Earth model assists Permian asset valuation

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Laredo Petroleum Inc.’s Permian-Garden City asset is an unconventional resource play with more than four potential stacked zones covering a 1,700 square-mile fairway in five counties in the Midland basin, Texas. Early in the play’s evolution, Tulsa-based Laredo recognized the need to develop a proprietary database along with a process to characterize each targeted reservoir.

This article describes a multi-domain model that Laredo, assisted by Halliburton Co., used to define the potential for the Permian-Garden City acreage. The model represents an integrated workflow combining geoscience and engineering data with multivariate statistics.

The process began with acquisition of high-quality data including 3D seismic, microseismic, cores, well completion and production histories, and petrophysical information. The data were then analyzed, processed, and incorporated into a predictive three-dimensional (3D) model. The result, demonstrated here, is a tool used in the planning of development wells to optimize initial production rates and estimated ultimate reserves and yield a better understanding of the complexities of a multi-zone stacked resource.

Midland basin
Conventional production began in the Permian basin in the 1920s and now covers more than 86,000 square miles in West Texas and southeast New Mexico. Fig. 1 presents the geologic architecture of the basin, showing the subdivision into the Delaware and Midland basins by the Central basin platform. Laredo Petroleum’s acreage in the eastern half of the Midland basin is highlighted in red.

Conventional production in the Permian comes from several horizons ranging in age from Permian down to Ordovician. Beginning in 2008, Laredo Petroleum targeted the more basinal source rock and tight carbonate reservoirs of the Wolfcamp and Cline formations, using horizontal drilling and hydraulic fracturing. Fig. 2 illustrates the Midland basin’s multi-stacked horizontal targets available for development.

Garden City
Laredo has developed extensive acreage on the east side of the Midland basin with interest in more than 350 sections representing 178,000 gross and 148,000 net acres with most concentrated in Glasscock and Reagan counties. Producing intervals to date include the vertical Wolfberry interval and the horizontal Wolfcamp shale (Upper, Middle, Lower), the Cline shale, and Canyon formations. Additional horizontal targets include the shallower Spraberry, the Strawn, and the deeper Atoka-Bend-Woodford (ABW) zones.

With an average combined thickness of more than 5,000 vertical ft for all of the targeted zones, the Midland basin is unique among US shale plays.

Early success with horizontal wells in both the Wolfcamp and Cline intervals encouraged Laredo Petroleum to build a large technical database from which to pursue early efforts to increase production and execute a full drilling program. All the targeted zones have flowed oil to the surface from offsetting vertical wells, but horizontal drilling and hydraulic fracturing have made these objectives economically viable.

Keeping in mind the goal of having an economic program that took advantage of what each stacked horizontal target had to offer, Laredo Petroleum understood that the number of horizontal wells to be drilled, the capital commitment it would take, and the associated operational considerations made integrated development planning mandatory.

Earth-model program
Laredo Petroleum invested in extensive data capture over its entire Garden City asset that included geophysical (3D seismic, gravity and magnetic data, and microseismic surveys), logs (conventional openhole and dipole), cores (whole and sidewall), and well testing data (single zone...
and production tests). A key element of the Laredo Petroleum–Halliburton partnership is integrating these data into a 3D geologic earth model, then using it to support decisions about well spacing, lateral length, and hydraulic fracturing design.

The program has two phases:

- Phase 1 focuses on the initial coarser scale assessment of the overall Garden City area.
- Phase 2 focuses on a detailed pilot area identified in the first phase.

The goal is ultimately to drill the best wells, as soon as possible, and determine the most efficient ways to accelerate that drilling for maximum net present value.

**EM: Phase 1**

The first phase confirmed previous work by Laredo Petroleum, focusing on the Wolfcamp and Cline formations in the Midland basin through attribute modeling of well and petrophysical data and using the extensive 3D seismic data Laredo Petroleum had acquired over Garden City.

Results from Phase 1 also provided insights into well spacing and prioritization of leases based on subsurface modeling and dynamic simulations including integration of microseismic, petrophysics and core data, production and history matching with dynamic simulation of producing wells, and geomechanical properties and fracture modeling.

One of Laredo Petroleum’s goals in Phase 1 was to obtain an overview of the rock property heterogeneity in each Wolfcamp and Cline zone over much of the asset. This process identified potential “sweet spots” based on such static-model indicators as hydrocarbon pore volume (HCPV) and geomechanical properties.

But a lack of production history over the acreage base made direct correlations to potentially indicative rock properties difficult. Laredo Petroleum and Halliburton recognized the need for a specific pilot program in which better production data were available.
Laredo Petroleum had accumulated indicated their properties had large resource potential, but further refinement of the earth model was needed to achieve early sequencing of drilling the highest potential acreage first and establishing the basis for the lowest cost-per-barrel unconventional development of the Garden City asset.

EM: Phase 2

The second phase focused on a specific planning area (Fig. 4), which has served as the primary pilot area for expanding the scope of the earth model and statistically tying the results to actual well production.

Phase 2’s focus has also been to provide a higher resolution understanding of such reservoir attributes as brittleness, total organic carbon, and HCPV based on actual well data and newly acquired and reprocessed full-wide azimuth seismic data. We analyzed more than 80 seismic, petrophysical, and engineering attributes to gain insight into those that would highlight the most productive intervals within each formation. Fig. 5 shows the general workflow for the earth-model process.

A key feature of Phase 2 was to add production data and history for dynamic reservoir simulation and add detail to the static model listed above. The goal was to correlate the patterns discerned from the static data with actual productivity results and to use multivariate statistics to help develop a predictive model. Shale resource plays are characterized by a wide variety of petrophysical properties both well and seismically derived. Robust multivariate statistics indicate which properties affect production, inclusion of many of which did not at first seem intuitive. Fig. 5 shows the general inputs.

Dynamic reservoir simulations then provide further understanding of reservoir performance and then these history-matched dynamic models refine both horizontal and vertical spacing in a multi-stacked, target-rich environment. The heterogeneity of the producing rocks from all the prospective Wolfcamp and Cline intervals is better understood by use of the earth model and allows Laredo Petroleum’s development program to be based on lower drilling and operating costs.

Laredo Petroleum used the fully integrated earth model developed in Phase 2 both in identifying overall “sweet spots” (both vertically and horizontally) and in picking landing points and geosteering the horizontal laterals. As Fig. 6 illustrates, the model, now tuned to integrate static properties and production results, is used to improve lateral placement within a given reservoir and the corresponding to validate results. Fig. 3 illustrates an example of the variation in HCPV for one Wolfcamp interval.

Results from Phase 1 highlighted how the earth model process could assist in well planning to build potential field development scenarios and estimate corresponding budget requirements. All the data
ideal landing point. The model then guides real-time geosteering, ensuring that the well maximizes contact with the most productive reservoir areas as opposed to more common industry practice of landing the well without steering and hoping hydraulic fracturing will touch enough productive reservoir rock to generate sufficient production.

A detailed understanding of both static and dynamic properties allows the well and stimulation designs to be refined. Halliburton’s Cypher engineering tools and workflow modelled and matched the existing horizontal wells to actual production history.

Improved fracture design is currently under way. The
of productivity compared with actual data from existing pre-earth model wells. To date, the model has been compared with actual results in more than 30 horizontal wells with an average correlation coefficient for the four Wolfcamp and Cline intervals of 0.85 (Fig. 7). A 90-day initial production volume from a specific lateral in an existing horizontal well is used to reduce variations in rate and flow back. Comparisons are then made between the actual 90-day production and the model’s prediction for the same lateral placement in the integrated model.

Fig. 8 shows this comparison for an 8,000-ft lateral in the Upper Wolfcamp. The predicted higher productivity zones are highlighted in the brighter (yellow) colors and predicted lower values in the darker colors. In this case, the well is placed in what would be considered a good zone and the volume predictions match well with the actual data.

Given this validation, a logical extension is to evaluate an existing low-performing well bore to see if the model matches actual volumes. It can then be examined for more productive zones in the same vertical drilling lane as potential future in-fill candidates.

As Fig. 9 shows, the test was an early pre-earth model horizontal well in the Lower Wolfcamp with actual production that is about half the average producer. This is consistent with what the model would have predicted, but in the same section are several zones that potentially would be higher in productivity based on the earth model, improving both estimated ultimate reserves and rate of return.

Given the stacked unconventional pays in the Midland basin, there is the potential for considerable production and cash flow acceleration by developing the entire column simultaneously. This requires an approach, however, that enables optimal lateral placement and design of the stimulation program so that fracturing in individual intervals does not interfere with those under and overlying.

Laredo Petroleum has chosen to characterize the Permian–Garden City asset with an earth model that will ultimately reduce uncertainty in production rates and estimated tools include a fracture simulator to assist understanding of the effect of complex fracture growth, integrated with a new compositional reservoir simulator capable of modeling and further defining the fracture patterns associated with successful resource plays.

**Comparison with 30 wells**

Evaluating the integrated model begins with its predictions

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**Production Correlation**

![Production Correlation Graph](image)

*90-day oil production.

**Upper Wolfcamp: Higher Productivity Zone**

![Upper Wolfcamp Graph](image)

**Comparison**

<table>
<thead>
<tr>
<th></th>
<th>Actual results</th>
<th>Model prediction</th>
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</thead>
<tbody>
<tr>
<td>90-day initial production</td>
<td>46,302</td>
<td>45,985</td>
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ultimate reserves. The science of unconventional shale plays requires that an operator understand that variation in productivity is driven by complex variations in lithology and rock properties. The building blocks of a successful earth model are a strong acquisition program, use of modern modeling technologies, and a well-defined workflow that receives input from multiple disciplines.

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