ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15–18 February 2015 Perth, Western Australia

Volcanic rock characterisation using the concept of Extended Elastic Impedance: A case study from a Middle Jurassic gas reservoir in offshore Western Australia

Iftikhar Arsalan Syed
INPEX
Level 22, 100 St Georges Terrace
Perth WA 6000
arsalan.syed@inpex.com.au

Kapil Seth
INPEX
Level 22, 100 St Georges Terrace
Perth WA 6000
kapil.seth@inpex.com.au

Keiichi Furuya
INPEX
Level 22, 100 St Georges Terrace
Perth WA 6000
keiichi.furuya@inpex.com.au

SUMMARY

Successful identification of volcanic rocks is critical in reservoirs where they have been previously intersected. This is because they impact on reserve estimates and influence fluid flow behaviour. Various studies using seismic inversion data were performed to try to characterise volcanic rocks in a sandstone reservoir in the Plover Formation. We noted that traditional techniques such as cross-plots between P-Impedance (Ip) and Vp/Vs was not very effective in this reservoir due to significant facies overlap at seismic resolution and inversion data quality. Therefore volcanic rock identification was attempted using advanced seismic attribute analysis. This involved testing and evaluating other elastic attributes, either individually or in combinations, to try and segregate volcanic rocks from other lithofacies.

Two approaches were adopted to find out a suitable single attribute to identify the volcanic rock: (i) scaling of elastic logs with a non-elastic trend; (ii) generating a single attribute using Ip, Is and LMR cross-plots. Log and seismic scale analysis proved the suitability of both methods in volcanic rock identification. Subsequently, Extended Elastic Impedance (EEI) was applied to generate the EEI equivalent of those single attribute yielding positive results.

Key words: Volcanic, EEI, Lambda-Rho, Mu-Rho.

INTRODUCTION

The area of study is located on the North West Shelf of Australia which is considered to be one of the most prolific areas in terms of hydrocarbon accumulation. Several discoveries have been made in recent past. The reservoir comprises Jurassic Plover Formation sandstones filled with gas. The Plover Formation was deposited in the Early to Middle Jurassic as a syn-rift sequence and comprises a thick sequence of fluvial to deltaic sandstones with carbonaceous mudstones interbeds, coal and basaltic volcanic rocks. The presence of high N/G sands as well as volcanic rocks has been confirmed in the study area by multiple well penetrations.

Identification of volcanic rocks is hence one of the most important elements to develop the gas reservoir.

Prior to this study, seismic inversion data were used to delineate the spatial distribution of volcanic rocks within the reservoir. However, significant overlap of lithofacies on P-impedance (Ip) vs Vp/Vs cross-plots resulted in an unreliable volcanic rock distribution map.

Accordingly, the requirement to find other attributes and/or different approaches was initiated. This paper introduces the methods and results of the study in which the applicability of advanced EEI techniques were tested using well log data both at log and seismic scale resolution.

METHOD AND RESULTS

The aims of this study were to identify a **single attribute** to discriminate volcanic rocks from other lithofacies and then **predict it** using the EEI concept. The method was first established at well log resolution and then at the seismic scale.

Finding a single attribute

The study was conducted in three different steps:

1. 1D histogram analysis
2. 2D cross-plot analysis
3. Test of EEI modelling

1D analysis of various log properties indicates that Lambda-Rho (LR) is the best single attribute to characterise different lithofacies.

On the other hand, 2D cross-plot analysis shows that the Ip vs. S-impedance (Is) and Lambda-Rho vs. Mu-Rho (LMR) cross-plots are the best among the selected attributes to segregate different lithofacies.

Further two different methodologies were adopted to enhance lithofacies discrimination and analyse them quantitatively.

Approach 1 involved new single attribute logs using two different cross-plots, namely Ip vs Is and Lambda Rho vs Mu Rho (LMR). These attribute logs were generated by calculating the orthogonal distance of each data point from the shale line as illustrated in Figure1. The log generated from the Ip vs Is cross plot was named DS_PS and the log generated from the LMR was named DS_LRMR. Lithofacies captured by applying constant cut-offs on the attribute log (shown in figure 2) show good agreement with the actual interpretation. The QC cross plot also shows good agreement between actual and predicted lithofacies both for volcanic rock and sandstone (Figure 3).

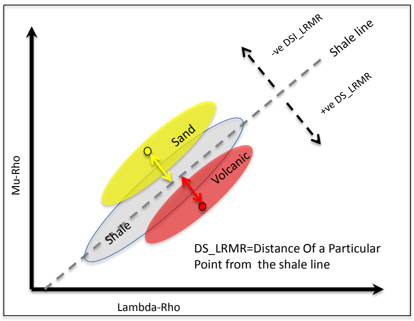

Figure 1. Schematic illustration of attribute calculation. The dotted grey line is the line of best fit across the shales.

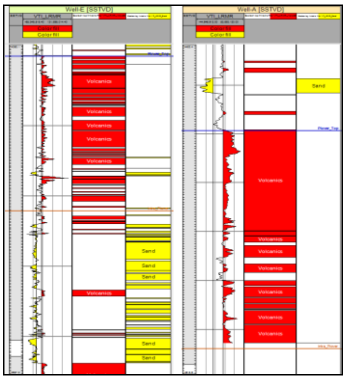

Figure 2. The first and second tracks show DS_LRMR and the actual lithofacies interpretation log, whereas the third and fourth tracks show the predicted volcanic rock and sandstone prediction using DS_LRMR.

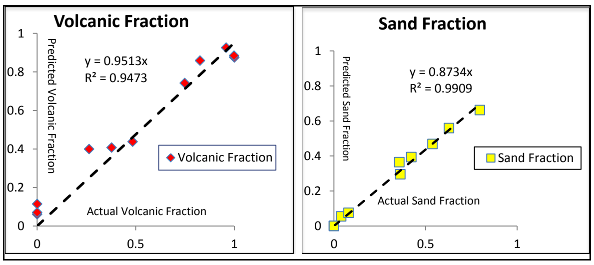

Figure 3. The left figure is a cross-plot between actual and predicted volcanic rock fractions for the reservoir interval in each well, whereas the right figure is the same for sandstone prediction.

Approach 2 is based on non-elastic scaling of an elastic log. Petrophysicists identify volcanic rocks based on the unique combination of GR and Neutron-Density log separation (NDS). Volcanic rocks exhibit low GR with a negative (-ve) NDS response, sandstones show low GR and positive NDS separation, and shales show high GR and negative NDS separation.

Using the above concept, a Scale Factor Log (SFL) was generated dividing the NDS by GR in order to incorporate effects from both GR and NDS into a single elastic log.

Figure 4 shows the schematic log response of the NDS and GR against three different lithofacies on the left and an example from a well on the right.

The left hand side of Figure 5 shows a schematic of the SFL log and the corresponding well example is on the right. On the SFL log, sandstones have a high positive value, shales have a low negative value, and volcanic rocks have a high negative value.

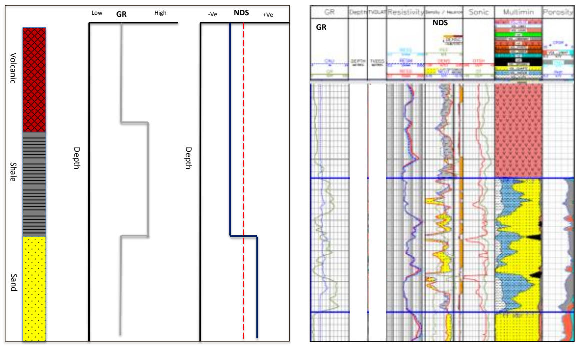

Figure 4. Left figure shows the schematic log response of NDS and GR against three different lithofacies and right hand side shows an actual well example.

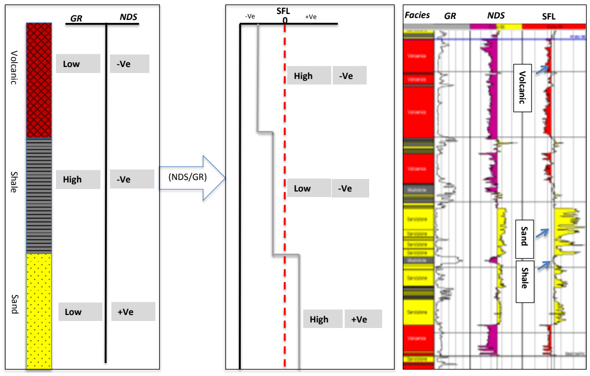

Figure 5. Schematic of SFL log derivation and its response against different lithofacies. An actual well example is given on the right.

The derived SFL log was used to scale the Lambda-Rho log. A constant single cut-off value was then applied to the resultant Scaled Lambda-Rho (SLR) log to segregate the lithofacies. Figure 6 shows the results of lithofacies prediction using SLR and Figure 7 shows a QC cross-plot between actual and predicted facies fractions for all wells.

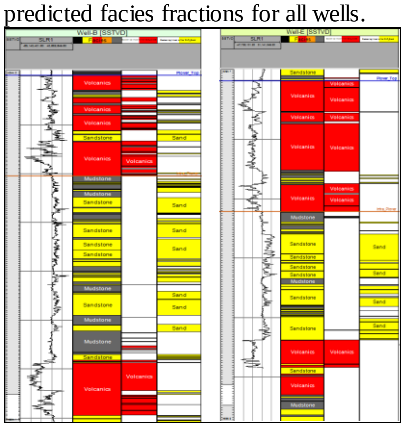

Figure 6. Well results of lithofacies prediction using SLR for two drilled wells. The first and second panels show SLR and actual facies interpretations respectively whereas the third and fourth panels show the predicted volcanic rock and sandstone facies.

From the above analysis, DS_PS, DS_LRMR and SLR were observed to effectively predict a lithofacies flag. In order to generate the above mentioned target logs (DS_PS, DS_LRMR or SLR) at an undrilled location, the Extended Elastic Impedance (EEI) method (Whitcombe 2000) was tested. EEI is a method through which one can find out the impedance equivalent of a target log so that an equivalent seismic stack can be generated. The Elastic Impedance concept was introduced by Connolly in 1991 (Reference 1) and then further developed into an Extended Elastic Impedance application by Whitcombe (Reference 2) in 2002.

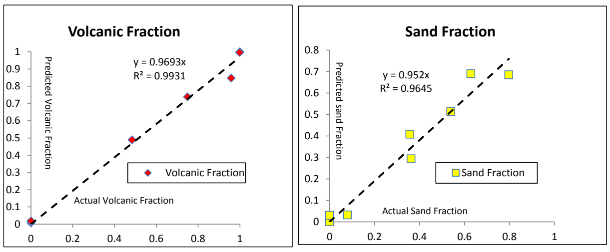

Figure 7. Left figure is a cross-plot between actual and predicted volcanic rock fractions for the reservoir interval in each well, and the right figure is the same plot for sandstone prediction.

Generating target logs using EEI:

P-wave velocity, S-wave velocity and density logs were used as input log data and DS_PS, DS_LRMR and SLR were considered as target logs. An EEI spectrum at Chi (χ) -90deg to +90 deg was generated and then an optimum χ was found for each target log to generate its EEI equivalent.

SLR: Figure 8 shows the correlation coefficient between the target SLR log and the EEI equivalent at various Chi angles. Each colour on the plot corresponds to a well. Overall, seven wells follow the same trend with a high correlation coefficient at a Chi of 21 deg; thus the EEI at a Chi of 21 deg is the equivalent of SLR at log resolution.

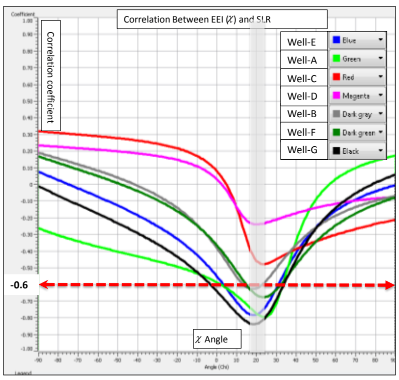

Figure 8.The correlation coefficients between EEI and SLR for range of values of Chi for all wells in the field penetrating the reservoir.

In the above plot, two wells show a lower correlation coefficient compared to the rest of the wells. These wells intersect a thick interval of complex lithology consisting of interbedded coal, pyrite and sandstone.

The SLR log and its EEI equivalent computed at a Chi of 21 deg. are plotted in a same log panel in Figure 9 to illustrate the degree of matching at log scale resolution.

Most of the wells show very high correlation coefficients between DS-PS and DS-LRMR and their respective EEI equivalents. Multi-well analysis shows a narrow range of Chi for the relevant target log.

The results of this EEI study at log resolution are encouraging and are motivating us to test this technique at seismic resolution.

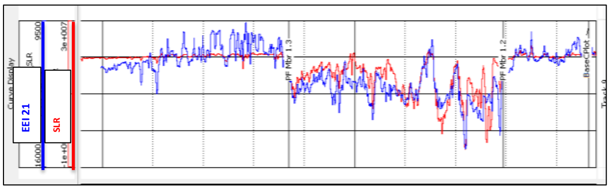

Figure 9. SLR (red) and EEI 21(blue) were plotted to illustrate the match between two.

DS_PS and DS_LRMR: Figure 10 shows the results using DS_PS and DS_LRMR has been used as target logs.

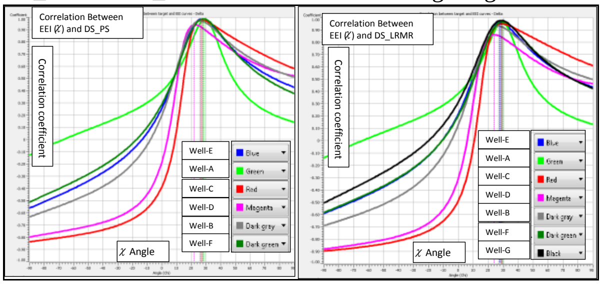

Figure 10. The correlation coefficients (a) between EEI and DS_PS, (b) between EEI and DS_LRMR for range of values of Chi for all wells.

Seismic scale analysis of well log data:

Since the study has found promising results at well log resolution, the next step was to check the applicability at the seismic scale. SLR logs were high cut (HC) filtered at different frequencies from 15Hz to 70 Hz. Each filtered SLR log was used to create a histogram, colour coded by lithofacies. It was found that the sandstone and mudstone facies in the lower frequency range overlapped significantly, but volcanic rock facies maintain their separation.

Figure 11 shows a comparison of the SLR at log resolution and 35 Hz HC filtered SLR. Masking of the sandstone and mudstone facies is visible on the filtered histogram; however, volcanic rock is well separated.

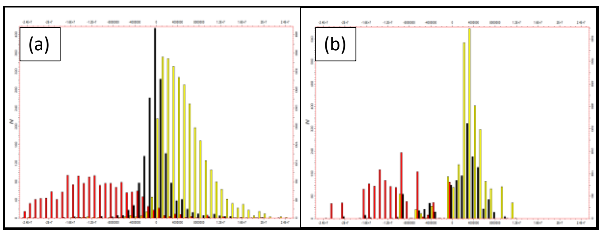

Figure 11.(a) Histogram distribution of SLR in well log resolution shows good separation of three different lithofacies (b) Histogram distribution of filtered SLR log (HC 35Hz) colour coded with lithofacies shows overlap of the sandstone and mudstone facies; however, volcanic rock is well separated.

35 Hz is equivalent to approximately 32 m given the seismic resolution at the depth of this reservoir. Hence whenever individual sandstones and shales are below this thickness, the

filtered SLR is unable to resolve them. However, volcanic rocks on the other hand are thick or have characteristically high elastic response, so their separation on the filtered SLR is to be expected.

Figure 12 shows an illustration of the volcanic rock prediction at a well using the filtered SLR log (35 Hz). Figure 13 shows the QC cross-plot between actual and predicted volcanic fraction for all drilled wells.

Figure 12. An example of facies prediction using the filtered SLR log at a well. The first panel is the Petrophysical facies interpretation, the second panel is the volcanic rock prediction at log scale and the third panel is the same at seismic scale.

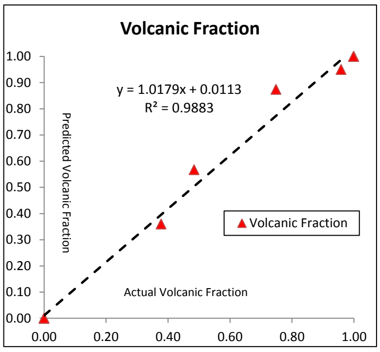

Figure 13. Cross-plot between actual and predicted volcanic rock fraction for all wells.

The filtered SLR was predicted using the EEI concept and Figure 14 shows the correlation coefficient where each colour represents a well. All the wells converge at a Chi of 18 deg.

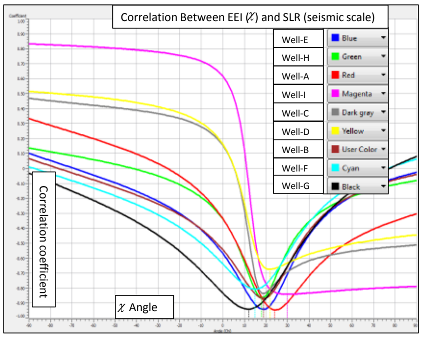

Figure 14. The correlation coefficients between EEI and 35 Hz filtered SLR for range of values of Chi for all wells.

The next step is to re-sample the filtered SLR to make it identical to the seismic attribute cube. This filtered SLR and its corresponding EEI is presented in Figure 15 and a good match is seen between them at a well location. DS_PS and DS_LRMR reveal the same conclusion as that of the SLR.

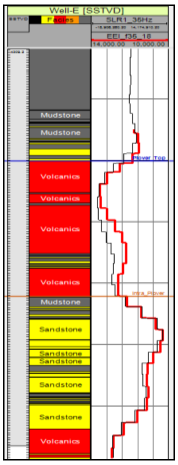

Figure 15. First panel indicates the actual facies interpretation whereas SLR (black) and EEI 18 (red) were plotted in second panel to illustrate the match between two.

CONCLUSIONS

The main conclusions from this study are:

- Three different facies, namely sandstone, shale and volcanic rocks are well separated in newly generated attribute logs such as SLR, DS_PS, DS_LRMR at well log resolution.
- At the seismic scale, only volcanic rock and sedimentary rock segregation is possible.
- The EEI concept is able to produce target non-elastic scaled logs (SLR).Other two attribute logs, DS_PS and DS_LRMR can also be effectively generated using EEI.
- In complex lithology, EEI fail to predict SLR with a high correlation coefficient.

This case study demonstrated the application of the EEI concept to segregate volcanic rocks from sedimentary rocks at seismic scale resolution. Where the reservoir comprises massive sandstones which are thicker than the limit of seismic resolution, it is envisaged that the EEI concept should be able to segregate sandstones from shales as well. The results of EEI technique using well data both log and seismic resolution shows enough merit to test its application using actual seismic data which is planned as the next step.

ACKNOWLEDGMENTS

The authors would like to acknowledge INPEX management and all joint venture partners for allowing us to publish this work.

REFERENCES

Connolly, P., 1999, Elastic impedance: The Leading Edge, 18, No. 4,438–452.

David N. Whitcombe, Patrick A. Connolly, Roger L. Reagan, and Terry C. Redshaw 2002, Extended elastic impedance for fluid and lithology prediction, GEOPHYSICS, VOL.67, NO.1 63-67