Multivariate Analytics of Seismic Inversion Products to Predict Horizontal Production in the Wolfcamp Formation of the Midland Basin

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Multivariate analytics of seismic inversion products to predict horizontal production in the Wolfcamp Formation of the Midland Basin

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Abstract

The Midland Basin Wolfcamp play is in the early stages of the development lifecycle, and provides a valuable opportunity to leverage production data from early delineation testing into a statistically valid model for predicting future horizontal production. In 2012 Laredo began testing methods of integrating geophysical, geological, petrophysical, completion, drilling, and production data to regionally high-grade drilling targets across their Permian Basin asset. Bi-variate analysis revealed that higher resolution multi-variate statistics were necessary in order to develop a local scale model that could forecast production. Utilizing multivariate statistical analytics on 82 seismic attributes (pre-stack, post-stack, and inversion), Laredo has created an "Earth Model" based on the combination of 5 seismic attributes in order to predict cumulative oil production volumes of horizontals at a set point in time. Historical well performance was then used for calibration. The model is normalized relative to completion length, completion testing, and spacing from the calibration data to understand the variations of the formation drivers on production.

The results of the model have undergone further refinement using microseismic, petrophysical, and empirical data, all of which ground truth the results to primary geological drivers of production. The model was confirmed utilizing a population of blind test wells which resulted in a correlation 0.85 of actual versus predicted cumulative 90-day oil production.

The goal of Laredo's Earth Model is to improve well performance by drilling high-potential landing points and maximizing lateral length in the most productive portions of the formation. This technique, based on high quality 3D seismic, can be utilized in any unconventional play where good sample sizes of production are available in order to high grade drilling inventories and improve individual well performance.

Introduction

Attempts in utilizing conventional mapping and high grading techniques on the Wolfcamp Shale of the Midland Basin have yielded regional graded areas that do not have the capability of delineating local variation that is sub scaled to the open hole log distribution. Due to the Wolfcamp Shale thickness requiring multiple landing points to fully develop the asset, the problem of ranking and high grading not only regional areas, but vertical development is paramount.

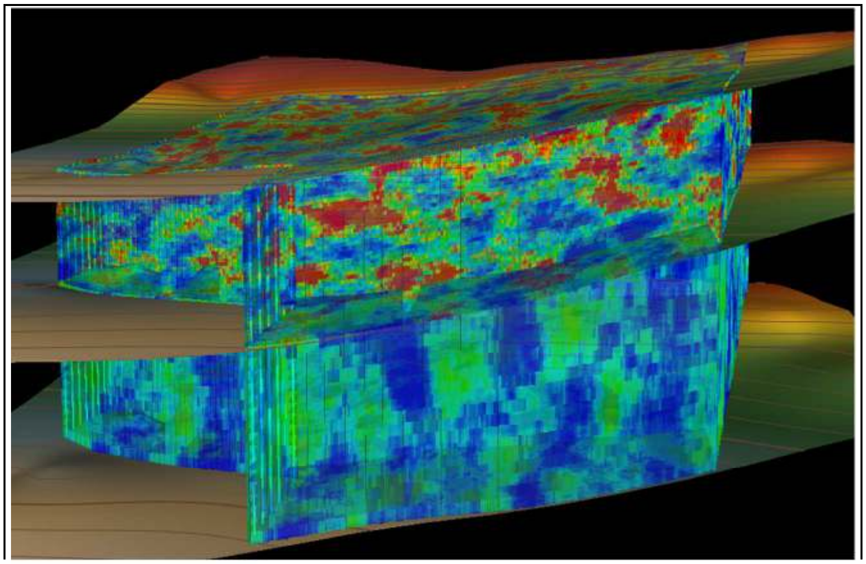


Figure 1: Example of Phase 1 geo-cellular model indicating lateral discontinuity in hydrocarbon pore volume and vertical dispersion that requires multiple lateral landing points to develop.

Laredo's entry into the Wolfcamp play began in 2011, and by the end of 2012 thirty-two horizontals were producing across the acreage position. The production results showed variations in production rate which could not be related to one known parameter. To understand the controlling factors on the variability in a laterally heterogeneous reservoir, Laredo's Phase 1 began with applying geocellular modeling to extrapolate petrophysical values in the subsurface more accurately (Figure 1) and, ultimately, to identify sweet spots within the acreage position (Figure 2).

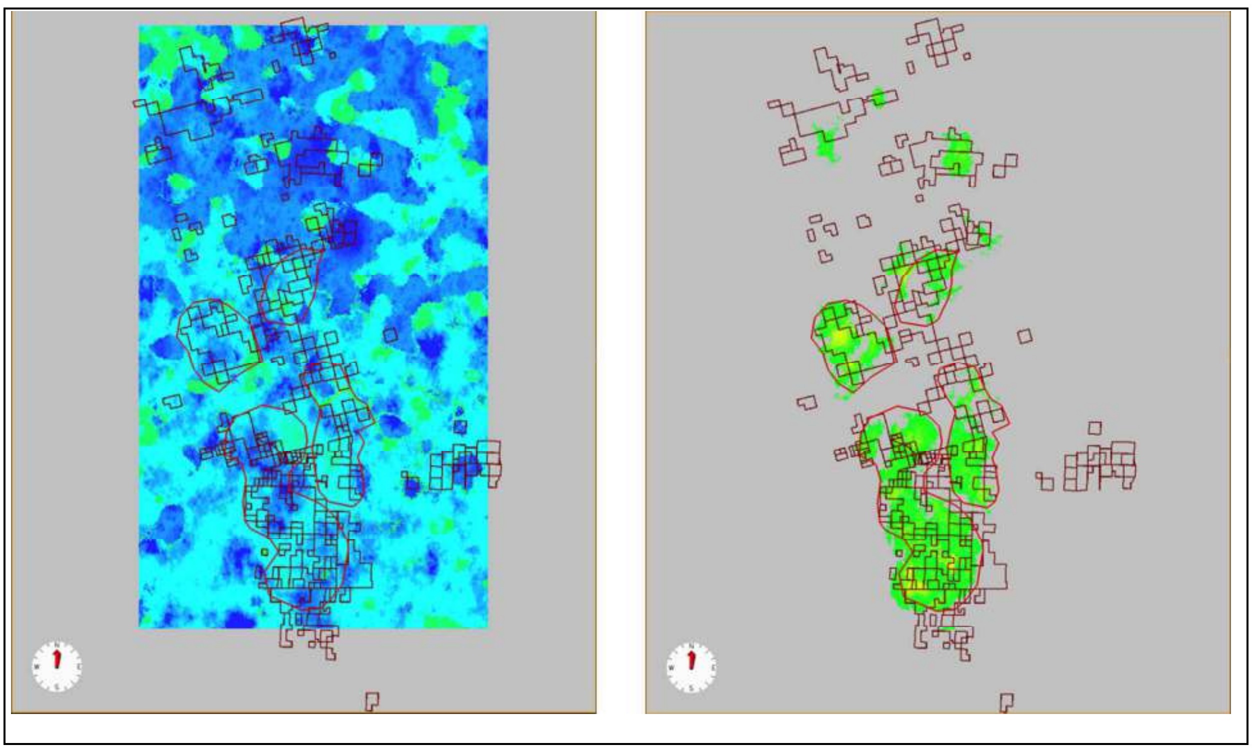


Figure 2: Example of Phase 1 regional grading based on hydrocarbon pore volume for a single landing point. Arbitrary cutoffs were used to high grade acreage.

Extractions of petrophysical variables along the length of the laterals were compared to the well performance utilizing bi-variate analysis. The correlation coefficients that were derived of 0.5 or lower showed weak relationships with lateral variability (Figure 3). This denoted that there was no single primary driver in well performance. It was quickly determined that grading multiple parameters based on arbitrary cut offs to predict areas of increased well performance would not yield an accurate result. A methodology would be required to statistically relate the combination of multiple parameters to well performance.

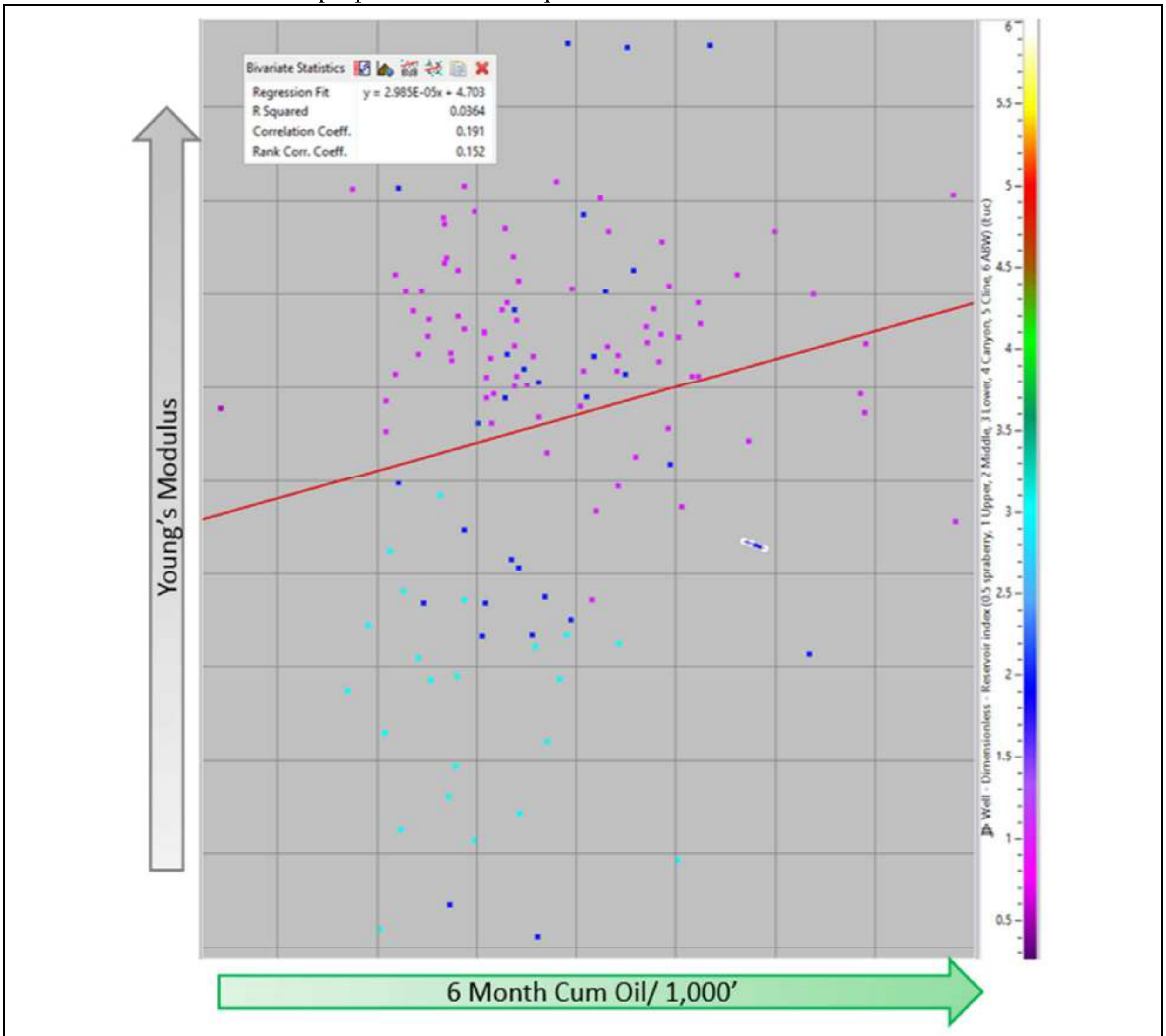


Figure 3: Example of Bi-variate cross plotting single variable against production metric. Bi-variate analysis yielded low correlation of any one variable to production.

A high density of core, seismic, and open hole logs, combined with an extensive aerial distribution of horizontal production, presented an ideal opportunity to implement the next round modeling, Phase II. Modeling utilized multivariate statistics to relate well performance to seismic inversion products based on petrophysical relationships that had been calibrated to core data. The integration and extrapolation of petrophysical responses in seismic inversion products is described by Young (2009).

Blind tested Phase 2 results

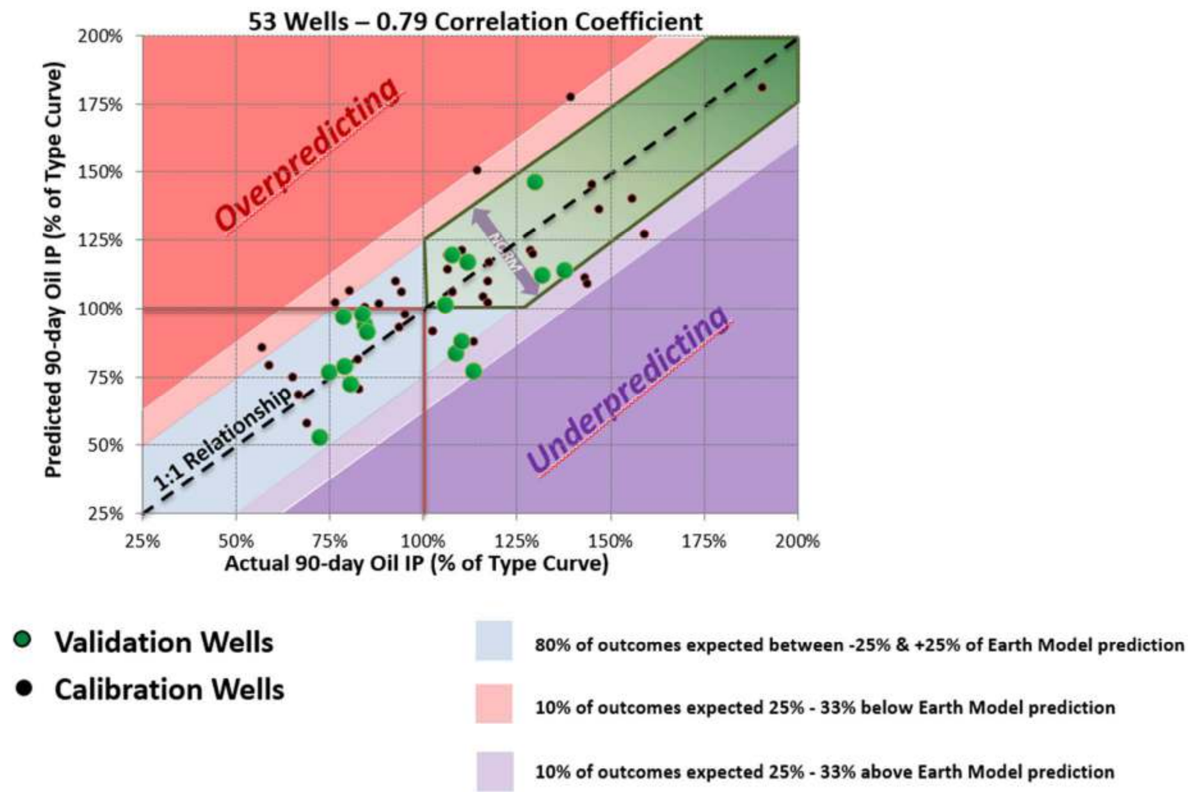


Figure 4: Validation of Earth Model with blind well performance.

The initial multi-variate model began with 21 horizontals that had 90-days of production. After normalizing the data to remove variation in completion type and operational issues, the model was developed with 17 horizontals. Fifty seismic attributes were utilized in comparison to production. The final product was a combination of 3 seismic attributes per model and the average of 5 models. Each of the 5 models had a mechanical factor (Young's modulus, MuRho), a structural or natural fracturing factor (Positive Curvature, Curvature Inclination, Maximum Curvature, Frac Factor) and an interval thickness variable (Spectral Decomposition). The correlation between the prediction and actual 90-day cum was 0.92. Additional information and description of Laredo's Phase I and Phase II process can be found in Curth**,** P.J. et. al., (2015).

The second iteration of the initial multi-variate model was done due to a significant increase in the amount of horizontals that had reached 90-days of production and represented additional control in all zones. The model included 41 horizontal wells and after normalizing for spacing, and completion impact, the model was created with 37 horizontals (19 Upper Wolfcamp, 11 Middle Wolfcamp, 4 Lower Wolfcamp, and 3 Cline). The number of seismic attribute products increased to 78. Through collinearity analysis and multi-variate statistics, 78 attributes decreased to 10 that were combined through 5 models of 4 to 5 attributes each. Each of the 5 models had a mechanical factor (Young's modulus, Shear velocity, Shear impedance), a saturation or lithology discriminator (porosity, resistivity), a structural or natural fracturing factor (Kpos, Kdip, Kmax, dip azimuth), and an interval thickness variable (Spectral Decomposition). The correlation coefficient of the prediction was 0.85. Blind wells tested the model's accuracy, this well set was referred to as the Validation well set. The resulting correlation was 0.79 (Figure 4). This volume was tested against production logs and single zone tests that showed the same directional relationships to the model response. Microseismic was plotted against the model and containment of events could be seen at areas of lower predicted production, and more events were seen in areas contacted by the intervals of higher expected production. The model was related back to rock parameters by extracting the prediction response at wells with petrophysical logs. Utilizing the petrophysical logs, a probabilistic relationship was developed to re-create the model's 90-day cum prediction as a log at any well.

Expansion multi-variate models were created in areas of significant well density utilizing the same workflow that was established in the initial model and subsequent models. The models were based on the same 88 sq. mile extents as previous models and had similar correlation coefficients. The benefit of the localized data sets was the mitigation of extrapolating predictions into untested areas and developing false positives. The limitations of localized models lie in the ability to create regional comparisons across the acreage position, and executing wells that transitioned between two models.

Regional multi-variate models were created by taking the pre-defined log probabilistic model and the seismic attribute model and relating the response to amplitude volumes to extrapolate the prediction across the merge data set. These models are referred to as Fast Track models. The Fast Track models have a correlation coefficient of 0.7 to the updated initial model. Since the model is based on parameters that control production in a localized 88 square mile area, the model is only used to compare acreage, potential production performance, and targets regionally.

Through multiple rounds of updates and expansions (Figure 5), the Earth Model now covers the majority of Laredo's acreage and utilizes 228 wells for calibration in a contiguous model that has 3 distinct sub-models based on stratigraphic intervals. The models are developed using 82 attribute products and the final models are a combination of 3 engineering based variables and up to 6 seismic products. To date, the Earth Model has been implemented in planning and drilling 75 horizontals with a correlation coefficient of 0.74 between predicted and actual production. The average accuracy for all wells that have used the Earth Model is 100%.

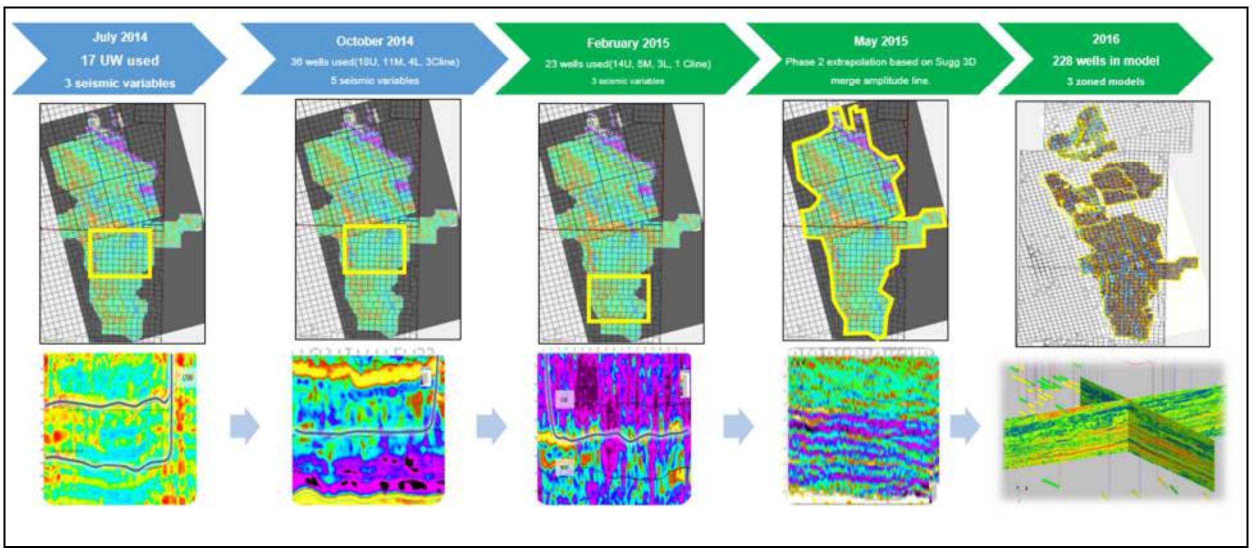


Figure 5: Progression of Earth Model during course of project to gain additional control and aerial coverage.

In addition to planning wells, the Earth Model prediction has been used to normalize the geological variation between lanes to better understand the impact of well spacing and completion design. This type of evaluation has assisted Laredo in developing a completion strategy of higher sand concentration. Further information on impacts of the Earth Model are outlined by Courtier et. al. (2016).

Earth Model creation methodology

The methodology described below has been refined through the course of iterations of the model development. The model workflow is illustrated in Figure 6. Initial requirement for model creation is depth-converted seismic volumes to accurately extract seismic variables. The utilization of all synthetic well ties in addition to all available well control helps to ensure minimum variation when relating petrophysical properties to seismic for the creation of post- and pre-stack attributes.

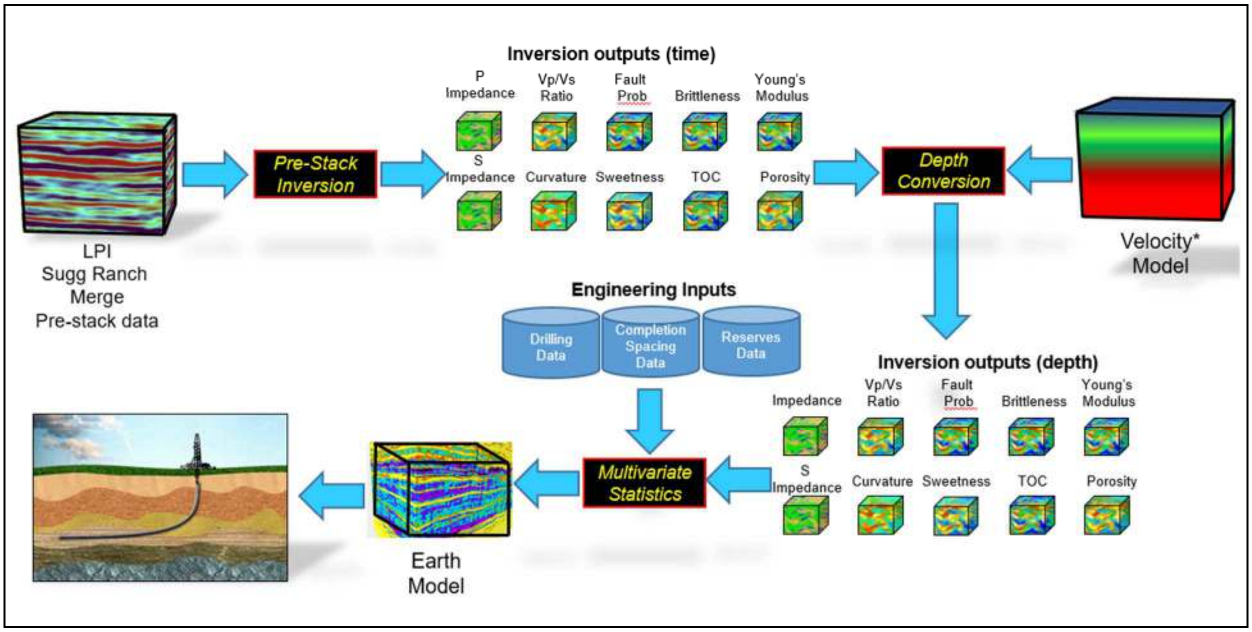


Figure 6: Workflow for creation of earth model.

First, seismic variables are sampled along the completed length of the lateral at multiple widths to assess the impact of radius size on the average seismic response at each lateral. Several tests determined that the amount of variation decreased at a sample radius of 80'. The seismic inversion product is averaged to a single response for the length of the lateral which can then be brought into analytics.

The response variables used to compare well performance are 90 and 180-day cumulative oil production with non-production time removed. The start time of the calculation is standardized to the first day of oil production during flow back. Horizontal wells are divided into groups that are in similar lithological and stratigraphic intervals so that parameters controlling well performance in one zone are not extrapolated to zones of differing deposition or sourcing. The current methodology in place separates the vertical interval into three distinct units.

Engineering variables are brought into the analytics in order to normalize well design parameters from geological contributions. Among these variables are completion length, proppant volume, stage spacing, acid volume, timing of artificial lift, well inclination, and azimuthal variation of the wellbore. Each variable is summed or averaged for the entire completed portion of the wellbore.

The primary multi-variate model was ran using engineering-only based variables in order to identify dominant controllers of production that will be brought into the seismic-based multivariate models. Engineering parameters identified as dominant controllers were lateral length, total proppant volume, and proppant concentration as shown (Figure 7).

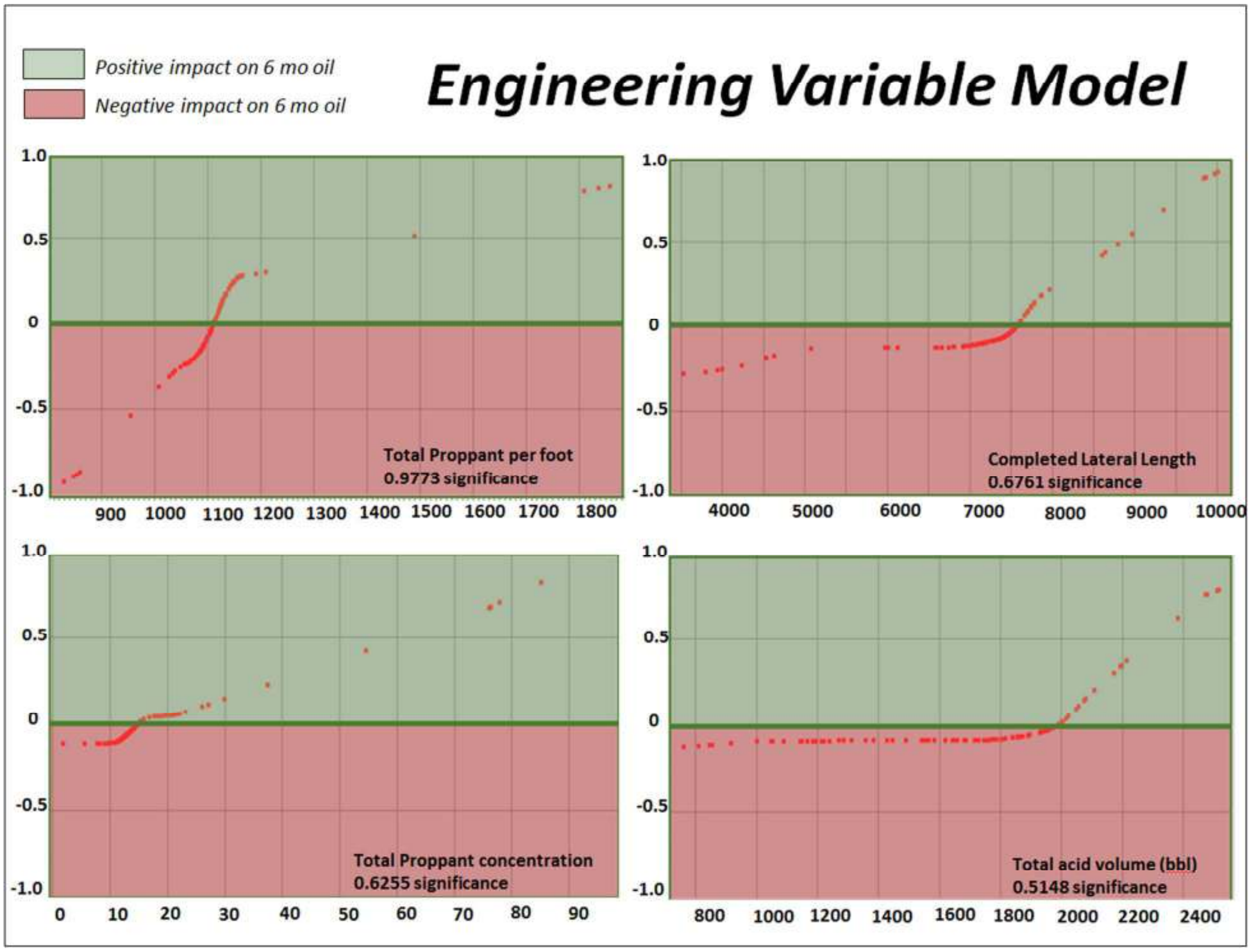


Figure 7: Engineering variable model, showing that lateral length and proppant volume as the primary drivers needed in the final modeling.

All variables are tested through multi-collinearity to remove any redundancy as well as to ensure that independent variables are tested in modeling. Variables that are correlated to direct measurements of fractures, lithologies, thickness, or mechanical properties are forced to be retained over ambiguous variables.

Variables are combined utilizing non-linear regression methodology and initially checked with N-fold validation. The number of variables per model are limited to a maximum of 1 variable per 10 horizontals in the control set. This ensures that the data is not over fit. Multiple models are created for each interval and those with the highest correlation are combined to produce a 3-D SEG-Y volume showing the predicted attribute. Engineering variables are held at the current completion and spacing parameters for the model's end result.

The validation process begins by extracting the model at vertical wells containing a significant amount of data to relate the prediction of well performance to known log responses (Figure 8). Wells with production information that didn't have all the parameters used in the calibration are utilized as blind wells. Current blind well tests must fall within one standard deviation of the prediction in order for the model to be considered valid. Model responses are qualitatively compared to single zone tests and production logs to ensure that the model is showing the same lateral variability as all direct measurements. Microseismic is compared to understand frac buffers and identify potential containment between zones.

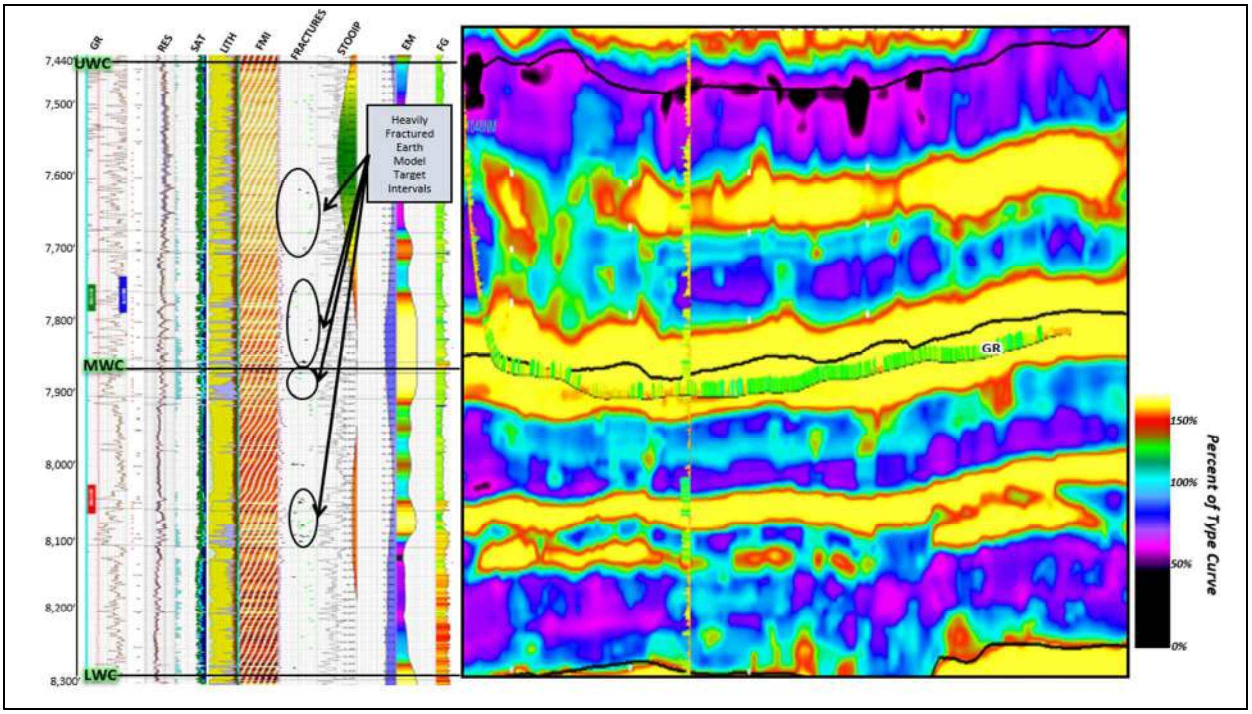
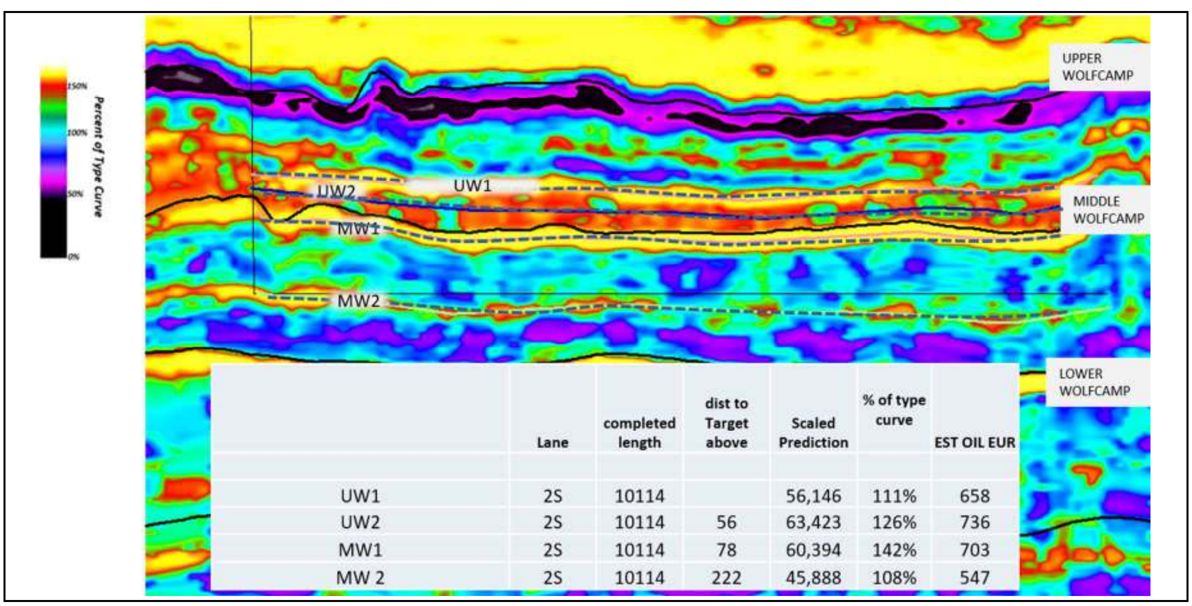


Figure 8: Validation of Earth Model by relating response to petrophysical and fracture measurements. Log (FRACTURES) are interpreted FMI fracture sets, and log (EM) is the petrophysical re-creation of the Earth Model response.

Location grading and well planning

Regional variation in the quality of targets can be viewed by looking at the average magnitude response of the defined intervals of interest to develop high graded regional areas. To provide insight of an economic impact with variation in landing point or lane selections, extractions are run for each landing point in each lane in order to grade the relative production for each target (Figure 9). The relative production output can then be scaled to show the impact of target selection on full development based on the current spacing assumption. Extractions can be scaled to the correct lateral length, completion volumes, and current spacing to formulate an estimate of oil production in 180 days which in turn can be incorporated into economic analysis.



	Lane	completed length	dist to Target above	Scaled Prediction	% of type curve	EST OIL EUR
UW1	2S	10114		56,146	111%	658
UW2	2S	10114	56	63,423	126%	736
MW1	2S	10114	78	60,394	142%	703
MW 2	2S	10114	222	45,888	108%	547

Figure 9: Ranking of lateral landing points in a single lane to high grade development.

To implement the proposed well path, a pseudo-directional survey is created based on the highest prediction target in the volume. A quality check is performed to ensure depth accuracy of the model to the offset petrophysical response along the well path, which is then sent to directional planning to produce a drillable well plan.

Future model improvements

The complexity of the data set, refinement of the inputs, and constant inclusion of new data demonstrates how the Earth Model is an iterative and dynamic process. A number of primary short term goals have been identified to improve the utility of the model and include:

- Seismic reprocessing improvements may provide more accurate imaging of events for depth conversion.
- Attempting to sample seismic attributes to stage intervals and perform analytics by stage.
- Improvement of petrophysical models that better correlate directly to impedance and amplitude volumes.
- Incorporation of petrophysical values extrapolated using seismic variables to give more transparency to model inputs.
- Utilization of public data to blind test model performance outside of core areas.

Conclusions

Utilization of seismic responses based upon relationships to rock properties can provide a tool to reasonably estimate horizontal well performance in unconventional plays. Laredo has developed models based on mechanical properties, natural fractures, saturations, and interval thickness to extrapolate well performance across our Midland Basin acreage position. This methodology can provide insight to economic evaluation and impact well performance by placing and steering wells in the higher potential zones.

The multivariate approach provides a methodology to condense large dynamic data sets into a form that can be interpreted and utilized to delineate the relative impacts of variables on production.

Acknowledgements

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