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Optimising Resource Plays – An integrated "GeoPrediction" Approach

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Summary

A mechanical earth model (MEM) is a fundamental tool for considering the relationships between stress, strength and elastic properties of unconventional resources. Together, these three elements aid the identification of production "sweet spots" and contribute to the design of intelligent stimulation plans hat lead to efficient lateral fracture growth, enabling economic production.

Historically, sweetspot identification has focussed on single parameters such as Brittleness Index, which may not necessarily yield optimal results. Multi-variant factors such as total organic content (TOC), clay volume and mineralogy, temperature (both present day and palaeo temperature), natural fracture patterns and permeability, all act to control/influence the presence of sweet spots (as well as their producibility), producibility and performance of the reservoir.

There are many different methods to create empirical and numerical mechanical earth models, however, empirical well-centric analyses are key to constraining interrelated criteria that can be used to map unconventional reservoir properties. In order to construct a robust MEM that permits successful prediction of sweet spots, pore pressure, rock physics and geomechanical properties must be determined as accurately as possible.

Introduction

Total production volume from unconventional resources in many instances is unevenly distributed amongst the producing wells and concentrated within specific locations referred to as "sweet spots" (Figure 1). Rather than retrospectively evaluating production success to locate new wells, we propose a forward looking predictive approach to sweet spot identification.

Methods that focus on a single, uncalibrated parameter to identify sweet spots such as Brittleness Index may not necessarily yield optimal results. In fact, factors such as variability in total organic content (TOC), varying clay volume and mineralogy, variation in temperature (both present day and in the palaeo-history) and natural fracture patterns and associated permeability, all act to control or influence producibility.

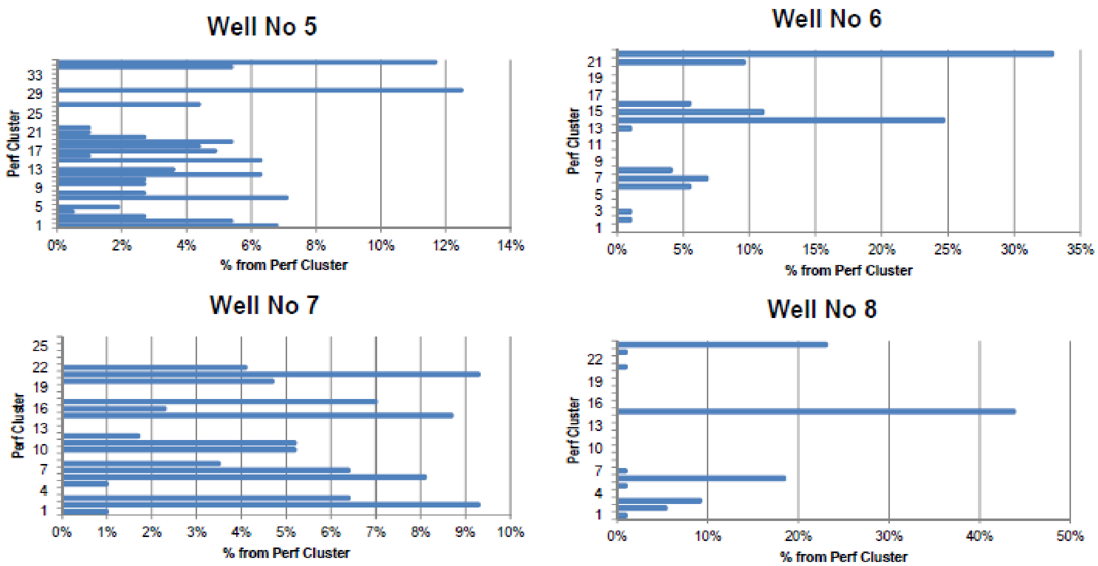

Figure 1. Examples of differences in performance of perforation clusters from selected wells. Basin not stipulated by Bratton (2012). A small number of fractures provide majority of production.

To model the relevant quantities and their interdependence, a multidisciplinary approach is required that incorporate rock physics, geopressure and geomechanics (Figures 2 and 3). Rock physics can relate mineralogy, total organic content and elastic properties to seismic parameters and in turn, these parameters can be used as fundamental inputs to a Mechanical Earth Model (MEM). A MEM is a fundamentally a tool for considering the relationships between stress, strength, elastic properties and pore pressure and directly influences hydraulic fracture placement, hydraulic fracture containment, permeability evolution of natural fractures, failure behaviour, mode of failure and orientation of failure.

Many geological factors present in most unconventional plays can have a significant impact on the derivation of accurate pore pressure, rock physics and geomechanical inputs into a successful model. These include;

• An increase in TOC is shown to significantly lower the magnitudes of velocity and density which may lead to erroneous pore pressure and elastic rock property responses. Conversely, a lower TOC leads to a more brittle rock often considered a positive when placing wells and designing fracture stimulations.

• A variation in clay content would affect the magnitude of pore pressure as well as Vp/Vs ratio and Poisson’s ratio.

• Elevated temperatures promote clay diagenesis changing the rock framework, affecting factors such as clay mineralogy, hydrocarbon saturation, reactive components, compressibility, porosity, AI and permeability.

• Natural fracture patterns reflect the local in-situ stress state at the time of fracturing. Stress directions can be inferred from image log analysis. The order in which fractures are stimulated can affect their size and maximise reservoir contact from each stage of hydraulic fracturing.

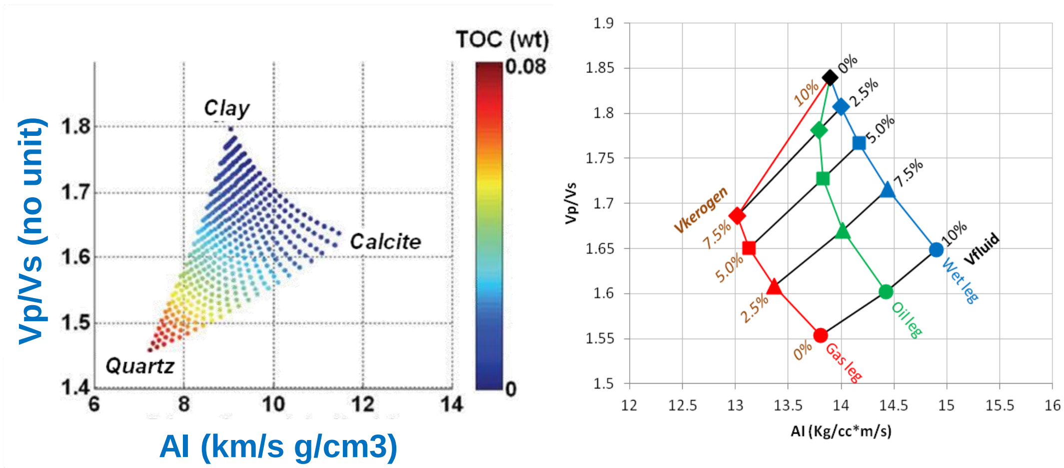

Figure 2 Sensitivity analysis of geophysical properties (AI & Vp/Vs); the left plot shows changes with mineral and TOC content (Zhu et al, 2010); the right plot shows changes with kerogen and fluid content for a constant porosity (10% total porosity) unconventional reservoir (Malaver, 2014). Pore pressure or geopressure will affect both Vp/Vs and AI.

Case Study

An unconventional borehole-centric dataset is used to demonstrate the use of multiple criteria to identify permeability zones. Figure 1 illustrates an empirical 1D geomechanical model for Cow Lagoon-1 located within the McArthur Basin, Northern Territory, Australia which was drilled by Armour Energy in 2012 (Mildren et al, 2013) to assess the unconventional prospectivity of the Batten Trough. Contemporary horizontal stress magnitudes vary considerably with depth and stress regimes range between strike-slip and extension within formations with differing elastic properties. This distribution of stress demonstrates the poroelastic effect expected in a high strain environment with low Youngs Modulus units correlating with low differential stress and high differential stress associated with high Youngs Modulus units. Stress, strength and elastic properties were analysed to identify relationships that correlate with natural fractures and documented hydrocarbon shows (Figure 11). Target horizons in the Batten Trough are characterised by low Young’s Modulus, low differential and low effective stresses and correspond with the following criteria: differential stress between 5 and 13.5 MPa, Youngs Modulus between 25 and 74 GPa and strength ratio (So/T) less than 3.

These criteria can be applied to a 3D mechanical earth model to map locations with matching characteristics that includes a greater potential for production based on the presence of permeable natural fracture populations with stress and strength conditions conducive to stimulation.

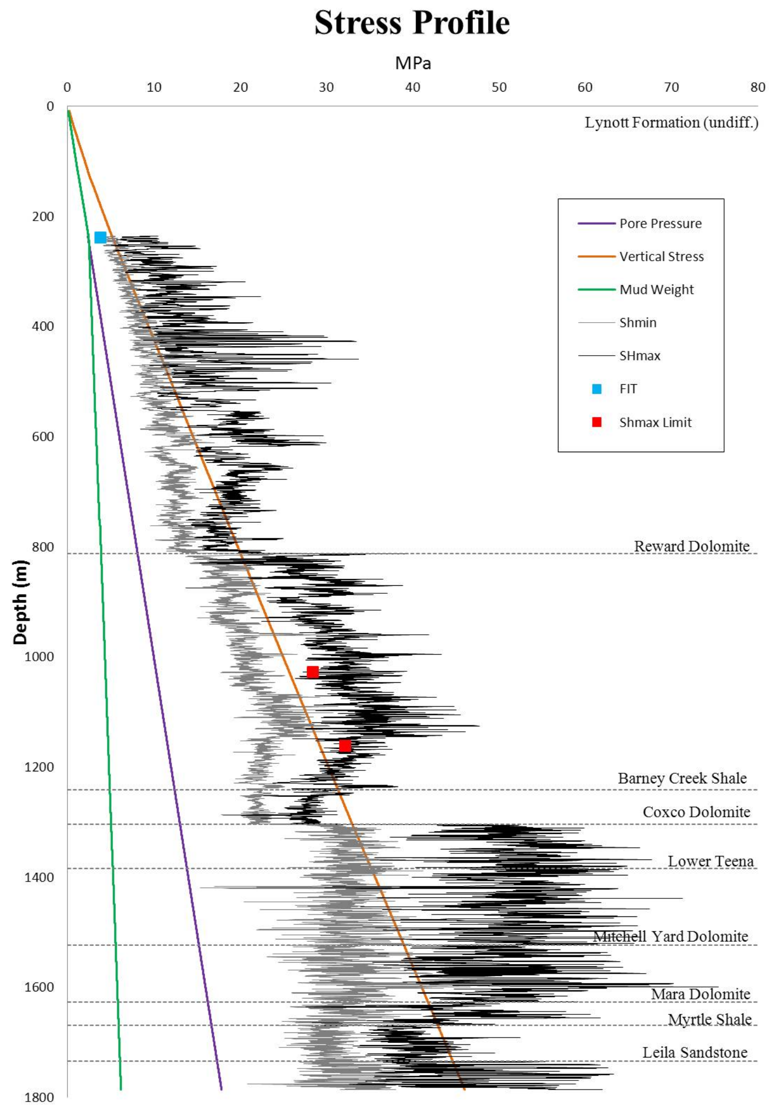

Figure 3 Stress profile at Cow Lagoon-1 showing a predominantly strike-slip regime with intervals of extension such as the Barney Creek Shale (Mildren et al, 2013).

Conclusion

Thus, in conclusion, we propose that the most robust model that can be developed to optimise these unconventional plays is an integrated mechanical earth model. This is a fundamental tool for considering the relationships between stress, strength and elastic properties of unconventional resources. There are many different methods to create empirical and numerical mechanical earth models, however, empirical well-centric analyses are key to constraining interrelated criteria that can be used to map unconventional reservoir properties such as fracture gradient, kerogen porosity, or directional permeability. These parameters can determined from the property model and the pore pressure which are obtained from inverted seismic data to model in multi-dimensions.

References

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