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Spatial mapping of seismic facies variations to mitigate reservoir risk in coal prone fluvial-deltaic settings

Dylan Cremasco*
Santos Limited
60 Flinders Street,
Adelaide SA 5000
dylan.cremasco@santos.com

Yahya Villareal Basman II
Santos Limited
60 Flinders Street,
Adelaide SA 5000
yahya.basman@santos.com

Judith Travers
Santos Limited
60 Flinders Street,
Adelaide SA 5000
judith.travers@santos.com

**presenting author asterisked*

SUMMARY

Seismic facies classification has been used to reduce risk in laterally heterogeneous reservoir prediction. Studies were focused on the Barrolka/Coolah/Durham Downs Trend in the south-west Queensland sector of the Cooper Basin. The primary reservoir targets are the fluvial channel sediments of the Toolachee Formation. Historically, well success rates across the area have been low, with highly variable reservoir development and connectivity identified as the limiting factors influencing well performance.

Conventional seismic attribute analysis has typically yielded inconclusive results, often associated to the presence of thick coals that dominate the seismic response. However, recent drilling campaigns utilised seismic waveform classification mapping, which resulted in an increase in technical success rate of wells. This study aims to investigate the concepts behind the success of the waveform classification method and to determine alternate techniques to further delineate reservoir presence.

Key outcomes from rock physics studies indicate subtle variances in the seismic wave shape could be attributed to changing reservoir thickness underlying coal formations. Cross correlation of the wave shape against well results confirmed the concept of dimming seismic amplitude response to be related to increased reservoir thickness. In an attempt to capture the lateral extent of these variances, three adjacent 3D seismic volumes, covering majority of the complex, were subject to a variety of attribute analysis methods. Unsupervised waveform classification was found to be the most efficient and effective method for capturing the dimming seismic reflector, and thus defining the channel trends. The strong correlation between waveform class and reservoir thickness measured in wells enabled the generation of risk-segment maps for the reservoir units.

Observed changes in wave shape on full stack seismic data have been related to lithological variations based on rock physics studies. These learnings have been used to select attribute extraction techniques that can best highlight the wave shape variations. Using seismic facies mapping to enhance reservoir prediction capabilities has reduced reservoir risk and improved the technical success rate of drill targets. The output maps from this study have been used to locate future opportunities in the region.

Key words: Seismic attributes, waveform classification, reservoir prediction, seismic facies, multi-attribute geostatistics

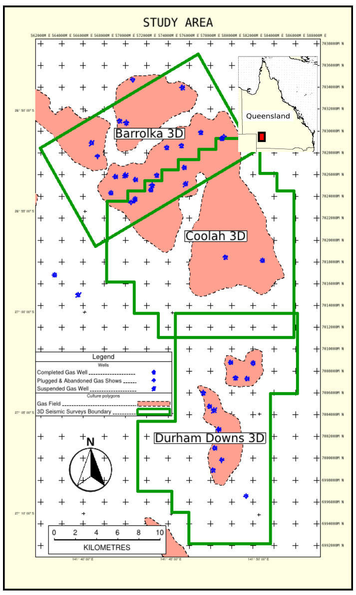

Figure 1: Study area location map

INTRODUCTION

The main purpose of this study is to investigate the application of seismic facies analysis to predict reservoir sands in the Cooper Basin, Australia (Figure 1). This paper will present the key findings from the study, and the seismic attribute outputs used to generate the reservoir risk segment maps. The area of interest for the study is the Barrolka/Coolah/Durham Downs Trend, approximately 50 km north of Ballera. The primary reservoir targets in this region are the gas-bearing fluvial sands of the Permian Toolachee Formation (Figure 2). The reservoir units sit underneath a regionally pervasive coal, which dominate the seismic response.

The northern sector of the study area, the Barrolka Complex, is currently topographically lower at the Top Permian than Durham Downs to the south. Structural analysis indicates the Barrolka complex to be a palaeo-high at the time of Permian deposition, with the basal Toolachee scouring deep into the unconformably underlying Patchawarra Formation. Fault movement is observed to have occurred post-Patchawarra deposition, and again during the mid-Toolachee unconformity, which is interpreted to have had an effect on sediment fairways.

A total of 34 wells have been drilled in the study area. Three overlapping seismic surveys have been acquired over the region, providing approximately 500 km^2 of full-fold coverage.

Reservoir development and lateral connectivity prove to be the risk factors controlling the success of any given well in the area. The seismic response of the Toolachee Formation is largely dominated by thick coals, which appear to overprint underlying formation responses in the full stack seismic data. Consequently, conventional seismic attribute extraction techniques are found to be ineffective at mapping reservoir extent. The seismic data indicates subtle variances in trace amplitude, shape and frequency, which are suspected to correlate with lithology changes. Recent drilling in the area utilised seismic waveform classification maps to guide well placement, resulting in an increase in well technical success (Basman II, 2015). While the method had yielded positive results, the theory behind the waveform variances was poorly understood.

A focussed rock physics, AVO and wedge modelling study identified reservoir thickness to alter the wavelet response when thick overlying coals are present. To capture these wavelet variances, a range of extraction techniques were trialled. Seismic waveform classification is found to be the most efficient of the techniques. The waveform classification maps correlate strongly with the combined seismic response of coal and reservoir sands. When analysed in conjunction with basic seismic interpretation techniques (i.e. isochron, seismic facies, and seismic terminations), these attribute maps facilitate the generation of reservoir risk segment maps for future well placement.

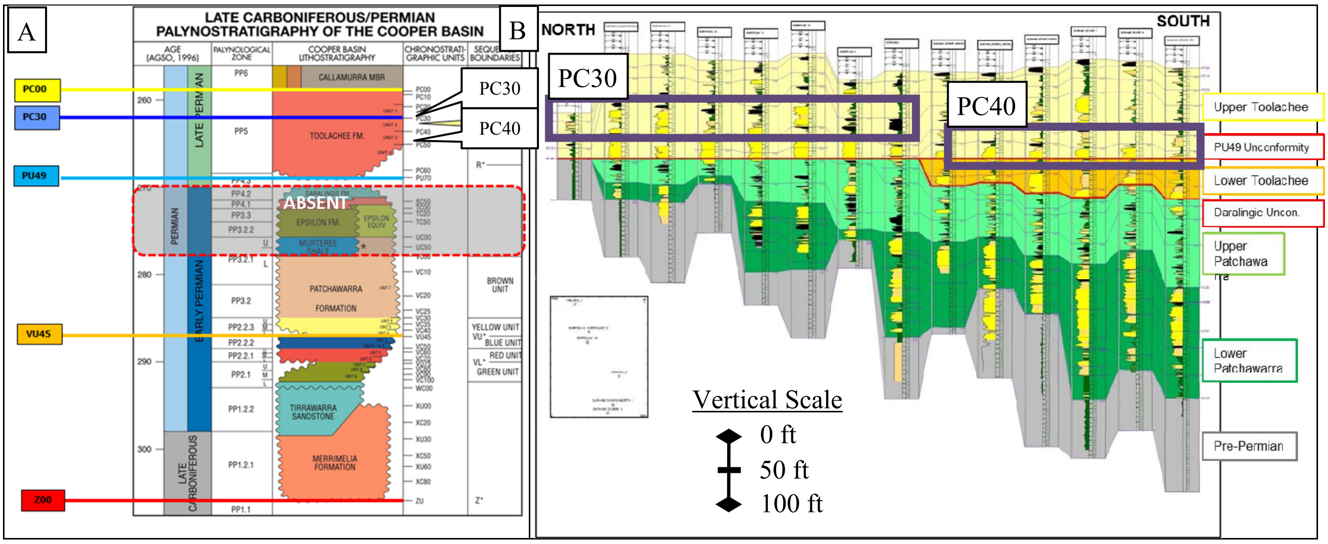

Figure 2: A) Stratigraphic section illustrating the Permian sequences in the Cooper Basin. B) North to South well cross-section highlighting the PC30 and PC40 reservoir targets.

METHOD AND RESULTS

The maximum reservoir thickness encountered in this area is below the seismic resolution. Attribute work is focused on the PC30 for the Barrolka and Coolah areas, and on the PC40 for the Durham Downs area. Coal bands are present atop of both of the reservoir units. The thickness and stratigraphic position of the coal remains consistent across the study intervals.

Rock Physics

The rock physics study indicates that AI and Vp/Vs can be used to separate sand, coal and shale on log scale. When this is up-scaled to seismic resolution, distinguishing between the lithologies on a cross-plot is not possible. Stochastic forward modelling of the near and far offset stacks indicate that in zones with coal and shale interbeds overlying sand, a dimming in amplitude strength is observed as offset increases. Similar dimming trends are observed in intercept and gradient attribute models. Combining the intercept and gradient attributes to generate attribute maps was found to effectively predict reservoir thickness trends in areas where the overlying coal and shale thickness is consistent, suggesting any waveform variations are likely caused by a changes in thickness of the underlying reservoir.

Generated wedge models use coal presence and PC40 sand thickness as variables. The modelling indicates that where coal is present and sand is thin, strong amplitudes are observed. As sand thickness is increased, with no relative change to the coal, the amplitude strength of the event decreases until a point where the phase is inverted. The outcome from the study highlights the ability to use subtle variations in the stacked wavelet as a proxy for areas with thicker developed reservoir sections.

Proportional Slice Amplitude Screening

Two-way-time interpretation picks were made above and below the target horizons on the full-stack seismic data. Coal is present above reservoir in nearly all wells drilled in the area; therefore attention is focussed towards identifying dimming reflector trends. The proportional slices are analysed in conjunction with arbitrary seismic sections to determine the character of the seismic response at the anomalous locations. Features identified are correlated against available well data to develop a geological conceptual model (Figure 3). The identified features are used as a baseline screening tool to cross check results from other attribute extractions in the workflow.

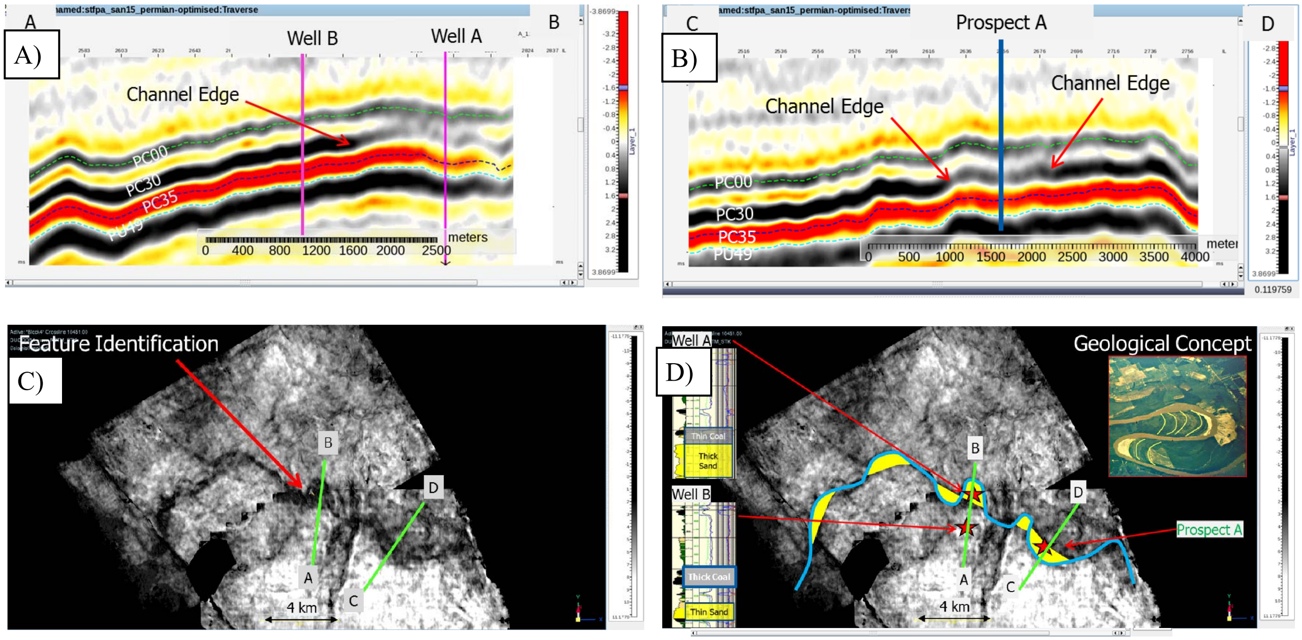

Figure 3: PC30 feature identification screening process. A&B) Observation of seismic character change between well locations on arbitrary section lines. C) Identification of observed feature on seismic amplitude data. D) Integration of well and seismic data to develop a conceptual geological model.

Waveform Classification

Unsupervised waveform classification was conducted on the full stack amplitude volume (Figure 4A). The unsupervised method uses a neural network classification process to discriminate the range of seismic trace responses over a given interval. A user-defined number of reference classes, called neurons, are then created (Figure 4B). Each trace in the survey is assigned to the neuron class with the lowest correlation error to generate the waveform classification map (Figure 5A). The unguided nature of the method means any variations observed are inherent in the seismic data. The geological correlation and interpretation of the waveform class patterns is conducted after the waveform class maps are generated.

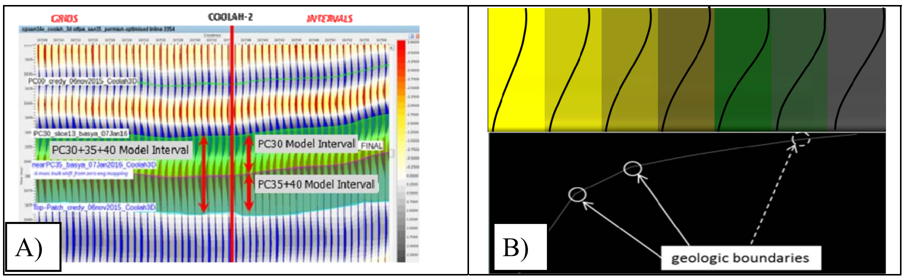

Figure 4: A) waveform classification extraction intervals. B) Neuron classes identified for PC30 interval during process.

Multivariate Geostatistical Analysis

Multi-variate attribute analysis was conducted using a full stack seismic volume and well log inputs to guide the attribute output volumes. Hampson Russel EMERGE® is used for multi-attribute analysis; using multi-linear regressions to identify transforms to derive log properties from seismic volumes. Hampson *et al.* (2001) provide a detailed explanation of the mathematics underpinning the multi-attribute summation process. Electrofacies logs are created for each of the wells with full log suites to divide log facies into distinct classes. The five lithology classes are sandstone, silty-sand, shale, coaly-shale and coal. The facies logs are used to calibrate the seismic data by determining the weighted combination of attributes with the lowest validation error at the well locations. The attributes are then generated across the entire volume. The attribute volumes are summed based upon weighting identified in the training process to produce the final output volume. The output volume attempts to predict the expected electrofacies class, and thus lithology, over the extraction interval (Figure 5B). This method is only applied over the southernmost survey due to the availability of suitable log data and high quality 3D seismic data.

Results

The output maps from each method are compared visually to identify common trends (Figure 5). Results indicate common features across the mapped area. Interestingly, methods with no well input data yield similar results to those calibrated to well logs.

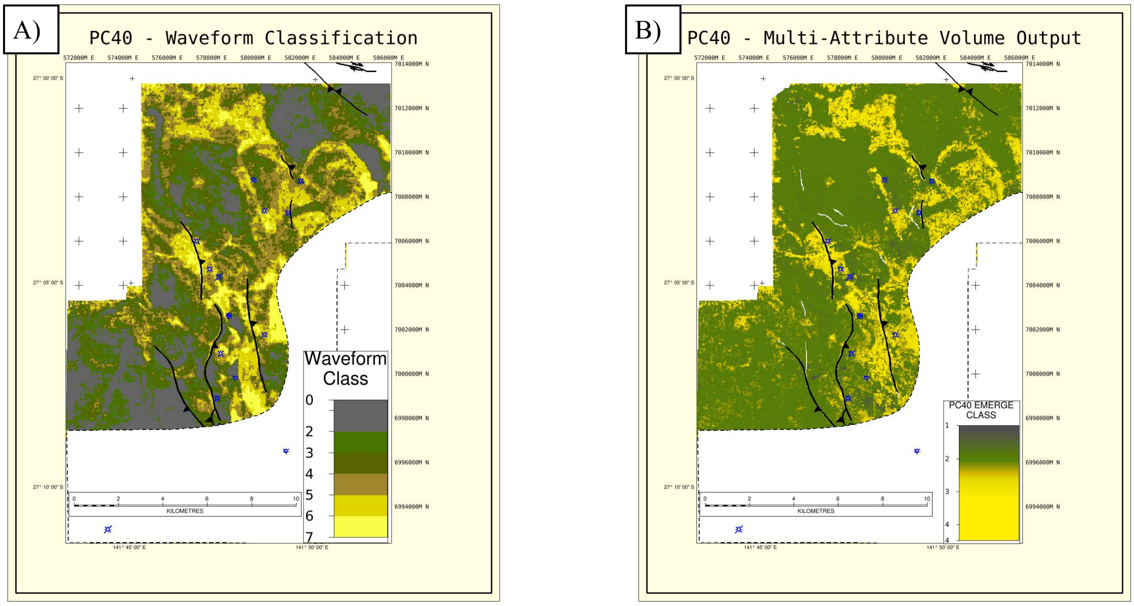

Figure 5: Output maps for A) Waveform classification, B) Multi-attribute analysis

The unsupervised waveform classification method is applied to the two remaining seismic surveys, as no input well data is required. The trends identified are observed to continue through independent surveys in areas of overlap. Cross checking seismic lines against the waveform classification shows the method to be effectively capturing the variances inferred to be related to reservoir thickness changes. The full field waveform classification model is presented in Figure 6A, showing the general trend of NW to SE deposition. This observation is supported by image log data. A reservoir distribution model is presented in Figure 6B. Reservoir risk segments are separated by reservoir interval. These are guided by waveform classification maps, isochron analysis and well log data.

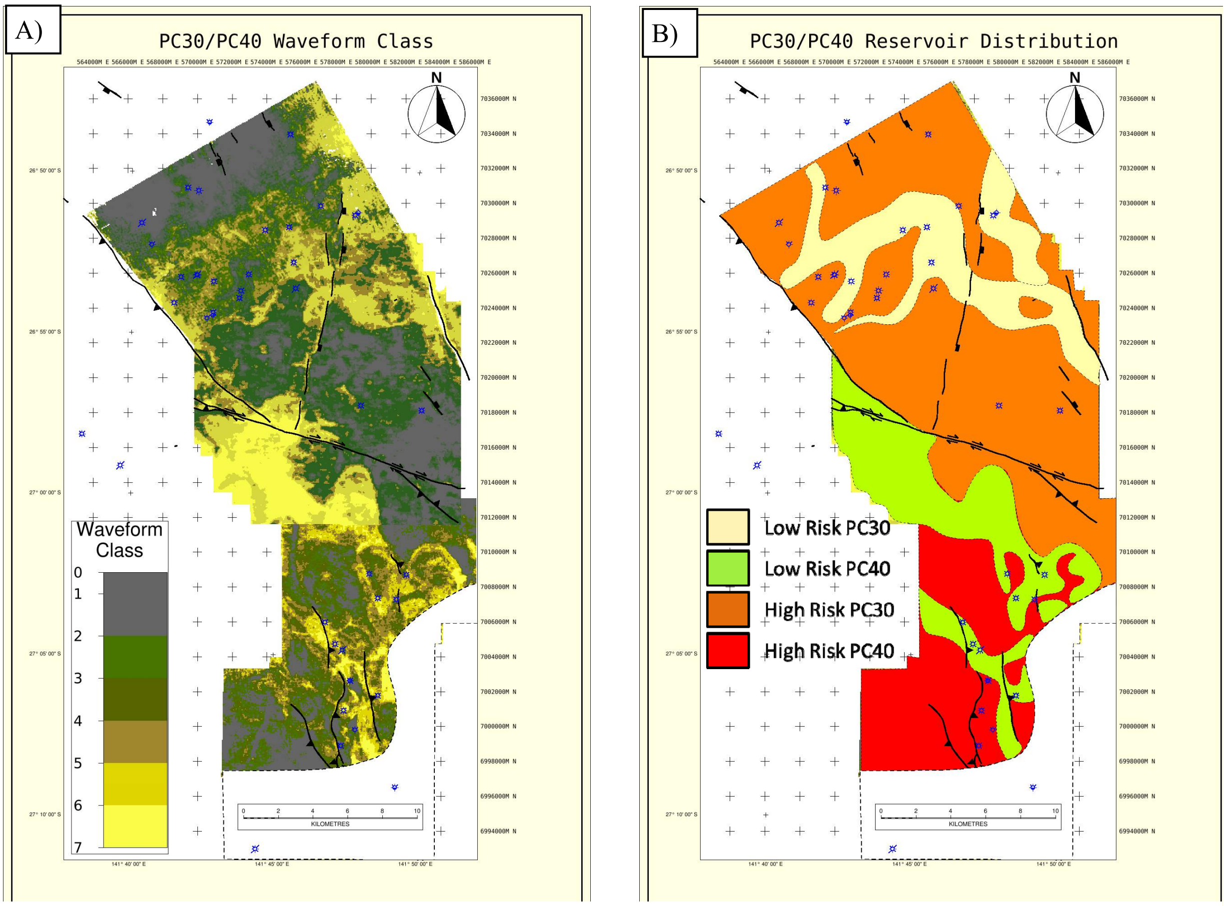

Figure 6: A) Waveform classification model for the three surveys. Risk of sand presence decreases with the higher class values. (Yellow = low risk reservoir, Grey = high risk reservoir). B) Reservoir distribution model and risk segment map incorporating the waveform classification model and well results.

CONCLUSIONS

Although coal presence is typically thought to reduce the viability of the useful application of seismic attributes, this study successfully used consistent coal presence to aid interpretation of reservoir regions. This is done by investigating changes in wave shape. The concept of reservoir thickness influencing the character of the seismic wavelet response underneath coal units is modelled as theoretically plausible based on rock physics studies. Seismic volumes are subject to a variety of attribute investigation methods in an attempt to map the spatial distribution of the waveform variances. The unsupervised waveform classification is found to be the most efficient technique to effectively map the targeted features. This is the simplest process to run, and requires no well input data. However, its final interpretation is dependent on well data.

Recent drilling campaigns and correlation with existing wells has proven the usefulness of the waveform classification technique in this study area. The presence of consistent coal units has been used to the advantage of the interpreter. The techniques outlined in this workflow are limited to regions where a consistent coal is present above the target reservoir. Output maps are noted to not be a quantitative measure of sand thickness, but are able to be used in a risk-reduction capacity to optimally place wells along reservoir trends.

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