Empirical anisotropy corrections in deviated well logs from the Malay Basin.

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Introduction

Shales in the Malay Basin are anisotropic (Ghosh et.al., 2010). Well log measurements of p-velocity and s-velocity are affected by shale anisotropy, especially in deviated wells. The magnitude of the anisotropy effect can depend upon the angle of well deviation. Anisotropic measurements create inconsistency within the data set and impact results and interpretation. In this paper we present a novel, empirical technique to correct for anisotropic effects in velocity logs, referenced to a rock physics model. Applied to a quantitative interpretation project in the Malay Basin, the method improved data consistency and enabled tighter integration of wells with seismic in deriving unbiased predictions of lithology and fluid distributions.

Method and results

Data comprised 22 wells including 15 with varying angles of deviation (up to 70°). The wells were spread across an area of approx 2,000 sq km, covered by seismic angle stacks. The project involved absolute seismic simultaneous inversion followed by lithology and fluid interpretation, calibrated to a statistical rock physics model. The rock physics work comprised picking end members for reservoir and non-reservoir lithologies on well logs, and establishing rock property trends. The trends defined the variation of elastic properties with depth and provided relationships between different elastic properties (e.g. p-velocity versus s-velocity) for the end member lithologies.

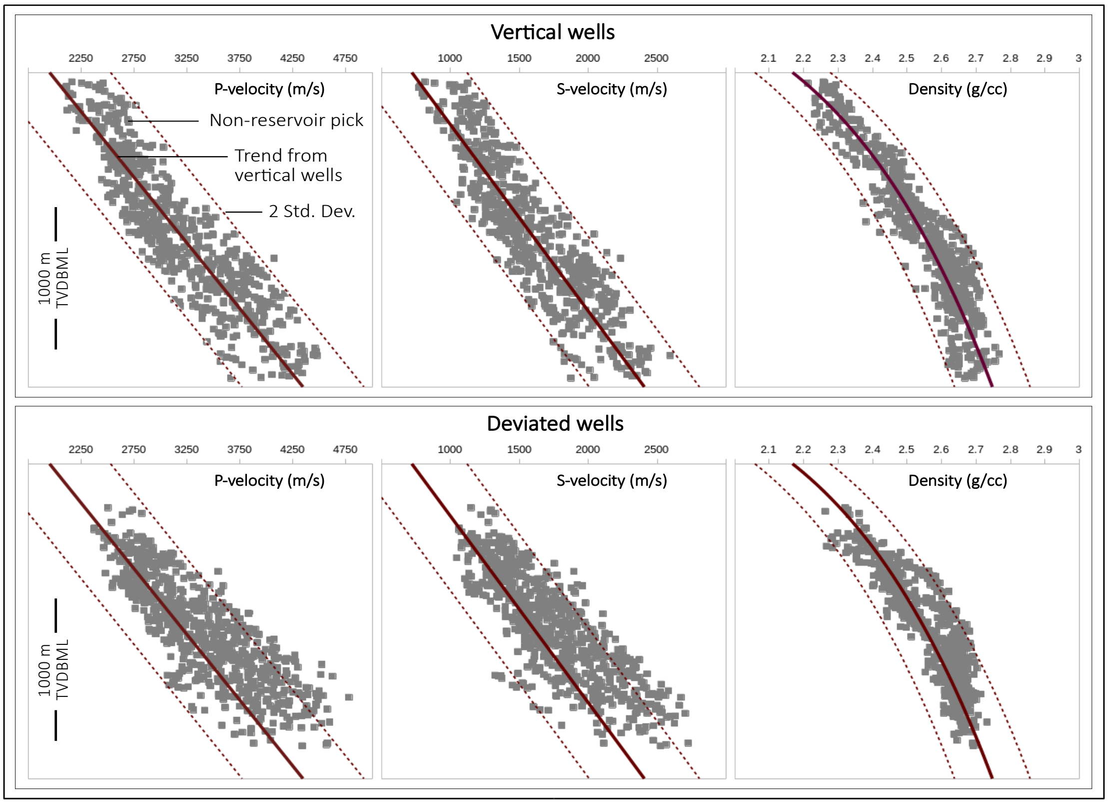

Figure 1 *Elastic property versus depth cross-plots for non-reservoir picks in vertical and deviated wells. The higher velocity values in picks from deviated wells are indicative of anisotropy affecting log measurements.*

Figure 1 displays, for some vertical and deviated wells, cross-plots of rock physics picks for non-reservoir lithology (all types of shale and silty shale). Both sets of plots are overlain by composite non-reservoir trends and their two standard deviations bounds established from vertical wells. The p-velocity and s-velocity cross-plots from the deviated wells show a tendency towards higher values relative to the vertical wells trend. In contrast, density measurements from deviated wells agree with the vertical wells trend and bounds. Density log measurements are not affected by formation anisotropy. The cross-plots demonstrate that the higher velocity readings in deviated wells are not from changes in geology. The inconsistency between elastic logs is due to shale anisotropy affecting velocity measurements.

Velocity logs from deviated wells were corrected for anisotropy. The correction involved adjusting low frequency trends of the logs to the trends from vertical wells for non-reservoir lithologies. Velocity logs from deviated wells were filtered to derive low frequency trends and de-trended logs. The trends from vertical wells were mixed with the low frequency trends from deviated wells in a manner proportional to the degree of well deviation – as deviation increased, the vertical wells trends carried greater weight. The trend mixtures were added to the de-trended well logs over non-reservoir intervals. Original velocity measurements were retained in reservoirs. The adjustment was performed for both p-sonic and s-sonic logs. Where s-sonic logs were missing or of questionable quality, they were synthesised using rock physics relationships from vertical wells, guided by petrophysical evaluations.

Figure 2 displays, for a deviated well, recorded elastic logs (grey), anisotropy corrected velocity logs (red) and shale trends from vertical wells (brown). The recorded density log is in agreement with the vertical wells trend. Anisotropic corrections have brought velocity logs into trend agreement with vertical wells and have removed their inconsistency with the density log. The magnitude of anisotropy corrections decreases proportional to deviation angle, as evident near the base of the displayed interval. Corrections were not applied to measurements in reservoirs. Cross-plots after anisotropy correction also show the improvement in velocity agreement with the vertical wells trend.

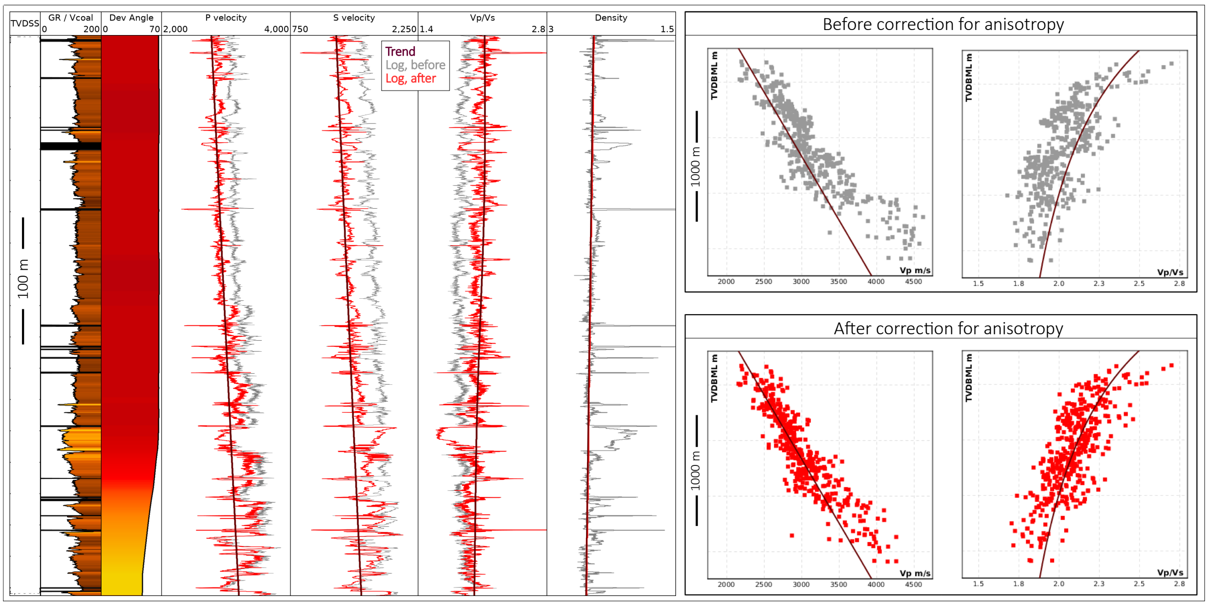

Figure 2 *Anisotropy correction in a deviated well. Velocity logs and non-reservoir picks after correction (red) show improved agreement with vertical wells trends (brown).*

Figure 3 displays cross-plots of deviation profiles for individual wells. The plots are coloured by the low frequency difference in velocity between the vertical wells trend and the log trend. High angles of deviation correlate with large negative velocity differences due to anisotropy. Following correction, the consistency of the velocity logs has improved across the data set.

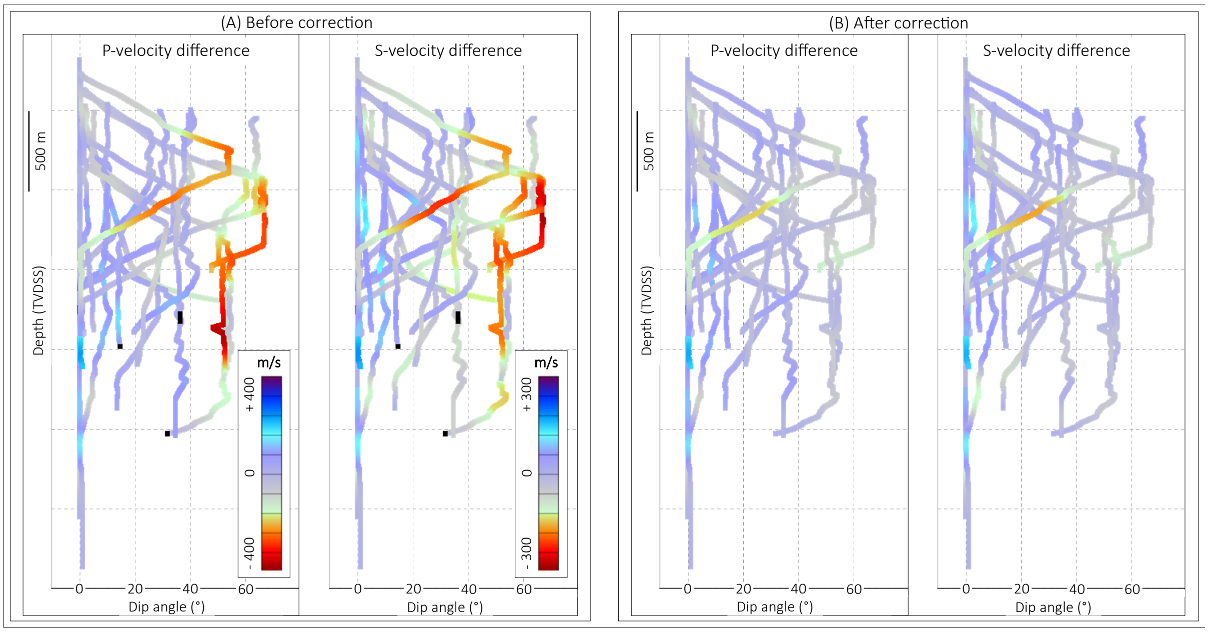

Figure 3 *Cross-plots of deviation profiles for individual wells coloured by the low frequency difference in velocity between the rock-physics trends of vertical wells and logs. Velocity consistency has improved across the data set following anisotropy correction.*

Figure 4 illustrates the implications to characterising the formation using elastic logs. The first set of panels display, for a highly deviated well, the petrophysical interpretation and corresponding computed lithology log. The following sets of panels display p-impedance and vp/vs logs before and after anisotropy correction compared against vertical wells trends. Also displayed are Bayesian probabilistic predictions of the formation lithology and fluid using these elastic logs. The interpretations are calibrated to a rock physics model derived from vertical wells. The interpretation framework is displayed in cross-plots as ellipses representing probability density functions for lithologies and fluids. Before anisotropy correction, log measurements characterise the dominantly non-reservoir formation with significant proportions of sand and hydrocarbon sand. Following anisotropy correction, the formation is properly identified as non-reservoir.

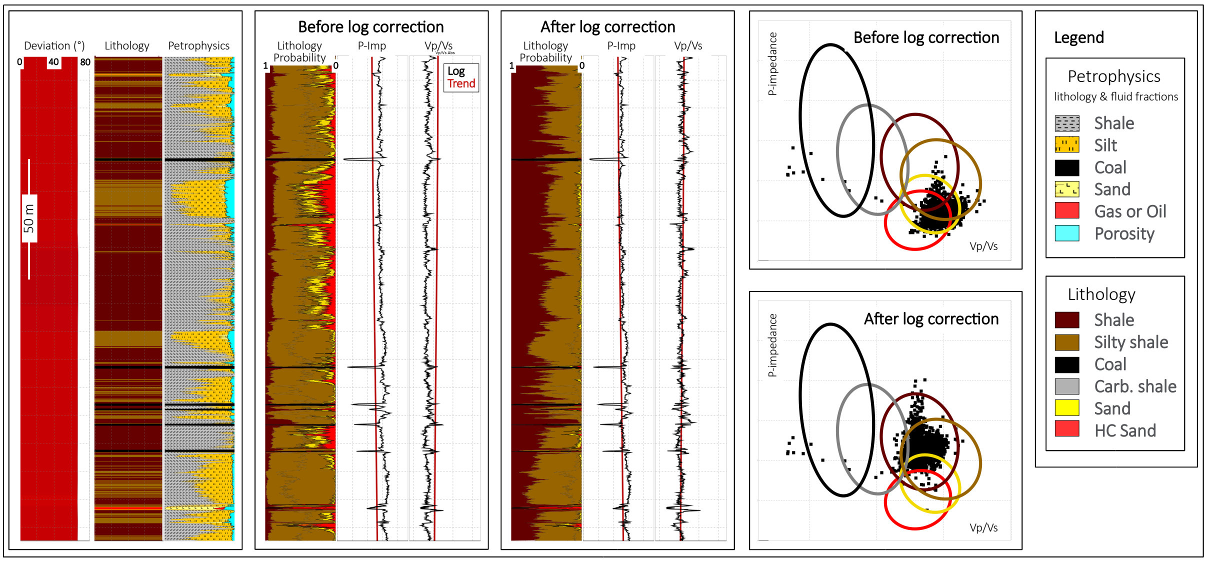

Figure 4 *Implications of anisotropy correction to formation characterisation using elastic logs. After correction, the formation is better interpreted as non-reservoir.*

Figure 5 compares the low frequency p-impedance log of a deviated well before and after anisotropy correction with a vertical well where no corrections were applied. The consistency in the data following anisotropy corrections enabled low frequency models to be built in agreement with all wells for use in simultaneous inversion.

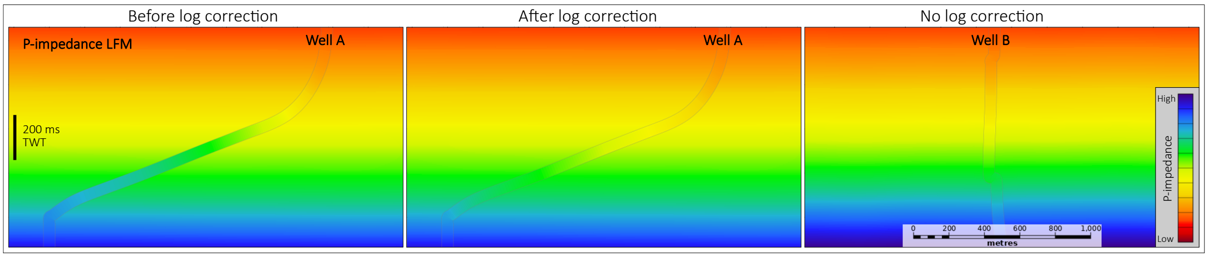

Figure 5 *Low frequency p-impedance well logs from a deviated well before and after anisotropy correction are compared with a vertical well and a background model used in seismic inversion.*

Figure 6 displays a map-view slice through a composite display of sand and hydrocarbon sand probability volumes computed from the results of absolute simultaneous inversion. The prediction is consistent with the petrophysical evaluation in the deviated well at the point of intersection. The empirical workflow for anisotropy correction implemented in this study has enabled such consistent rock physics calibrated interpretations of lithology and fluid distributions to be made across the study area.

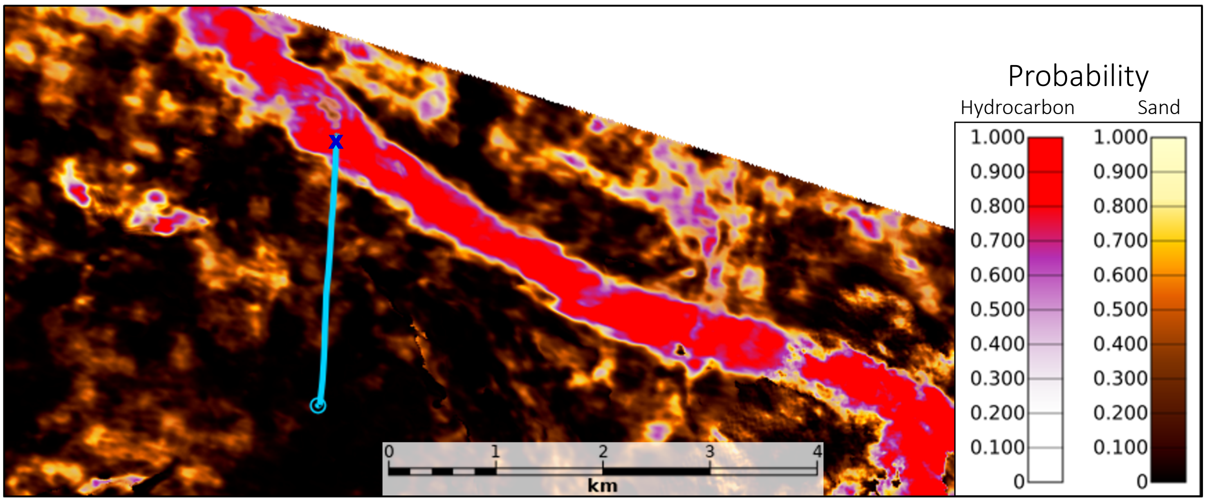

Figure 6 Composite sand and hydrocarbon sand map slice intersecting a deviated well at location x.

Conclusions

Anisotropy corrections improved the consistency of elastic logs across wells and enabled their tighter integration with seismic for reservoir characterisation in a data set from the Malay Basin.

Acknowledgements

Thanks to Hibiscus Petroleum, Petronas and DUG Technology for permission to present this work.

References

Ghosh, D., Halim, M.F.A., Brewer, M and Viratno, B. [2010]. Geophysical issues and challenges in Malay and adjacent basins from an E & P perspective. *The Leading Edge*, 436-449.