patrick Connolly, SEG Distinguished Lecture).

Examples

The well 'A' was drilled to identify hydrocarbon presence within a complex geological sequence where the reservoir is low porosity, low permeability Class I sands. In the well 'A', hard shale and hard sand interval were encountered above the main objective interval. This hard sand interval is characterized by hard acoustic impedance. Two sand zones saturated with gas were encountered below the hard sand. A thick water sand zone was encountered below gas bearing sands. Low reflectivity massive sand rich interval is encountered below the water sand. Numerous cross-plots between different elastic well logs of Well 'A' were generated from overlying shales to reservoir section to understand the discrimination between different kinds of lithology and fluids.

Besides well logs such as P-velocity (Vp), Density (Rhob), Acoustic Impedance (AI), Gradient Impedance (GI), Porosity (Phi), Extended Elastic Impedance logs were studied for this analysis. Mainly EEI(-70) for lithology discrimination and EEI(20) for fluid discrimination were used. Minimum of the shale volumes computed from density - neutron and resistivity has been used as volume of shale. The insitu logs and the Fluid Replacement Modeled (FRM) logs were used for this study.

A cross-plot between insitu P-velocity and density is shown in Figure 2. The cross-plotted interval is shown on the right. Over plotted on the data are iso-impedance line (lines representing equivalent acoustic impedance). For this study, sands are considered to have a Vshale of less than 30%, while shales have a Vshale greater than 70%.

From Figure 2, it is very clear from the analysis that the overburden shales exhibit much lower impedance than sands. Reservoir gas sands and water bearing sands have similar compressional velocity with only a slight variation in density. The gas bearing sands are acoustically hard. The hard sands have higher acoustic impedance compared to the gas and water bearing sands.

A cross-plot between Fluid Replacement Modeled (FRM) P-velocity and density well logs is plotted for the sands with VSH<0.3 in Figure 3. It is observed that the gas sands have lower density than brine sands but the p-velocities are very similar. The gas and brine sands show similar acoustic impedance.

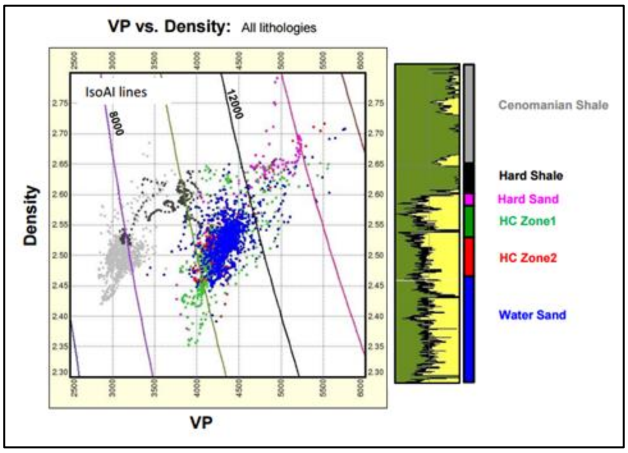

Figure 2.Cross-plot between insitu P-velocity Vs. density for all types of lithology.

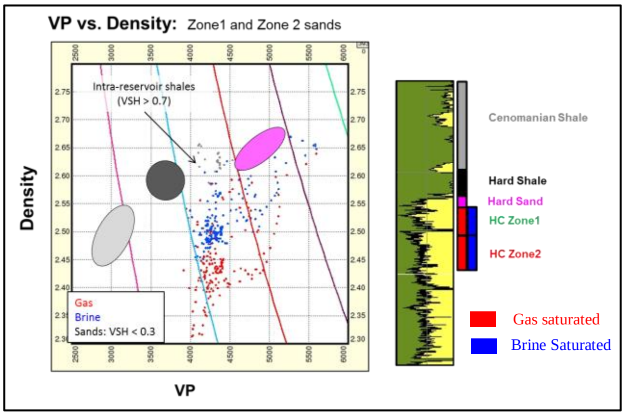

Figure 3.Cross-plot between Fluid Replacement Modeled (FRM) P-velocity Vs. Density well logs sands within the reservoir interval with VSH < 0.3.

Similarly AI and GI well logs were computed. The cross-plots were built between insitu well logs (Figure 4) as well as fluid substituted sands with VSH<0.3 in Logarithmic scale (Ln AI Vs Ln GI) in AI-GI space (Figure 5).

From the Figure 4, a very good discrimination between shales and sands is observed. HC Zone1 sand is slightly separated from HC Zone2 sand. But a big overlap between HC Zone2 sand and water sands are observed from the cross-plot. It is observed from Figure 5, that the fluid discrimination is quite challenging in the low porosity, low permeability Class I reservoir sands in.

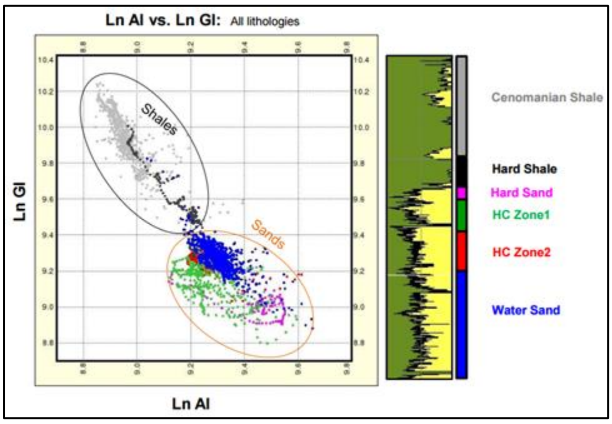

Figure 4.Cross-plot between insitu Ln AI Vs. Ln GI for all the lithology.

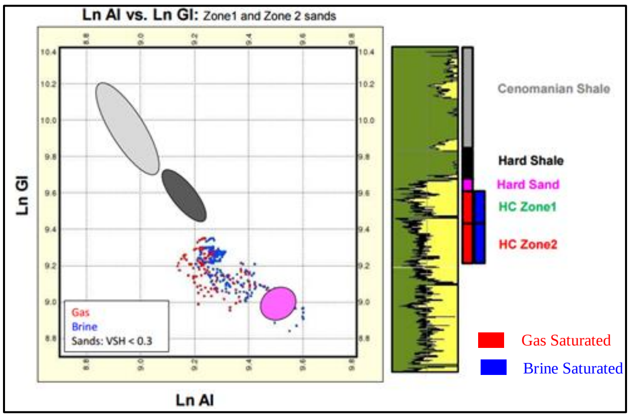

Figure 5.Cross-plot between Fluid Replacement Modeled (FRM) well logs Ln AI Vs. Ln GI for reservoir sands with VSH < 0.3.

The EEI logs were used to analyze whether it is possible to separate the reservoir fluids in a complex reservoir of low porosity, Low permeability Class I sands. The possible benefit of an EEI approach is that the rotation angle can be optimized to improve the correlation with the reservoir parameter rather than the elastic parameter.

The EEI logs for different angles are generated and correlated with the Vshale log. From Figure 6, it is seen that EEI(-70) log shows a good match with the Vshale log and also nearer to GI projection. Similarly good match with elastic parameter Mu is also seen (Figure 6). Hence, EEI(-70) is considered as the lithology indicator and an angle orthogonal to EEI(-70), EEI(20) is used as fluid indicator. Hence, EEI(-70) has been used for lithology discrimination and EEI(20) for fluid discrimination.

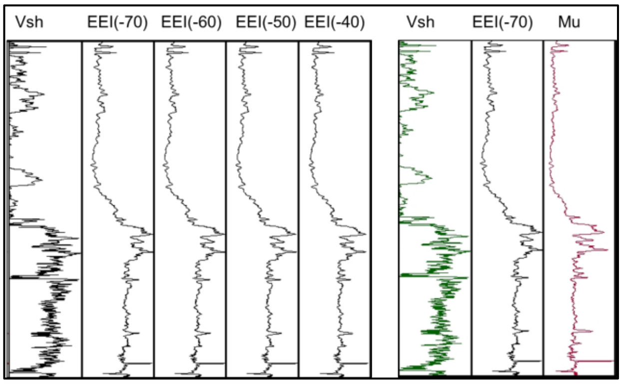

Figure 6. EEI(-70) log showing better match with the Vshale log and Mu log.

A cross-plot between insitu EEI(-70) Vs. Porosity for all lithologies plotted as shown in the Figure 7. The separation between shale and sands are clearly seen. From Figure 8, the histogram plotted for EEI(-70) for all lithologies clearly shows separation between shales and sands suggestive that EEI(-70) is a good lithology indicator.

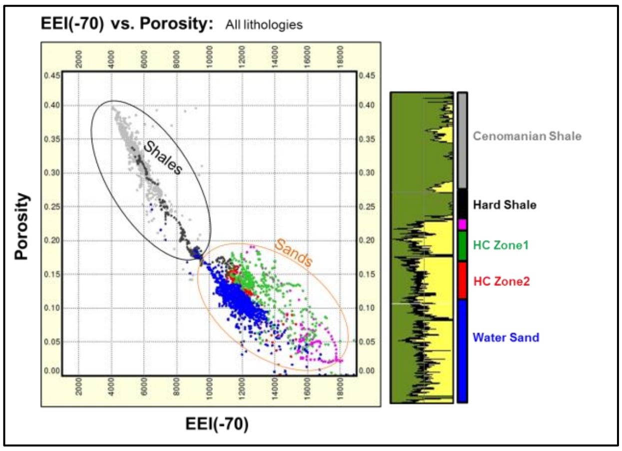

Figure 7.Cross-plot between insitu EEI(-70) Vs. Porosity for all types of lithology.

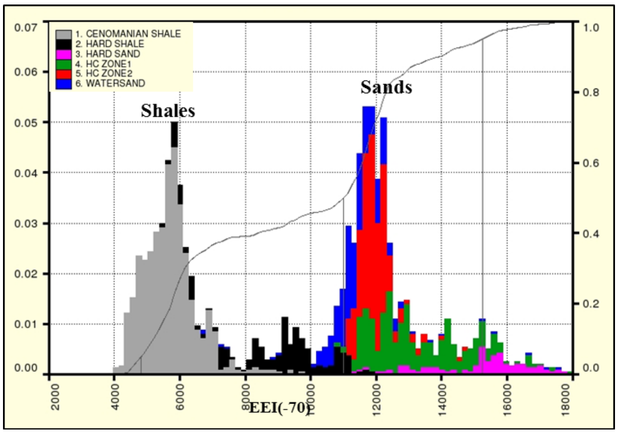

Figure 8. The histogram plotted for EEI(-70) for all lithologies.

A cross-plot between insitu EEI(20) Vs. porosity for all lithologies is shown in the Figure 9. The HC Zone1 sands separated from HC Zone2 sands and water sands, but a big overlap of HC Zone2 sands and water sands is visible.

A cross-plot with fluid substituted sands with VSH < 0.3 is plotted as shown in the Figure 10. From Figure 10, it is clearly observed that the fluid discrimination between reservoir fluids is challenging in low porosity Class I sands. Only a minimal fluid separation is observed at higher porosities.

From Figure 11, the histogram plotted for EEI(20) for reservoir fluids shows that the separation between reservoir fluids is very minimal for low porosity Class I sands.

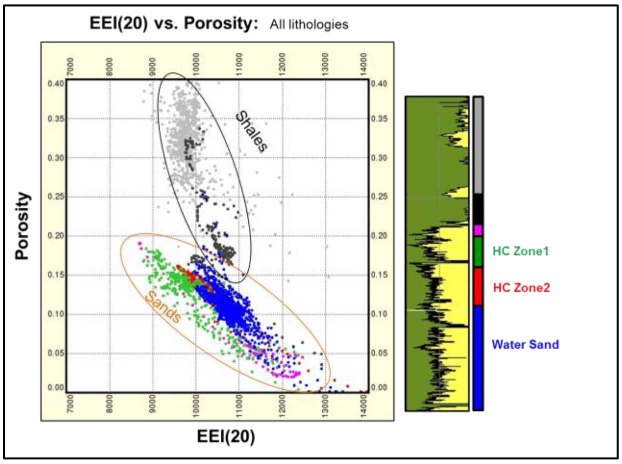

Figure 9.Cross-plot between insitu EEI(20) Vs. porosity for all types of lithology.

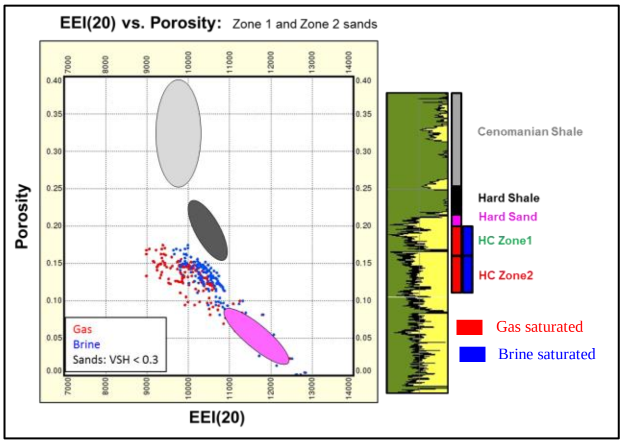

Figure 10. Cross-plot between Fluid Replacement Modeled (FRM) EEI(20) Vs. porosity for reservoir sands with VSH < 0.3.

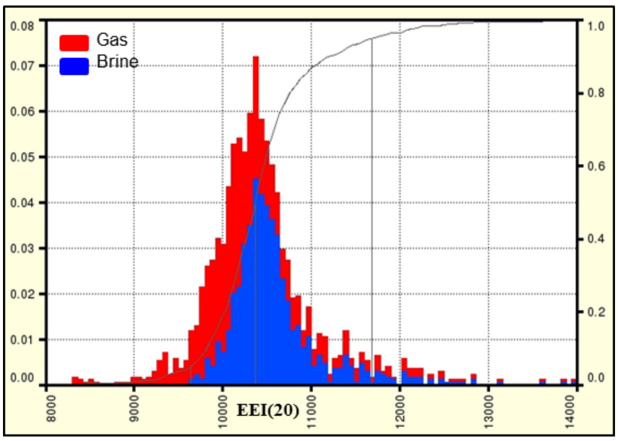

Figure 11. The histogram plotted for EEI(20) for Reservoir fluids.

Conclusions

The reservoir characterization of sands in the study well 'A' which was drilled in a geologically complex sequence is geophysically challenging. The EEI technique has been used in this study for lithology and fluid discrimination, where the reservoir is low porosity Class I sands. The cross-plots plotted between different log data suggest a clear discrimination between shales and sands. Fluid discrimination in the EEI space, is challenging in low porosity Class I sands. Only a minimal fluid separation is observed between the reservoir fluids at higher porosities. Similar study carried out in the nearby wells is in conformance with the present study.

References

Patrick Connolly, "Robust Workflows for Seismic Reservoir Characterization". SEG Distinguished Lecture; April 2010, CSEG RECORDER.

David N. Whitcombe, Patrick A. Connolly, Roger L. Reagan, and Terry C. Redshaw (2002). "Extended elastic impedance for fluid and lithology prediction." Geophysics 67, Special Section—Seismic Signatures of Fluid Transport, 63-67.

Russell B. H., K. Hedlin, F.Hilterman and L. R., Lines, 2003, Fluid property discrimination with AVO: "A Biot-Gassmann perspective", Geophysics, 68, 29-39.

Connolly, P., 1999. "Elastic impedance". The Leading Edge, April, 438-452.

Stewart RR, Zhang Q, Guthoff F, 1995 "Relationships among elastic-wave. **values;Rpp,Rps,Rss,Vp,Vs,k,σ,ρ"** CREWES Report #7.

Acknowledgments

The authors would like to extend sincere gratitude to the Quantitative Interpretation team especially Ashok Yadav, Shantanu Chakraborty for providing the inputs and support during the execution of this project. The authors would like to thank Ajoy Biswal for critical review of this work and Robert Marten for his support during the project execution. The Authors is grateful to Head of Exploration for assigning this project, and extending support and encouragement during the completion of this project. Additionally, we thank Reliance Industries Ltd for granting permission to publish this work.