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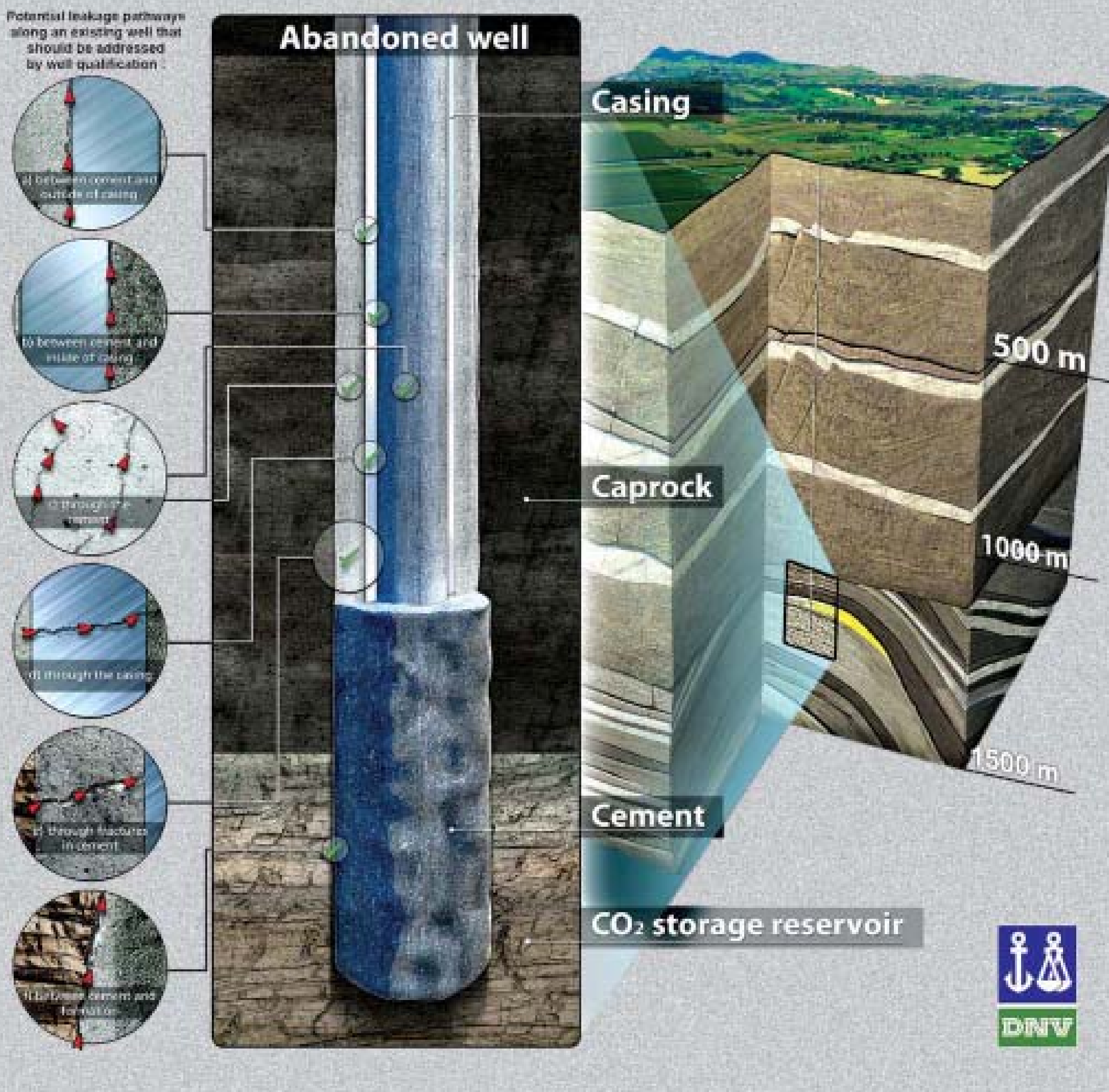
New well integrity guideline provides solution to CO_2 storage challenges



Optimized well design and real-time stratigraphic positioning of the wellbore in unconventional reservoirs: A Barnett Shale example

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This unique combination of applicationsprovides a comprehensive solution to shorten well planning cycle times, improve wellbore placement and reduce drilling risk, with applicability to many of the challenges that characterize unconventional reservoirs. Additionally, 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 3D structural or reservoir model.

Today's Challenges

The challenge of producing hydrocarbons economically from increasingly complex unconventional reservoirs drives the need for wellpath and engineering design optimization at every stage of the planning and drilling process. Just as designing wells within a 3D structural model or interpreted seismic volumecan shorten well planning cycle times, improve well placement and reduce drilling risk, the ability to interactively updatethose 3D models, based on real-time LWD responses, enables rapid re-planning and re-engineering while continuing to drill ahead.This approach can optimize well placementand maximize production.

This article describes an integrated software solution that has been successfully applied to horizontal drilling projects in several onshore and offshore plays around the world, includingunconventional plays in North America. Specific reference is made to its use withina geologically challenging area in theFort Worth Basin Barnett shale play where extensive geologic modeling has been conducted prior to planning and drilling of a new multi-well pad.

Collaborative Workflow

Key to the effectiveness of this solution is use of integrated, multi-disciplinary tools operating on a shared data management and interoperability framework, allowing experts from drilling, geology, petrophysics and geophysics to work concurrently and share data.

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

Where real-time data feeds are available from the rigsite, this work can be conducted in a real-time centre, enabling an expert multi-disciplinary team to evaluate operational decisions.

Geologic Modelling

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 3D 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 was determined using a combination of a modified Passey method and the principles of optimizing petrophysics.These results (Fig 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 the

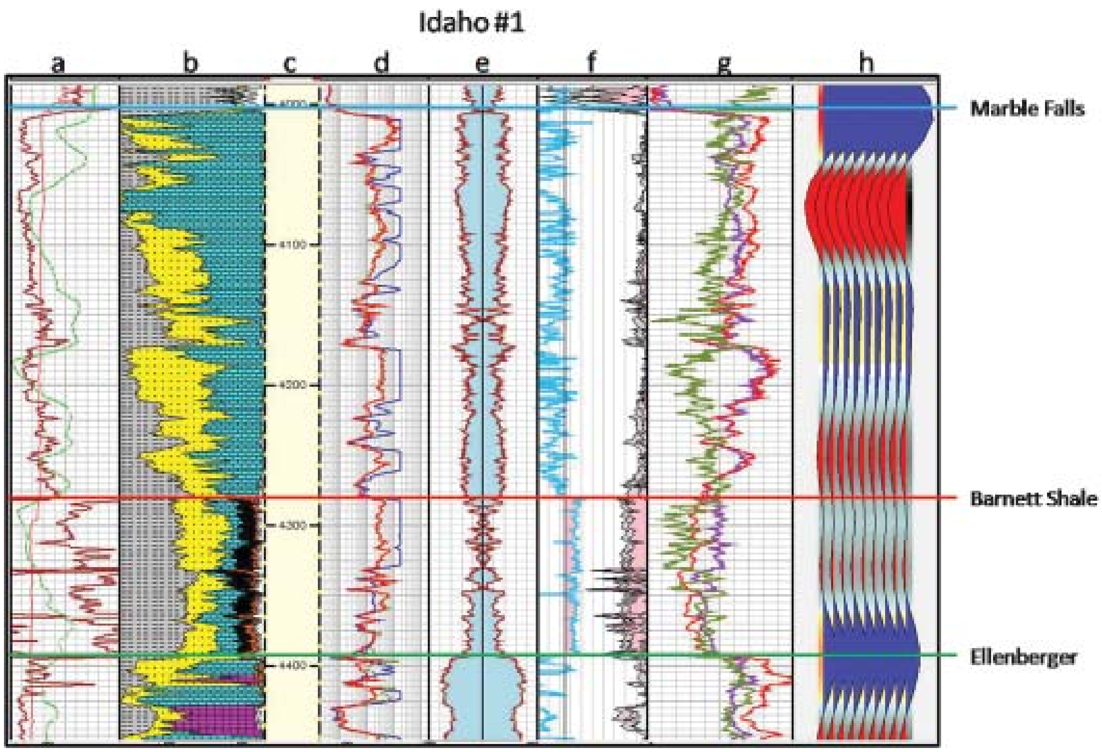

Fig.1 Petrophysical analysis of the Marble Falls, Barnett Shale and Ellenberger formations. a) Gamma Ray b) Lithology c) Depth d) Resistivity e) Closure Stress f) Water Saturation, Porosity, Gas Volume g) Poisson's Ratio, Young's Modulus, Brittleness h) Seismic Trace

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 placement of 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 which need to be avoided to reduce the risk ofcommunication between the water-saturated Ellenberger and the Barnett Shale. Prospective unfaulted areas were identified. The top of the Barnett provides a very weak seismic reflection and was therefore 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 usingNeural Network technology to identify elevenfacies 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. Karsts chimneys extracted from the fault enhanced data as multi-Z geobodies often exhibited intersecting fault planes that propagated beyond the karst geobody limit, extending the area of permeability risk. The integration of maps, faults and karsts allows identification of areas to be avoided, and optimal prospective drilling area.

Well Planning

The 3D structural model, defined in industry-standard file formats, may 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 applicationto 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 wellbore at every stage of the design process (Fig 2). For optimized wellbore placement, all known geologic factors and their relative influence on the well should be considered.

In our Barnett example, the key considerations areorienting the planned wellsin a perpendicular manner to the local NE-SWstress field to assist with planned fracing operations, avoidance of the multiple karst intrusions in the area,and achieving accurate

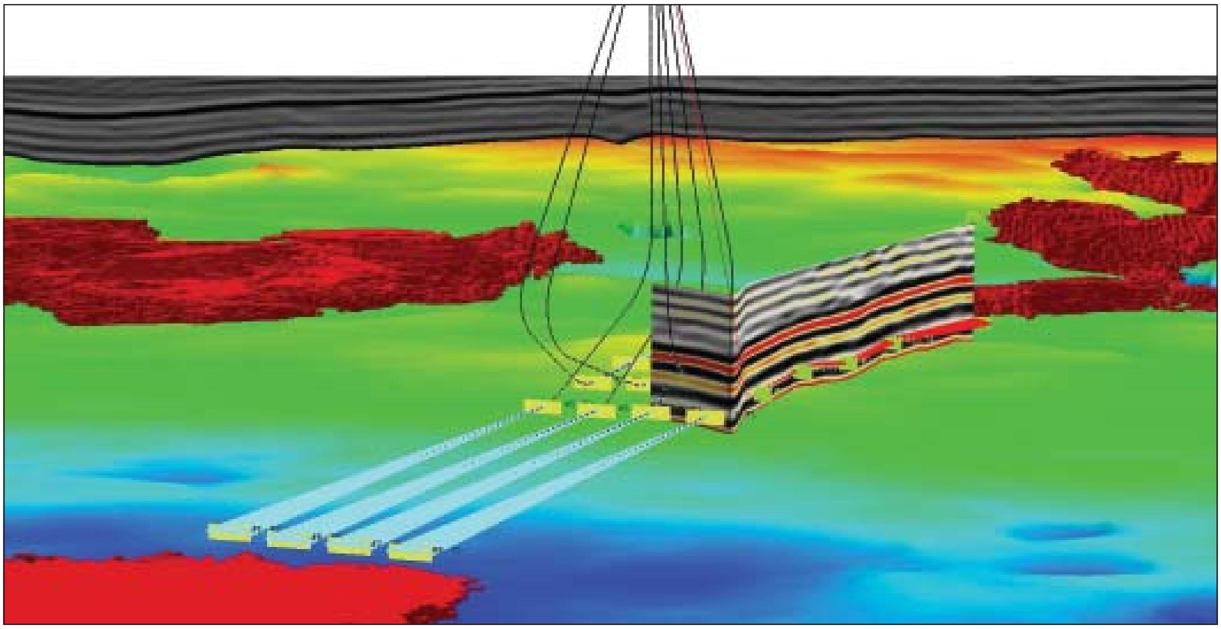

Fig.2 Comprehensive well planning and engineering within an interpretation environment

stratigraphic placement of the well within the particular zone in theUpper Barnett where rock properties indicate an optimal interval for frac stimulation.

Other fundamental trajectory constraints such as lease boundaries and proximity to offset wellbores are explicitly addressed as part of the planning phase.

Engineering Analysis

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 & drag, hydraulics, cementing and casing design. These different analyses can be run concurrently on a common wellbore and provide the means to quickly identify, understand and resolve any engineering issues (Fig 3). The ability to quickly retrieve previously defined items from a

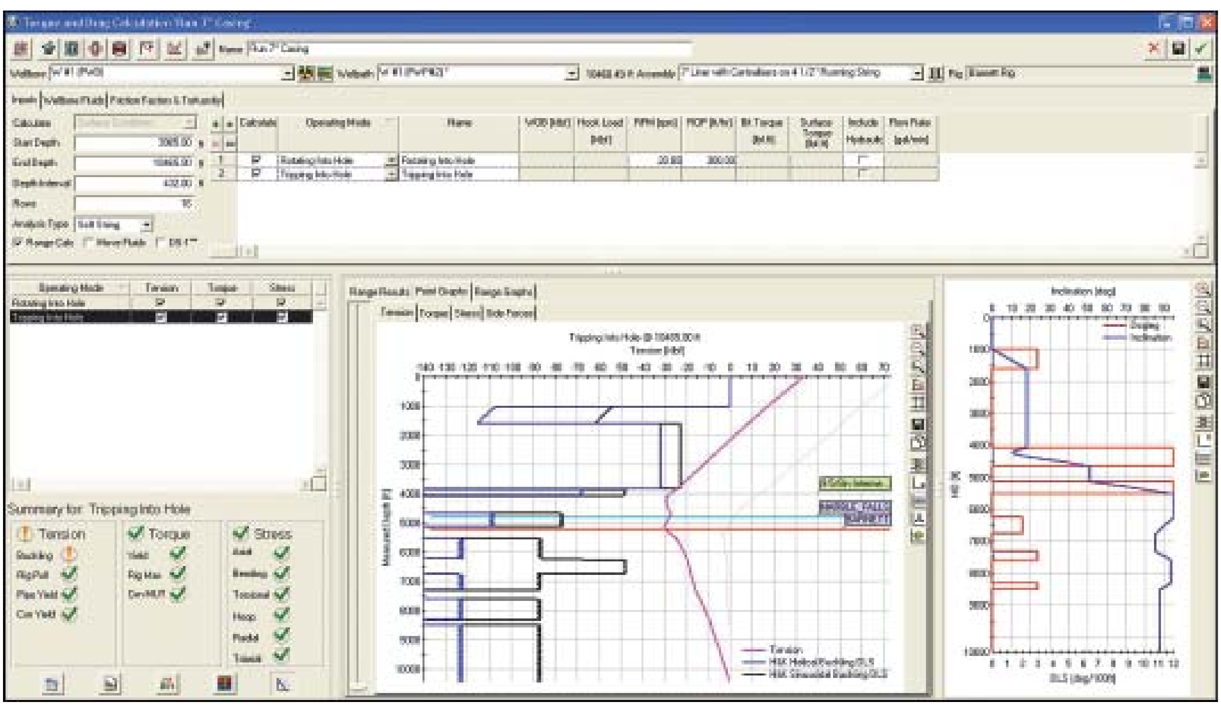

Fig.3 Integrated engineering analysis allows efficient identification and resolution of drilling issues

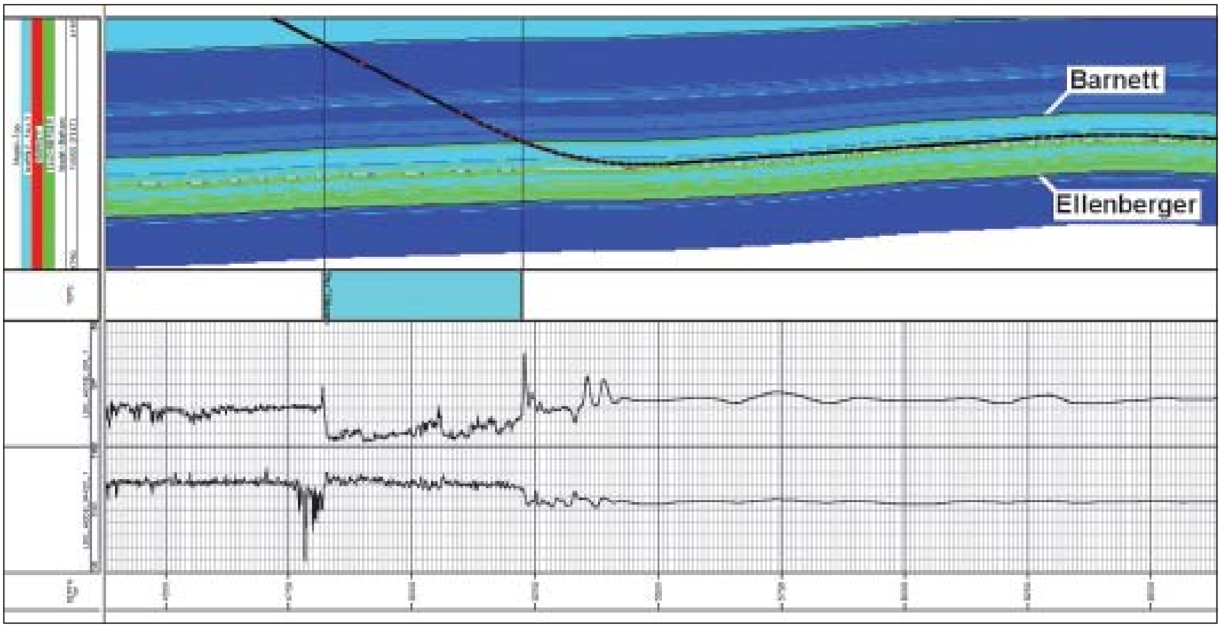

Fig.4 The pre-drill model provides anticipated log responses and structure along the well

catalog such as drill strings, casing strings, rig parameters and drilling fluids contributes to workflow efficiency.

In our Barnett example, the primary engineering considerations for the wells relate to avoidance of buckling in both drilling and casing operations.

Log-Scale Geosteering Model

The 3D structural model and the final proposed wellpath 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 pre-drill model of predicted log responses for the planned well.

The pre-drill 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 (Fig 4). The pre-drill log property model provides the backdrop against which new information is displayed as it is received during the drilling operation.

In our Barnett example, the gamma log provides distinct signatures for the top and base of our target zone within the Upper Barnett and is used as the primary geosteering log property.

As drilling progresses, timely incorporation of new data into the model is essential. Historically, this data has come in the form of individual files from the contractor or via 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 via 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 becomes 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 against the predicted logs

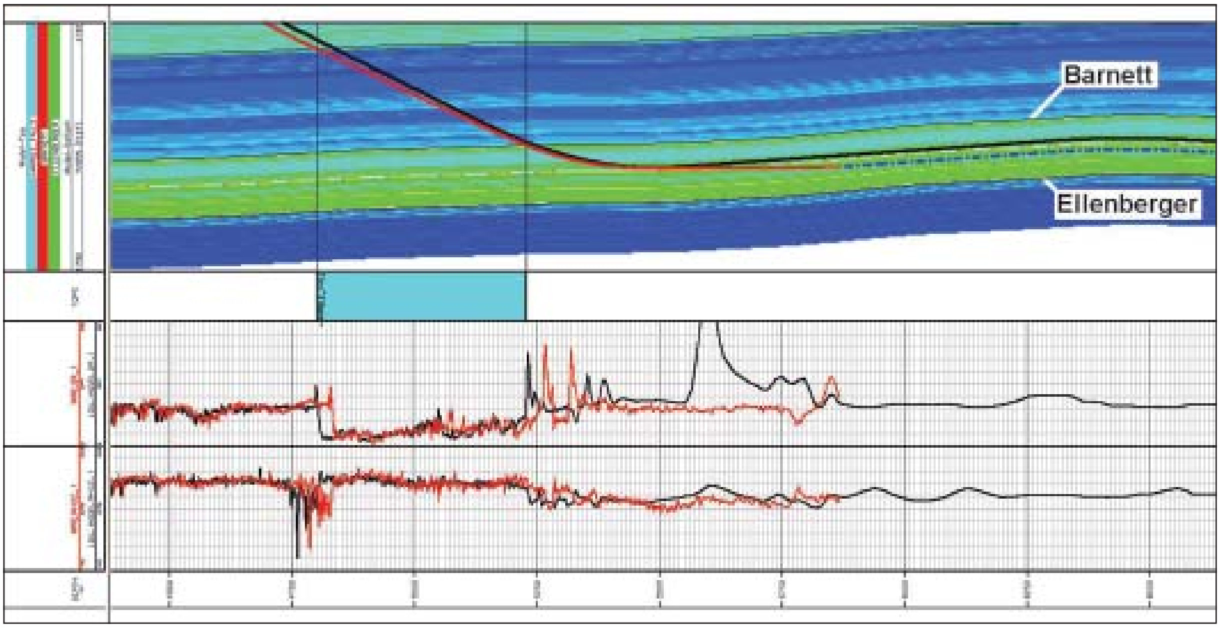

Fig.5 LWD data is loaded and indicates that the model requires update

Drilling and Geosteering

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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 user to determine the stratigraphic position of the wellbore within the reservoir and to gain 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 to stay in the zone.

Discrepancies between the pre-drill model and actual results can arise from a number of sources. Using knowledge of the reservoir, it is possible to reconcilesuch 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 is expected. By interactively editing the pre-drill model, the geosteering user 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 affect the modeled log responses. Additionally, geologic constraints regarding conformability of surfaces from the initial model will be honored during editing 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 case of our Barnett example, correlation reveals that the overall structural framework is generally deeper than anticipated and indicates the presence ofa previously undetected sub-seismic scale fault with a throw of approximately 20ft (Fig 6).Through model update, it becomes clear that the actual wellbore, although deeper than the plan, remains approximately 5 ft higher than desired stratigraphically and requires trajectory adjustment.

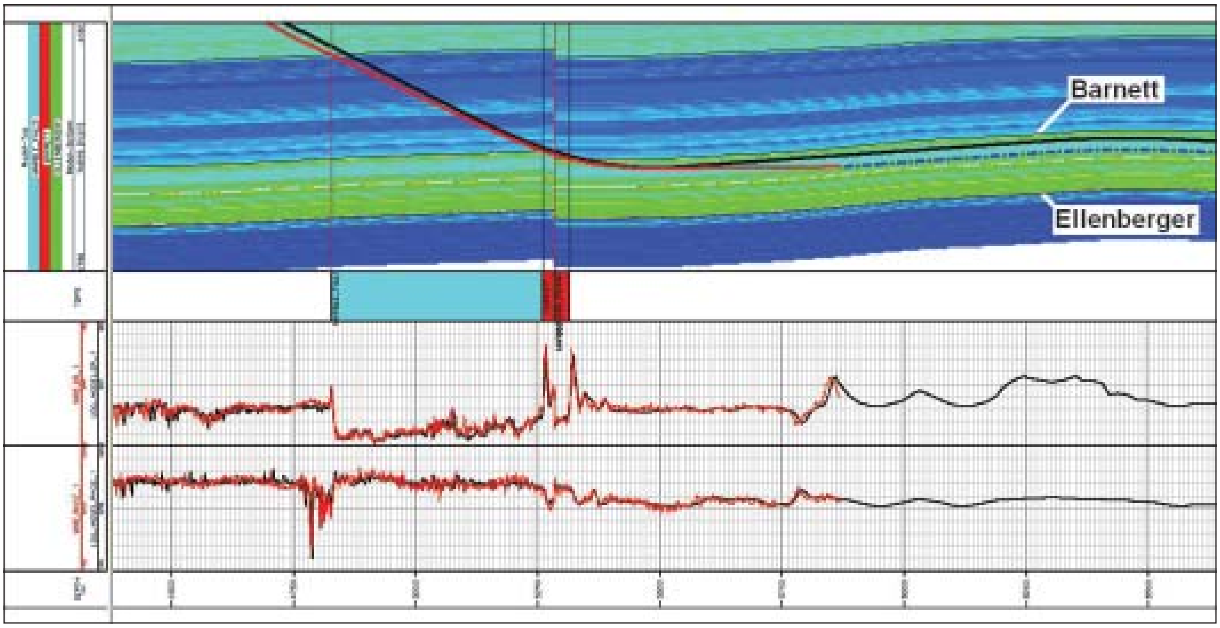

Fig.6 A repeat sequence in the actual log response allows identification of a sub-seismic fault

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.

Re-Planning While Drilling

In cases where geosteeringmodel updates result in significant TVD adjustments,the updated 3D structure can be used by the engineering application to re-plan the well based upon the most up-to-date geosteering interpretation, allowing stratigraphic recovery of wellbore position (Fig 7). 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 re-plan becomes the new reference plan within the geosteering application and correlation continues as drilling

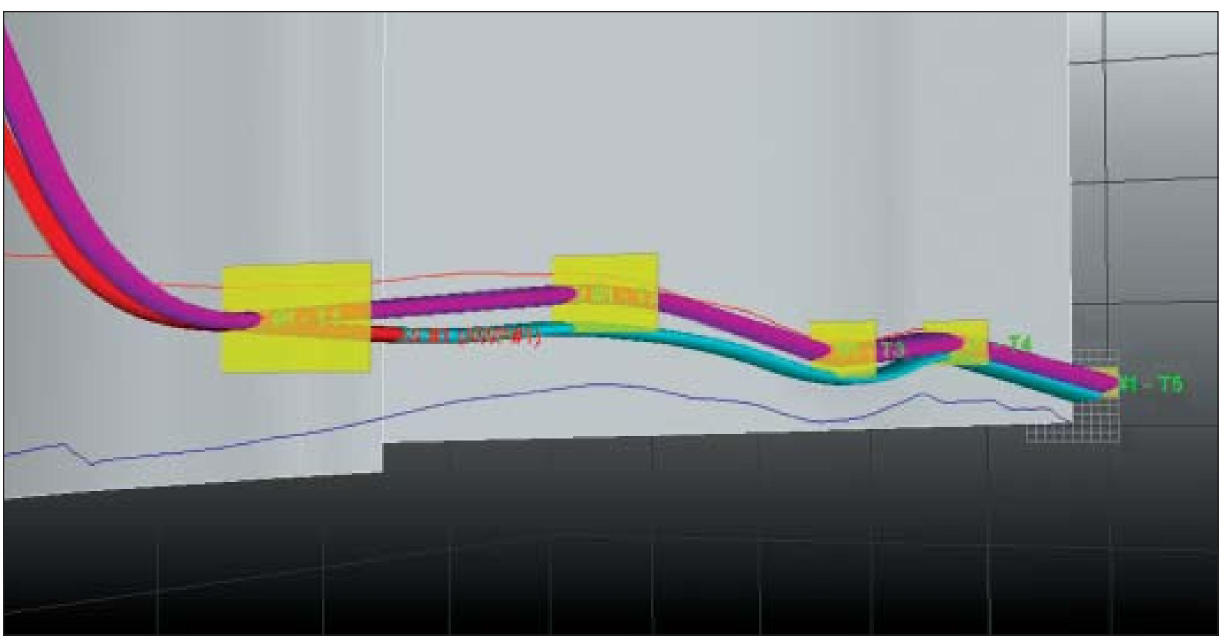

Fig.7 The well is re-planned within the updated structural model while drilling

proceeds. If necessary, a sidetrack can be planned and thegeosteeringprocess repeated for the planned sidetrack.

Post Well Correlation

The ability to update the model while drilling is not only key to achieving optimal wellbore placement for the current well, it also provides a means ofanticipating the likely structural features to be encountered in any neighboring wells to be drilled in the future. For instance, in our Barnett example, the deeper structural framework and specific fault identified on our initial well will probably be encountered in the next parallel well in the drilling program.

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

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Summary

This unique combination of applications provides a comprehensive solution to shorten well planning cycle times, improve wellbore placement and reduce drilling risk, with applicability to many of the challenges that characterize unconventional reservoirs. Additionally, 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 3D structural or reservoir model.

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