Logging Through the Bit

Increasing use of horizontal drilling has spurred E&P companies to look for more cost-effective ways to log their wells. To meet this need, an innovative logging service has been developed. Operators are now capitalizing on a unique conveyance method that uses small-diameter tools to obtain formation evaluation data in highly deviated or extended-reach wells.

Advances in drilling and completion technology are helping E&P companies open and develop new plays previously deemed uneconomic. In many of these plays, operators are turning to horizontal drilling and hydraulic stimulation to increase wellbore exposure to productive formations. However, horizontal or high-angle wells can be difficult to evaluate. Often, these wells cannot be logged on wireline without specialized conveyance equipment, which frequently results in added expense and operational delays. An unfortunate consequence is that some operators forgo the acquisition of petrophysical data entirely.

In high-angle wells, the combined effects of borehole trajectory and geology hamper an operator’s ability to acquire the data needed to assess a reservoir and develop a stimulation program to enhance payout. To meet the challenges of high-angle wells, the industry has steadily refined technology for acquiring openhole logs. Logging while drilling (LWD), tractor conveyance and various pipe-conveyed logging techniques are just a few of the options currently available. Nevertheless, there are costs—in the form of tool rentals or rig time—associated with these alternative methods.

In the unconventional plays of North America, such costs may adversely impact development strategies. A major factor in field development economics is the cost of drilling and completing each horizontal well. It is therefore common in some unconventional plays for operators to limit use of logging suites. Often, gamma ray logs obtained by measurement-while-drilling (MWD) tools are used during geosteering to determine stratigraphic position. For some wells, the MWD gamma ray log may provide the sole petrophysical input for designing perforating and formation fracturing programs. Although the gamma ray log may help geologists identify target zones through correlations with offset well logs, gamma ray measurements alone are not sufficient to characterize reservoir properties that impact production. Measuring lateral and vertical variations in lithology, mineralogy, grain size, porosity, permeability and fluid content in complex unconventional reservoirs requires a suite of logging tools.

The capability to identify changes in reservoir rock, which petrophysical logs provide, can significantly affect a well’s completion program and its economics. This is particularly relevant for unconventional plays or other tight formations, in which fracture treatments must be divided into several stages to stimulate a pay zone that extends thousands of feet along a horizontal wellbore. By excluding some zones, while selectively perforating and stimulating the intervals most likely to be productive, operators may reduce the number of stages required to optimally fracture a reservoir. Decreasing the number and length of stages conserves water, sand and other resources, thereby reducing expenses and the overall impact of well stimulation.

A unique, cost-effective logging system has been developed to help operators obtain valuable formation data in high-angle wellsbores. The system, developed by ThruBit LLC, uses mud pump pressure to deliver small-diameter logging tools down the center of the drillstring and out through a specialized bit to log the open borehole beyond. Traveling through this drillpipe conduit to TD, the tools are pumped through the bit opening where they can survey the formation as the drillpipe is tripped out of the hole. Schlumberger acquired ThruBit LLC in 2011.

This article provides an overview of the equipment and deployment system that make the ThruBit logging technique possible. Datasets obtained with this system help demonstrate its quality and usefulness.

**Logging Essentials**

The concept of logging through the bit centers on two requirements: logging tools that are small enough to pass through the open borehole. The ThruBit logging system uses specially designed logging tools that combine small diameters with high-pressure, high-temperature capabilities. At 2½-in. diameter, all tools in the SureLog suite are small enough to pass through the center of most drillpipe, jars, collars and bits (above). Each tool can withstand temperatures to 300°F [150°C] and pressures up to 15,000 psi [103 MPa]. These tools can be run in combination to obtain a full suite of measurements during a single logging run.

The SureLog telemetry, memory and gamma ray device is run as the topmost logging tool to provide communications and memory functionality for the entire logging string. The gamma ray detector measures naturally occurring gamma rays in the formation to provide a qualitative evaluation of clay content. A multiaxis accelerometer in the tool monitors downhole tool orientation, motion and vibration. The tool also measures borehole inclination and temperature.

The array induction tool has five median depths of investigation and three vertical resolutions. In some configurations, a combinable spontaneous potential (SP) tool is run immediately below the induction tool. The SP measurement gives a qualitative indication of formation shaliness and permeability and can be used to determine equivalent formation water resistivity. A mud resistivity sensor is built in for array induction tooling in formations whose compressional and shear velocities are faster than the tool. This allows extended measurements for environments rich in clay. The raw measurement processing includes a correction algorithm that preserves overall density accuracy across a wide range of borehole sizes, mud types and mud weights. The tool’s scintillation detectors are housed in an articulated pad for better contact with the formation to improve overall measurement quality in deviated and rugose holes (next page, top left). The density tool uses a single-arm caliper to measure hole size and to press the tool against the formation.

The SureLog waveform sonic tool has a monopole transmitter and a six-receiver array. Waveforms recorded at each of the six receivers are subsequently processed using a slowest-time coherence technique to obtain compressional (T<sub>p</sub>) and shear (T<sub>s</sub>) velocities. Monopole shear velocity can be determined from the sonic measurement in formations whose compressional and shear velocities are faster than the acoustic velocity in mud (V<sub>med</sub>). The Portal PDC bit is designed to allow logging tools to pass through the end of the drillstring without requiring removal of the bit. This bit is hollow at the center, with a 2½-in. [63.5-mm] opening at its crown—the center of the bit face (next page, top right). The bit design is adaptable to almost any PDC bit model ranging in size from 5½ in. to 12½ in. in diameter. The bits are manufactured in a variety of blade and cutter configurations to accommodate drilling and lithology requirements.
A hangoff sub, positioned above the Portal bit, enables the logging sensors to extend immediately beneath the bit when logging in memory mode. In this mode, the wireline is detached from the toolstring and retrieved to the surface. Batteries power the tools, and the log data are stored in onboard memory. The hangoff sub precisely positions the logging tools as they extend through the opening in the bit. This sub restricts the movement of a no-go collar located near the top of the logging toolstring. The sub prevents the no-go collar from traveling farther downhole while permitting the logging sensors to protrude into open hole, just beyond the bit face.

ThruBit surface pressure equipment is designed to control the well in the event of an unexpected surge in pressure. This equipment allows the driller to rotate and reciprocate the drillstring and to circulate while deploying logging tools. A float valve may also be installed in the bottomhole assembly (BHA) to provide an added measure of well control. This flapper-style float valve allows logging tools and ancillary equipment to pass through the valve in both directions.

**Downhole Deployment**

The ThruBit deployment system uses the Portal bit to ream and condition the wellbore in preparation for logging. Once the BHA has reached logging depth, the drilling crew trips the BHA out of the hole to install a Portal bit and hangoff sub. As the Portal bit and hangoff sub are tripped back into the hole, the driller uses the Portal bit to ream past ledges and tight spots encountered on the way to TD. Once the wellbore is conditioned for logging, the driller positions the bit just above the base of the lowest interval to be logged, leaving only enough open hole for the logging sensors to extend beyond the bit.

With the Portal bit at target depth, the logging crew inserts the SureLog toolstring into the drillpipe, installs pressure control equipment and lowers the SureLog suite of tools on wireline. The wireline connection allows the ThruBit logging engineer to create a downlog and monitor toolstring functionality from the moment the logging tools leave the surface until they are switched to memory mode. The drillpipe protects the logging tools and wireline as they are lowered downhole.

At the point where wellbore inclination prevents gravitational descent, the rig’s mud pumps are engaged to pump the tools to the end of the drillstring. The drillpipe provides a smooth bore to ensure that the small-diameter tools deploy to the bit face. Pump pressure and mud flow force the logging sensors out through the opening in the Portal bit. The tools stop once the no-go

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3. In some wells, the ability to circulate during logging may prove helpful in reducing borehole temperature when the bottomhole temperature approaches the tool’s temperature rating.

The device near the top of the toolstring reaches the hangoff sub.

The logging engineer performs a final check of toolstring functionality before opening the caliper on the density tool. Accelerometers inside the tool verify that the density skid is oriented against the low side of the hole. The logging engineer then signals the toolstring to release the wireline. The wireline and the upper part of a dropoff and retrieval assembly are reeled back to the surface and removed from the drillstring. This leaves a fishing neck exposed at the upper end of the logging tools to permit ready retrieval of the tools and the density and neutron sources through the drillpipe at any time—eliminating the need to trip pipe.

Operating in memory mode, the logging tools survey the formation and record the data as the drillpipe is tripped out of the well. After the zone of interest has been logged, the logging crew can lower a retrieval tool on wireline to retract the logging tools back through the Portal bit and drillpipe. With the toolstring retrieved to the surface, the driller is free to resume normal operations in preparation for the next phase of well activity (above). Alternatively, the tools can simply be tripped to the surface with the pipe.

ThruBit logging sequence. A Portal bit is used to ream to TD to prepare the hole for logging (1). The driller pulls the bit off bottom, leaving enough room to accommodate the SureLog suite of logging tools. The logging toolstring is pumped through the drillpipe (2). With tools positioned beneath the bit, the ThruBit logging engineer verifies tool function, then disconnects the wireline and draws the cable back to the surface (3). As the drilling crew trips pipe out of the hole, the logging tools survey and record formation data (4). Logging is complete when the tools are pulled up into the casing (5). With the bit and tools inside the casing, the logging crew lowers the retrieval tool on wireline, latches the tools and retrieves them to the surface (6). Once the logging tools are recovered from the drillstring, the driller is free to ream to the bottom or resume other operations in preparation for the next phase of drilling (7).
However, early retrieval permits the data to be downloaded, verified and transmitted while the pipe is still being pulled out of the hole—providing more time for the operator to plan completion operations.

This deployment system can positively impact a logging operation. The rig time spent on acquiring logs is reduced because deployment and acquisition can take place during the conditioning trip. Because they are not deployed until the bit is in position near TD, the tools receive less exposure to shocks, vibrations and high temperatures. Risk is minimized because the tools are retrievable and the system provides the driller with full well control capability. Thus, if well conditions deteriorate, and the drillpipe becomes stuck, the logging tools and the density and neutron sources can be retrieved prior to activating jars or implementing other stuck pipe procedures. With the logging string laid out on the catwalk, the driller may jar the drillstring without fear of damaging the tools.

The flexibility of this system is opening the way for its use in other challenging logging situations.

**Field Applications**

The geometry of extended-reach wells makes them inherently difficult to log. Unconventional plays, commonly exploited through horizontal wells, have created a demand for specialized conveyance techniques. As the number of plays proliferated across the US, they provided a proving ground for ThruBit logging technology. The use of this technology has since expanded to other unconventional plays where high-angle wells make logs difficult to obtain.

In North Dakota, USA, Oasis Petroleum, Inc. utilized the ThruBit logging system to evaluate a Bakken Shale well drilled to 20,766 ft [6,330 m] MD with a 10,000-ft [3,050-m] lateral section. The well had a 29.5°/100-ft [29.5°/30-m] radius of curvature and was deviated up to 91° from the vertical (below). Oasis used a Portal bit during the reaming run to prepare the hole for logging prior to running production liner. The

^Logging an extended-reach well. Oasis Petroleum used the ThruBit system to log a well drilled in the Bakken formation. The 20,766-ft well, with a 10,000-ft lateral section, was deviated up to 91°. The hangoff assembly, battery and retrieval tool (inset) enable logs to be recorded in memory mode as pipe was tripped from the well. The tools can be retrieved at any time after the wireline is released. (Adapted from Reischman and Porter, reference 4.)
ThruBit system enabled the driller to maintain circulation as logging tools were deployed around the curve and through the extended lateral section. The SureLog suite of logging tools safely passed through the drillpipe and out the bit to acquire formation evaluation data as the pipe was tripped out of the well. In a single logging run, Osage geoscientists obtained the petrophysical data they needed to evaluate the Bakken section.

In Barber County, Kansas, USA, Osage Resources, LLC sought to optimize perforation placement and length of fracture stages in a horizontal well drilled in the Mississippi Lime play. This play, initially discovered and exploited through vertical drilling, is being revitalized through horizontal wells and multistage fracture stimulation treatments. The Mississippi Lime is highly variable, consisting of limestone, dolomite and siliceous deposits of tripolite, chert and spiculite. To properly evaluate the well, Osage needed more than an MWD gamma ray log.

The ThruBit logging crew made up a SureLog quad-combo toolstring, consisting of gamma ray, caliper, resistivity, neutron, density and sonic tools. This toolstring was pumped down through 4-in. drillpipe, and the logs were recorded in memory mode as drillpipe was tripped out of the hole. Once the logging tools reached casing, they were retrieved to the surface by wireline. With the 6½-in. Portal bit still downhole, the driller was able to ream back to TD for a final cleanup trip in preparation for a subsequent casing run.

The log data revealed significant lithological changes along the length of the lateral wellbore (next page). This information prompted Osage engineers to reassess their initial stimulation strategy and shift focus toward treating the toe of the wellbore, where better reservoir conditions were found. Sonic data were used to compute a brittleness curve. This curve provided a basis for dividing the stimulation into separate intervals according to rock type, which helped the operator optimize stage lengths, pad sizes and perforation clusters. Sonic waveform data indicated where the formation was naturally fractured along the wellbore, which helped Osage engineers design a hydraulic fracturing program that minimized the risk of early screenout during stimulation. They added another fracturing stage to the plan and successfully completed the revised stimulation program. The well is producing significantly better than other Mississippi Lime wells in the area.

South Texas, USA, has seen a resurgence in drilling as oil and gas companies pursue new unconventional plays. In Gonzales County, Forest Oil Corporation has drilled several wells to develop the Cretaceous Eagle Ford play. To exploit a rather narrow oil window, the company drills high-angle wells that target a 20 ft [6 m] thick sweet spot within an 80- to 110-ft [24- to 34-m] reservoir section. These wells are typically drilled to around 12,000 ft [3,660 m] MD, and are deviated between 87° and 92° with lateral sections of about 5,500 ft [1,675 m] through the Eagle Ford.

Working from 3D seismic data, Osage geoscientists have identified a number of locations within the Eagle Ford to develop further. These locations were drilled with input from an MWD gamma ray tool for geosteering. Once drilled, early wells were stimulated using a geometric approach: divide the lateral section into 300-ft [90-m] stages, then perforate and fracture, pumping 240,000 lbm [109,000 kg] of sand into each stage. To execute this strategy, Forest engineers used the “plug and perf” method, in which a bridge plug is set between fracture stages to isolate perforation clusters.

After completing several of these wells, Forest geophysicists and engineers had acquired enough data to evaluate production in the Eagle Ford. The engineers noted that, although several wells had been drilled and completed in a similar manner, production varied widely once the wells were brought on stream. Some wells were producing significant volumes of high-salinity water, not common to either the Eagle Ford or the adjacent Austin Chalk formation above. This water was attributed to the Buda or the Edwards Limestone and indicated that the hydraulic fractures had penetrated below the Eagle Ford, providing a water migration pathway to underlying formations.

Forest Oil engineers and geoscientists mounted a study to determine why some wells stood out—either as good or bad producers—and to fine-tune their drilling and completion strategies in this formation. Their investigations sought to achieve the following outcomes:

- optimize the landing section in future horizontal wells
- improve fracture cluster efficiencies and fracture initiation
- prevent water production from underlying formations
- reduce stimulation and completion costs.

Central to their study was the capability to acquire and analyze log data from the horizontal wellbores; thus, they carefully weighed the conveyance options. Forest had concerns with slickline retrievability of MWD components, needed for geosteering, in the event that LWD tools were used to evaluate the formation; other pipe-conveyed methods for logging consumed extra rig time. Needing to evaluate the producing zones, Forest used ThruBit logging to obtain a suite of logs in horizontal wells slated for an upcoming drilling campaign.

As these wells were drilled, the driller made a series of short trips to clean out cuttings beds from the horizontal section. Once the hole was conditioned, the driller tripped the directional BHA out of the well and ran back in the hole with a Portal bit and hangoff sub, reaming past any tight spots on the way to TD. The SureLog quad-combo logging suite was then pumped through the drillpipe to TD on wireline. The logging tools were pumped out through the Portal bit. Once the logging engineer verified toolstring operability, the tools were released from the wireline, which was reeled back to the surface. The logging tools recorded formation data in memory mode as the drillpipe was pulled out of the hole. After it reached the casing shoe, the toolstring was retrieved on wireline and the data were downloaded. If needed, the driller could then make another conditioning trip back to TD before laying down pipe for a casing run. By combining the logging run with a conditioning trip, the operator saved more than 24 hours of rig time when compared with the time needed for conventional pipe-conveyed methods.

Forest Oil geophysicists used sonic and density data to derive rock properties such as Young’s modulus and Poisson’s ratio. Shear-wave anisotropy from the SureLog sonic tool enabled Forest geophysicists to compare attributes of natural fractures in the wellbore with those seen in 3D seismic data. This information was instrumental in mapping new exploration targets and providing a better understanding of the seismic attributes needed to evaluate their extensive acreage position for future drillsite selection.

Forest was able to capitalize on a more selective approach to fracturing. The mechanical properties data processed from the SureLog suite proved crucial for grouping hydraulic fracturing stages by highlighting rock of similar
Evaluating a lateral wellbore in the Mississippi Lime Formation. After running a SureLog quad-combo logging string in a horizontal well, Osage Resources engineers determined that formation properties varied considerably throughout the length of this horizontal interval. Porosity (Track 3) varies from 4% to 16%. The sonic waveform and shear semblance curves indicate natural fractures (Track 4, yellow) through some intervals. A brittleness calculation (Track 5), which is used to produce a quicklook curve related to the stress profile, also shows contrasts in brittleness. Based on these curves, along with elevated resistivities (Track 2), Osage Resources was able to select optimal zones for hydraulic stimulation (Track 4, yellow).

Evaluating a lateral wellbore in the Mississippi Lime Formation. After running a SureLog quad-combo logging string in a horizontal well, Osage Resources engineers determined that formation properties varied considerably throughout the length of this horizontal interval. Porosity (Track 3) varies from 4% to 16%. The sonic waveform and shear semblance curves indicate natural fractures (Track 4, yellow) through some intervals. A brittleness calculation (Track 5), which is used to produce a quicklook curve related to the stress profile, also shows contrasts in brittleness. Based on these curves, along with elevated resistivities (Track 2), Osage Resources was able to select optimal zones for hydraulic stimulation (Track 4, yellow).
Forest Oil log montage. This Eagle Ford formation evaluation interpretation combines ThruBit data with cuttings analysis and computed rock properties to determine the optimal placement of fracture stages in a South Texas well. Although gas spikes (Track 5, green) are seen throughout this interval, the sweet spot in this horizontal well extends from about W,700 to Z,400 ft measured depth. Onsite geochemical analysis of wellbore cuttings obtained through this interval shows a marked increase in total organic carbon, or TOC, (Track 2, black dots) and S2—hydrocarbons generated by thermal breakdown of kerogens (Track 2, purple curve), key indicators of source rock quality. Sonic data (Track 7) show a clear change in the elastic properties of the formation in this zone. While the P-wave maintains a constant slowness (solid black) throughout the interval, the S-wave splits into two distinct arrivals. The spread between the fast (dashed black curve) and slow (black dotted) S-wave slownesses is an indicator of anisotropy, possibly attributed to fractures. Using all of the data together, Forest Oil elected to divide the stimulation program into 19 stages. After the stimulation treatment, tracer logs (Track 6) helped verify that modifications to the stimulation program created more complex fractures throughout each stage, opening more rock face to production. This optimized completion strategy resulted in increases in production relative to surrounding wells that had used simple geometric fracture treatments.
properties (previous page). This information was used in 3D fracture design programs to optimize and confine the fractures to the Eagle Ford and overlying productive Austin Chalk formations. Based on these log data, the company now plans 220-ft [67-m] fracture stages and has saved on stimulation costs by reducing the volume of sand pumped into each stage by one-third. Wells stimulated in this manner are producing significantly better than those fractured using the previous geometric approach, and none have produced the high-salinity water associated with deeper formations. Overall, Forest Oil has reduced completion cost per stage by about 60% while increasing the number of stages per lateral section. Also, oil production averaged over a 30-day period has doubled in comparison with the output of earlier wells.

**Evaluation Tools**

To increase wellbore exposure to unconventional reservoirs, operators usually need to drill horizontal wells. These formations generally exhibit high natural gamma ray activity, so gamma ray logs are useful for distinguishing lithologies. Although effective as correlation tools, gamma ray measurements are not sufficient for distinguishing productive from nonproductive zones, much less for designing stimulation programs.5

Rather than relying on a geometric approach to developing these wells, operators who run a comprehensive suite of logs across the target zone can base their completion programs on reservoir quality and geomechanical properties. With this information, operators can selectively target the best zones to stimulate, while eliminating unproductive zones from their completion program. Compressional and shear velocity measurements from the SureLog multireceiver monopole sonic tool provide input for the ThruBit Geo-Frac analysis program to compute rock properties, Poisson’s ratio, static Young’s modulus and minimum horizontal stress gradient. The stress data and indicators of reservoir quality, such as clay content and porosity, are useful in selecting optimal completion zones for hydraulic stimulation. Using the Geo-Frac analysis, the operator can identify zones along the lateral that are most likely to be productive (above).

Data from the Geo-Frac program may also be imported into Mangrove stimulation modeling software, which was developed by Schlumberger to address unconventional hydraulic fracture design. The Mangrove system generates a score based on reservoir quality and completion quality to rank the intervals of similar rock properties along a wellbore. Those intervals that score high in reservoir quality and completion quality are prime candidates for hydraulic fracture stimulation. This evaluation facilitates selection of locations for optimal completion stages and perforation clusters.

**Portal of Opportunity**

High-angle and extended-reach wells have been central to the development of new plays in tight reservoirs and organic-rich source rocks. To increase wellbore exposure to productive zones in these plays, many operators drill horizontal wells; but drilling is only part of the story—well stimulation is another key to unlocking resources from formations previously deemed unproductive. Hydraulic fracturing is typically required to stimulate these tight formations, and a number of advanced programs have been developed to help operators optimize the fracturing process for each well. All of these programs rely on petrophysical data.

Well logs are vital for identifying intervals likely to benefit most from stimulation. Operators who use this data-driven approach to selecting fracture intervals are able to reduce the amount of sand, water and horsepower expended. Without log data, they might be left with no choice but to stimulate the entire length of horizontal section—with little regard to reservoir and completion quality.

The ThruBit conveyance system helps E&P companies obtain valuable formation data along the entire length of the wellbore. It provides a cost-effective and operationally efficient alternative to standard wireline conveyance or LWD logging while saving trip time. With a Portal bit conditioning the hole before the slim-diameter logging tools are run, the ThruBit system can acquire petrophysical data in the challenging, high-deviation and extended-reach wellbores that are common to unconventional plays. Using the drillstring as a protective conduit for the logging tools and wireline, this system reduces tool exposure to the openhole environment. ThruBit logging increases the likelihood of acquiring quality reservoir log data on the first attempt, particularly when hole conditions threaten the success of conventional conveyance methods. If the bit can reach the target, so can the logging tools. —MV