THE AMERICAN OIL & GAS REPORTER®
SEPTEMBER 2018
The "Better Business" Publication Serving the Exploration / Drilling / Production Industry

Approach Optimizes Well Geosteering

By Christopher Viens
and Mark Tomlinson

HOUSTON–Geosteering in horizontal wells involves correlating logging data to a type log from a nearby offset well to characterize the zone of interest. Correlating against a type log requires the bedding thickness and gamma character of the target well to be close to that of the type log, which can be offset by miles in some cases. If not, the resulting geosteering interpretation will have unreasonable bed dips that do not accurately reflect the target lithology being drilled, leaving the geosteering geologist running multiple simultaneous interpretations in the hope that one will start to make sense as new data come in during drilling.

Azimuthal gamma imaging, in conjunction with continuous inclination measurements, brings clarity to stratigraphic position, bed dip, faults and zones where bedding is laterally discontinuous or completely absent. In many of these situations, geosteering cannot be performed with traditional solutions. Through enhanced visibility of the subsurface by azimuthal gamma imaging, geological anomalies can be identified quickly and handled in the best possible manner.

Utilizing azimuthal gamma imaging data to identify faults, laterally continuous/discontinuous bedding, stratified/unstratified zones, and high-energy sedimentary deposition improves interpretation accuracy. Azimuthal gamma logging tools measure the incoming gamma radiation from all sides of the borehole and provide a clear indication of whether a change in total gamma resulted from stratigraphic movements up or down in horizontal drilling applications.

When a change in total gamma is not associated with an up or down movement through stratigraphy, it indicates faulting, a depositional anomaly, heterogeneity, or bedding that is not laterally continuous or stratified. Because the fundamental basis of geosteering is correlating to marker beds that have lateral continuity, in situations where lateral continuity is absent, only a low level of interpretation confidence can be achieved using traditional correlation methods.

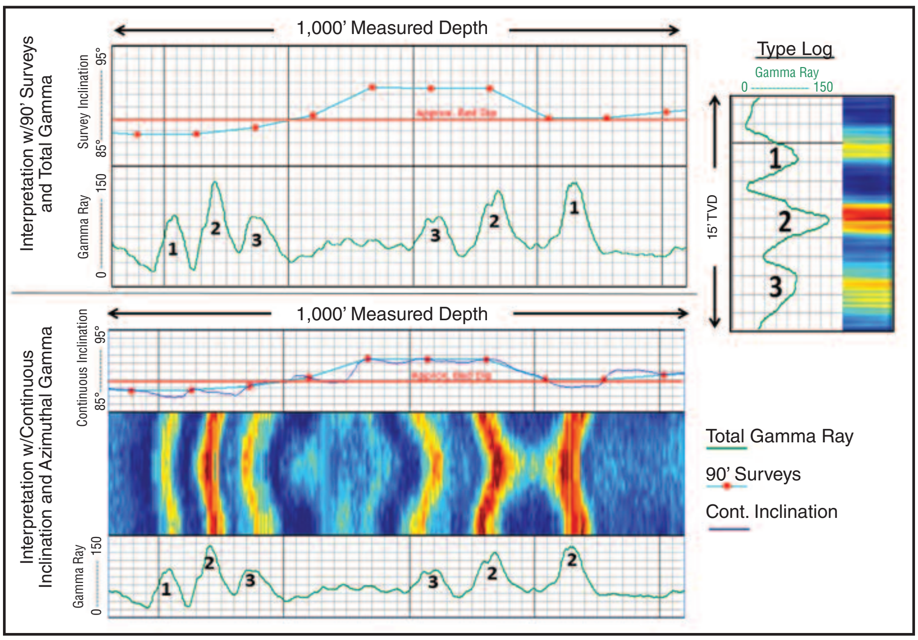
To maximize the benefits of azimuthal gamma imaging, a protocol has been developed to identify and handle challenging geosteering situations using a model-based 3-D geosteering solution rather than conventional 2-D geosteering software. By integrating multiple well and seismic surface inputs, this approach gives the geosteering geologist the information to confidently resolve abrupt bed dip changes, identify faults, identify areas of lateral continuity/discontinuity, identify stratified/unstratified zones and understand formation-related directional drilling trajectory phenomena, etc.

Laterally Continuous Bedding

In areas with laterally continuous strata, the gamma character in the type well typically will be present at the

FIGURE 1

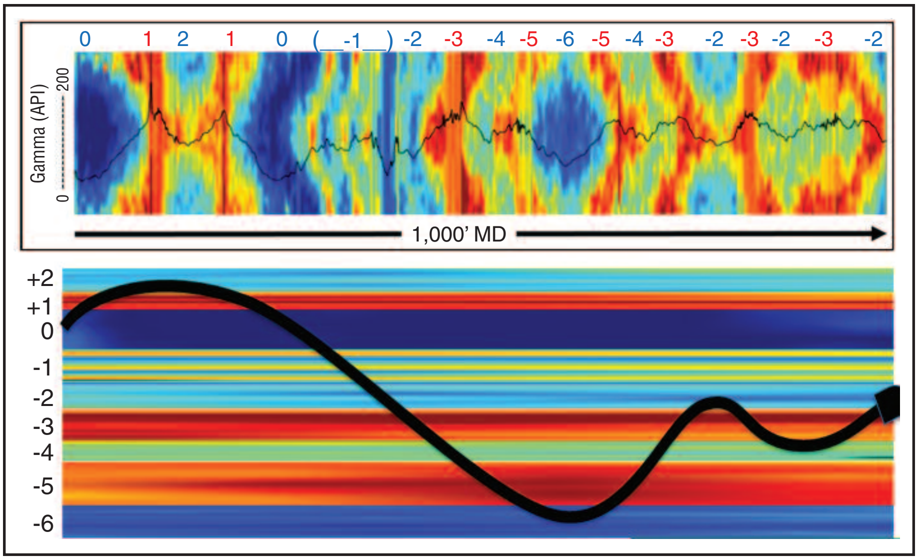
Incorrect (Top) and Correct (Bottom) Geosteering Interpretations With Type Log (Right)



Reproduced for DynaView with permission from *The American Oil & Gas Reporter* www.aogr.com

FIGURE 2

Bed Counting Method to Track Stratigraphic Position



landing point and throughout the wellbore's lateral length. This type of bedding is ideal for geosteering since a proper interpretation will overlay the type log with little deviation. While these cases are ideal for geosteering, they are still subject to ambiguity when utilizing a 90-foot survey and only total gamma data.

Figure 1 demonstrates how geosteering interpretations can be ambiguous and highly subjective as a result of the position of 90-foot surveys, as well as a lack of up or down stratigraphic movement indications from the total gamma measurement. The type log at right shows a 15-foot vertical profile of a zone. The interpretation at the top is based on 90-foot surveys and total gamma data. In contrast, the lower interpretation uses continuous inclination and azimuthal gamma imaging. The different stratigraphic position as indicated by the numbering is a result of the definitive direction indication from azimuthal gamma, and the continuous inclination curve bringing visibility to wellbore inclinations not characterized by the 90-foot surveys.

Figure 1 shows only 1,000 feet of measured depth in a lateral. One can imagine how many incorrect interpretations may be made over the course of a 5,000-10,000 foot lateral simply because of data ambiguity if the proper measurements for accurate wellbore placement are not utilized.

In laterally continuous zones without faulting or strata pinching, the bed counting method (Figure 2) can be performed to track stratigraphic positioning relative to the landing point. This is a powerful method for validating stratigraphic positioning without actively performing a geosteering correlation. However, the method is not effective for landing a curve because of its downward-cutting trajectory.

Synthetic Data Between Wells

When improved imaging visibility is combined with 3-D geomodeling incorporating on-the-fly correlation and updating, a higher level of correlation confidence can be achieved. Geomodeling permits the creation of synthetic petrophysical data by propagating data from all nearby wells, accounting for thickening and thinning according to the geometry of surfaces within the model. These synthetic properties can be projected through the model and compared with actual data. Correlation adjusts surface depths and thicknesses, resulting in a corresponding change of character in the synthetic curves, resulting in validation of the geosteering interpretation.

A correctly interpreted correlation is reflected in high character coherence between the actual and synthetic curves behind the bit. Surface deformation is propagated ahead of the bit with a corresponding change in projected synthetic petrophysical curves. This permits greater understanding of expected properties ahead of the bit to mitigate unnecessary steering changes based on misinterpretations, and allows smoother and more gradual steering adjustments to remain in the target zone while mitigating increased wellbore tortuosity.

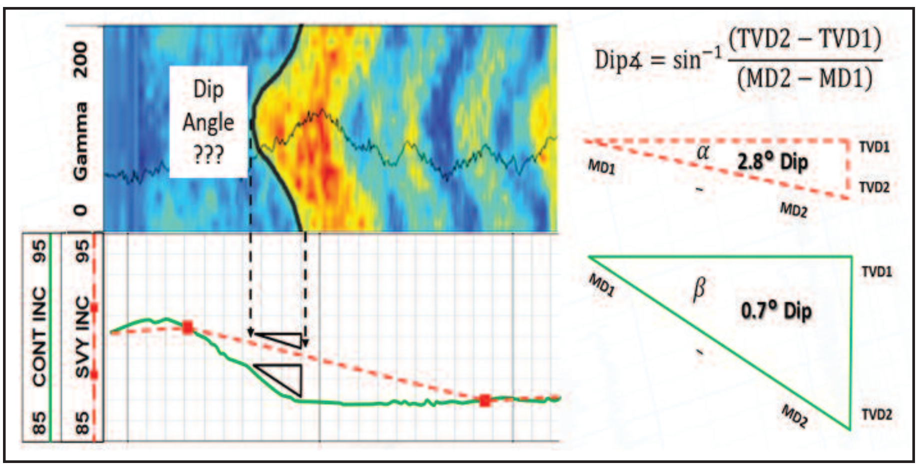
This continuous updating with new data and correlations results in a high-quality geomodel that can be used in laterally continuous bedding to model the azimuthal gamma response along a projected well path. As real-time gamma image data are logged, a close match between the synthetic azimuthal gamma image and measured azimuthal image is a sign of an accurate stratigraphic position interpretation.

This projection method reduces unnecessary course corrections and increases correlation confidence. To achieve an accurate synthetic image, a 3-D model is required to account for bed thickening/thinning and topographical changes. A close match between both images gives the geologist a high level of confidence in the interpretation and the accuracy of the geomodel. When encountering unexpected laterally discontinuous bedding, the 3-D model provides greater confidence in maintaining trajectory until correlatable laterally continuous and stratified features are encountered again.

Since azimuthal gamma image features are a result of wellbore trajectory, bed dip angle and wellbore direction, to accurately generate synthetic images that honor measured images, utilizing a continuous inclination-generated survey results in a more accurate match. The relationship between bed dip, wellbore survey and gamma image features are presented in Figure 3, which demonstrates discrepancies between a 90-foot survey position (left)

FIGURE 3

Bed Dip Calculation Utilizing 90-foot Surveys Versus Continuous Inclination



and continuous survey position gamma image (right) for the same dip pick. In this case, the continuous survey shows a 2.1-degree difference in bed dip compared with the 90-foot survey calculation.

The lack of wellbore inclination characterization is one of the largest contributing factors to true vertical depth measurement errors. This error presents itself in bed dip calculations when dip picking azimuthal gamma image features, as well as across correlation cells in geosteering interpretations. A lack of TVD characterization can lead to an inability to understand local bed dips, as well as give bed boundaries the appearance of being jagged or having shifting surface angles with every new segment/correlation cell. Proper wellbore inclination characterization with continuous inclination results in more realistic bed dip calculations and removes much of the undulation often seen in geosteering interpretation cross-sections.

Laterally Discontinuous Zones

Higher-energy depositional environments often result in chaotic bedding, with little lateral continuity or stratification. In these environments, logging data characteristics exude little coherency from well to well, making correlation difficult and inaccurate. In marine depositional environments, distal and proximal depositions can be in direct stratigraphic contact with one another. As a result, small stratigraphic movements of the wellbore–whether from trajectory change, pinching out or faulting–can result in encountering lithology with very different depositional bedding characteristics.

When using a total gamma measurement only for geosteering, the transition into a zone of laterally discontinuous bedding may not become apparent until the logging data cannot be correlated against the type log with any degree of certainly. At this point, correlation confidence is lost and various actions must be taken to try to identify where the wellbore is located stratigraphically. This adds drilling time, uncertainty and potential for lost pay zone exposure. All of this can be avoided through azimuthal gamma imaging's enhanced visibility.

Geosteering based within a 3-D model aids in understanding where the wellbore should be drilled when traditional correlation no longer can be carried out because of a lack of laterally continuous bedding from faulting, deformation strain or high-energy deposition. In all cases, geological complexity hinders accurate wellbore placement. Integrating well data and geological horizons (using seismic horizons or synthetic surfaces tied to regional offsets) permits the propagation of offset information from multiple wells to the actual drilled well location.

When encountering zones in a lateral wellbore where an azimuthal gamma image identifies chaotic bedding or lateral discontinuity, the 3-D model can be used to project a well path ahead of the bit that will maintain the trajectory within the theoretical zone of interest until definable bedding or correlatable points are re-encountered. Through these zones of correlation uncertainty, synthetic petrophysical curves can be created from a variety of offset wells to identify any correlatable features that may not be immediately apparent in a type log.

The model-based approach eliminates the need to carry out unnecessary trajectory changes to locate a point of known stratigraphic position, and in the event bedding is too chaotic for any regional or local correlatable feature, the 3-D model can be used as a guide to maintain the well path in the target lithology.

Rapid interpretation of information also is aided through data visualization that can be extracted from a 3-D model. Contour maps of encountered horizons can account for lateral wellbore trajectory changes, and also assist in interpreting stratigraphic positional changes related to a trajectory change.

For example, should a well drift azimuthally because of a lithologically or structural directional trend, a 2-D interpretation only would indicate the vertical transition out of a zone of interest. If the well then is steered back to the desired azimuthal trajectory and an inclination change is made to account for the inter-

FIGURE 4

Wellbore Visualization in Structural Geological Context

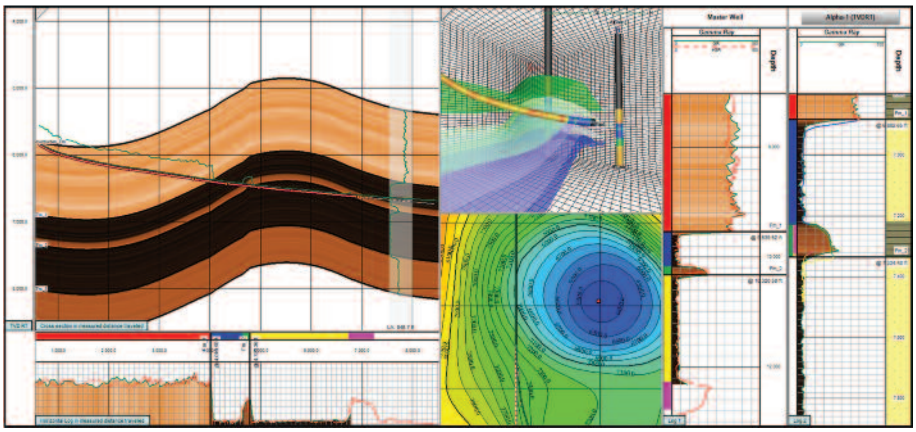
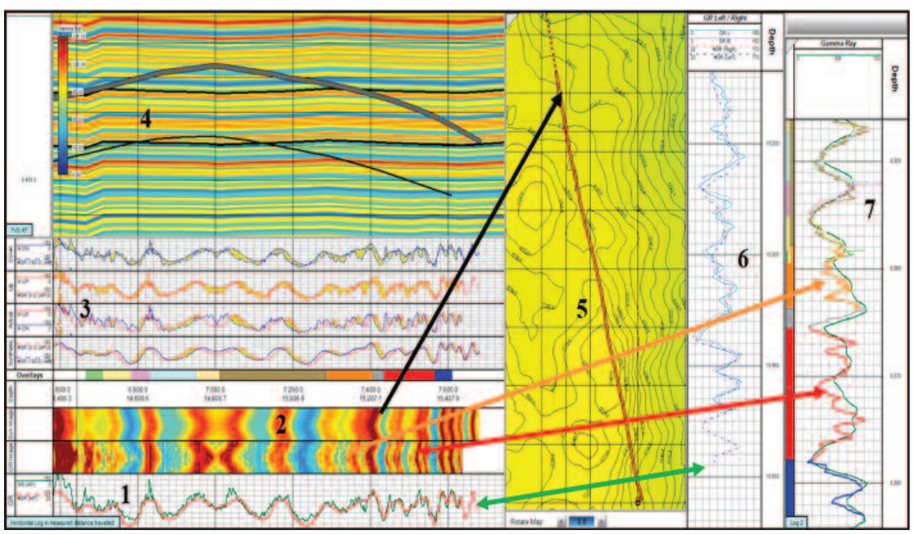


FIGURE 5

Fully Integrated Dataset from 3-D Model



preted vertical transition, a greater-than-required adjustment will be carried out and the well may be oversteered and exit the target on the opposite side. Visualizing this information, in conjunction with the resulting effects on synthetic curve and image character, assists in both image interpretation and minimizing oversteering.

An example of an integrated wellbore visualization in structural geological context is shown in Figure 4, demonstrating how inputting seismic-defined surfaces or synthetic surfaces from nearby wells brings visibility to geological structures ahead of the bit.

Fully Integrated Dataset

An example of a fully integrated dataset of synthetic and actual images with geological context from a 3-D model is shown in Figure 5. The integrated data displays seven key elements, as numbered on the figure:

- (1) An actual gamma ray (green) curve plotted with a synthetic gamma ray (dashed red) as a primary correlation verification tool. Scaling is adjusted on the synthetic curve at a location of high correlation confidence prior to the lateral portion of the well to account for differences in tool readings between wells.
- (2) Actual (below) and synthetic (above) gamma ray images. The synthetic image in this example is created using a wellbore path based on continuous inclination data and azimuthal readings extrapolated from surveys. Using a 3-D geomodel allows correlation tie-ins that update images based on full 3-D bed dip change effects. An example of this is indicated by the black arrow. The actual image comprises a slightly asymmetrical bedding feature, which is apparent on the synthetic image and corresponds to a topographical feature, as seen on the corresponding map location.
- (3) Curve plots of synthetic and actual gamma ray up and down provide a visual correlation check and stratigraphic direction verification.
- (4) The curtain view cross-section backdrop is a synthetic gamma ray propagated through the 3-D model from the offset well used for the synthetic image generation for a visual stratigraphic image log interpretation. The gray well path is calculated from continuous inclination and the black well path from 90-foot surveys, demonstrating improved absolute wellbore location with increased data resolution.
- (5) Contour maps allow a quick visual explanation for features occurring as a result of lateral variability according to the well path and its azimuthal deviation from the vertical section azimuth.
- (6) Curve plots of synthetic and actual gamma ray left and right verify azimuth-related gamma ray and image log trends.
- (7) Traditional overlay plots add further verification to correlations. The red and orange arrows indicate regions in the well where a traditional overlay correlation deviates from the type log well and could cause unwarranted trajectory changes to be carried out. Within the portion of the well where the overlays do not fully match the type log, a combination of real-time azimuthal gamma ray data, tied in to synthetically modeled data, permits a high-confidence correlation to be carried out. The green arrow indicates a forward-modeled synthetic gamma ray for generating a synthetic image ahead of the bit using the 3-D model to assist in predicting changes and permitting gradual changes to planned trajectories. ❐

CHRISTOPHER VIENS

Christopher Viens is subsurface interpretation subject matter expert at Nabors Drilling Solutions in Houston. He joined Nabors in 2011 working on the development, commercialization and application of MWD/LWD technology focused on geosteering, directional drilling and efficient wellbore placement. Prior to working with Nabors, Viens served as a geologist in the Gulf of Mexico and U.K. North Sea. He holds a B.S. in geology and earth systems from the University of Massachusetts, and is pursuing an M.S. in petroleum geology from the University of Houston.

MARK TOMLINSON

Mark Tomlinson is technical director for the Petram Group and the lead software designer for DynaView™ 3-D modeling and real-time data interpretation geological software. With more than 20 years of industry experience–including as a wellsite geologist at Hess Corp., ConocoPhillips, BHP Billiton, Cairn Energy, BP, Total and Statoil–he has been engaged in operations geology supporting exploration and development drilling campaigns from the deepwater Atlantic to South Texas. Tomlinson holds a degree in petroleum geology from the University College of London.