Seismic-Based Production Forecasting for Shale Plays*

Alice Guest[1], Simon Voisey[2], and Gabino Castillo[3]

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[1]Magnitude, Calgary, AB, Canada (alice.m.guest@gmail.com)
[2]Apache Corporation, Houston, TX, USA,
[3]CGG, Houston, TX, USA

Abstract

It is known that production of wells in hydraulically stimulated unconventional resource plays varies on the large as well on the small scales. The exact reasons for such variability are not clear but are related to changing reservoir conditions and/or the completion of wells. The purpose of this study is to evaluate the key effects that affect well production based on the physical laws and variability of properties as oppose to the studies based on the correlations between the production and the individual properties. We use an analytical solution of the linear flow to determine well production while estimating spatial variations of some of the key parameters entering the equation from seismic and log attributes. This calculation is done on a spatial grid with a map of estimated productivity for a region as an output. In this study, we focus on a case of a gas flow from Haynesville shale formation.

Method

We calculate the production on a map grid covering a region and we assume that each grid point of the map contains a well of a specific design (length and number of stages) that is surrounded by constant properties that are equivalent to the properties of the particular grid point. The production then determines a potential for production for a well with such properties. Because the production from individual fractures is additive, the production of a well of any orientation is an average of the potential productions around the path of the well.

The properties that enter the equation of the linear flow (Table 1) can be divided in two sets: the first set includes pore pressure, water saturation, porosity, height of the reservoir, and permeability. These properties are dependent on the geological settings of the reservoir and cannot be changed. The second set is dependent on completion parameters and includes hydraulic fracture half-length, flowing pressure, permeability enhanced during stimulation and skin effects. Properties like pore pressure, porosity, and water saturation can be obtained from 3D seismic attributes (that are tied to well properties) and also the height of the reservoir can be estimated from 3D seismic attributes using the mechanical properties, like Young's modulus. The other variables have to be modeled, for example the fracture length, or estimated from microseismic events. Some properties are assumed constant because either they do not vary or the variation is not known.

In order to validate the calculations and choice of properties, we performed history match between the predicted and observed productions for one well and then we altered the properties to understand the sensitivity to the properties. Table 1 below shows the effect of the properties on Estimated Ultimate Recovery (EUR) and Instantaneous Production (IP) based on the parametric study assuming a horizontal well with 13 stages. The most sensitive parameter is permeability for which unfortunately the variability estimates in a region do not exist and must be assumed constant. The other parameters, like porosity, water saturation, pore pressure, fracture half-length and height are similarly sensitive and their specific effect depends on the variability in the region.

Results

On the scale of 2x2 km, the calculated EUR (Figure 1) varies in the region from 7.6 to 9.6 bcf, with only one EUR difference within the well pad. The anomaly in the EUR of one bcf can be explained by a combined effect of porosity and water-saturation variations. Porosity increase adds 0.5 bcf and water-saturation decrease adds another 0.5 bcf. The effects of pore pressure and reservoir height are negligible at this scale.

In order to validate the results, we compared the calculated values to the observed values. For this pad, the only public information available was the instantaneous production. The correlation between EURs and IPs of wells in the larger region shows that there is a positive qualitative dependency between the values and therefore high IP is indicative of high EUR and low IP is indicative of low EUR. On the Figure 1, we see nice match between the predicted and observed highs and lows: the eastern part the pad has low production, the central and western parts have high productions. In order to match predictions on the western end we needed to take into account that the extent of microseismicity is ~ 100-200 ft shorter at the western end and that an envelope to all microseismic events (SRV), is smaller at the western end (Figure 2; Castillo et al., 2014). The 100 ft longer fracture length corresponds to the increase in EUR predictions by one bcf (using Table 1) and increase in IP by ~5 MMcf/day.

Discussion and Conclusions

For Haynesville shale, the predicted variations of production on a scale of a well pad (~ 2x2 km, consisting of 8 wells) can be explained by varying porosity, water saturation obtained from seismic attributes and fracture half-length obtained from microseismic monitoring. The variations in pore pressure and reservoir height are negligible at this scale. The microseismic signature of the hydraulic-fracture half-length also correlates with Young's modulus and fracture propagation pressure (Castillo et al., 2014).

This study shows that production of a well is not dependent on one parameter but on a set of parameters that have to be considered together. The importance of various parameters can vary from region to region and from scale to scale therefore, it is important to consider the complete set of possible variables first. Seismic attributes are evidently very suitable for providing at least the limits for the variables and ideally the spatial coverage. The simplified technique is promising for giving a physical insight into the production variability in a region.

Acknowledgements

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Reference Cited

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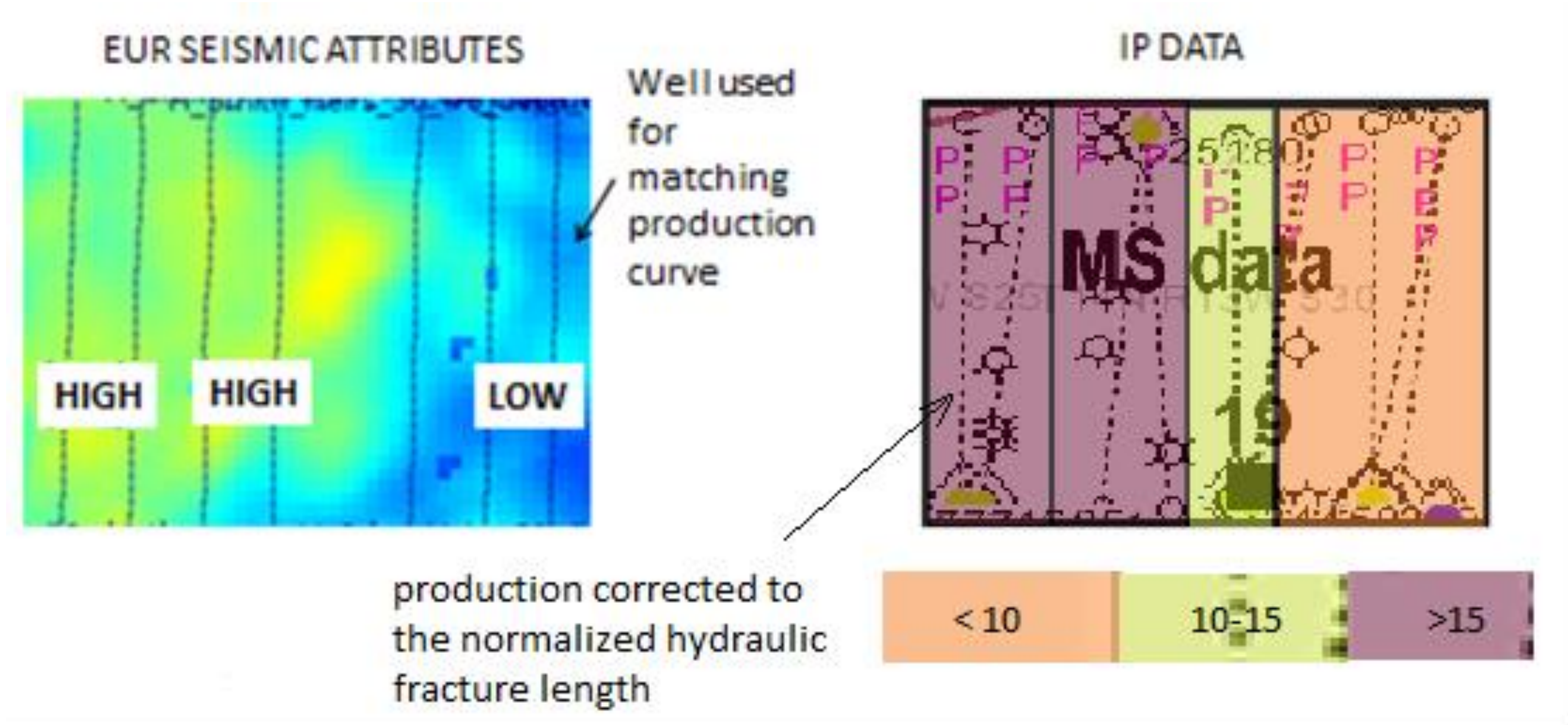

Figure 1. Left: Predicted EUR; Right: Instantaneous production for the region taken from public data and normalized to the constant hydraulic fracture length.

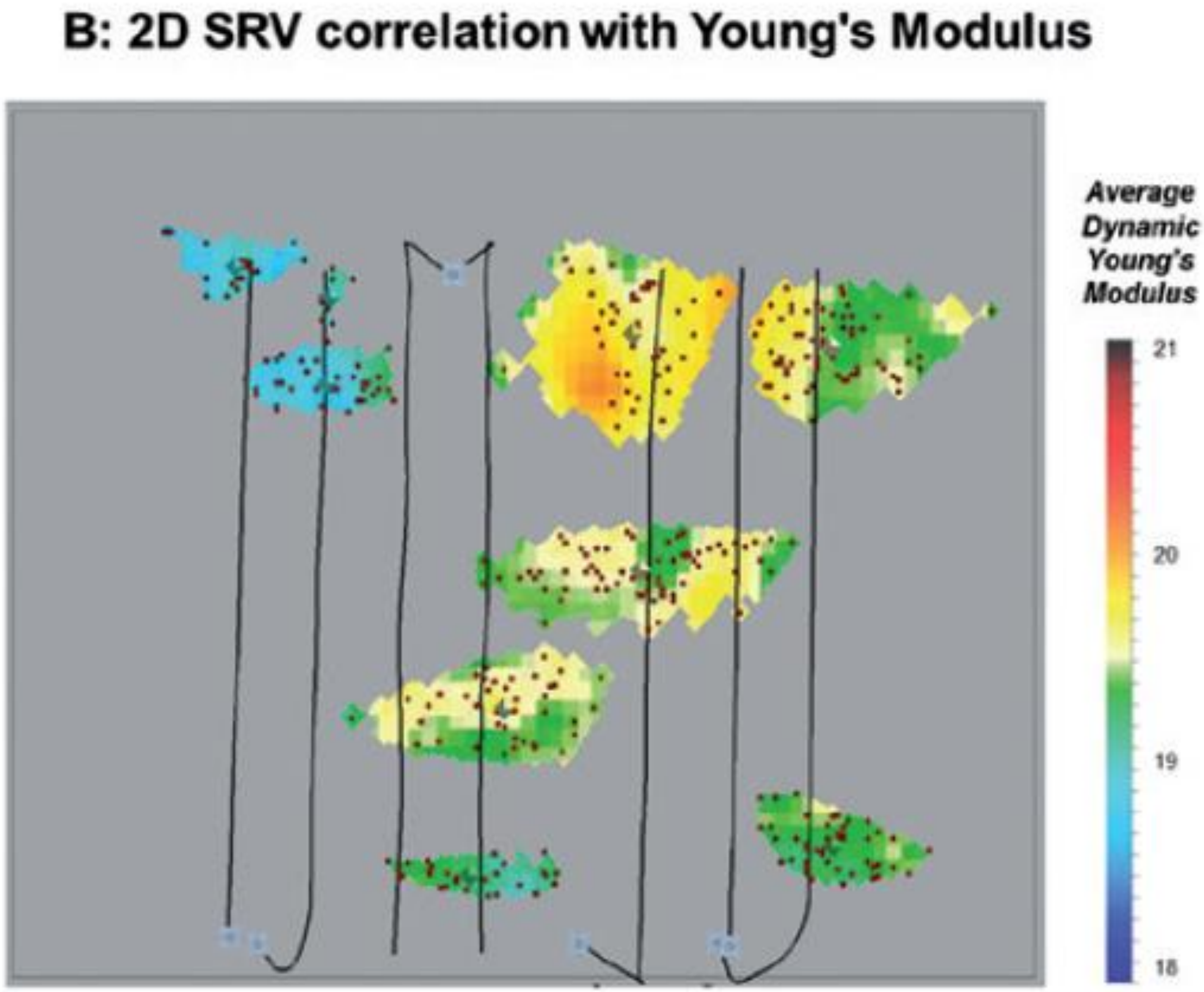

Figure 2. Left: Examples of microseismicity and areal envelopes around the events on seven wells (taken from Castillo et al., 2014).

Variable	Change of	has an effect on EUR [bcf]	and on IP [MMcf/day]
Lf [ft]	114	1	5.43
h [ft]	10	1	3.75
k [nD] *	13	1	4.44
Porosity [%]	3.64	1	3.64
Temperature [F]	67	-1	-4.67
Water Saturation [%]	20	-1	-3.50
Pressure [psi] **	2000	1	4.00
pwd [psi] ***	1143	-1	-4.00
Molecular Weight [1/psi]	0.5	0	0.00
Formation Compressibility	0.000001	0.025	0.25
Gas Gravity [1]	0.2	0.025	0.50
*not linear dependence; for 100 nD matrix perm reservoir			
**dp=pressure-pwd=const			
***pressure=const			

Table 1. Summary of the effects of variables on EUR and IP. Variables obtained from seismic attributes (height, porosity, water saturation, pore pressure) or logs (temperature) are shown in green, the completion variables are shown in orange, the constants are in gray. Permeability has a special position.