Integrating core and wireline log datasets – a pathway to permeability from AvO seismic?

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SUMMARY

Improved reservoir modelling and simulation is sought by assigning permeability using AvO seismic. The integration of sidewall-core porosity and permeability with wireline logs represents one possible pathway for differentiating the seismic amplitude responses of different reservoir flow-unit facies.

Two sand facies with differing porosity-permeability trends were defined in the reservoir interval of a Paleocene oil field in a shallow offshore clastic setting. Available sidewall-core data from several wells were added to their respective log datasets as discrete, depth-matched points and used to pinpoint the extraction of relevant log values corresponding to each point. The extracted Vp, Vs and density values enabled calculation of AI and Vp/Vs for each sample. Fluid substitutions using the Gassmann equations were then performed on points within the two sand facies.

A statistical comparison of brine and oil porefill cases for each sand facies in this study showed a clear shift due to the hydrocarbon effect. However, only minor differences were observed in an AI-Vp/Vs cross-plot when the two sand facies with common porefill were overlain. Compositional similarity between the sand facies appears the most likely cause for the lack of significant difference in AvO response. Thin carbonates with high AI are also present in the reservoir interval and lateral variation in carbonate volume of as little as 5-10% would overprint the small differences observed between the sand facies. This method should be revisited for sand facies possessing greater compositional differences or where a larger porosity-permeability distinction between facies exists.

Key words: porosity, permeability, seismic, AvO, acoustic impedance (AI), Vp/Vs, facies, core, log

INTRODUCTION

Permeability exerts strong control over fluid movement during production of an oil reservoir. It can be highly variable in a given reservoir (Zhi-Qi *et al.* 2015) and is the most challenging reservoir characteristic to ascertain and predict (Afshari and Shadizadeh, 2015). Zhi-Qi *et al.* (2015) used a patchy-saturation model to analyse changes in the seismic reflection response resulting from variations in permeability. They noted the strongest effect upon P-wave velocity, attenuation and dispersion when the impedance of the reservoir is closely matched to that of its surroundings. 4D seismic is able to show variation in saturation and reservoir pressure and has also been used to estimate porosity and permeability during production (e.g Dadashpour *et al.*, 2009). However, little work has been undertaken that establishes a plausible method for integrating permeability and seismic data for mapping purposes *prior to* production commencing.

We seek to integrate permeability data from sidewall-core with coincident log information to understand if a link exists between permeability and reservoir elastic properties (Vp, Vs, density) and, in turn, seismic reflection data in our study area. The primary aim was to determine whether it would be possible to perform reservoir modelling in a clastic system by assigning permeability from AvO seismic. The Paleocene reservoir studied was deposited in a shallow shelf environment dominated by waves, featuring "washover" deposits and secondary beaches, during a time of active halokinesis. In-house petrographic analysis of sidewall-core data identified five (5) end-member groups with unique Vshale cut-offs: arkose/lithic arkose sandstone (SND1); feldspathic greywacke arkose/lithic arkose sandstone (SND2); siltstone (SLT); shale/claystone/silty shale (SHL), and; limestone (LMS). SND1 and SND2 were the two target facies, with potentially differing poro-perm trends, that we aimed to differentiate between using AvO seismic.

We take a "cherry-picking" approach to our rock physics analysis of the sandstone facies identified in the study area, using the sidewall coring locations to focus attention of elastic properties with known porosity and permeability. Following careful preparation of the log data, including the use of Gassmann fluid substitution, we draw our conclusions using rock physics templates suitable for interpretation of AvO-inverted seismic. We show that there is insufficient difference between the sand facies analysed to produce a robust separation in amplitude response, with any disparity likely to be overprinted by the presence of carbonates in the system.

METHOD AND RESULTS

Integration of sidewall-core (SWC) data and geophysical log data was undertaken by overlaying discrete, depth-matched SWC data points on existing brine-case well logs. For each pinpointed depth, small working intervals of 0.1524 m centred on each position were generated to enable extraction of average log values corresponding to the SWC data. These intervals fall below the vertical resolution of the elastic property logs, which lies between 1-2 m for the modern density and sonic logging tools used. When values are extracted at points away from bed boundaries, the average log values carry only logging errors and will also correlate directly to the measured SWC poro-perm values, provided that the SWC samples are representative of an interval corresponding to the log resolution.

In practice, this means that errors could be introduced into the correlation between the extracted elastic log properties and SWC poro-perm measurements if a SWC is taken close to a bed boundary. An accurate but expensive and time-consuming alternative would be to make lab measurements of Vp and Vs on a statistically significant number of SWC core plugs (Lebedev *et al*., 2013).

With limited time and budget it was decided to employ a pragmatic solution to this dilemma by removing samples from the cross-plot when the log-predicted porosity (derived from the density log) did not match the SWC measured porosity. This approach had the desired effect of removing some obvious outliers in the rock physics cross-plots (Figure 3). Any remaining error might affect the degree of scatter within the data clouds for each sand facies, but the mean position of the data cloud should remain quite robust.

Only samples from the main Paleocene reservoir unit were analysed, reducing any bias introduced by higher/lower permeability in adjacent units of the study area. SWC porosity and permeability data, along with extracted elastic properties (Vp, Vs, density) and calculated acoustic impedance (AI) and the Vp/Vs ratio, were combined in a spreadsheet to display the values for common depths below mudline.

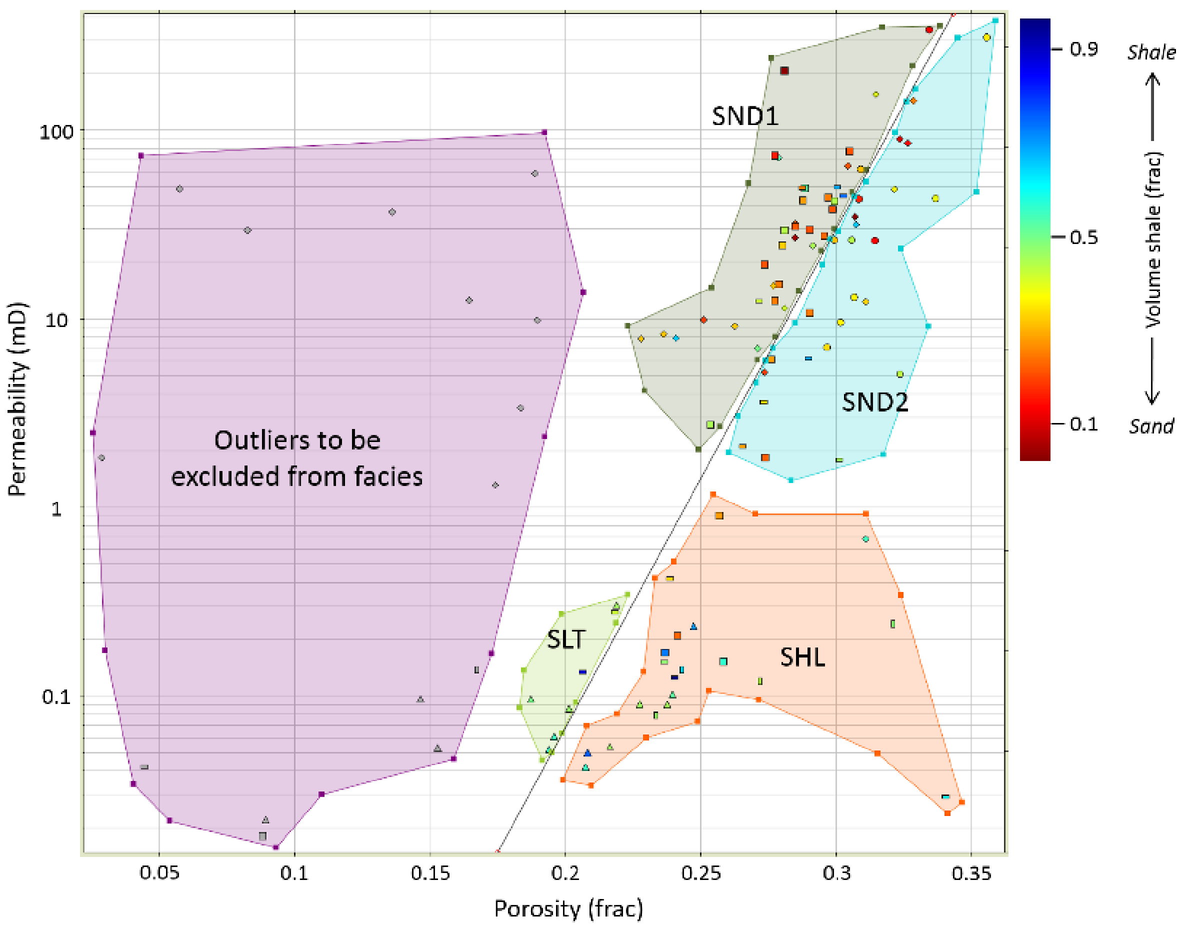


Figure 1: SWC poro-perm plots – alternative facies zonation, defined by porosity and permeability rather than Vshale, for Vp/Vs vs. AI cross-plotting.

The porosity-permeability plot for the Paleocene interval showed one predominant linear, positive trend with some obvious outlier points. For a porosity roughly equal to 30%, sand permeabilities can range from 10-120 mD, when noted as a deviation either side of the central trend line (Figure 1). When cut-offs for each of the petrographically-defined end-members were applied to the poro-perm cross-plot, there was no clear isolation of facies, particularly when attempting to discriminate between the two sand units. This lead to facies being redefined based on their poro-perm characteristics (Figure 1).

Using the Gassmann calculations, fluid substitutions were made in both sand facies (SND1 and SND2) to generate oil case elastic properties. While a clear hydrocarbon effect was observed between the brine and oil cases, overlaying the sands with equivalent porefill suggests there is insufficient separation between the two sand facies to enable exploitation within an AvO inversion scheme (Figure 2).

Rapid increases in sonic velocity and density, manifested as 'spikes' on logs, indicate the presence of high-AI carbonates in this Paleocene reservoir (supported by petrographic analysis of SWC). These carbonates do not occur as continuous layers of limestone, instead comprising dispersed shell fragments and other bioclasts, likely to be transgressive lag deposits. Of the Paleocene SWC, only one sample is representative of this carbonate facies, however analogous samples of these carbonates are present in adjacent units. A 10% variation in the amount of dispersed carbonate within this system, would likely overprint the small separation observed on an AI-Vp/Vs cross-plot, as modelled using Backus averaging of calcareous sand properties derived from logs (Figure 2). Given that these carbonates are manifested as thin carbonate beds, they are below seismic resolution which generates representation issues when upscaling from AI data to seismic.

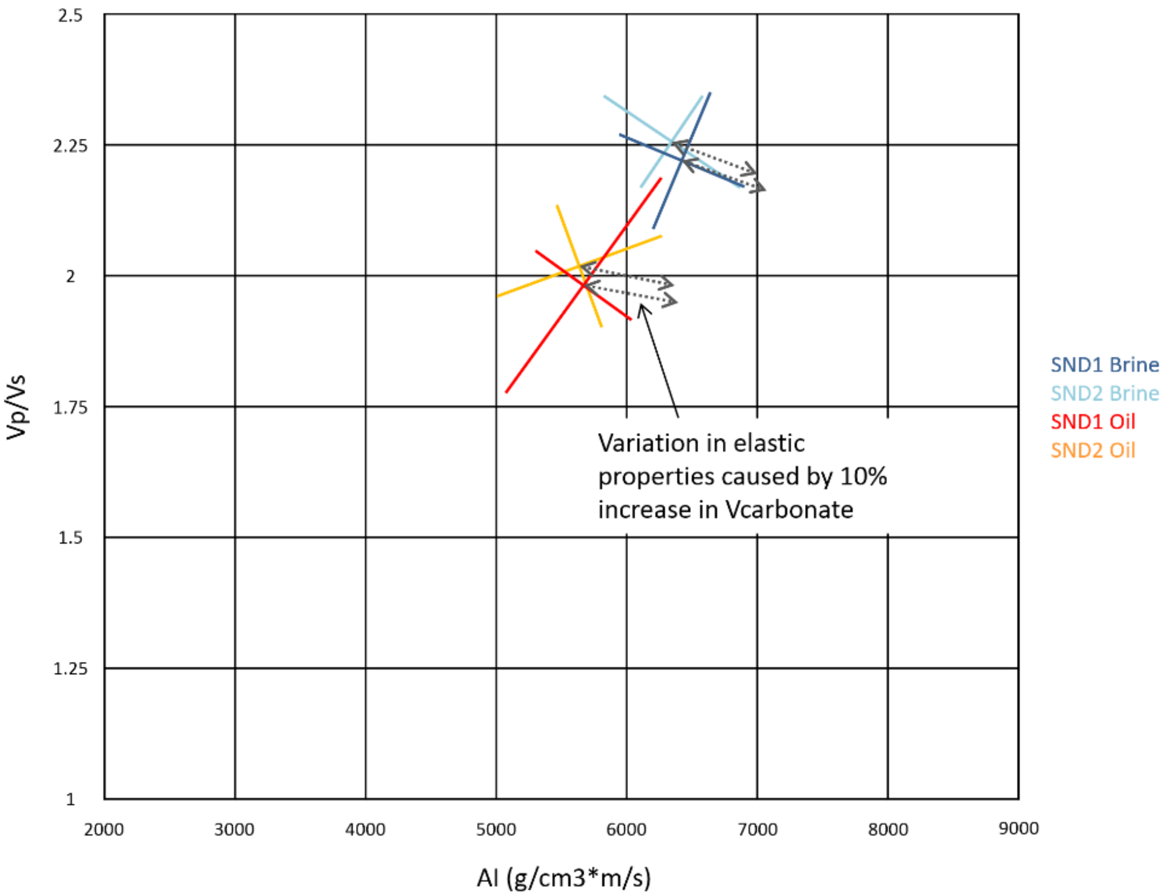
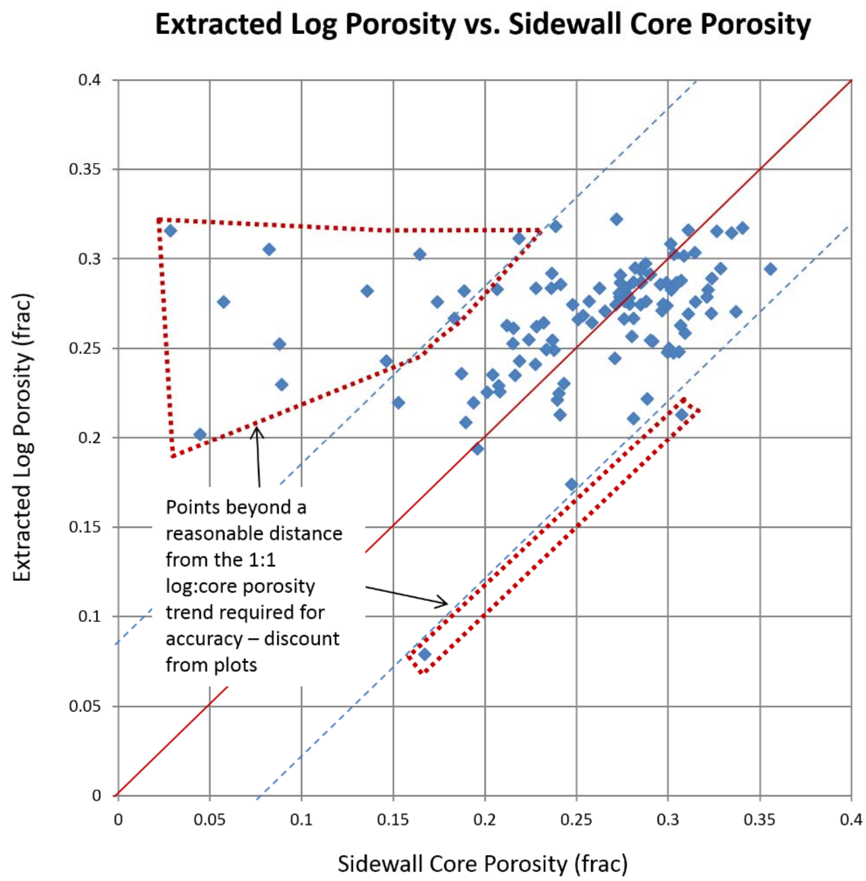


Figure 2: Vp/Vs vs. AI for brine and oil with principal component axes for 1 SD of each fluid case – minimal shift in centre point for same fluid cases, with variation in carbonate content able to overprint small separations that do exist.

a)



b)

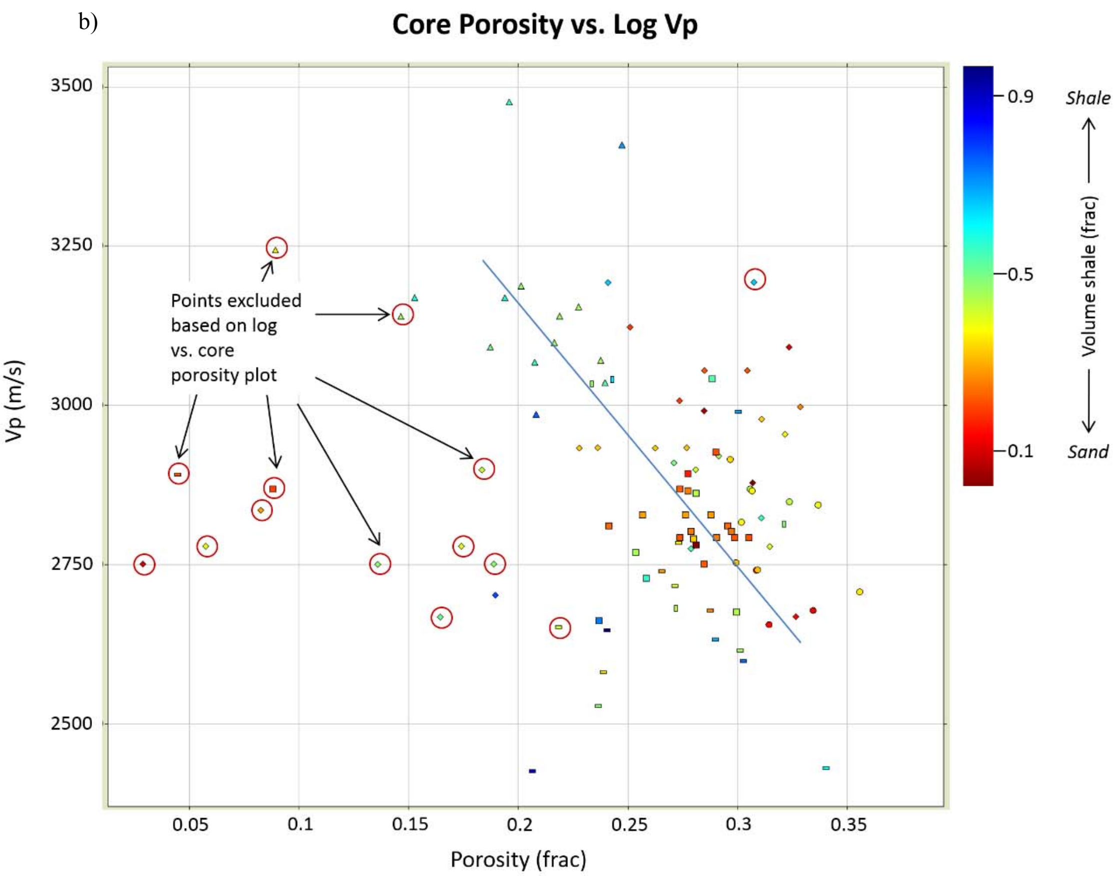


Figure 3. a) Cross-plot of log-derived prosity and measured SWC porosity to determine points to be excluded from plots; b) Example of removing points excluded in a) to remove many outlier points

CONCLUSIONS

The overarching conclusion reached in this study is that there is no significant difference between amplitude responses of SND1 and SND2, and any small separation that is observed could be overridden by variation in the volume of carbonate within the reservoir. A potential source of error within this study may come from the inability of logs to preserve high resolution cyclic laminae and the impact of the shoulder effect of logs at bed boundaries that, when compared to the resolution of core plugs, may contribute to any lack of correlation between core and log data. Some of the difference in log-derived versus measured SWC porosity values that resulted in the exclusion of outlier points from cross-plots could be attributed to a difference in resolution between core plugs and geophysical logs (even for density which is fairly high resolution) that may alter AI-Vp/Vs plots from their true values. Obtaining measured Vp and Vs of core plugs may minimise this discrepancy.

Both SND1 and SND2 showed a clear hydrocarbon effect from between brine and oil fluid cases on AI-Vp/Vs plots when Gassmann fluid substitutions were applied, however, overlaying different facies of the same fluid cases shows such a negligible shift such that any separation could not be exploited by amplitude mapping. Further, a change in the volume of high-AI carbonates within the system of as little as 10% will skew the apparent AI values towards higher numbers, thus overprinting any small differences originally present between facies. Compositional similarity between the sand facies is a likely cause for the lack of significant difference in AvO response.

SND1 and SND2 have very similar lithologies and poro-perm trends and alterative facies zonations ascribed based on poro-perm data (in place of utilising petrographic Vshale cut-offs) do not change the final interpretation of this analysis as the overlap between facies is still abundant. Based on this study, there is currently little support for using seismic amplitudes to assign permeability differences in reservoir modelling. This method should be revisited if measured Vp and Vs of core plugs could be obtained, or for new sand facies encountered during future drilling that possess greater compositional differences, or where a larger porosity-permeability distinction between facies exists.

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