Technical Geosteering

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U.S. horizontal drilling activity is booming. From five years ago, industry estimates show a five-fold increase to about 400 rigs per day. These increased market pressures have stimulated refined horizontal well data processing techniques that reveal a world of small-scale geologic features, like faulting, zone undulation, and transient dip-direction reversal. The economic results are increased production rates from more footage drilled in the reservoir "sweet spot" and—in some cases—cost savings from elimination of pilot holes.

Geosteering—the task of estimating well path position within the stratigraphic setting and occasionally changing the remaining planned path accordingly—has traditionally for smaller companies been a niche practice often handled entirely onsite. However, more offsite oversight is becoming the norm because 1) accelerated production of reserves increasingly relies on correct stratigraphic placement of the lateral; 2) the logistics of onsite-to-office data transfer are simple with modern communications; and 3) technical geosteering software is available that when correctly applied enables a quantum leap of interpretation confidence compared to legacy geosteering methods that rely only on drafting tools.

Technical Geosteering

Technical geosteering is a computational signal-mapping task. Timely and depth-accurate logging while drilling formation evaluation (LWDFE) data is transformed—using a geometric location estimate of a marker bed—to plot on a representative stratigraphic type log. An acceptable "fit" suggests a good estimate of the marker bed location.

Gamma Ray

The most common LWDFE measurement applied to technical geosteering is omni-directional gamma ray. Gamma ray is chosen because of its relatively insensitive signal response to varying pore fluids, rock porosity, rock permeability, and circumferential borehole quality. Another favorable gamma ray attribute is a short depth of investigation (e.g., 4-6 inches); with less rock "seen" by the tool there is less chance for signal complication.

In oil and gas geosteering applications the measured depth (MD) frequency of gamma ray data is typically 0.5 or 1 ft, which enables fault-crossing recognition. Some operations rely on focused gamma ray measurements (e.g., borehole high side and low side readings) to either outright drive technical geosteering or to augment interpretations relying primarily on omni-directional gamma ray measurements.

3D Curved World

What complicates the software engine of technical geosteering is addressing the fact that both the well path (known-location) and the payzone (unknown-location) simultaneously change and curve in three-dimensional (3D) space. A two-dimensional (2D) technical geosteering analysis—one based on vertical section for example—inherently suppresses resolution and introduces distortion, especially with '3D' wells and or '2D' wells with thin payzones.

3D Technical Geosteering

In 2006, Stoner Engineering LLC developed a 3D technical geosteering methodology that eliminates the shortcomings of 2D analysis. Two new geologic terms resulted from this work: 3DStratBlock and relative stratigraphic depth.

A 3DStratBlock (3DSB) is a planar surface that mathematically represents the 3D location of a geologic marker—usually the top of the payzone. The target well path is at some offset distance parallel to this marker. A 3DSB is defined with a true dip, a true dip direction azimuth, map coordinates corresponding to a MD along the actual well path, and a control point true vertical depth (TVD).

Relative stratigraphic depth (RSD) is simply a stratigraphic distance relative to an "arbitrary" reference point (i.e., the marker). With respect to gamma and MD data from a logged vertical offset well or pilot hole, with horizontal beds, stratigraphic depth can simply be MD. With respect to gamma and directional survey TVD data from a directional offset well or pilot hole, with horizontal beds, stratigraphic depth can be TVD. If the beds are not horizontal then TVD should be corrected with regional dip to produce gamma versus stratigraphic depth data. Stratigraphic depth and gamma data, along with a reference depth designation, produce a RSD type log.

With respect to a 3DSB however, RSD is calculated and is the minimum 3D distance from a respective coordinate—at a MD along the wellbore from where gamma data was recorded—to the plane that is the top of the 3DSB. The parameters that define the 3DSB are calibrated to produce an acceptable mapping of gamma data on to the type log. When deviation becomes unacceptable, a new 3DSB is started because in most cases the payzone has curved and or faulted.

3DSB Calibration

The most common 3DSB parameters to calibrate are the true dip and the MD range over which the respective 3DSB applies. After initial setup, control point TVD only needs adjustment when a fault is interpreted since continuity from the prior 3DSB otherwise makes sense. True dip direction azimuth is calibrated on the landing to produce maximum signal expansion ("stretch") or maximum signal compression ("squeeze"), and thereafter remains constant until a transient dip-direction reversal is evidenced. When a transient dip-direction reversal is evidenced, which almost always occurs multiple times along a horizontal well, the true dip direction azimuth is simply "flipped" 180 degrees.

Thus, a 3DSB is a 3D planar location estimate of the beds being drilled. As long as the actual geologic structure is planar, the gamma data will map—as calibrated via the 3DSB—on to the type log with minimal/acceptable deviation and therefore produces a good estimate of well path position within the stratigraphic setting, even though the wellbore always is curving in a varied fashion. The 3DSB/RSD concept produces a spatially dynamic coordinate system inherent to the stratigraphic target.

Pilot Hole—Optional!

If the type log "shape" is very persistent and if regional true dips are low, often there is no need to drill a pilot hole preceding the main lateral because during the landing, technical geosteering produces constant feedback about how far the target is relative to the actual wellbore. See Figure 1.

Some horizontal drilling operations design and execute the landing to penetrate through most or all of the payzone in order to confirm the gamma signature and acquire such signal magnitude respective to the specific gamma tool in the bottom hole assembly. This methodology goes hand-in-hand with a landing-derived type log.

Candidates for Technical Geosteering

A target zone for application of technical geosteering evidences a formation evaluation signal whose functional form persists aerially and features sufficient magnitude contrast from nearby beds. This "type log" is essential for landing the horizontal well in the payzone.

Technical geosteering software called SES—developed by the author—allows for derived type logs to be created from the landing. This allows for gamma functional form *and* magnitude to play a role in calibrating future 3DSBs. A landing-derived type log is used to geosteer the rest of the well. See Figure 2.

Technical Geosteering Value

By observing a cross-section of TVD versus MD that displays the entire well path and the payzone as defined from the 3DSBs, the best "big picture" can be seen and drill-up/hold-steady/drill-down planned well path revisions can intelligently be made. See Figure 3. In practice, the number of target changes communicated to the directional driller can range from few to dozens. Updating the target entails specifying inclination and TVD at vertical section of zero.

Post-drilling application of technical geosteering provides value by training personnel on how to geosteer/interpret, and it produces a most-complete understanding of the geologic structure and actual well path / reservoir completion. Such "in/out" understanding is often critical for example for reservoir simulation of wells drilled horizontally. It can also affect completion procedures that use fracture stimulation. The best possible geologic interpretation can be attained after drilling because there are no data depth-lag issues or general human fatigue conditions that inherently accompany live operations.

Technical geosteering is a numerical tool that augments other data sources—akin to another "dimension"—to assist the operator to interpret where the wellbore is stratigraphically located. Other data that may help with geosteering may include multiple fluid-return-line-derived measures, such as sample drill cuttings analysis, gas chromatograph measurements, oil shows, gas flare height and casing pressure in underbalanced drilling operations, and general rate of penetration characteristics. Most fluid-derived measures suffer from bottoms-up lag-time issues and relatively significant source-depth uncertainty compared to LWDFE data.

Technical geosteering defines locally and helps to refine globally the geologic model of the marker bed along and nearby the actual drilled wellbore. Small-scale geologic features—often ignored with legacy geosteering methods that rely only on plain drafting tools—like faulting and zone undulation become better communicated via the TVD versus MD cross-section displaying calibrated 3DSBs and may help explain subsequent production behaviors related to hydrocarbon and or water flows, and issues related to water sumps in wellbore low-spots.

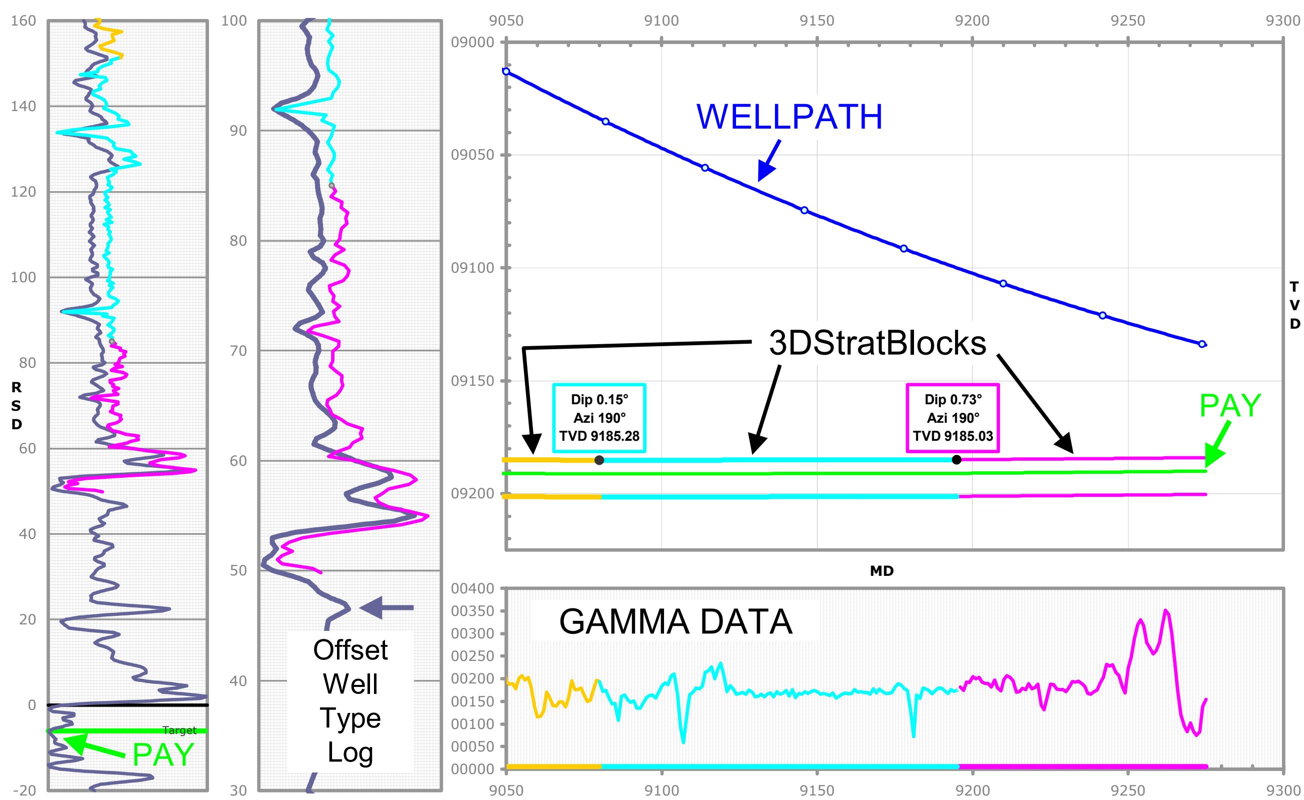

Figure 1: Landing a horizontal well using technical geosteering. Gamma ray readings recorded at measured depth are mapped on to a stratigraphic type log based on calibrating 3DstratBlocks that represent the location of the payzone. Satisfactory mapping means a valid estimation of its location.

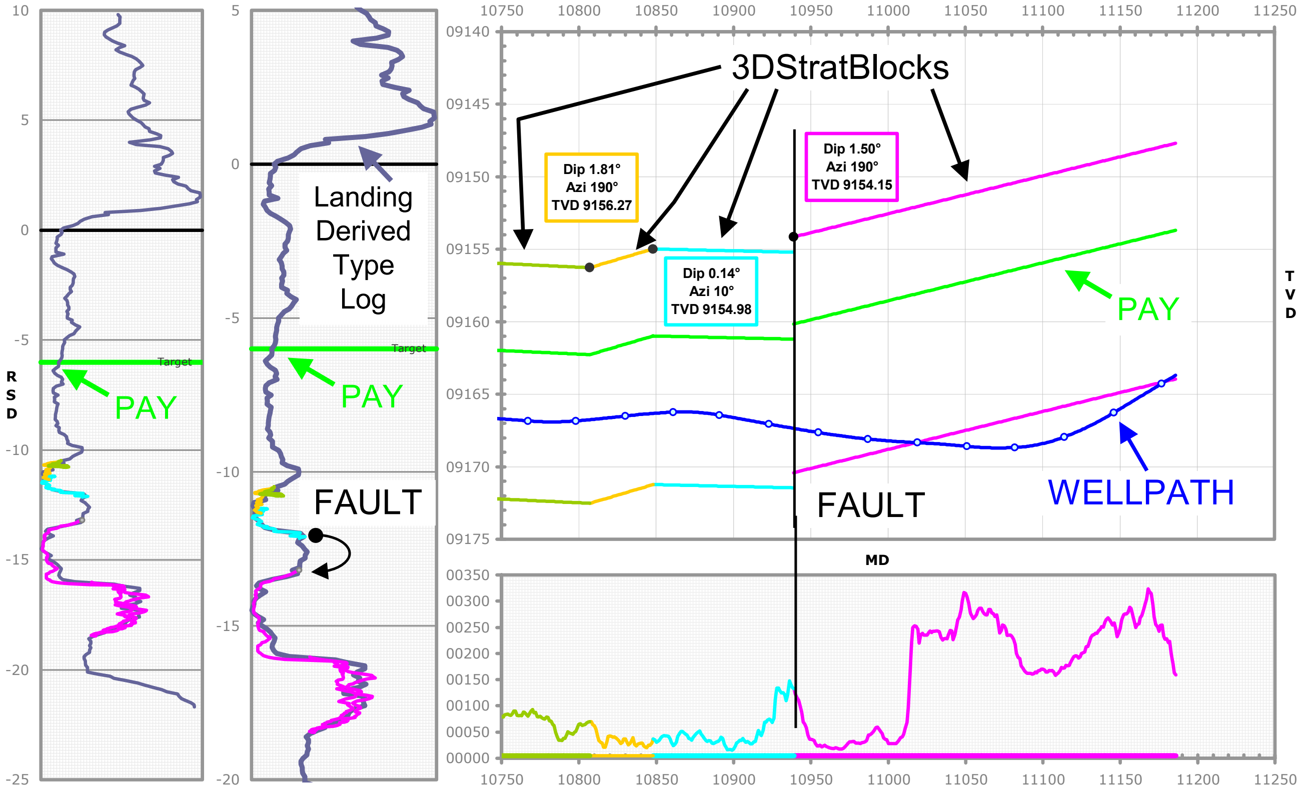

Figure 2: A landing-derived type log allows for signal shape and magnitude to help with 3DStratBlock calibration. A small fault is evidenced at the start of the leading edge 3DStratBlock and the wellbore briefly exits the base of the payzone shortly thereafter.

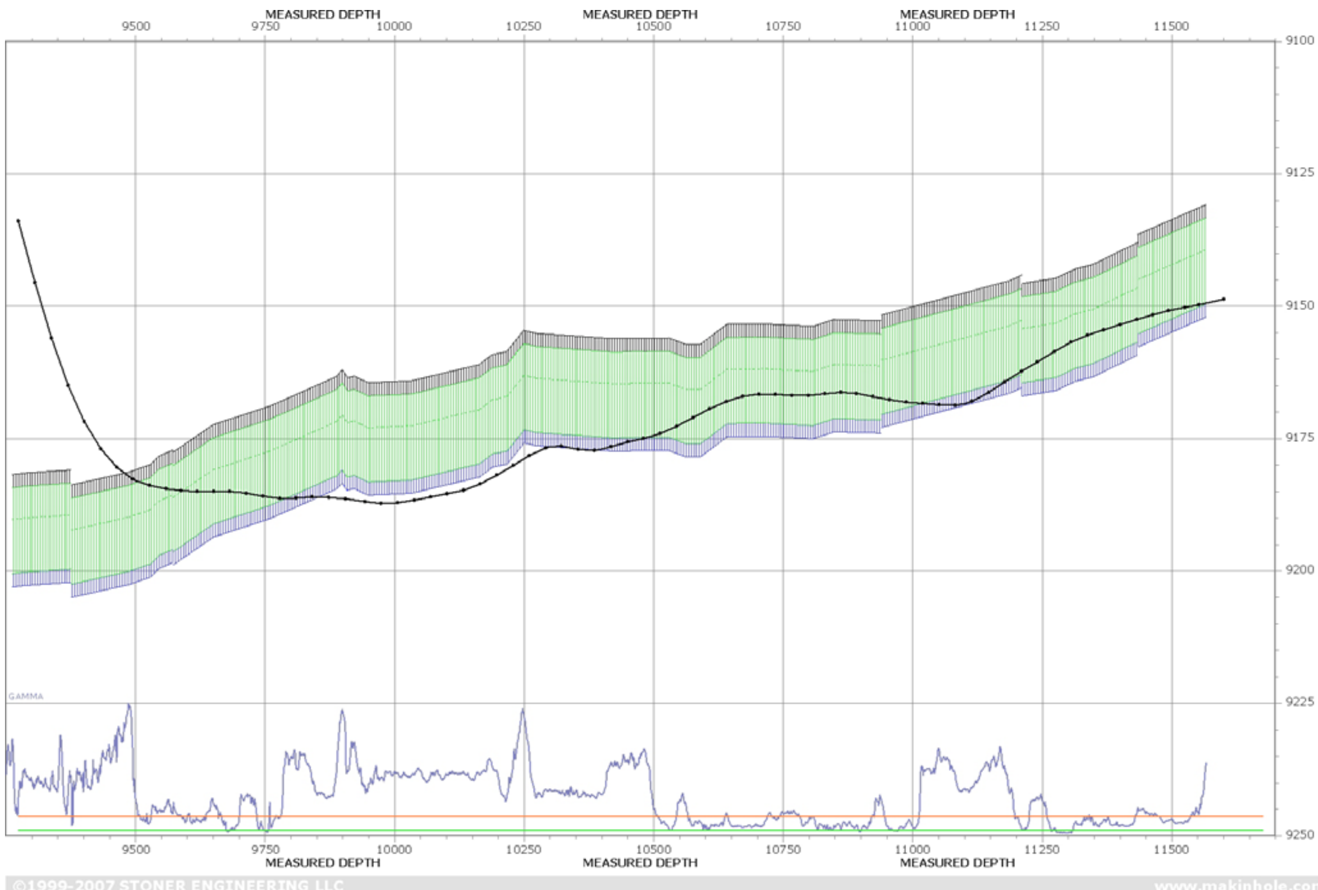

Figure 3: With each 3DStratBlock calibrated, the total-well cross-section shows the “big picture” of the stratigraphy drilled and leads to target path revisions and an understanding of in-zone completion.