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3-D Modeling Optimizes Well Placement

By Doug Gilmour

HOUSTON–The challenge of producing hydrocarbons economically from increasingly complex unconventional reservoirs is driving the need for well path and engineering design optimization at every stage of the planning and drilling process.

Just as designing wells in a 3-D structural model or interpreted seismic volume can shorten well planning cycle times, improve well placement and reduce drilling risk, the ability to interactively update those 3-D models, based on real-time logging-while-drilling responses, enables rapid replanning and re-engineering while continuing to drill ahead. This approach can optimize well placement and maximize production.

Integrated software technology has been developed and successfully applied to horizontal drilling projects both on- and offshore, including unconventional plays in North America to provide real-time stratigraphic positioning of horizontal well bores during drilling. A key to the effectiveness of this solution is using integrated, multidisciplinary tools operating on a shared data management and interoperability framework, allowing experts from drilling, geology, petrophysics and geophysics to work concurrently and share data.

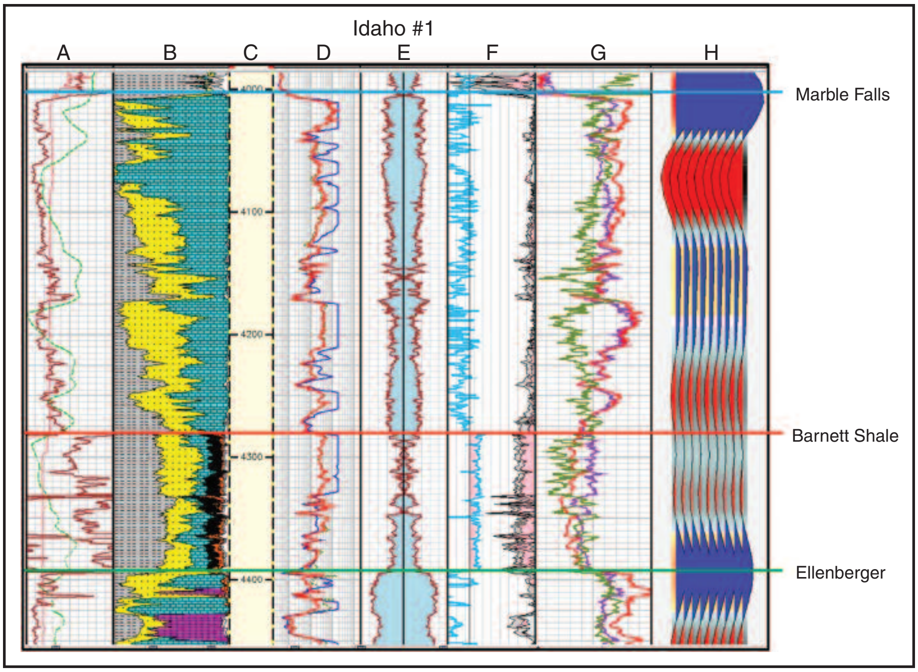
Using a geosteering solution, in combination with a unified well planning and drilling engineering application, delivers a workflow that supports the rapid creation of log scale geosteering models ahead of drilling, facilitates interactive updates to geosteering models while drilling, and enables efficient replanning of wells within the updated geologic model.

Where real-time data feeds are available from the rig site, this work can be conducted in a real-time operations center, enabling an expert multidisciplinary team to evaluate operational decisions.

This technology was applied in a horizontal drilling project in a geologically challenging area in the Barnett Shale play in the Fort Worth Basin, where extensive geologic modeling was conducted prior to planning and drilling a new multiwell pad.

FIGURE 1

Petrophysical Analysis of Marble Falls, Barnett Shale and Ellenberger Formations



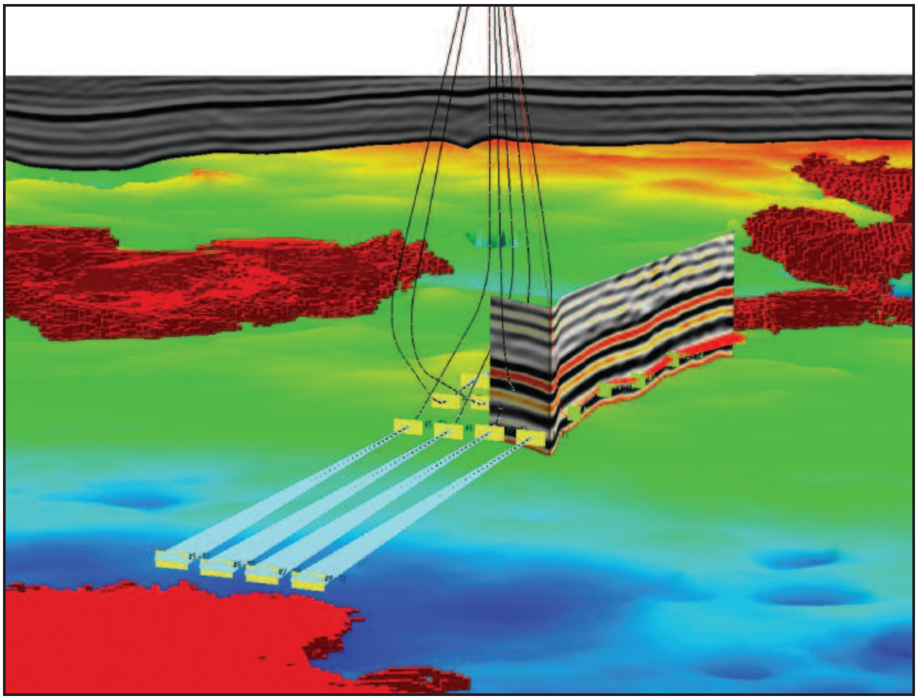
Integrated Geologic Model

Prior to well planning and drilling operations, an integrated geologic model was created, based on specialized petrophysical analysis of a nearby vertical well, detailed horizon mapping, seismic trace shape classifications, geobody extractions and 3-D structural attributes. This determined both an optimal interval within the Barnett Shale and the most prospective geographic area to explore.

The porosity, gas volume and kerogen content of the Barnett Shale were deter-

FIGURE 2

Comprehensive Well Planning and Engineering within Interpretation Environment



mined using a combination of a modified Passey method and the principles of optimizing petrophysics. These results (Figure 1) were confirmed with whole core analysis. The results of the analysis indicated that the entire Barnett interval had fairly consistent gas volume, kerogen content and porosity. However, an analysis of the rock characteristics indicated that the upper portion of the Barnett was more brittle and had a lower closure stress, making this zone more amenable to fracture stimulation and the most appropriate interval for placing horizontal wells.

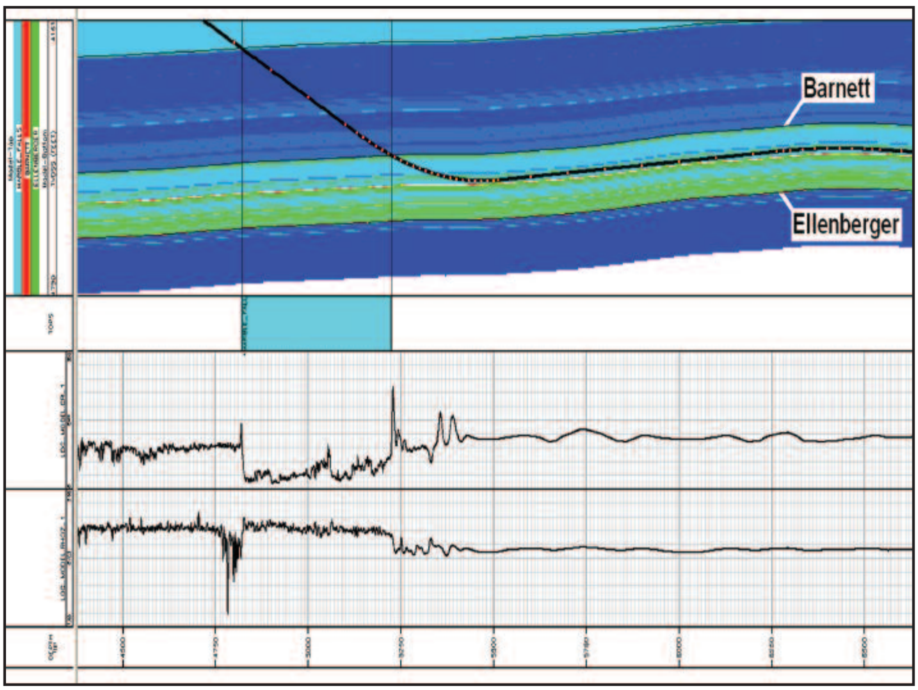
The Marble Falls and Ellenberger formations were accurately mapped using both wave form tracking algorithms and manual interpretation methods, revealing major fault systems and karst regions that must be avoided to reduce the risk of communication between the water-saturated Ellenberger and the Barnett Shale. Prospective unfaulted areas were identified. Since the top of the Barnett provides a very weak seismic reflection, it was mapped by converting a proportional slice between the well-defined Marble Falls and Ellenberger horizons.

The seismic wave shape varies throughout the Barnett interval and was evaluated using neural network technology to identify 11 facies classifications. The facies classification for the prospective unstructured zone proved relatively continuous, suggesting a geologically consistent Barnett interval in that area.

Both fault azimuth and fault-enhanced attribute volumes were generated from coherence data to allow detailed interpretation of faults and karst bodies. Karst chimneys extracted from the fault-enhanced data as multiple Z-value geobodies often exhibited intersecting fault planes that propagated beyond the karst geobody limit, extending the area of permeability risk. Integrating maps, faults and karsts identified areas to be avoided as well as an optimal prospective drilling area.

FIGURE 3

Predrill Model with Anticipated Log Responses And Structure along Well Path



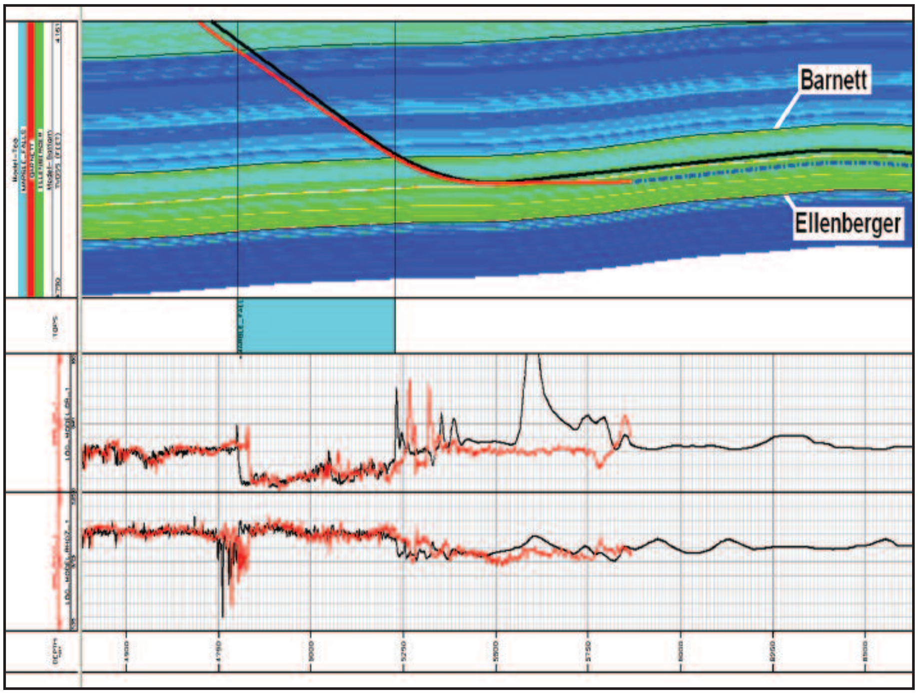
Well Planning And Modeling

The 3-D structural model, defined in industry-standard file formats, can be loaded to the well planning and engineering application to allow well design within the context of a detailed structural representation of the subsurface. Alternatively, the same well planning and engineering application may be linked directly with the interpretation application to support a fully collaborative planning operation involving drillers and geoscientists.

The ability to conduct comprehensive well design within a volume-based interpretation environment allows full geologic validation of the well bore at every stage of the design process (Figure 2). For optimized well bore placement, all known geologic factors and their relative influence on the well should be considered.

FIGURE 4

LWD Data versus Predicted Log Responses in Updated Model



In the Barnett example, the key considerations were orienting the planned wells in a perpendicular manner to the local northeast-to-southwest stress field to assist with planned hydraulic fracturing operations, avoiding the multiple karst intrusions in the area, and achieving accurate stratigraphic placement of the well within the particular zone in the upper Barnett, where rock properties indicated an optimal interval for frac stimulation. Other fundamental trajectory constraints such as lease boundaries and proximity to offset well bores were explicitly addressed as part of the planning phase.

The delivery of all well planning and engineering functions within a single integrated application allows rapid validation and optimization of the proposed trajectory from the perspective of critical engineering concerns, including torque and drag, hydraulics, cementing, and casing design. These different analyses can be run concurrently on a common well bore and provide the means to quickly identify, understand and resolve any engineering issues.

The ability to quickly retrieve previously defined items from a catalog such as drill strings, casing strings, rig parameters and drilling fluids contributes to workflow efficiency. In the Barnett Shale example, the primary engineering considerations for the wells related to avoiding buckling in both drilling and casing operations.

The 3-D structural model and the final proposed well path are shared with the geosteering application. By combining the structural framework along the well path with representative log signatures obtained from one or more offset wells that penetrate the formations of interest, it is possible to perform forward modeling in the true stratigraphic thickness domain. This produces a detailed predrill model of predicted log responses for the planned well.

The predrill model typically incorporates a curtain display of the structure along the planned well path and one or more log tracks to display the predicted log(s) associated with that path. The application supports the modeling of tools regardless of the chosen contractor. If required, synthetic image logs can be generated. It is also possible to display the full property map for any modeled log property within the curtain display (Figure 3).

The predrill log property model provides the backdrop against which new information is displayed as it is received during the drilling operation. For the Barnett Shale project, the gamma log provided distinct signatures for the top and base of the target zone within the upper Barnett and was used as the primary geosteering log property.

Real-Time Geosteering

As drilling progresses, it is essential to incorporate new data into the model as timely as possible. Historically, these data have come in the form of individual files from the contractor or through a proprietary real-time data source. Today, where available, Wellsite Information Transfer Markup Language (WITS-ML) provides an open standard format for real-time data transmission that can be automatically streamed into both the engineering and geosteering applications using a real-time data acquisition utility.

By dispensing with the previous practice of manually loading individual files, this automated approach allows faster access to the latest data and reduces the chance of data loading errors. As data become available, the latest position of the actual well is updated in the curtain display and compared with the planned well. Similarly, actual LWD log responses are updated in the log tracks and compared with the predicted logs (Figure 4).

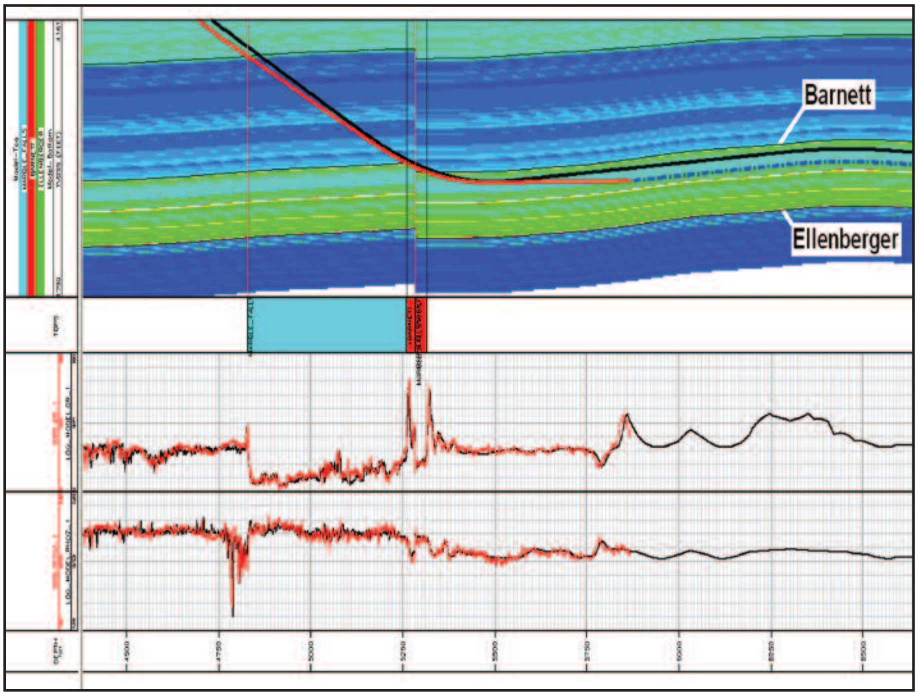
Differences between the predicted and actual logs signal changes in geology and indicate that the model needs to be updated. Updates are achieved through interactive editing of the structure so that modeled logs are correlated with the actual logs. This process allows the geosteering engineer to determine the stratigraphic position of the well bore within the reservoir and gain an understanding of the likely structural trend ahead of the bit. Gaining this knowledge in a timely manner can be crucial to making the necessary drilling decisions to correctly land the well and stay in the desired zone.

Discrepancies between the predrill model and actual drilling results can arise from a number of sources. Using knowledge of the reservoir, it is possible to reconcile such differences and incorporate this information into the existing model.

In some cases, the original structural framework may be off depth, while in others, the log character may be different from what was expected. By interactively editing the predrill model, the geosteering engineer can reconcile differences between predicted and actual responses. The user has the ability to interactively alter the dip of a given formation, alter its thickness, or insert a fault to see instantly how these edits impact the modeled log responses. Additionally, geologic constraints regarding the conformability of surfaces from the initial model will be honored during editing

FIGURE 5

Repeat Sequence in Log Response Identifies Sub-Seismic Fault



operations. Undesirable edits can be removed easily and an alternative edit made.

There are often several possible interpretations of the types of situation encountered while geosteering. This solution provides the user with sufficiently flexible tools to examine several "what if" scenarios before making any decisions.

In the Barnett Shale project, correlation revealed that the overall structural framework was generally deeper than anticipated and indicated the presence of a previously undetected sub-seismic scale fault with a throw of approximately 20 feet (Figure 5). Through model updating, it became clear that the actual well bore–although deeper than the plan–remained approximately five feet higher than desired stratigraphically, requiring trajectory adjustment.

In parallel to the geosteering process, the driller can use the engineering application to monitor drilling progress against plan, calibrate friction factors, and project ahead from the real-time bit position to ensure that the well remains drillable from mechanical and hydraulic perspectives, and that the casing or completion string can be installed. Clearance analysis can be performed at any time to ensure that the well will not collide with any existing wells in the area.

Well Replanning

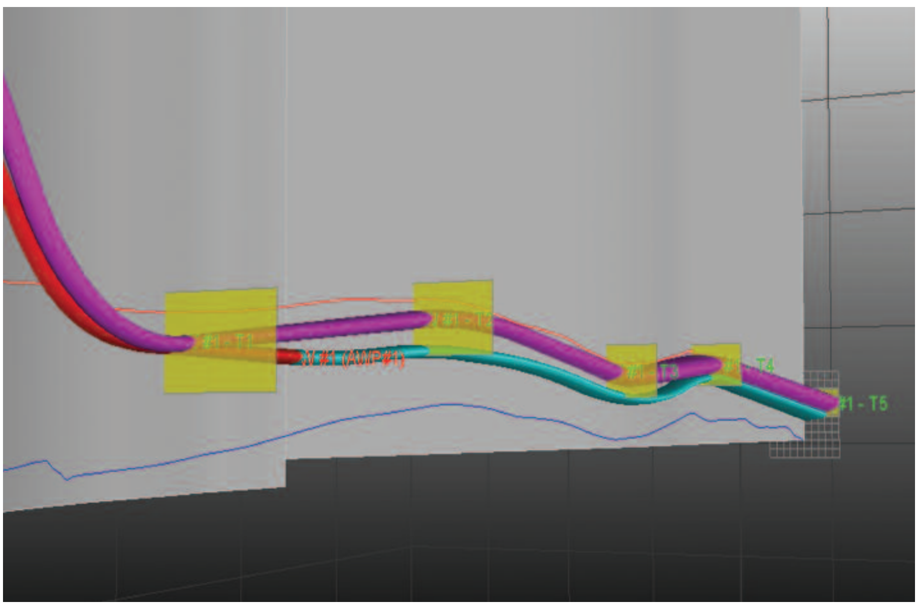
In cases where geosteering model updates result in significant true vertical depth adjustments, the updated 3-D structure can be used by the engineering application to replan the well based on the most up-to-date geosteering interpretation, allowing stratigraphic recovery of well bore positioning (Figure 6). In cases where high doglegs are required to land the well, engineering analysis can quickly determine if the proposed trajectory is drillable.

Once validated from an engineering perspective, the replan becomes the new reference plan within the geosteering application and correlation continues as drilling proceeds. If necessary, a sidetrack can be planned and the geosteering process repeated for the planned sidetrack.

The ability to update the model while drilling is not only key to achieving optimal well bore placement for the

FIGURE 6

Well Replanning within Updated Structural Model while Drilling



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current well, but it also provides a means of anticipating the likely structural features to be encountered in any neighboring wells to be drilled in the future. For instance, in the Barnett example, the deeper structural framework and specific fault identified on the initial well probably will be encountered in the next parallel well in the drilling program.

In addition to analyzing live wells, the geosteering application also can be used to perform post-well correlation on existing horizontal wells in the area. The local structural updates associated with any number of wells then can be used as a guide for reinterpreting regional-scale geologic models.

This unique combination of applications provides a comprehensive solution to shorten well planning cycle times, improve well bore placement and reduce drilling risk, with applicability to many of the challenges that characterize unconventional reservoirs. In addition, post-well correlation of one or more wells in a given area provides a mechanism for delivering updated surfaces that can be merged into the regional 3-D structural or reservoir model. ❐

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