The value of production logging combined with 3D surface seismic in unconventional plays characterization

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Summary

Unconventional gas reservoirs are characterized by low porosity and low permeability. Due to the low permeability in these types of plays, hydraulic fracture stimulation is required to achieve gas production. An effective stimulation connects the existing natural fractures and effectively links as much reservoir rock as possible with the wellbore.

Previous studies have shown that, if used under the right perspective, Lambda-rho/Mu-rho cross plots can be used to quantitatively grade reservoir rocks in conventional as well as in unconventional plays. The validity of this statement is corroborated with actual field data. Specifically, production logs recorded in four neighboring horizontal wells in the Lower Barnett after hydraulic fracturing was carried out, strongly agree with the hypotheses that:

1. Low values of Lambda-rho and Mu-rho are indicative of high porosity and therefore high reserves in place, in this case gas.

2. For any given porosity or original gas in place (OGIP), the recovery factor and therefore the gas rate increases with decreasing Poisson's ratio.

This study shows that production logs such as the temperature log and the differential gas production log when plotted in the Lambda-rho/Mu-rho background are in agreement with the two hypotheses. High temperatures correspond to high gas rates; therefore, high temperatures and high gas rates are clustered together towards the lower left hand side of the Lambda-rho/Mu-rho cross plot, while lower temperature and lower gas rates cluster towards the upper right hand side of the cross plot.

Introduction

The use of engineering tools such as production logs analyzed under a background of a surface 3D seismic volume enable us to evaluate the effectiveness of the hydraulic fracturing treatment and relate it to the heterogeneities that are intrinsic to the shale rocks.

Even though shale plays were first considered continuous gas accumulations (Figure 1), the drill bit has been shown and 3D seismic attributes corroborate that they are by no means homogeneous (Schenk and Pollastro, 2001). By mapping these heterogeneities Engineers and Geoscientists are interested to more efficiently and economically produce these resources. For this reason, our goal is to attempt to identify the best place to locate wells to produce the maximum amount of hydrocarbons with the minimum drilling and stimulation. It is, maximize the absolute Estimated Ultimate Recovery (EUR) in the reservoir.

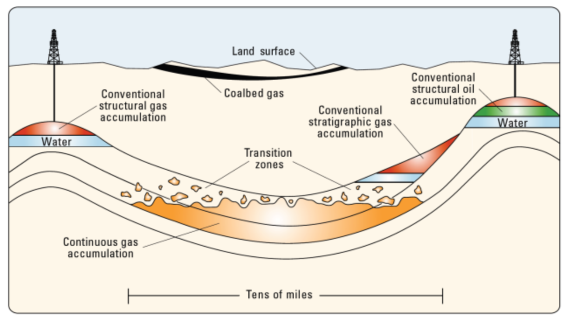

Figure 1. Categories of oil and natural gas occurrence as used in the National Assessment of Oil and Gas Project (Schenk and Pollastro, 2001).

Although the Barnett shale is the most studied and well known Shale play in the US (Boyer et al. 2006), there is still much work that can be done to more finely characterize the reservoir. For example, we found Perez et al. (2011) templates of Lambda-rho/Mu-rho for different mixtures of quartz and clay, varying the composition from 60/40% quartz/Clay to 100% quartz and varying the porosity from 0% to 20% (Figure 2) to be particularly useful. On this plot, the curves describing the porosity increase indirectly show the direction of original gas in place increase; the change in rock composition is directly related to the brittleness of the rock. Quartz rich rocks are brittle while clay rich rocks are ductile. The brittleness of the rock is directly related to how effective the hydraulic fractures will be. The Recovery factor (Rf) or fraction of hydrocarbons in place that can be produced vary accordingly. Brittle rocks can sustain propped fractures effectively, while ductile rocks will heal themselves against the proppant. Figure 8 shows actual values of gas rate extracted from the interpretation of production logs and the 3D seismic available.

Since production logs are available for only 4 neighboring horizontal wells in the lower Barnett, the results from this study can be used as a predictive tool

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to grade the remainder of the reservoir based on the seismic data available.

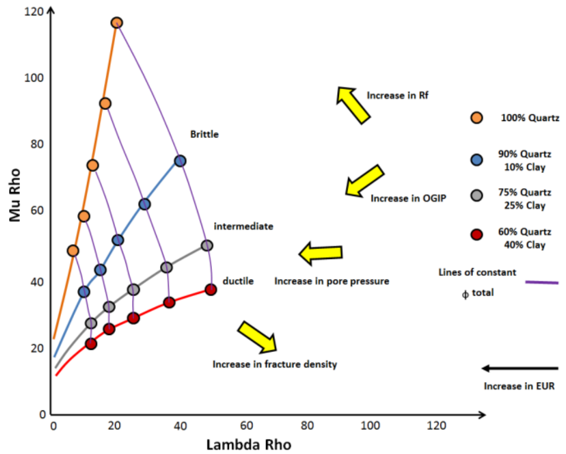

Figure 2. Heuristic template to interpret Seismic, Well Log, or Laboratory rock properties in terms of EUR, Original Gas in place (OGIP), Recovery factor (Rf), Pore pressure, fracture density, and closure stress scalar. Reproduced from Perez et al. (2011).

Method

We have a seismic volume, already depth migrated, covering one of the fields that Devon Energy is exploiting in the Fort Worth basing (Figure 3), plus a suite of production logs corresponding to four horizontal and parallel wells (Figure 4) located in the north east part of the field and targeting the Lower Barnett shale formation. Our goal is to identify which seismic attributes are the ones that better correlate with the best and the worst producing zones within the four wells.

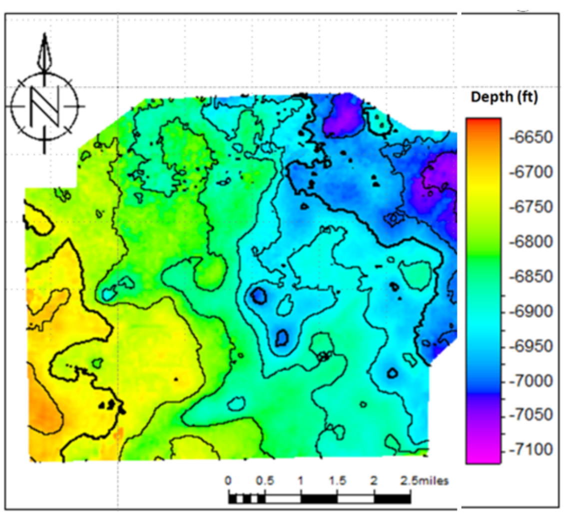

Figure 3. Depth structure map of top of the Lower Barnett Horizon corresponding to the 3D Seismic Survey.

We explored different seismic attributes to find a good correlation with gas production. Specifically, we correlate the Most positive curvature, most negative curvature, Lambda-rho and Mu-rho. With the curvatures, there was no evident relationship, but when the gas rate is plotted as function of the Lambda-rho and Mu-rho (Figure 7) the relationship becomes evident.

To create the cross plots in Figures 7, 9, 10, 11,12, and 13, the values of Lambda-rho and Mu-rho along the wellbores were extracted from the seismic volume and then compared with gas rate and the temperature at the same points according to the production logs.

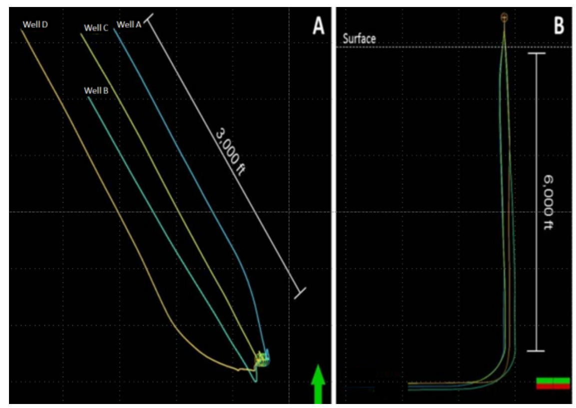

Figure 4. A) Map view of four parallel horizontal wells drilled in the Lower Barnett Shale. B) Lateral view of the same wells.

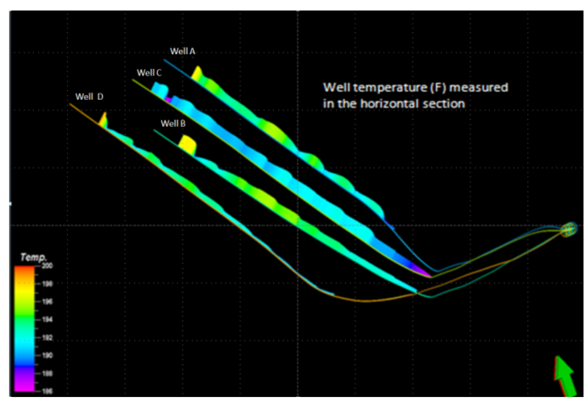

Figure 5. Well temperature along the horizontal section of the four parallel horizontal wells drilled in the Lower Barnett Shale.

The suite of production logs included the temperature log (Figure 5), differential production (Figure 6), which indicates how much gas is coming from a particular perforation, and gamma ray. These logs were all recorded after the rock was hydraulically fractured as a mean to evaluate the stimulation effectiveness.

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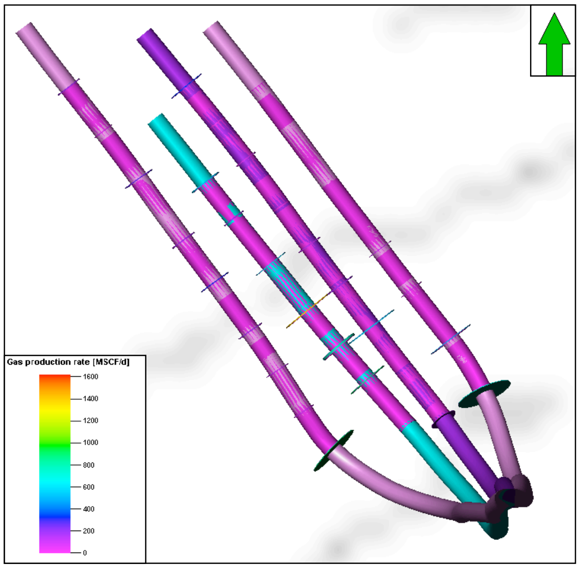

Figure 6. Differential gas production indicated by the color and diameter of the discs along the wellbores. The background is a seismic attribute called ant-tracked coherence.

Results

When plotted against Lambda-rho/Mu-rho, the production rate coming from each individual stage starts making sense (Figure 7). In this crossplot, iso-Poisson's ratio lines can be considered lines of similar frackability or brittleness. Figure 8 shows such a crossplot for the Lower Barnett displaying well defined color bands representing portions of the data having similar Poisson's ratio. Not surprisingly, the highest stage gas rates are located in portions of the wells where the Poisson's ratio is smallest. Conversely, the smallest individual gas rates are coming from zones where the rock is extremely ductile or where the Poisson's ratio is 0.24 or larger. The ovals are enclosing the observed values along the perforated zone in WELL A, WELL B, WELL C and WELL D.

Figure 8 also shows that there is a strong correlation between the Poisson's ratio and the well production rate. For example, WELL B, which is the one that exhibited the highest total gas rate during the production logging, is also the one whose Lambda-rho/Mu-rho points fall in the region with smallest Poisson's ratios. On the other hand, WELL A is the one with the smallest production rate and is also the one that none of the Lambda-rho/Mu-rho points measured in the producing zones falls in the "brittle" (magenta-dark blue) region. At least one of the points in WELL C and WELL D plot in the low Poisson's ratio region and the production rate for both of them is in between the production of WELL A and WELL B.

Figures 9, 10, 11, and 12 are displaying the same information shown in Figure 7 but discriminating the points by well. The objective of these figures is to remark that considering the wells individually, the most producing zones exhibit lower Poisson's ratios. In other words, the hydraulic fractures are more effective in the zones where the rock is more brittle.

Finally, Figure 13 shows the same crossplot as in Figure 7 but now the color represents the temperature of the well. Basically what can be observed is that the higher the gas rate the higher the well temperature. In other words, the temperature in the well is being driven by the hot gas coming in. This is why WELL B, which produces the highest gas rates, is also the one exhibiting greatest well temperatures.

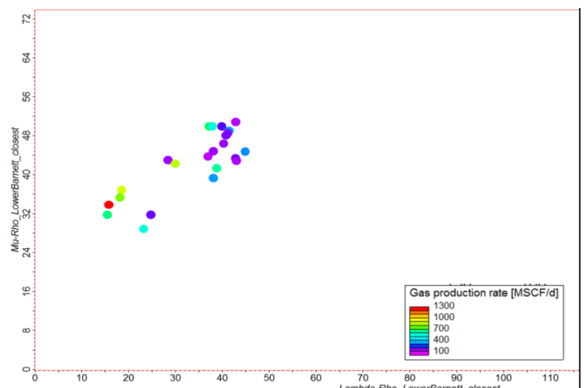

Figure 7. Seismic Lambda-rho/Mu-rho extracted along the wellbores with production logs. The color indicates the gas rate at each individual stage.

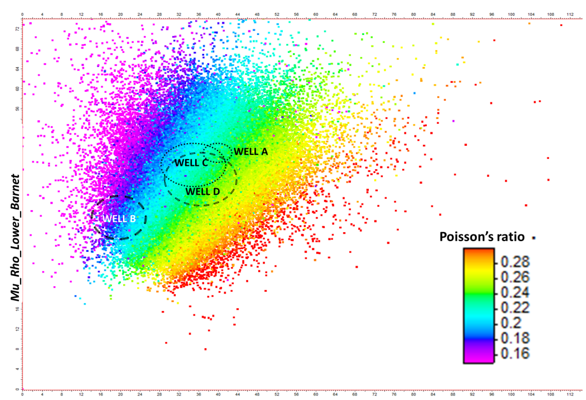

Figure 8. Lambda-rho/Mu-rho crossplot for the Lower Barnett Shale. Color indicates the Poisson's ratio. Ovals indicate the range of values observed in the producing zones for each well.

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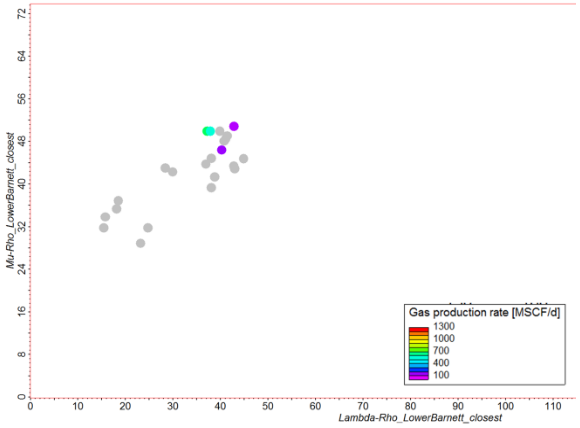

Figure 9. Seismic Lambda-rho/Mu-rho extracted along the wellbores with production logs. The color indicates the gas rate at each individual stage in WELL A.

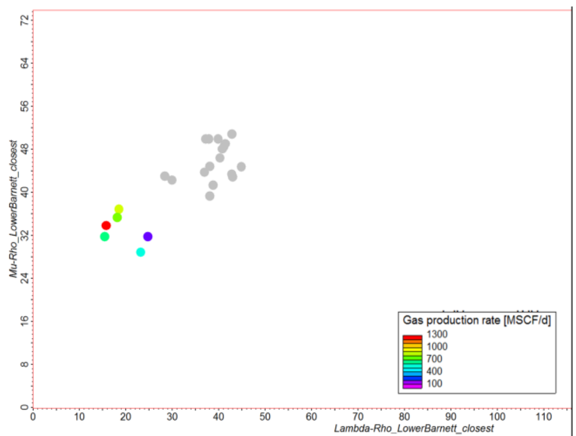

Figure 10. Seismic Lambda-rho/Mu-rho extracted along the wellbores with production logs. The color indicates the gas rate at each individual stage in WELL B.

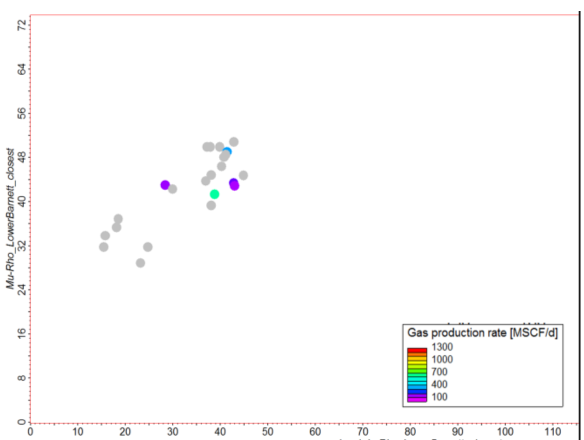

Figure 11. Seismic Lambda-rho/Mu-rho extracted along the wellbores with production logs. The color indicates the gas rate at each individual stage in WELL C.

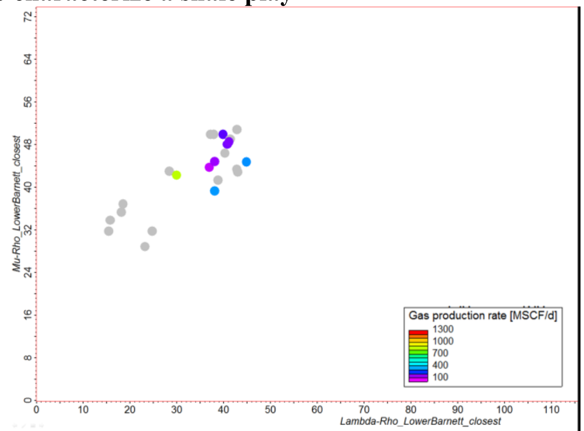

Figure 12. Seismic Lambda-rho/Mu-rho extracted along the wellbores with production logs. The color indicates the gas rate at each individual stage in WELL D.

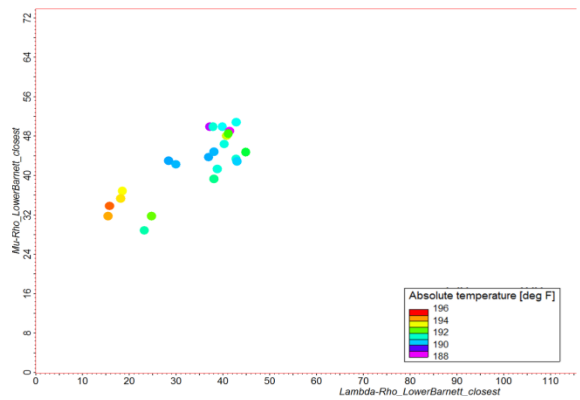

Figure 13. Seismic Lambda-rho/Mu-rho extracted along the wellbores with production logs. The color indicates the well temperature in the producing zones**.**

Conclusions

Actual field data corroborates that Lambda-rho/Mu-rho cross plots are effective tools to predict where in the reservoir hydraulic fracturing will be the most effective. Figure 7 shows that the most producing zones are those having low values of Lambda-rho and Mu-rho.

The most producing well, WELL B was completed in a zone with overall better brittlenes than the others as can be observed in Figure 8.

The results found can be used as a predictive tool to use in the rest of the field where seismic data is available but production logs are not.

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EDITED REFERENCES

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