Improving the Recovery of Your Well

BETTER INSIGHT, BETTER FRACS, BETTER PRODUCTION

Delivering the Lowest Cost per BOE

HALLIBURTON
Getting the Most Return on Your Investment

Gathering Data from Both Vertical and Horizontal Wells

Part of your investment needs to be in collecting data to get insight into your reservoir so you can make informed decisions. However, the data only has value if you can use it to make economic decisions, increase production, or decrease cost. Let us help you leverage that data to get the best return on your investment.

It’s well understood that openhole logging in vertical wells is the best opportunity to gather data directly from the reservoir itself. But the value of formation evaluation in horizontal wells and cased holes is just as critical.

Due to heterogeneities in the reservoir, each well is different, so gathering data from the horizontal section of individual wells is the only way to know exactly how and where to frac to optimize production. By gathering detailed information from individual wells, you can dramatically improve the effectiveness – and reduce the cost – of hydraulic fracturing.

In the following pages, you will learn how Halliburton can help you gain insight on your horizontal wells, then use that data to plan stimulation programs that maximize profitability in prospective, unproduced, and existing wells.

Halliburton is dedicated to helping you improve profitability. No matter where your field is in the well life cycle, we offer solutions to maximize BOE and optimize production for more efficient pay. If increasing recovery is your goal, Halliburton can help you reach the fullest potential.
Assessing Investment Potential

Success in complex unconventional systems requires a precisely orchestrated effort that applies a unique set of techniques. No single approach defines the path to unconventional reservoir optimization. Instead, success in each asset depends on understanding the reservoir and the nature of its hydrocarbon content to determine such fundamentals as where to drill, where to target horizontally, where to perforate, and how to stimulate for production. Answers to these and a host of other critical questions depend on highly variable unconventional reservoir characteristics. Challenges range from accurately determining mineralogy and hydrocarbon volumes, calibrating complex mechanical properties, and even predicting effective permeability. Halliburton offers industry-leading tools that can help you acquire insight faster and more reliably than ever before so you can assess investment potential.

It’s All about the Fluids and the Rock—Pressurized Rotary Sidewall Coring

Core analysis is valuable for gaining a better understanding of well conditions and estimating the storage characteristics of the matrix. Traditional coring tools can allow 50-70% of fluids in the core to escape as they depressurize during retrieval. As a result, analysis had to be based on estimates of fluids lost, rather than measurement of fluids in place. Also, conventional coring could take hours to days to retrieve just one core.

The award-winning Halliburton CoreVault® technology is changing the way reservoirs are evaluated. Unlike traditional logging and coring services, the CoreVault tool utilizes pressure-tight containers to lock in 100% of the hydrocarbons in the core. This enables direct measurement of reservoir fluids so you can avoid dry holes and accurately predict production. In an unconventional field, you can know a lot more — a lot sooner — about the size of the prize. The samples taken with the CoreVault system often reveal dramatically more oil and gas in place than previous estimates would indicate. The information obtained can significantly enhance economic value and reduce exploration and development risk for our customers.

CASE STUDY

COREVAULT SYSTEM CONFIRMS 2.5X MORE GAS IN PLACE THAN EXPECTED.

An operator in Ohio and West Virginia acquired 150 samples in five wells using the Halliburton Xaminer® Coring Tool technology with the CoreVault system. Measurements of the samples showed 2.5 times more oil and gas in place than previously estimated. This helped the operator determine the economic viability of the well and accurately predict production. For more case studies, go to www.Halliburton.com/CaseStudies

The Halliburton CoreVault system locks 100% of the hydrocarbons in the core.
Using VSPs for Azimuthal Anisotropy, Fracture Detection, and Horizontal Well Placement

Halliburton Borehole Seismic Services (BHS) helps enhance characterization and understanding of the unconventional reservoir using customized high-resolution data for AVO calibration, anisotropy estimations, and fracture detection from various types of Vertical Seismic Profile (VSP) surveys.

Understanding natural fracture orientation and density is key for understanding reservoir permeability and avoiding water production from faults and thief zones. The BHS Walkaround VSP surveys give azimuthal information about the reservoir by using a circle of seismic sources around the wellbore with the geophone array in the borehole. This method can help define fracture orientation and intensity from the velocity azimuthal anisotropy and fast shear-wave polarization direction, as well as provide important local stresses around the wellbore for determining the optimal direction to drill and frac the well.

The BHS Walkaway VSP surveys provide information about the subsurface from lines of surface seismic sources and geophone arrays in the borehole. The data can be used to help steer the horizontal wellbore section, as well as provide improved velocity and attenuation analysis for use in surface seismic processing. Also, the accuracy of the imaged stimulated fractures from microseismic monitoring can be greatly improved from the Zero-Offset VSP vertical velocity analysis and the Walkaway VSP transverse velocity anisotropy analysis. The Walkaway VSP service also estimates reservoir properties directly from the reflection amplitudes as a function of angle of incidence or offset (AVO).

BHS Walkaway and 3D VSP services provide high-resolution seismic images and reservoir properties to help identify faults and position future wells. The 3D VSP survey collects data using a large number of surface seismic sources spread out in a grid or spiral pattern.

Calculating Critical Frac Parameters—Acoustic Logging Technology

Laminated clay-rich shales often exhibit large differences between vertical and horizontal elastic properties. This anisotropy can be quantified in a 3D stress analysis utilizing fast shear, slow shear, and a Stoneley shear slowness from an oriented X-Y dipole sonic (Xaminer® Sonic Imager tool). The resulting computed 3D closure stress is a much better predictor of true fracture geometry when used in 3D frac-modeling software. The fast shear can be used for improved directional well planning. Orientation of the HTI (Horizontal Transverse Isotropy) fast shear azimuth happens to be in the direction of maximum principal stress, which is orthogonal to the optimum horizontal well direction.
Knowing the Rock Composition—
Geochemical Logging Technology

A good understanding of mineralogy is required for integrated volumetric and geomechanic characterization. The Halliburton GEM™ elemental analysis tool delivers rapid elemental weight percentages used to accurately determine the mineralogy of the reservoir. When combined with other formation evaluation tools, this data can help create very accurate estimates of reserves, more consistent rock properties, and fluid compatibilities required for drilling and production.

Defining What is in the Pore Space—
Magnetic Resonance Logging Technology

When assessing the potential of unconventional reservoirs, nuclear magnetic resonance imaging can help pinpoint the most profitable zones. The Halliburton Magnetic Resonance Imaging Logging (MRIL®) technology provides the only matrix independent method of measuring and partitioning total porosity into oil, gas, and water volumes for production.

In tight-gas sand environments, MRIL measurements are used to predict permeability for fracture flow potential and water cut analysis. This is particularly true in fine grained, or laminated, potentially low-resistivity sands containing a lot of capillary bound water. A separate time constant ratio analysis, T1 vs T2, can also be used for accurate hydrocarbon fluid typing.

In organic shales, MRIL technology has proven to be the only log porosity measurement that directly matches core measured porosity. Since solid kerogen is invisible to magnetic resonance logging technology, the difference between a conventional density-neutron crossplot porosity and the MRIL porosity is the solid kerogen volume. By knowing the existing kerogen volume and the total porosity, a Total Organic Content (TOC) material balance is done to determine the source rock's thermal maturity, independent of kerogen type. The ability to rapidly determine the rock's thermal maturity, which is related to source rock quality, enables better reservoir insight for further development.
When Resistivity isn’t Enough—
Dielectric Logging Technology

Estimating the amount of movable hydrocarbons in a reservoir is vital when making decisions about whether or not to develop it. In unconventional reservoirs, traditional resistivity measurements are often insufficient for this. A better technique for evaluating movable hydrocarbons is to measure the Bulk Volume of Water (BVW). The Halliburton LOGIQ High-Frequency Dielectric Tool (HFDT) uses a microwave signal to measure BVW in the flushed zone. Applications include measuring water saturation in the flushed zone (Sxo) and irreducible water saturation (Swr) in oil-based mud. Since the HFDT-measured BVW porosity is dependent on a well-defined matrix, complex organic shales also require geochemistry/GEM data for precise mineralogy. The difference between the HFDT-measured BVW and an MRIL total porosity is a direct hydrocarbon volume that is independent of any resistivity interpretation.

Advanced Source Rock Reservoir Analysis—
ShaleXpert® Interpretation Service

Engineers and geoscientists need reservoir characterization solutions that will define the best techniques to deliver the most shale gas and oil to the market. To define the economics of a resource play before full-scale horizontal development begins, the following interpretations are needed to provide critical information on where to place and how to stimulate your wells:

- Total Organic Content (TOC) estimation and organic maturity
- Fluid and minerals evaluation
- Advanced modeling, mechanical properties, and brittleness
- Permeability
- Pay analysis
- 3D stress analysis and orientation

Based on a calibrated workflow for organic shales, the Halliburton ShaleXpert® interpretation service integrates geochemistry, volumetric formation evaluation, and geomechanics to achieve a full understanding of shale characteristics, and enables building accurate reservoir models to exploit your resources. The final analysis brings together various workflows for primary sweet-spot identification, in-place reserve estimates, and all the data required for engineering a fracture stimulation design.
Advanced Tight-Gas Reservoir Analysis—
TightGasXpert™ Interpretation Service

Since unconventional tight-gas sands demonstrate much higher matrix permeability than organic source rocks, a tailored asset solution also exists to both optimize and predict fracture flow performance from these reservoirs. Clay typing for completion fluid planning is important; therefore, geochemistry/GEM data is often required. This asset solution requires MRIL permeability as the key input for a fracture flow simulator. Fracture geometry planning is aided with the use of the 3D stress analysis as previously described. The integrated vertical well analysis is used to group zones into individual fracture stages using similar \( k_h \) (perm thickness) and stress parameters.

All reservoir properties are supplied to a fracture flow production model. The final product includes a fracture flow rate analysis for varying fracture half lengths along with a corresponding decline curve analysis for each vertical frac stage.
Ensuring Return on New Investments

**Gather High-Quality Data, Directly from the Source**
Horizontal wells have enormous variances in reservoir properties along their length. As a result, operators that gather data from the horizontal section before they frac have a huge advantage: they know exactly where – and how – to frac in order to ensure maximum efficiency and performance for their completion and stimulation. Halliburton offers products and services for both vertical and horizontal wells to ensure and maximize your new well’s potential and return on investment.

**Cased-Hole Logging to Optimize the Stimulation—Pulsed-Neutron Logging and Acoustic Technology**
Cased-hole solutions offer advanced formation evaluation through casing and an economical alternative to openhole logging when needed. The cased-hole Reservoir Monitor Tool-3 Detector™ (RMT-3D™) service is an effective solution for evaluating the reservoir. The tool not only provides oil, gas, and water saturations, but also porosity, mineralogy, and other parameters used as input for stimulation design. When the cement is bonded to the casing and formation, cross-dipole acoustic tools (like the Xaminer® Sonic Imager) can measure formation elastic moduli and anisotropy. The acoustic and pulsed-neutron results provide information that details rock mechanical properties and reservoir characteristics along the well path, including current production zones. These integrated results optimize stimulation program design for entry locations and grouping of frac stages when needed, thereby enhancing the success of the fracture stimulation operation and the resulting production.

**Identifying Where and How to Frac—FracInsight® Interpretation Service**
Planning for stimulation in a new well requires data about the reservoir so you can identify where and how to frac. The Halliburton FracInsight® service is an advanced unconventional reservoir characterization workflow that leverages any available horizontal well logging data to optimize completion and stimulation operations. It helps planning for inconsistent breakdown and treating pressures, and minimizes untreated areas through engineered placement of perforation and fracture initiation points. This saves time and money because it is estimated that 33% of all stimulated clusters in North American shale plays contribute nothing to production.

The FracInsight service also offers a rigless solution via cased-hole logging data and is a critical component in the Halliburton portfolio for delivering the lowest cost per BOE in unconventional reservoirs.
Preparing the Well for the Best Stimulation Results—Perforating Technology

Plug-and-perf completions are by far the most widely used methodology for creating multiple hydraulic fractures in a horizontal well completed with a cemented casing/liner. Tight-gas and organic shale wells require specialized “tailored to the interval” stimulations to be productive. They also require specialized fracture design, placement, and fluids/proppants that enable the fracture network to maintain conductivity. Consistent hole size is an important parameter to ensure that each perforation tunnel contributes equally during the fracture treatment. Injection rates during any stimulation are directly proportional to the perforation hole size; therefore, gun systems with irregular casing hole diameters result in variable injection pressures, and potentially early screenouts. Large variations in perforation entrance hole diameters can increase the effects of near-wellbore tortuosity and can result in perforation holes not contributing to the stimulation, causing suboptimal fluid and proppant distribution and higher injection pressures. The Halliburton MaxForce®-FRAC charge provides the most consistent entry-hole diameters around the wellbore currently available, thus improving pressure distribution across the perforations as well as stimulation efficiency.

The Halliburton MaxForce®-FRAC charge provides the tightest variance of the entrance hole diameters currently available, thus improving pressure distribution across the perforations as well as stimulation efficiency.
Expert Analysis and Collaboration

Gathering information is just the first step toward improving performance. Halliburton experts help interpret the data and make recommendations to maximize production and minimize costs. Through active collaboration with customers and other Halliburton product lines, we can improve efficiency, saving time and money.

FIELD DEVELOPMENT PLANNING: A FULL WORKFLOW FOR UNCONVENTIONAL PLAYS

Formation evaluation is just one aspect of a larger workflow. The Halliburton CYPHER™ service effectively integrates geoscience, reservoir, drilling, and proprietary completion design in a collaborative process, enabling you to better predict and produce reserves in shale and tight reservoirs. The complete seismic-to-stimulation CYPHER service helps you navigate the entire life cycle of unconventional fields.

From exploration to mature-field harvesting, the CYPHER service can help you maximize profitability during every phase of development in a shale asset. The CYPHER service workflow is designed to address the four major field development requirements of “Where to Drill,” “How to Drill,” “Where to Frac,” and “How to Frac.” The FracInsight service is the “Where to Frac” portion of the CYPHER workflow. While the FracInsight service can be executed as a standalone service on single wells, its applicability for optimized reservoir contact and drainage is enhanced as an integral part of the CYPHER multiwell field solution.
Increasing Return on Existing Investments

In wells with declining production, detailed reservoir characterization is vital for optimizing the restimulation operation to achieve or exceed the goals for the return on investment. Halliburton has been highly successful in increasing production in existing wells through refracturing treatments. With decades of experience and thousands of operations in every kind of well, our experts have the knowledge to gather and analyze critical information from vertical and horizontal wells to give our customers the edge in revitalizing unconventional plays. Whether you’re interested in accessing new parts of the reservoir or refracturing existing wells, we can help you increase recovery and value in existing assets.

Diagnosing Production Challenges—Production Logging Technology

For restimulating or reinvesting in your reservoir, it’s important to have the right data to make the most out of your well. Production analysis can help provide insight on what zones were less effective so that a restimulation program can be optimized using the additional information.

The Halliburton Array Production Logging suite provides detailed information on the production coming into the wellbore from each stimulated area. If anomalies are found, the production data is analyzed further with reservoir and fracturing information to determine reasons for variances. This type of analysis can be used to develop procedures that will help optimize further stimulations or restimulation.

Array production logging is also used to determine effectiveness of the restimulation in different stages. The data provides the design engineers with much needed information and verifies that projections of well data still have high confidence. If it does not, additional logging information would be needed to pick fracture entry points in the reservoir for a more complete stimulation of the well in viable areas to increase production.

Checking the Well before Restimulation—Cement Bond Integrity

In unconventional wells, well integrity can play an important factor in the decision on where and how to restimulate the well.

Cement evaluation in the horizontal section of a well is becoming a more common practice in the oil and gas industry, especially in unconventional wells. Operators need accurate data to ensure that there is isolation and integrity around the casing. It will help ensure that the stimulation fluids drive into the targeted formation rather than up or down the casing annulus. The Halliburton CAST™ (Circumferential Acoustic Scanning Tool) solution uses ultrasonic sensors with complete azimuthal measurement capabilities to create a 360° image of the casing and cement bond in real time. When cement bonding needs to be known, Halliburton cement evaluation services are paramount for your well.

Horizontal production logging can provide detailed information related to the well’s flowing dynamics and contribution from each zone. Illustrated is a section of a horizontal well showing how the phase holdups can change rapidly.
Restoring Initial Production—
FracInsight Refrac Interpretation Service

Up to 80% of frac stages contribute little to no production. To address this, the Halliburton FracInsight Refrac service leverages the same FracInsight software used to ensure the return on your initial investment. When analyzing for refracturing, it combines all the information gathered and simplifies it into optimum perforation points, with the additional rock properties information required by the frac planners. This makes it easier and clearer to make the right restimulation plans to optimize performance.

When refracturing a horizontal well, it is crucial that similar fracture gradient points are picked in between existing fractures so that we can access all points for refracturing. When frac gradients vary greatly, the higher gradient entry points may lead to portions of the well not being restimulated. Since most unconventional wells are drilled with minimal logging-while-drilling (LWD) data, picking the optimal perforation points can be challenging to say the least. However, when we combine the FracInsight Refrac service with the RMT-3D pulsed-neutron logging service, we can achieve an accurate picture of the best new fracture entry points in the well. By having correct entry points identified with new detailed information, the new refracture program design will increase stimulation effectiveness and production performance on the well.

The FracInsight Refrac service uses the data available to project stress magnitudes, brittleness, Frac Index, Production Index, and other data to help engineering to design the most optimum fracture treatment.

Halliburton has the experience and knowledge to successfully restimulate your well. In this example from Eagle Ford Shale (gas window), refracturing the well led to a 300% increase in production, improving the overall recovery potential.
Delivering the Lowest Cost per BOE

Our People: Transforming Technology into Value

Reservoir characterization technology and the data it produces have no value unless our customers can use the information to make economic decisions. The value is in the interpretation. Halliburton Formation and Reservoir Solutions (FRS) transforms customers’ data into reservoir insight, creating a clearer understanding of the formation so that operators can make sound decisions. Our FRS team works hand-in-hand with the Halliburton Tech Teams in a collaborative effort to improve recovery of your unconventional wells, no matter where they are in their life cycle.

Formation and Reservoir Solutions

Halliburton FRS is a large, international group of geoscientists who transform reservoir characterization data into reservoir insight through data processing and interpretation services. This insight allows our customers to make better decisions in developing their reservoirs. FRS provides expertise in borehole geophysics, borehole geology, petrophysics, reservoir engineering, production evaluation, and completion evaluation.

Our industry-leading reservoir characterization workflow-based interpretations include ShaleXpert, TightGasXpert, CarbonateXpert™, TurbiditeXpert™, and FracInsight services. FRS also works hand-in-hand with Halliburton Tech Teams to assist our customers in consistently achieving optimal production from unconventional reservoirs.

Tech Teams

Halliburton Tech Teams embody more than three decades of unconventional development knowledge from operations in all of the major basins in North America, and around the world. Their ability to transfer and modify best practices from one play to another, while accounting for differences in local geology or geography, is an advantage that only Halliburton offers. Each Tech Team brings basin-specific engineering expertise in drilling, logging, perforating, zonal isolation, completions, and fracturing. They also specialize in integrating the application of these technologies for maximum results in terms of optimized production and reduced cost per BOE. They do this, in part, by building and constantly evolving models with a focus on maximizing initial and high sustained recovery over the life of the shale well. The Tech Teams are also responsible for deploying the Halliburton CYPHER service. This service enables strong collaboration between customer asset teams and local Halliburton Tech Teams through a complete, integrated unconventional development workflow.
Sales of Halliburton products and services will be in accord solely with the terms and conditions contained in the contract between Halliburton and the customer that is applicable to the sale.

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