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Using traditional methods to predict pore pressure in Devonian Black Shale Basins of North East British Columbia

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Summary

In unconventional resource plays, pore pressure plays a critical role in the ability to predict fracture behaviour, and hence in the exploitation of these plays. Yet it is a parameter that is poorly understood, and little work has been done to understand whether it can be predicted in an unconventional setting.

The case study presented here shows how the traditional methods (Eaton Ratio and Equivalent Depth) can be used to predict pore pressure using a Pressure Reference Trend (PRT) in-lieu of a Normal Compaction Trend (NCT) that would be used in the offshore environment. The PRT is not linked to the expected compaction behaviour of the rock (as inferred from an NCT) but it is simply an empirical depth trend from which the pore pressure can be predicted using industry standard formulae.

Introduction

Traditional pore pressure prediction assumes that all shales are geologically young with low temperatures, are at their maximum burial depth, and have a demonstrable porosity/effective stress relationship where disequilibrium compaction is the mechanism of pressure generation. The critical assumption in traditional pore pressure prediction is that the wireline data are varying due to changes in porosity that can be converted using standard methods (e.g., the Eaton Ratio method) into a magnitude of pore pressure.

In reality, shales in unconventional plays are (or were) at high temperature, are often dramatically uplifted, and have been affected by chemical processes in addition to mechanical compaction such that porosity is not directly relatable to effective stress. Furthermore, the link between pore pressure and log response may be further disrupted by the presence of organic material (high TOC). An increase in TOC has been shown to significantly lower the magnitudes of velocity and density (Passey et al., 1990). Slow velocity (either due to TOC or to free gas in the pores) and low density are typically attributed to an increase in pore pressure so this effect needs to be removed from log data in order to correctly predict pore pressure. The actual presence of higher pore pressure can lead to “sweet spot” preservation and even natural fracturing that can enhance production without the need for artificial stimulation.

However, in spite of the issues reviewed above, it can still be possible to derive an empirical relationship between wireline data and the pressure magnitude. For example, Zhang and Wieseneck (2011) present a case study from the Haynesville and Bossier plays in the southern United States where they were able to link direct pressure data (kicks and/or DFIT-type data) to velocity. In this example, compressional velocity was computed from measured shear data using a calibrated Castagna approach to avoid the slowing effect of gas on measured compressional velocity. This approach was further modified by Couzens-Shultz et al., (2013) who showed that shear velocity data could be used to predict pore pressure in the same unconventional plays without needing to use the Castagna conversion into compressional velocity.

Theory and/or Method

The two most common methods for pore pressure prediction in the offshore environment are the Eaton Ratio method and the Equivalent Depth Method (EDM). The Bowers technique is also common but requires a larger dataset to calibrate successfully; it was a Bowers-type approach used by Zhang and Wieseneck (2011) and Couzens-Shultz et al., (2013). In both the Eaton and EDM processes a normal compaction trend (NCT) is required. This is a depth trend that represents normally pressured rocks at all depths. The difference between measured wireline data and the NCT allow estimation of the pore pressure magnitude. Through knowledge of shale compaction these NCTs can be constrained geologically quite sensibly. However, as discussed above, the same constraint cannot be applied in unconventional plays.

If we replace the NCT with a different depth trend, referred to here as a Pressure Reference Trend (PRT), then it should be possible to use traditional techniques in unconventional plays. The advantages of using either the Eaton or EDM approach is that they are more suited to datasets with less wells and fewer direct pressure measurements, as is often the case in unconventional plays. The PRT is developed in the same way as an NCT, i.e., data from several wells are used to build and calibrate the models (e.g., overburden) while a few wells are excluded to be used as blind test wells to verify the applicability of the PRT as a predictive tool. The PRT is not linked to the expected compaction behaviour of the rock (as inferred from an NCT) but it is simply an empirical depth trend from which the pore pressure can be predicted using industry standard formulae. Figure 1 shows an example of a multi-layer PRT for the Liard Basin in which each stratigraphic package has been calibrated to offset wells.

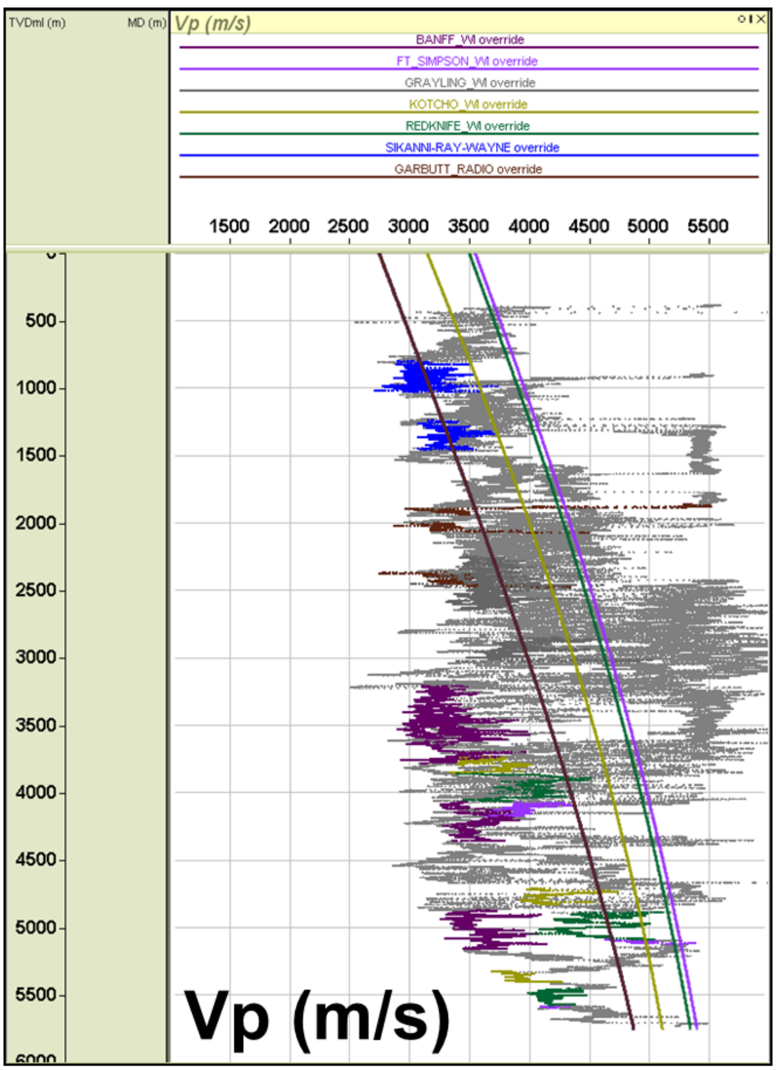

Figure 1: An example of a Pressure Reference Trend (PRT) for the Liard Basin. In this example several PRTs have been developed for different stratigraphic sections.

Examples

Below are two examples from wells in North East British Columbia. The first well (Well A; Figure 2) is an offset well used as part of the PRT calibration process. The results shown in Figure 2 (Blue = EDM Vp, Red = EDM Rho, Pink = Eaton Vp) show a close degree of agreement with each other and match the static mudweight used while drilling the well and the production test taken at ~3700m. This well shows that the wireline data (both Vp and Rho) can be easily translated into a meaningful pore pressure curve with minimal uncertainty and with a clear depth trend predicted for the deep, overpressured intervals.

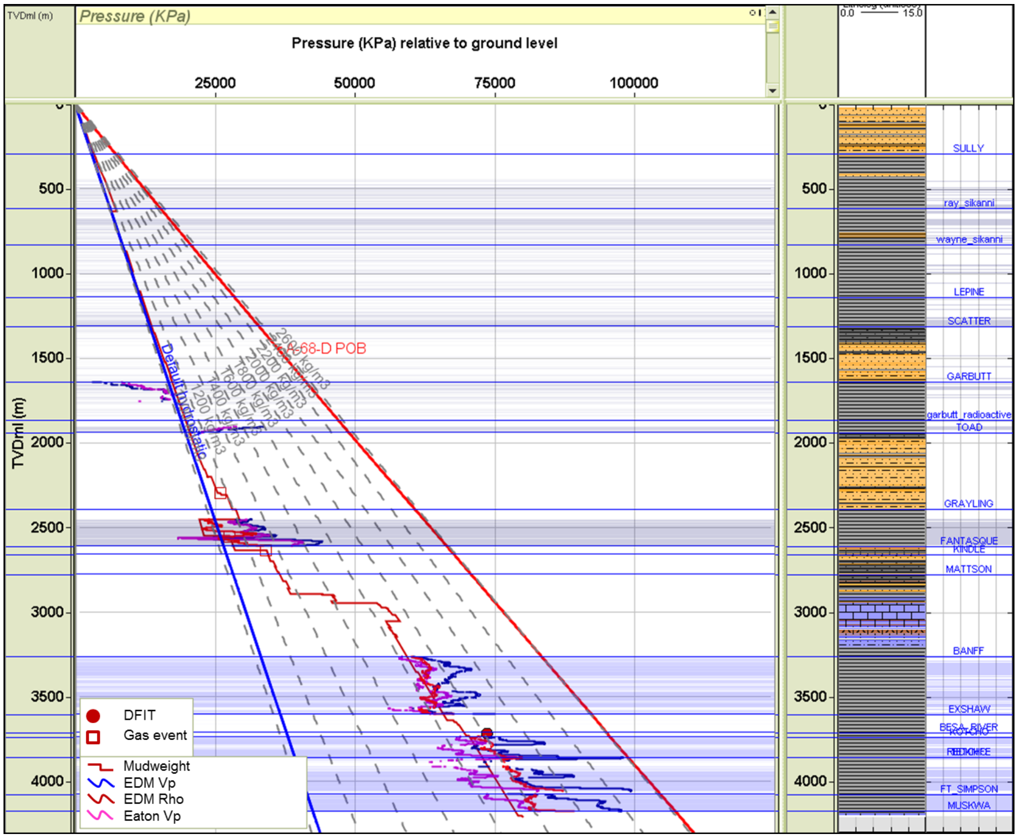

Figure 2: An example of a pressure prediction for Well A (an offset well) which was used to calibrate the PRT for this area. The predicted pressures match the mudweights and the production test (red circle) taken in this well.

The following example (Well B; Figure 3) is a well that was excluded from the PRT calibration process and was used to blind test the model. This well is interesting because the mudweight used to drill the well provided a much lower overpressure than in Well A well implying that the in-situ pore pressure was much lower. However, the production test taken in this well reveals that the overpressure is much higher than the mudweight suggests. This shows that these wells can be drilled underbalanced without experiencing overly detrimental wellbore stability problems. More importantly, mudweight cannot be used as a proxy for pore pressure as it can severely underpredict the magnitude of pore pressure, which will have a significant impact on the development of hydraulic fractures.

The predicted pore pressure from the PRT for Well B is shown in the same blue, red, and pink curves as shown for Well A. The critical observation is that the predicted pressures are on trend with the production test taken in the well, i.e., the PRT accurately predicts the in-situ pore pressure as measured in the well. The accuracy of the PRT is critical in this area as it gives confidence in the magnitude of the predicted pore pressure and a more accurate hydraulic fracturing plan (mechanical earth model) can be derived. This leads to more efficient fracturing and more cost effective wells. Although not shown in this abstract, the PRT model was also used to generate a regional 2D line of pore pressure that can be used to characterise inter-well regions for future exploration and exploitation of the resources in the basin.

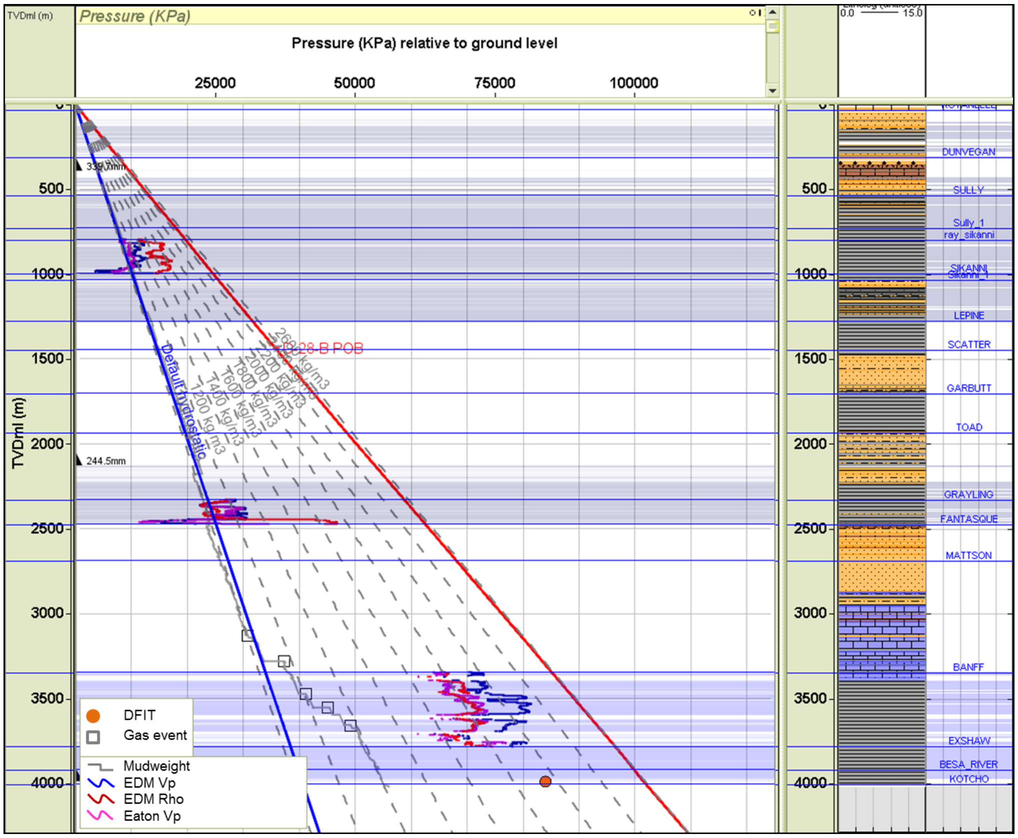

Figure 3: An example of a pressure prediction for Well B (a blind test well) which was used to test the PRT for this area. The predicted pressures do not match the mudweights but they do match DFIT taken in this well. Note that the DFIT is much higher magnitude than the mudweights.

Conclusions

This paper presents a case study showing that traditional pore pressure prediction techniques (Eaton, Equivalent Depth) can be adapted to predict pore pressure in an unconventional play, such as North East British Columbia. The advantages of using these techniques is that they are standard to most industry software, they work better than other techniques (e.g. Bowers) in areas with less data, they work with industry standard logs (e.g., Vp, Rho), and they can be easily translated into the 2D/3D domain for predicting pressure in inter-well regions.

Accurate pore pressure is important not only to safer, faster drilling of cleaner boreholes but also as an important input into mechanical earth models. These are used to design hydraulic fractures and as an input for rock physics model such as those used to predict lithology and fluid fill.

Acknowledgements

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References

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