

Optimizing the Development of a Stacked Continuous Resource Play in the Midland Basin

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Optimizing the Development of a Stacked Continuous Resource Play in the Midland Basin

James Courtier*, Joe Wicker, Travis Jeffers, Pat Curth. Laredo Petroleum Inc.

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Summary

Developing a continuous resource play with multiple productive zones of varying geological complexity that total in excess of 4,500 gross feet, requires careful consideration in order to maximize value while fully addressing the inherent technical and economic challenges. Laredo has developed a proprietary “Earth Model” workflow that integrates seismic, well, production and completion data using multivariate statistical methods to denote the highest productivity potential throughout the entire prospective section. Building an early appreciation of the development potential allows the prioritization of highest value zones, design of landing points and wellbore geometries to seek optimized production and planning for no detrimental impact on future development. Production results from a growing population of wells demonstrate improvements in cumulative 90-day oil production that are in line with forecasted Earth Model expectations. This continues to assist in ranking development areas and prioritizing exploration acreage. The Earth Model workflow represents an “evergreen” process that can be iterated and updated on an ongoing basis with new data, including new complexities and changes to development designs providing an improved platform that may further improve well EUR’s and economic returns.

Introduction

Laredo recognized early during the evaluation of its Garden City acreage positioned on the eastern side of the Midland Basin (Figure 1) that development of multiple zones require a holistic and rigorous technical workflow, integrating all available data types, in order to fully exploit the total resource package. With resource potential aggregating into billions of barrels, this represents a development that requires careful consideration and oversight.

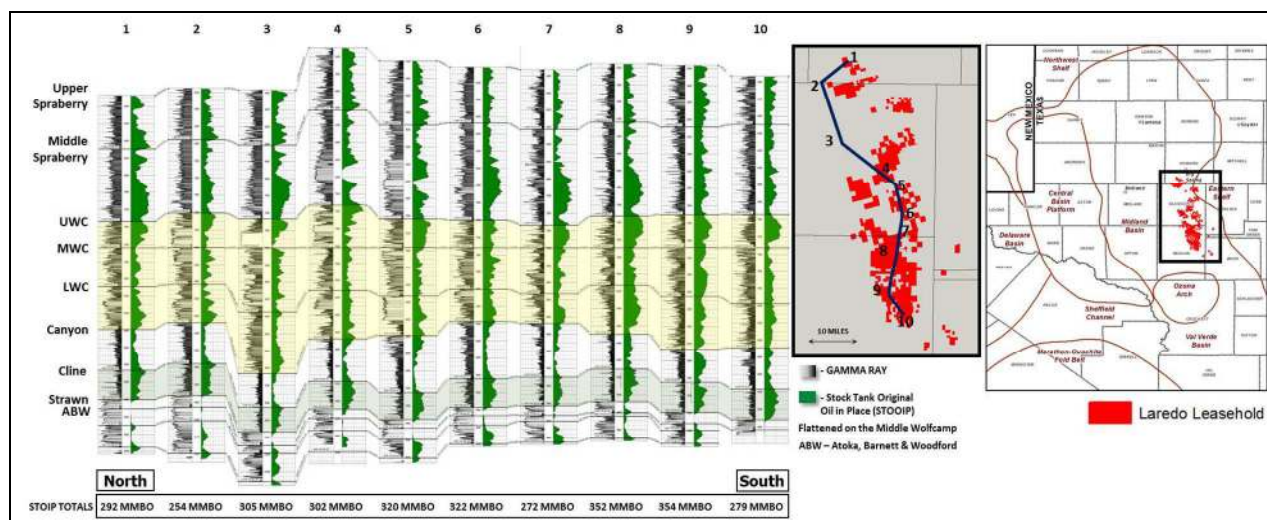


Figure 1: Gamma ray & stock-tank original oil in place cross-section across Garden City acreage.

The multi-stacked nature of the Midland Basin tight unconventional oil play presents additional challenges in terms of vertical and horizontal spacing when designing the overall development and building the appropriate scale of facilities necessary for exploitation of these resources (Figure 2).

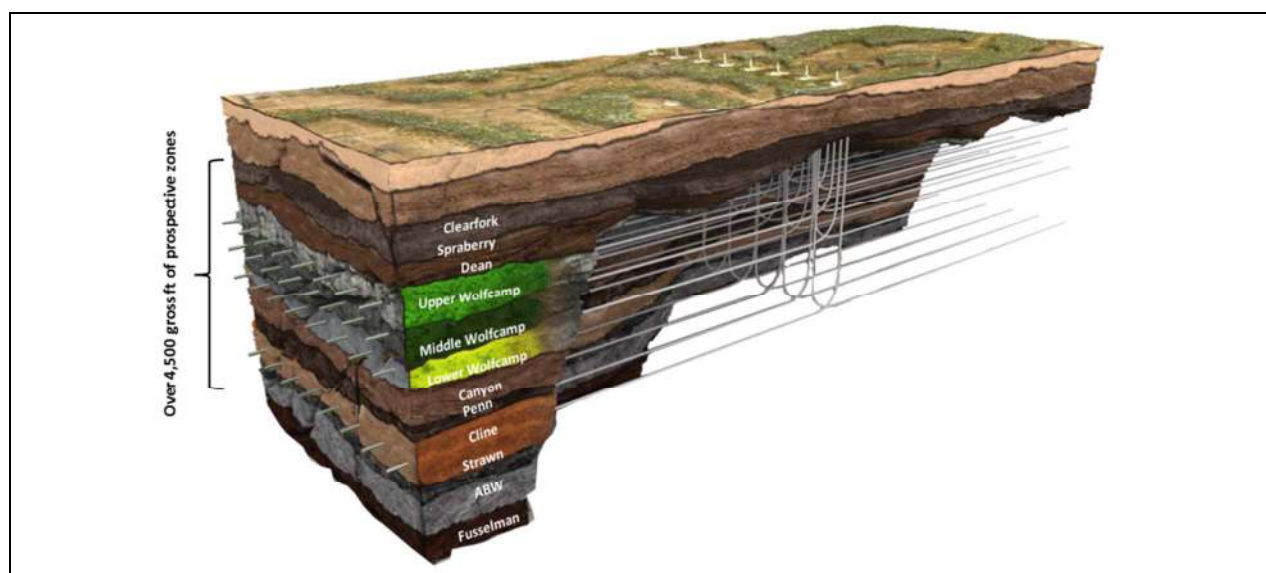


Figure 2: 3D graphical representation of 4-zone stacked development with cutaway demonstrating example wellbore geometries.

A key starting point to building any type of high quality 3D geocellular Earth Model is acquiring the right data at the right time in order to initiate this process. A cornerstone principle in Laredo's operating philosophy is that a better understanding of the subsurface via integration of data, science and technology leads to improvements in value creation for the company's stakeholders. Laredo acquired over 400 square miles of high fold (>200) 3D data over

their Garden City assets. New efforts to acquire seismic data in the Permian Basin are very much a trend in response to the success of horizontal drilling, as explained by Dunham (2013).

Between 2012 and 2015, Laredo acquired 100 dipole sonic logs. High quality 3D seismic, in combination with an excellent population of dipole sonic logs distributed relatively evenly across the survey, allows for the development of a very high quality series of acoustic impedance inversion products and associated derivative attributes. Laredo has been developing inversion attributes relating to reservoir, lithology, stress, natural fractures and geomechanical properties since 2013. These attributes and the derivation thereof are outlined by many contributors to this dedicated applied area of geoscience research (Sayers 2010, Goodway et al, 2010, Pendrel et al, 2000, Hampson et al, 2001).

Method

Bivariate Statistical Shortcomings

During early appraisal of the Wolfcamp play, after a reliable and standardized slickwater frac design had been established, operators favored “leading theories” of underpinning production driving mechanisms, with a common culprit often deliberated as original oil in-place (OOIP). While an important factor in any tight-oil play, early bivariate analysis revealed limited correlation between OOIP and production over the area of interest. In fact, as discussion ensued, bivariate analysis of an extensive list of log properties and seismic attributes versus production demonstrated poor correlation in most instances. Figure 3 shows four separate seismic inversion properties correlated to 6-month cumulative oil production in a bivariate sense with low correlation coefficients. Clearly this is problematic, as it stringently impedes the ability to be predictive during any development program and results in a much higher degree of variance in anticipated well results.

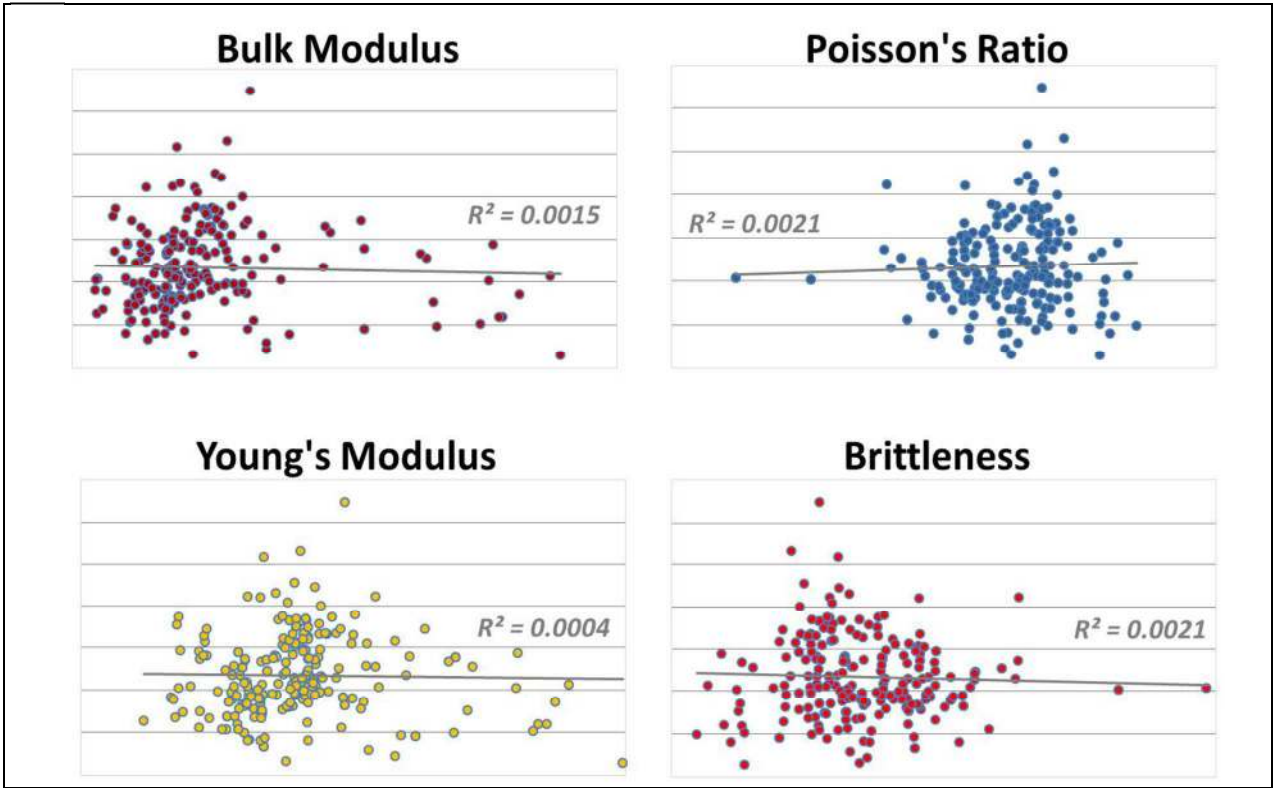


Figure 3: Series of individual average extracted attribute values (x-axis) versus cumulative 6-month oil (y-axis) revealing very low bivariate correlation coefficients and r-squared values.

Adopting a Multivariate Approach

A breakthrough occurred when non-linear multivariate statistical methods were applied to multiple attributes simultaneously. Developing non-parametric, non-linear multivariate models incorporating attributes representative of reservoir quality, mechanical properties and natural fracturing evaluated holistically with valid sample sizes, transformed the historical bivariate approach. By combining these effects, underlying relationships to production were revealed with correlation coefficients commonly seen at 0.7 - 0.85. Further details on the multivariate workflow and process are outlined by Wicker *et. al.* (2016). Figure 4 shows an example of a multivariate model from 2015.

Importantly, a mutual interaction between reservoir quality, mechanical properties and natural fracturing appear to correlate to production. No single parameter or attribute appears to exert an overriding effect. Given that individual attributes developed for this study vary spatially across the area of interest, different attributes contribute in varying degrees with other attributes, which in turn affects the productive capability. While many seek a lone “silver bullet” production driver, the data and resultant interpretation suggest the opposite; whereby a combination of variables is the key.

Similar multivariate approaches have been outlined by other authors, including Ballie (2016).

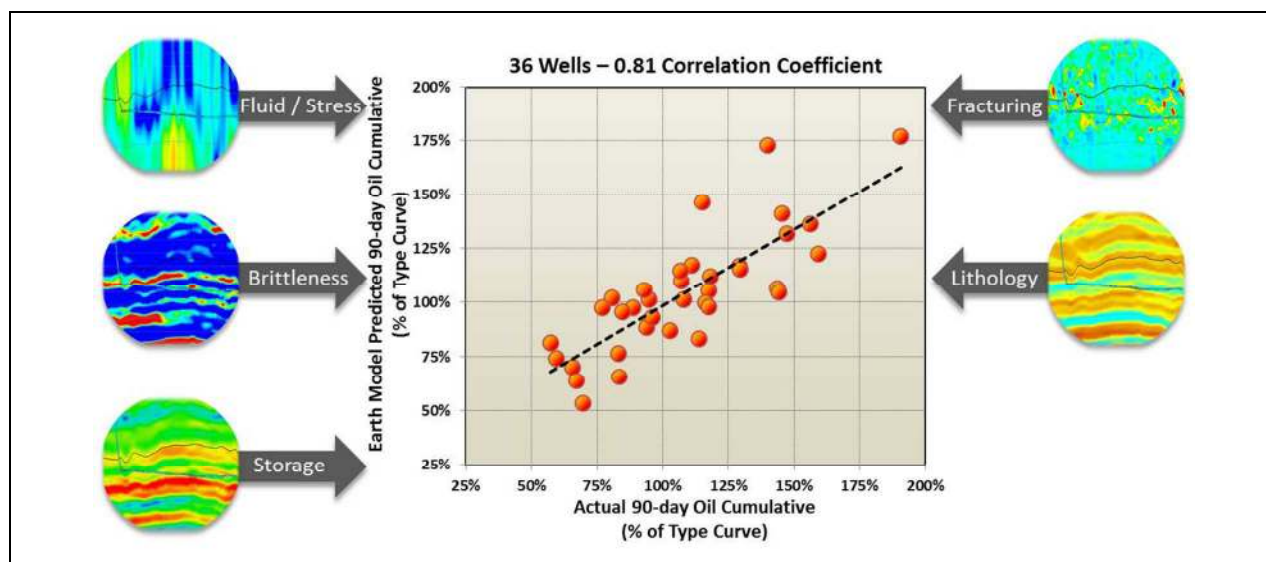


Figure 4: Multivariate model example from 2015.

Once a mathematical relationship is derived from the multivariate statistics to cumulative oil production, this can then be applied to the 3D attributes highlighted in the modeling workflow in order to develop a regionally extensive 3D “Production Attribute” (Figure 5). This in turn provides a pragmatic tool to define zones, both vertically and spatially in a predictive sense, that have the highest production potential.

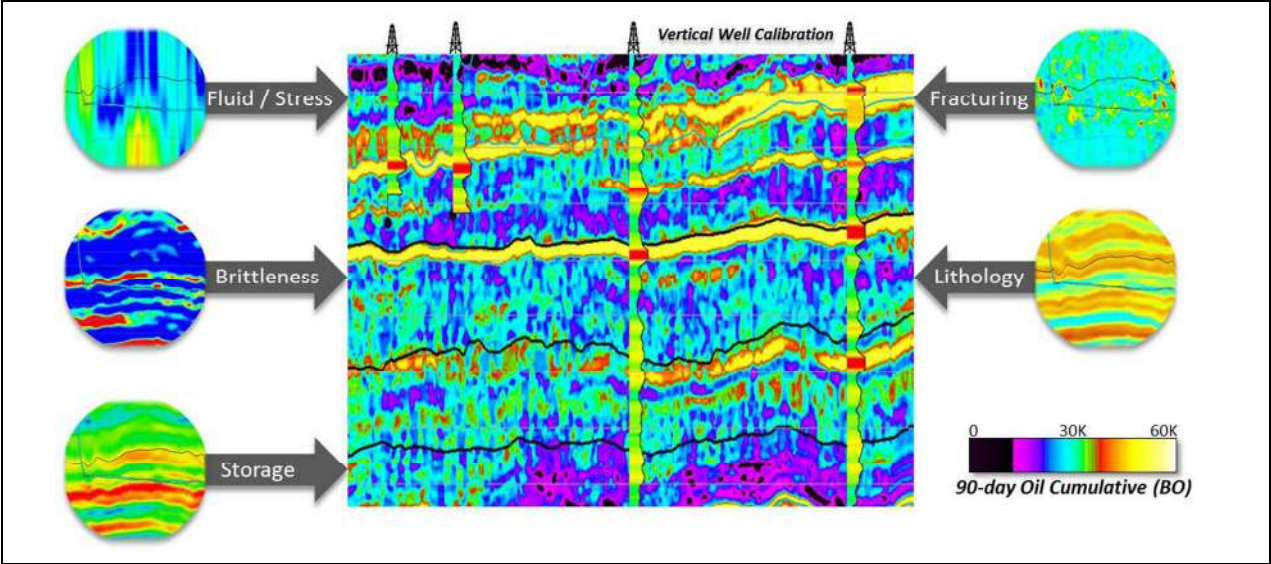


Figure 5: 2D line taken from the 3D Production Attribute with example input attributes shown. Color bar scaling approximates 90-day cumulative oil relative to a 7,500' completion interval on a horizontal wellbore. Vertical calibration wells demonstrate replicated Earth Model Production Attribute response derived from log and dipole sonic properties.

Early versions of Laredo’s Production Attribute were developed for 90-day cumulative oil, which later extended to 6-month cumulative oil. The principal reason for opting for 6-month cumulative oil versus 90-day cumulative oil is due to a stronger correlation between 6-month cumulative oil and oil EUR (Figure 6). Given oil production provides approximately 80% of total revenues at the time of this publication, the Production Attribute derived from this Earth Modeling approach becomes a fundamental driver for value creation within field development planning.

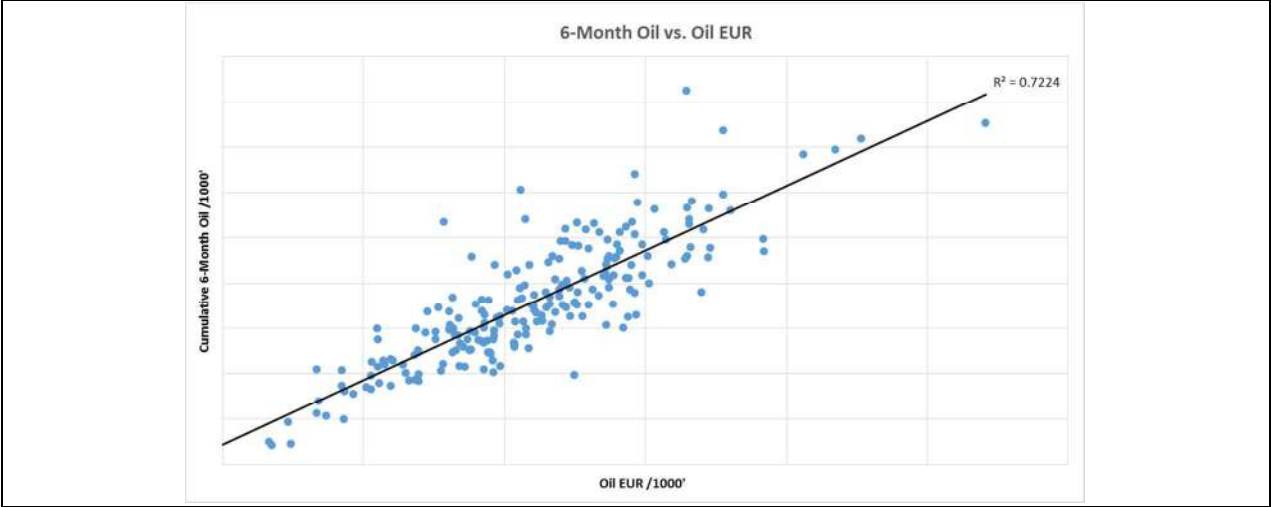


Figure 6: Correlation between 6-month cumulative oil and oil EUR

Upon review of the Production Attribute, zones of higher production potential were evidently laterally extensive, related to depositional facies and structural setting within “like” rock properties. A key observation is that contrasting zones of low productivity potential are interbedded within zones of higher productivity potential. This appearance repeats within each productive sequence being targeted for development (Wolfcamp Series). Higher production potential attribute values illustrated by Laredo’s Earth Modeling process, when contrasted with lower production potential attribute values in any given zone, can vary by 50%, thus significantly impacting EUR and value (Figure 7). Therefore the Production Attribute represents an important tool for development planning in terms of selecting optimum landing points.

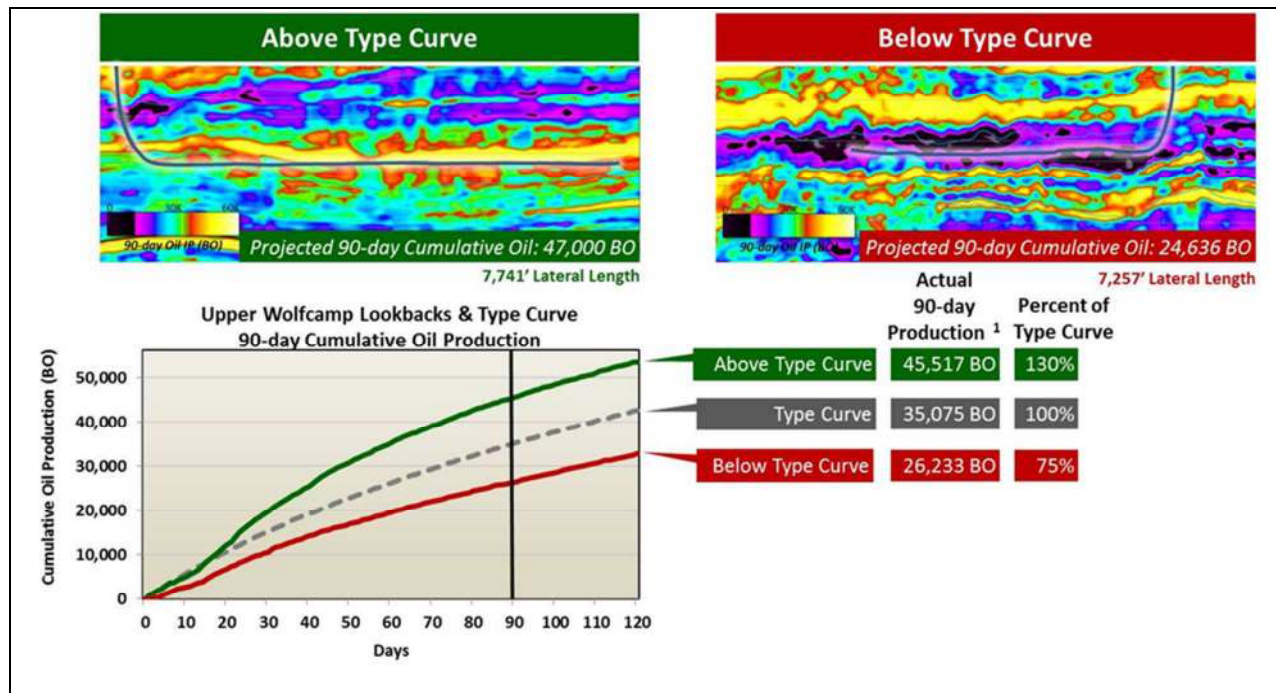


Figure 7: Example of 2 different wellbores landed in different zones within the 3D Production Attribute. The Above Type Curve example, demonstrates the wellbore being located mainly in higher values of the Production Attribute. Conversely, the Below Type Curve example shows the wellbore located in significantly lower values of the Production Attribute.

Model Validation Process

The primary Production Attribute validation comprises two steps. The first step involved recreating the Production Attribute at specific well locations using modern electric logs with dipole sonic data. This was accomplished via application of an iterative multivariate approach, in order to match an equivalent response derived from the Production Attribute. Figure 5 shows a series of right color-filled continuous logs which represent results of this proprietary in-house process. Overall a good match was observed with a 0.85 correlation coefficient with a population of over 30 wells. Initially, this technique excluded a number of the 3D attributes derived solely from the seismic inversion process, which were later extracted at the wellbore and combined to improve the correlation in instances when the logs alone did not provide sufficiently high quality correlations. This also demonstrates that no single factor alone is driving well production, but instead a combination of variables.

The second validation step represents a process of review of actual results versus prognostications from the Production Attribute response. Initial field test validation was performed against a population of blind test control wells (which we will refer to as validation wells), available for comparison soon after the development of the workflow. Importantly, while locations of these validation wells were within the Earth Model area of interest, landing points had not been optimized utilizing the Production Attribute, enabling a sufficient sampling of lower and higher Production Attribute values. Figure 8 displays the calibration well data set along with a subset of wells used to build the initial Production Attribute showing continuity with the model.

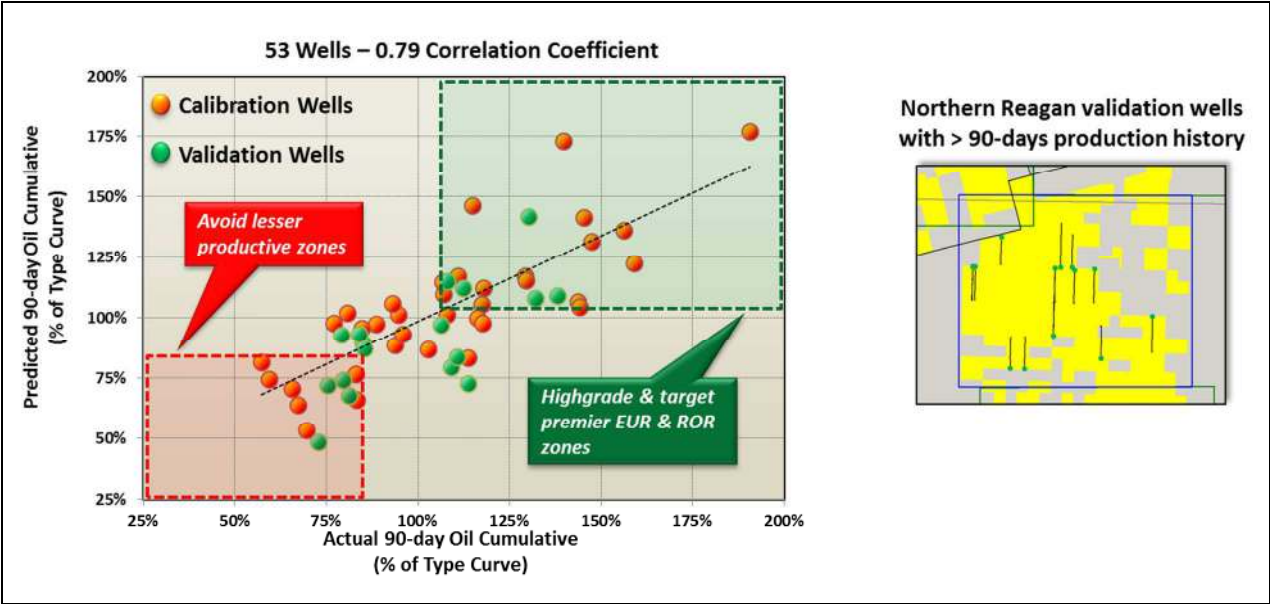


Figure 8: Earth Model cross-plot of actual production versus predicted production for calibration and blind test validation wells.

Over time, additional well results, recently acquired empirical data and new interpretations have revealed further complexities related to production drivers. The workflow adopted allows for new findings to be included.

Development Planning Workflow Evolution

Laredo’s Earth Model has been fully integrated into development planning and operational execution workflows. This allows efficient comparisons between development options with consideration of existing producing wells (both vertical and horizontal), along with mechanical frac barriers present within the stratigraphy.

Once a particular area of the field has been selected for development, a review of potential occurs across all zones to determine the vertical and spatial distribution of landing points. Highest 3-month and 6-month (if available) predicted production from various landing points are reviewed with values being entered into economic valuations. Given that different zones at different depths have variable drilling and completion considerations, the Earth Model results provide timely information for well planning purposes.

A simple example is shown in Figure 9, comparing two standalone wellbores separated by approximately ½ mile. The Standard Wellbore demonstrates an approach to select the landing point based on using logs alone. In this particular example, proximal dipole sonic logs were available pre-drill to assist in this decision process.

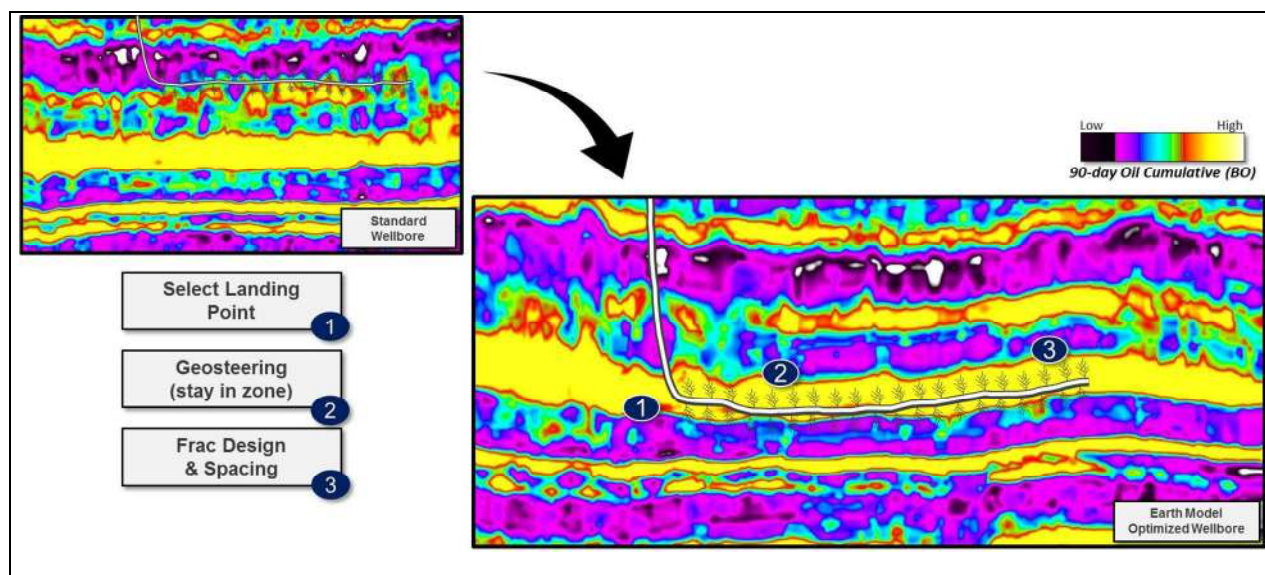


Figure 9: Example of Standard Wellbore and Earth Model optimized landing points shown with the Earth Model 3D Production Attribute.

Figure 10 shows these two landing points superimposed on a simplified dipole sonic log display. Without having the Production Attribute available, the high stock-tank original oil in place along associated with reasonable other rock properties (including clay content & frac gradient) strongly influence selecting the Standard Wellbore landing point. The Earth Model optimized landing point isn't necessarily obvious when interpreting log data alone. The additional attributes in the Earth Model workflow are key to revealing landing points with the highest potential, clearly indicated by the yellow colored zones of higher Production Attribute values (Figure 9).

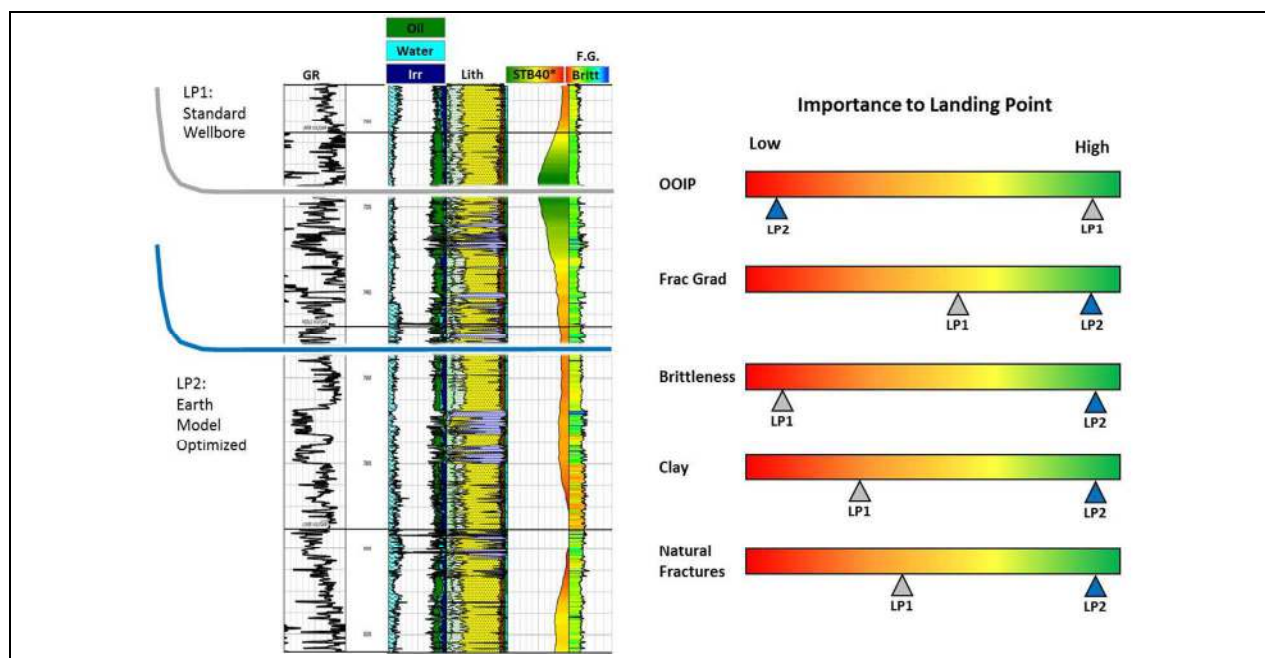


Figure 10: Standard Wellbore and Earth Model optimized landing points overlain on simplified dipole sonic log. The STB40 curve represents a 200' running window average of stock-tank original oil in place per 40 acres. Qualitative landing point considerations are shown with relative importance noted.

In this specific comparison, production results from the Earth Model optimized location far exceed those of the Standard Wellbore.

Results

Earth Model Including “More Sand” Completion Optimization

Over time, it was evident that including completion design variables and examining inter-wellbore distances both vertically and horizontally allowed for a higher degree of calibration. Since 2015, Laredo has been transitioning from a standardized slickwater frac design, to one that includes higher proppant concentrations and tighter spacing of perforation clusters. Figure 11 shows results from over 20 wells where completions with higher concentrations of sand (more sand) in combination with optimized landing points from the Earth Model, are demonstrating impressive early production behavior relative to published corporate type curves.

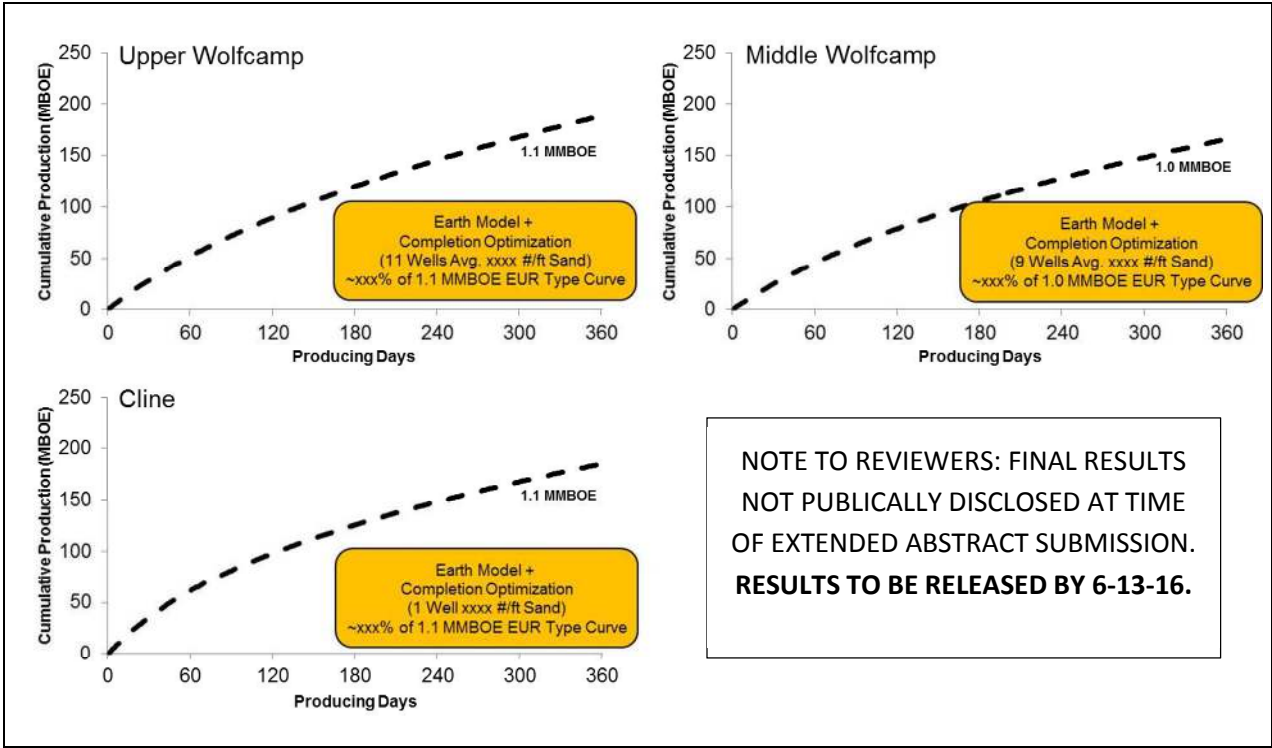


Figure 11: Production performance utilizing Earth Model in combination with “more sand” completions. Production Scaled to 10,000ft EUR Type Curve with non-producing days removed (for shut-ins). 1 well removed due to choke management schedule reducing early life production rate.

Engineering & Well Design Multivariate Statistics

The basic concept outlined thus far is one where engineering variables have been normalized during the multivariate workflow to model the changeability of reservoir quality, geomechanical and natural fracturing attributes. With growing successes endorsing multivariate analytics in the industry and with a high quality data base having been established, the opposite can be done. Geological variables were normalized using X & Y coordinates and gamma ray logs in order to model production behavior as a result of the variance of engineering and well design parameters.

A multivariate model was built for 6-month cumulative oil production with 97 wells including X-coordinate, Y-coordinate, wellbore completion length, toe-up/toe down factor (a derivative of average wellbore inclination), along with four other engineering input variables. This model resulted in a correlation coefficient of 0.8. Particular variables showed strong ranked correlation coefficients and were examined individually, with the remaining variables held at mean values and a Monte Carlo simulation run on variables of interest. When this was conducted on completed wellbore length, no distinct degradation is observable in increasing wellbore length from 7,500’ to 10,000’. Being able to recognize and understand this finding is critical in optimizing development. Furthermore, in

analyzing the toe-up/toe-down factor, a negative result is attained anytime the average wellbore inclination is essentially off the horizontal.

Rapid fact-based results can then be reviewed in a multidiscipline sense to determine appropriate actions. It is important to realize that multivariate analytics is essentially the first step in recognition of relationships. Considerable additional studies (not covered in this paper) based on scientific first principles can then ensue to examine and study the relationship in question. Results gained alone from multivariate statistics are not necessarily cause to immediately change the status quo.

Multivariate Analytics Practice and Pitfalls

While multivariate statistics are continuing to gain popularity in their usage to unlock complex relationships within tight oil unconventional plays, there are fundamental limitations that are intrinsically present in this approach.

Given this methodology is a statistical forecasting technique, both Type I and Type II errors are likely present within the 3D Production Attribute, which can be easily misinterpreted. In short, both zones of low and high potential illustrated by the Production Attribute can be misleading, particularly when testing new zones, or stepping out long distances from control points.

Early analysis of the multivariate relationship revealed a good correlation, yet there is still divergence from the absolute prediction. Furthermore, additional field-level influences can also affect lookback accuracy – therefore carefully acknowledging specific test wells and excluding those as necessary is an important step.

Conclusions

While operators of tight oil plays may seek a simplified “silver bullet” answer to what is fundamentally controlling production, the data, empirical observations and resultant interpretations suggest in this particular instance, that it is a combination of variables that matter.

Thus far, Laredo’s 3D Production Attribute has been implemented in planning and drilling 75 horizontals with a high correlation coefficient (Wicker *et. al.*, 2016).

Keeping an open mind is crucial when conducting this type of workflow, as additional variables continue to emerge with respect to importance as production drivers. These can be either primary or secondary in nature. Building and maintaining a data base that includes log, seismic, completion, production, well design and drilling variables is a crucial step to unlocking hidden production driver mechanisms. This requires a diligent and deliberate focus of manpower and project prioritization. Without this important step, the final results and understanding cannot be achieved.

Maintaining a healthy awareness of false positives and false negatives is a complementary step to any multivariate analysis. Step out from known data points with caution, recognizing the local spatial distribution of the original calibration data set. While new landing points may appear in profusion, fundamental physics-based geomechanical frac modeling in conjunction with the assessment of reservoir quality, are still integral to maximizing results.

Expect variance in the outcome of individual well results that are in line with the prediction accuracy from the multivariate analysis. Applying conventional variance analysis and probabilistic graphical techniques can assist in communicating the associated predicted limitations of this workflow (Wicker *et. al.*, 2016).

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Authors (Name all): James Courtier*, Joe Wicker, Travis Jeffers, Pat Curth., Laredo Petroleum Inc.

Author/Authorized Agent Name (Please Print): James Courtier


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