Why Choose Halliburton as a Deepwater Partner?

- Dynamic Health, Safety, Environment, and Service Quality philosophy permeates all of Halliburton’s work, from the top management down. Our ethic, enforced throughout the company, states that every person is responsible not only for their own personal safety, but that of the people who work around them. All employees are empowered with Stop Work Authority, compelling any unsafe work to cease until a resolution is created.

- Comprehensive training and competency of all employees is enforced throughout the organization. Working safely and protecting the environment is a condition of employment, and is an absolute requirement at all our work locations as well as the communities in which we work. Compliance with applicable laws and regulations is mandatory.

- Innovative research and development and manufacturing centers include 15 state-of-the-art facilities around the world. Two of these centers opened in the past year (Houston Technology Center in 2012, Singapore Manufacturing and Technology Center in 2013), with another, in Rio de Janeiro, arriving soon. These centers enable closer collaboration with the customer to deliver deepwater-specific answers to any challenges that may arise.

- Groundbreaking deepwater-specific technologies enable new reserves to be recoverable that were not previously accessible. These solutions maximize recovery in deeper, more complex, and more remote environments while minimizing nonproductive time without sacrificing safety, quality, or ecological responsibility.
  - The award-winning Enhanced Single-Trip Multizone (ESTMZ™) FracPac™ completion system is designed specifically for deepwater and ultradeepwater to reliably deliver a high volume of proppant at a high flow rate in just one trip, thus stimulating more of the reservoir in less time. This increased efficiency saved 18 days, on average, and reduced costs by approximately $22M for an average Gulf of Mexico Tertiary Completion.
  - The EquiFlow® Autonomous Inflow Control Device (AICD) minimizes migration of unwanted fluid (such as water) to the wellbore, enabling a well to be more productive. It has won many technical awards around the globe.
  - The VersaFlex® Low Equivalent Circulating Density (ECD) expandable liner-hanger system is ideal for deepwater and mature assets. This system has trip-in speeds and circulation rates up to 90 percent better than standard liner-hanger systems, and a high torque rating to enable aggressive reaming and drill-in without the risk of the well packing off at the hanger area or presetting.

- Flexibility to procure and deliver to remote locations, enabling new frontiers to be developed where the oil and gas were previously unreachable.

- Integrated global presence, including shore bases and completion boats strategically placed to efficiently serve the customer with fit-for-purpose solutions no matter the challenge, capacity, or location.

Halliburton is committed to delivering safe, reliable, and efficient solutions that bring “bottom-line value” to the oil and gas stakeholder.
HALLIBURTON’S COMMITMENT TO EFFICIENCY AND RELIABILITY

As water depths and distance to shore increase, as reservoirs and completions become more intricate, and as budget pressures intensify, we must constantly find new ways to deliver reliable solutions that enhance safety, increase efficiency and protect the environment to solve the many challenges of deepwater oil and gas development.

Halliburton's success in this effort stems from our ability to bring reliable equipment, resourceful people and innovative technology to bear on each project. Our goals are higher ultimate recovery, lower development cost, minimum environmental impact, and a shorter time to first production. And we deliver these results by reducing uncertainty, applying comprehensive reservoir characterization solutions, and driving ultra-reliability and integrity in every deepwater well construction and completion project.

Without HSE, however, there can be no efficiency or reliability. Strong health, safety, and environmental and service quality principles permeate our organization and guide each element of our global operations.

Halliburton has built these strengths on a multi-decade track record that continues to meet the increasingly complex challenges of deepwater operations. We collaborate with our customers and across our organization to ensure each project is viewed from a full range of perspectives. And we apply the lessons we have learned to enhance the value of deepwater assets from the US Gulf of Mexico, to West Africa, to the Asia Pacific region, and elsewhere around the globe.

From the first well, Halliburton played a role in helping Brazil become a leader in deepwater development; our focus on that region now includes a Technology Center. Behind our deepwater success are dedicated, resourceful and innovative people prepared to apply Halliburton resources to help you find, evaluate, develop, produce and optimize the value of your deepwater projects.

Dave Lesar
Chairman, President and CEO, Halliburton
HSE AND SERVICE QUALITY EXCELLENCE

Effective health, safety, and environmental (HSE) and service quality processes permeate Halliburton’s global business, and provide the foundation that makes our broad range of services efficient and effective.

To achieve our HSE goal of zero incidents, Halliburton depends on a methodical approach to continuous improvement of our HSE systems.

We believe that zero HSE incidents is an attainable goal. It has been achieved in various business lines and in many of our locations across the globe. Our mission is to make these examples of HSE excellence repeatable across all of our business lines in all locations—all the time.

The following principles guide our global operations, including deepwater asset development:

- HSE incidents are preventable
- Leadership and management commitment are fundamental
- HSE performance is each individual’s responsibility
- Compliance with applicable laws and regulations is mandatory
- Working safely and protecting the environment are conditions of employment
- Stop any task or operation if a concern or question regarding an HSE risk exists

Halliburton also is at the forefront of regulatory compliance. Our products meet or exceed federal and state governmental regulatory requirements and help to reduce HSE concerns.

To ensure our operations and materials contribute to the continued development of oil and gas, especially where environmental restrictions are rigorous, Halliburton recently implemented an HSE strategy defined by six key objectives:

1. **Provide effective leadership and commitment.**
   To demonstrate their commitment to HSE, our leaders will conduct workplace inspections and incident investigations, establish clear expectations for their team members, and encourage each employee to become a workplace HSE leader. If performance falls short of expectations, leaders will take action to improve results.

2. **Maintain strict adherence to the Halliburton Management System (HMS).**
   Following established processes is critical in mitigating HSE risks and reducing the number of HSE incidents. HMS, comprising all our work-level processes and procedures, enables employees to deliver service that is safe, environmentally sound, and reliable.

3. **Ensure the training and competency of the workforce.**
   Halliburton HSE training gives employees the skills and knowledge to perform their jobs safely and competently. That training prepares employees to recognize hazards, prioritize risk and assign controls to reduce risk to an acceptable level; and to understand internal and external reporting requirements. It also provides a basic knowledge of applicable regulatory requirements and emergency response procedures.

4. **Encourage employees to communicate and address risk.**
   Employees are expected to observe each other’s HSE performance and intervene when necessary. All employees or contractor personnel who observe an unsafe action or condition have an obligation to intervene by taking one or all of the following actions:

   - Communicate concerns directly to the persons involved
   - Correct the condition or situation
   - Relay the concern to the appropriate supervisor or customer representative
   - Shut down the job (within the scope of responsibility) if clear and present danger exists
5. **Continuously improve technology and processes.**
   Our continuous risk management process uses rigorous risk assessment tools to identify and reduce risk on the path to an incident-free workplace. Our Management of Change (MOC) process helps ensure that the impact of new risks is managed and documented properly. Because data show that the highest risk to our employees at work comes from vehicles, pressure releases and dropped objects, we maintain strategic efforts in these areas.

6. **Verify and assure expected performance.**
   Halliburton verifies the effectiveness of its HSE management systems through global HSE audits, HSE site self-assessments, and tiered inspections (routine inspections of work areas). It is the job of management at each site to review findings and to make the changes needed to ensure improvement.
RESOURCES PEOPLE FOR EACH JOB, EVERY LOCATION

There may be no oil and gas development challenge for which being “resourceful”—creative, practical, capable, quick-witted—is more critical to success than that posed by deepwater operations.

Halliburton’s deepwater personnel are some of the most experienced in the industry. These resourceful people apply their experience and specialized competencies throughout our global organization to optimize the efficiency of manufacturing, supply chain management, R&D efforts, and field operations.

At the heart of any deepwater project is the safe, efficient execution of day-to-day field operations. To ensure safety and enhance efficiency, Halliburton’s deepwater offshore personnel must have documented competencies for their specific jobs. The result of applying these competencies is a significant positive impact on the project’s life cycle economics.

There is another way our resourceful people can have an impact on project efficiency. If you lack a sufficient number of qualified personnel, we can provide support for the design, planning, and operational activities, and assist with overall field and logistics management. This support can help ensure that consumables arrive at the well site on time and are installed properly.

DESIGN AND BUILD

One of Halliburton’s key differentiators is the ability to design and build our own equipment. Because Halliburton field personnel have direct input into equipment design, our tools serve the multiple goals of reliability, safety and efficiency. An added benefit is a unique level of standardization that makes components more readily available, helping to minimize nonproductive time (NPT).

Another key benefit of building our own equipment is our flexible manufacturing schedule. If a deepwater operator needs equipment to speed development of a major project, Halliburton can control manufacturing schedules to meet the operator’s timetable and facilitate quick equipment deliveries.

SUPPLY CHAIN MANAGEMENT

Because deepwater operations are remote from established infrastructure, Halliburton’s supply chain management system is designed to deliver consumables and capital equipment to any location in the world in a timely manner.

We also have extensive experience in responding to operators’ requests to establish warehouses and maintain the inventory for a project. These successful efforts are aided by an efficient inventory management system that does not burden the project with excessive overhead costs.

Weather is an inevitable—and uncontrollable—influence on the efficiency of deepwater projects. Halliburton has minimized the impact of adverse weather on our logistics by positioning our supply areas to avoid a total shutdown of all operations in a region when harsh weather threatens only a portion of that region. To serve the Gulf of Mexico, for example, we have storage locations in Galveston, Texas; and in Louisiana at Cameron, Berwick, Port Fourchon, and Venice.
DEEPWATER R&D

In 2009, Halliburton and Brazil's state energy company, Petroleo Brasileiro (Petrobras), signed a three-year technical cooperation agreement to research and develop efficient solutions to the challenges faced in developing Brazil's deepwater pre-salt resources.

The center piece of the agreement is the establishment of the Halliburton Brazil Technologies and Solution Center in Rio de Janeiro, on Fundao Island.

Brazil's highly prospective pre-salt areas pose the usual challenges of deepwater, along with those related to the special care needed when drilling through salt, and the presence of significant amounts of CO₂ in the well stream.

Halliburton is developing several R&D projects to solve these and other pre-salt complexities. Up to 15 projects are planned, including studies on fluid contamination in oil wells, lab simulation of well production, and research on cementing in salt and carbon dioxide formations.

Halliburton Brazil Technology Center in Rio de Janeiro, located on Fundao Island.
PLANNING DEEPWATER WELLS
Halliburton is also building other solutions that will provide you even more control of your asset.

For the Lower Tertiary workflow now in development, our goal is to meet logistical challenges without sacrificing completion and stimulation performance. It will perform calculations to ensure an optimum treatment is created, and mechanical and operational limitations are not exceeded.

By modeling tubing mechanics, we can understand how tubulars will react to intense heat and pressure during stimulation. It is also possible to pump less volume while creating denser fracture networks in reservoirs with internal pressures up to 20,000 psi (138 MPa) by using our industry-leading high-density, high-efficiently fluids.

To aid compliance with government regulations, we are developing a program that will monitor the barriers set to obstruct unwanted sub-surface flow during drilling.

Halliburton is also developing a robust well risk assessment program that makes it possible to plan appropriately for mechanical risk, and geological and execution uncertainty.

CASE HISTORY: Failure Diagnosis and Risk Mitigation in Record-Depth Well
In the US Gulf of Mexico, the Green Canyon discovery well required that casing be set in a 15,000-ft (4,572-m) thick section of tectonically active salt. After casing collapsed in the initial wellbore, a comprehensive model was developed to characterize wellbore stability, the salt creep mechanism and its implications for well design, and mitigation options for future wells.

The model predicted accurate in-situ stresses and pore pressures, making it possible to drill a bypass well that successfully reached a record depth of 34,190 ft (10,421 m). The modeling process also is applicable to most Gulf of Mexico extended-reach wells that will be drilled through salt sections.

To create models characterizing the interaction of casing and salt, regional pore pressure and in situ stress settings were analyzed. This analysis revealed that pore pressure shows a significant regression in the subsalt formations; if not accurately predicted, this regression can cause wellbore breakouts and losses of drilling fluids.

Models were used to replicate wellbore instability, salt creep and the interaction of halokinesis, wellbore geometry, casing stress, and drilling fluid hydrodynamics. Those models revealed that the primary cause of failure of the lightweight casing was the non-uniform contact of salt on casing, resulting in stresses greater than its yield strength.

The same model showed that heavier casing could withstand identical non-uniform stresses if loading was diametric and not axial.

This model was used to prepare an optimized drilling program that mitigated the risk of non-uniform application of stresses by salt and non-uniform application of slip loading. Recommendations included under-reaming in the slip zone, the use of drilling fluid of appropriate composition, and cementing practices that improve the stress distribution on the casing.

SPE 114273
“Casing Ultradeep, Ultralong Salt Sections in Deepwater: A Case Study for Failure Diagnosis and Risk Mitigation in Record-Depth Well.” Jincai Zhang¹, William Standifird, Knowledge Systems, Inc. (a Landmark Graphics Corporation company); Chris Lenamond, Nexen Petroleum U.S.A., Inc.

¹Current affiliation: Shell Oil Co.
**VISUALIZATION AND INTERPRETATION**

From the exploration phase, to planning the first well to field abandonment, massive amounts of data are gathered and analyzed for deepwater development. The easier the access to all the data across the field life cycle, the more efficient is the work of everyone involved in the project.

Landmark’s DecisionSpace® Desktop software is a unified visualization, interpretation, and modeling workspace that gives asset teams the ability to share data and collaborate more effectively. It delivers a true, multi-user environment with integration across multi-domain workflows and data types, all on the data-management foundation of Landmark’s OpenWorks® database.

The software delivers an enterprise-scalable, collaborative workspace and data management solution that can help harness a company’s collective expertise to evaluate hydrocarbon potential, weigh design and economic scenarios, and enhance an asset’s life cycle value. Geoscientists and engineers are able to share data, vital knowledge and ideas more effectively. The software fosters previously unimaginable levels of interpretation and modeling workflow integration and collaboration across geophysics, geology, earth modeling and well planning.

Visualization of the proposed asset development enables better ideas to be created for a more efficient asset.
ADDRESSING RESERVOIR UNCERTAINTIES

Deepwater exploration drilling is marked by uncertainty, including unknown pressures and fluids that can pose safety risks. The challenge is to acquire accurate information needed to minimize the risks in a timely, efficient way.

It is costly to pull out of the hole and run a bottomhole pressure/fluid identification assembly, especially in long drilling intervals. But drilling a low angle well that will accommodate wireline sampling—until now the only way to acquire fluid samples—then plugging back and drilling a development well is also expensive and time consuming.

CORING SOLUTIONS

In coring deepwater hard rock formations the challenge is to achieve 100% core recovery with zero NPT. Halliburton's solution is a robust coring swivel assembly (drive mechanism) that has no temperature limits and a vibration-compensating spring.

This solution, the RockStrong™ coring system, has four times the normal space out capacity and a stable double-bearing system. Formation specific, impregnated core heads provide as much as a fourfold increase in ROP in very hard rock. It is the most efficient coring system for high-temperature, high-pressure deepwater environments, allowing longer core barrels to be run, resulting in fewer trips in high spread rate deepwater environments.

Deepwater applications often require coring of unconsolidated formations, where it is critical to employ a coring assembly that captures and brings to surface core samples that can be as unconsolidated as beach sand. Halliburton's Conventional Full Closure System (CFCS) provides a complete sealing inner barrel system that is run on a conventional type core barrel swivel assembly.

ROCKSTRONG™ SYSTEM DESIGN AND ADVANTAGES

- Robust swivel assembly for harsh environment coring
- Preloaded adjustment system to withstand vibrations
- No temperature or pressure limitations
- Reliable anti-jamming design
- Secure locking mechanism to ensure proper space out
- Double bearing keeps the shaft in position
- ROP four-fold compared to previous products, with ten Ci3000 series diamond impregnated coreheads have improved ROP and long life in even the hardest rock, enabling use of longer applications, while diamond impregnated coreheads deliver high efficiency. It is the most efficient coring system for high-temperature, high-pressure deepwater environments, allowing longer core barrels to be run, resulting in fewer trips in high spread rate deepwater environments.

CASED-HOLE SAMPLING

Halliburton’s Armada® tubing-conveyed fluid sampling solution is designed for cased-hole environments ranging from normal to hostile, and can sample heavy or viscous fluids. The smooth, full-bore design allows unrestricted passage of wireline tools without damage to the samplers.

Designed for extended service in HP/HT environments, each of the nine Inconel® samplers, rated for 400° F (204.4° C) and 20,000 psi (137.9 MPa) service, will collect a 400-cc sample that is kept monophasic by nitrogen pressure. A common nitrogen section provides the flexibility to collect from one to nine samples.

A junk chamber in the sampler piston isolates the initial surge of potentially non-representative fluid. An embedded piston locator gives an early indication of sampling success as soon as the tool is recovered.

*A mark of Special Metals Corp.

REAL-TIME DYNALINK® TELEMETRY SYSTEM

DynaLink® telemetry system – a state-of-the-art wireless acoustic telemetry system for data acquisition in deepwater and extra-heavy oil conditions, is an innovative system that allows access to real-time bottomhole data. The DynaLink system can obtain acoustic communication across electro-submersible pump, and provide the client with the real time data that is needed in these deepwater, extra-heavy oil conditions.
**SUBSEA SAFETY SYSTEMS**

A reliable subsea safety system is a critical part of deepwater well testing, completion, and intervention. The subsea tree deployed within the blowout preventer stack provides dual-barrier well isolation and a method to disconnect the landing string.

Halliburton’s subsea safety systems provide the necessary well control and make both emergency and planned disconnect/reconnect procedures safer.

We provide two subsea safety systems. Our large bore, 6 3/8-in. (16.2 cm) configuration is for landing a completion in a horizontal production tree. A 3 in. (7.6 cm) system is used for drillstem testing, and provides BOP and wellhead interface.

During a well test, a temporary “completion” string allows the well to be flowed to draw down bottomhole pressure. The subsea safety tree makes it possible to shut in the well and disconnect in case of rig-positioning or well control problems. The well test does not require a production tree, so the subsea safety tree lands within the well head on the tapered wear bushing.

During completion or well intervention, the subsea safety tree runs as part of the production completion string, and also enables well shut in and disconnect capability. This system includes hydraulic lines for surface control of the tubing hanger, tubing hanger running tool, surface-controlled subsurface safety valve (SCSSV), chemical injection mandrels, and interval control valves.

Halliburton offers a suite of 15,000-psi (103-MPa) working pressure subsea safety systems that better enable operators to safely complete or work over their deepwater wells.
Our safety tree is a critical part of any landing string used to flow back hydrocarbons to a semisubmersible or dynamically positioned drilling vessel. Deployed within the drilling blowout preventer stack, the safety tree features:

- 15,000 psi (103-MPa) working pressure
- 0 to 250° F (0 to 121° C) working temperature
- Full dual-barrier well isolation
- Coiled tubing cutting ability
- 6.375 in. (16.2 cm) and 7.375 in. (18.7 cm) full bore
- Design, approval, and certification to API 6A and 14A by Bureau Veritas

**FIELD DEVELOPMENT PLAN**

Once the data from the first exploration wells are analyzed, it is critical to develop a field development plan that is cost efficient, and optimizes recovery and life cycle asset value.

To ensure that all possible field development scenarios are considered and fully understood, Halliburton’s Front End Loading (FEL) solution aligns the operator’s technical and business goals to generate a comprehensive field development strategy.

Integrating multi-disciplinary data with the industry’s latest technology, the FEL approach increases project definition and lowers risk to minimize overall project cost and maximize return on investment.

The software enables our consultants to efficiently analyze hundreds of field-development scenarios, resulting in a ranked set of economically viable development options.

Landmark’s AssetPlanner™ and Field Scenario Planner™ software on the DecisionSpace® Desktop application enables our consultants to efficiently analyze hundreds of field-development scenarios, resulting in a ranked set of economically viable development options.
REDUCING NON PRODUCTIVE TIME WHILE DRILLING
Deepwater operators face steadily increasing pressure to achieve all of a well's objectives safely and at the lowest cost.

To meet these goals, the wellbore must be delivered as quickly as possible and with the quality necessary to allow casing, cementing and completion operations to take place efficiently and without difficulty.

Halliburton's solution to this challenge is based on implementing the seamless workflow approach of the Digital Asset® framework that enables real-time collaboration to take full advantage of a range of technologies.

As an element of Digital Asset workflow, the Optimized Drilling Performance environment drives collaboration among Baroid, Halliburton Drill Bits and Services, and Sperry Drilling.

Rather than focus on discrete technologies, Optimized Drilling Performance takes a holistic approach to well construction that lowers overall well cost.

During planning, this approach solves challenges in wellbore trajectory design and integrity analysis, and the design of drilling fluids, BHAs, and hydraulics.

During execution, ODP solves these drilling challenges:
- Wellbore integrity/pore pressure/hazard avoidance issues
- Wellbore trajectory/well placement
- Rock destruction
- Drilling dynamics
- Hydraulics management

RELIABLE HOLE CONSTRUCTION
Due to narrow pressure margins, deepwater wells may need extra casing strings, which could require hole-opening operations. Often the introduction of a hole enlargement tool into a drilling BHA leads to drilling dysfunctions such as slip-stick and other modes of vibration. The risk of hole problems is minimized by use of a reamer XR™ Reamer that can be activated and deactivated on demand and has built-in vibration mitigation technology to make it the most reliable hole enlargement tool in the industry.

PORE PRESSURE AND HOLE STABILITY
Because a deepwater well can have a very narrow margin between pore pressure and fracture gradient, minimizing risk to personnel and the environment requires that these upper and lower limits be measured accurately.

Drillworks® software, Halliburton's solution to this challenge, can identify and analyze pressure compartments and perform subsalt pore pressure analysis to reduce risk and improve drilling performance. The tool can identify potential wellbore stability issues and calculate stress conditions to allow fine tuning of fluid weights and well trajectories.

We also measure pore pressure using real-time LWD data. Our QBAT™ sonic sensor can operate in holes sizes up to 30 in. (76.2 cm), allowing compaction trends to be established early in the drilling process. Downhole pressures encountered during drilling are measured with PWD sensors; during static conditions they are measured with the Replay® data capture service. Real-time monitoring of conditions during drilling using our DrillSaver™ III, PWD sensor, and TEM™ Torsional Efficiency Monitor sensor, can provide early warning of the onset of salt creep so drilling fluid properties can be managed. Real-time imaging tools designed for a variety of mud types including the Azimuthal LithoDensity (ALD™) and Azimuthal Focused Resistivity (AFR™) tools can build high resolution images that show the details of borehole breakout.

In deepwater, gas or water flows from shallow formations can result in serious well control events. Drillworks software can be used to assess these hazards while downhole PWD, QBAT™ Sonic, Gamma, and EWR® sensors can help detect unwanted influxes in time to take action.

The performance and life of the drilling assembly has a significant impact on project economics. Halliburton's solution is the MaxBHA™ design tool that configures the bottomhole assembly to drill the optimal well path and reduce NPT by improving tool reliability.

Also critical to ROP is fluids design. Baroid's drilling fluids graphics (DFG™) software provides the most accurate hydraulics modeling software available.
STAYING ON BOTTOM
Accurate modeling can help drilling assemblies stay on bottom longer. Halliburton’s Geo-Pilot® XL rotary steerable system in combination with a full triple-combo LWD string has been able to stay downhole in a deepwater environment for more than 300 hours. The tool uses the GeoForce® power sections to increase torque at the bit while reducing string rotation to minimize casing wear. Our DrillDoc™ drilling dynamics sub contains multiple sensors to monitor weight, torque, and bending movement at the tool. A state-of-the-art sensor delivers a full suite of vibration measurements.

Additional systems such as DrilSaver III system can quickly identify damaging downhole vibration by acquiring and storing surface drilling information at very high data rates and performing Fourier analysis on the data.

Halliburton’s ADT® drilling optimization service uses the “model-measure-optimize” principle to leverage specialized software and surface and downhole measurements to optimize drilling efficiency and minimize downtime.

ENVIRONMENTAL FRIENDLY FLUIDS
Halliburton’s solution to increasingly rigorous environmental regulations is our synthetic-based fluid, an alternative to oil-based fluids which helps lower the risk of severe downhole losses and reduce well costs.

Our ester/internal olefin blended mud is a combination of esters—the most biodegradable and least toxic base fluids—that will pass regulatory requirements.

For operations in Brazil’s Campos, Santos, and Espirito Santo basins, for example, we customized the fluid solutions to minimize cost and provide stable viscosities through a wide range of temperatures, high resistance to contaminants, and very low ECDs.

CASE HISTORY: Synthetic-Based Fluid Helps Save 21 Days on Deepwater Well
When a major operator wanted to drill a deepwater well in the Gulf of Mexico using the most efficient drilling practices, Baroid designed the ACCOLADE® drilling fluid system that allowed Sperry Drilling Services to pump the maximum allowable flow rate with minimum ECD. The goal was to drill the well as quickly as possible while providing good hole cleaning.

Time on location was cut by 21 days, saving the operator $1,050,000.
CASE HISTORY: Synthetic-Based Fluid System
Saves Rig Time and Mud in the GOM

An operator planning to re-enter an existing deepwater Gulf of Mexico well planned to drill four cement plugs and two cement retainers, set a cement kickoff plug, and drill a sidetrack.

The challenge was to do the job without encountering barite sag, or synthetic-based mud issues with the existing clay-free fluid that had been between plugs for 34 months.

Our solution was an all-isomerized olefin version of the ACCOLADE® fluid technology.

Two bottoms-up samples of the existing fluid were checked and the only treatments required were base oil for the ENCORE® system, emulsifier, weighting agent, and a small concentration of thinner. Mud weights ranged from 15.7 lb/gal to 16.0 lb/gal.

The active system then was used to successfully drill 2,664 ft (812 m) of 8 1/2-in. (21.6 cm) x 9 7/8-in. (25.1 cm) hole without issue.

The one-well savings of $250,000 resulted from eliminating the two days of rig time that would have been needed to perform cleanup runs, and avoiding the need to dispose of 450 bbl (71.5 m³) of existing fluid in the wellbore.

RISK MANAGEMENT

The complexity and cost of deepwater operations make effective risk management an especially critical element in Halliburton’s commitment to reliability in deepwater development.

An effective risk management program complements a well-designed HSE strategy to help ensure that risks are understood, the potential for loss is minimized, and damages can be mitigated if an incident occurs.

Boots & Coots, a Halliburton Service, created the Safeguard Risk Prevention services to provide customized training, risk analysis, contingency planning, audit programs, and well inspection, as well as blowout prevention and control counsel, and assistance in addressing identified risks. Safeguard can reduce the likelihood and consequences of accidents, assess the integrity of facilities, and help improve productivity.

Boots & Coots’ pre-event services make use of extensive experience with deep, high-pressure, high-temperature offshore wells to guide the early stages of a project. To help build efficiency into the project, consultation, well planning, dynamic kill modeling and intervention planning can be supplied prior to an incident occurring.

Prevention programs and services help save time and money by helping reduce the frequency of critical well events. Getting production back on line as quickly as possible with as little impact as possible is a key goal. Preventive services include the following:

- Well integrity programs
- Risk assessments and management
- Consequence analyses
- On-site first responders
- Crisis management
- Emergency response, well control and firefighting training
- Well control mentoring and competency
- Well control drilling specialties
- Audits and gap analysis

SPE 98279-MS

SPE 99142

SPE 92588
RELIABLE RESERVOIR CHARACTERIZATION

Data acquisition is critical to the safe, efficient construction of individual deepwater wells. Accurate data are just as vital in optimizing a development project’s ultimate recovery and its lifecycle value.

From well planning to field abandonment, key decisions affecting the safety of personnel, equipment and the environment depend on reliable information. It must be available to all parties collaborating on a project in time to take appropriate action.

From well placement to completion design—even the very viability of a deepwater project—timely data are crucial.

Halliburton’s solution to the deepwater data-gathering and interpretation challenge is a broad range of formation evaluation tools that can be deployed by either an LWD system or by wireline.

Throughout a well’s life cycle, formation evaluation data are fundamental to pore pressure analysis during drilling, for correlation to aid critical casing/coring point picks, and to evaluate potential reservoirs.

Our Optimized Formation Evaluation solution can minimize the flat-time during logging operations while ensuring data quality. Common sensors, analysis tools, and presentation formats across our formation evaluation services enable a collaborative data acquisition environment.

Halliburton’s latest generation of tools incorporates deeper-reading, higher-resolution LWD sensors and faster telemetry through data compression and customizable data streams. Greater reliability stems from component integration that puts fewer electrical contact points at risk.

When a deepwater rig has limited deck space available, requirements can be minimized by the use of a “super-combo” unit that combines SDL, MWD/LWD and wireline services.

Delivering optimized drilling performance, accurate evaluation and precise wellbore placement in real time provides greater reservoir drainage.
PORE PRESSURE
Pore pressure uncertainties are a major challenge in deepwater environments. The solution is using real-time data collected while drilling to help determine these pressures.

Our QBAT™ sonic LWD tool can provide real-time compressional data for pore pressure analysis in hole sizes as large as 30 in. (76.2 cm) and as small as 5 7/8 in. (14.9 cm). The ability to log formations in large holes eliminates the need to drill pilot holes to log these upper hole sections. The tool also provides input for advanced calculations, including synthetic seismograms and wellbore stability analyses.

It is able to acquire measurements in noisy drilling environments and poor hole conditions and use multiple acquisition modes for acoustic interpretation and evaluation in a wide range of formation velocities.

Applications of this sonic LWD tool include:

- Real-time pore pressure modeling and interpretation
- Synthetic seismograms
- (Sourceless) porosity determination
- Gas detection
- Rock mechanical property determination
- Wellbore stability analysis
- Fracture identification
- Seismic reconciliation (AVO)
- Cement bond/top-of-cement indicator

Measuring formation pressure directly in porous and permeable formations is essential in optimizing mud weights and selecting casing points.

Halliburton’s industry-leading LWD directional, gamma, resistivity, and PWD has operated successfully in deepwater to well depths over 35,000 ft (10,680 m), and at pressures greater than 32,000 psi.

The tool obtains formation pressures via LWD for real-time reservoir characterization. It can help reduce risk and uncertainty in complex reservoirs and improves economic performance in high-cost deepwater environments. The GeoTap eliminates costly wireline trips and associated rig time, and provides data within hours by reducing pump out time.
WELL PLACEMENT

Because deepwater reservoir sections can be relatively thin, accurate wellbore placement is especially important in achieving maximum production.

Halliburton’s solution is to combine geosteering with our Geosteering for the Digital Asset™ (GDA) tool with our ADR™ azimuthal deep resistivity tool to detect the direction and distance to adjacent bed or fluid boundaries. With the StrataSteer® 2.0 software, multiple wells can be modeled; with the GDA workflow, earth models can be updated in real-time.

By applying the GDA workflow to model, measure, and optimize your deepwater asset during planning, interpretation and drilling, we can decrease cycle time, enhance efficiency, and improve data quality.

In modeling geological and petrophysical properties, it is possible to:

- Use multiple offset wells to create a single integrated model
- Update predicted logs and well paths across the field based on all available data
- Create synthetic logs

REAL-TIME IMAGES

Borehole images can provide critical information about the characteristics of potential reservoirs and the condition of the borehole.

Halliburton’s LWD tools (Azimuthal Litho-Density, ALDTM and Azimuthal Focused Resistivity, AFR™ tools) provide these images in real time. Our AFR tool can provide images of the highest resolution, allowing details such as fractures and sedimentary features to be identified, and borehole breakout to be seen clearly.

Our ability to identify these features and measure their orientation provides an essential insight into wellbore conditions and an early indication of potential problems.

Our azimuthal deep resistivity tool (ADR™) acquires measurements in 32 discrete directions and 14 different depths of investigation to determine distance and direction to multiple bed boundaries. Its deeper readings improve reaction time, boosting ROP and reducing drill-out risk.

Fully compensated petrophysical-quality resistivity measurements and deep-reading geosteering measurements are combined in one tool to minimize BHA length. Azimuthal readings provide for derivation of anisotropy values (Rh and Rv) and dip.

SPE 121894

“Azimuthal Wave Resistivity Opens a Window on the Geology Away from the Wellbore Path.”
Roland Chemali, Michael Bittar, Bronwyn Calleja, Donald Hawkins, and Carlos Manrique, Halliburton Sperry Drilling. 2009 SPE EUROPEC/EAGE Annual Conference and Exhibition, Amsterdam, Netherlands, 8–11 June 2009. Copyright Society of Petroleum Engineers.
GAS ANALYSIS

Obtaining consistent and reliable gas analysis measurements that are needed for geological correlation and gas ratio analysis during drilling in deepwater is a challenge.

Certain aspects of the gas extraction process can influence gas response, skewing the measurement. For example, accurate analysis of mud-gas returns can be affected by the cooling effects of long risers.

Sperry Drilling’s services’ solution is the Eagle™ gas extraction system which heats the mud sample under a constant degassing temperature. When combined with our DQ-1000™* mass spectrometer, it can provide a detailed gas analysis of heavy hydrocarbons up to C_{10}.

By addressing the deficiencies of conventional gas traps, this system offers a true constant-volume, constant-temperature gas-in-mud extraction with consistent, repeatable results. It helps analyze drilling mud-contained gases to make reliable predictions on formation fluid type and reservoir compartmentalization, and efficiently extracts heavier hydrocarbons.

*DQ1000 is a trademark of Fluid Inclusion Technologies (FIT).

Reliable, consistent gas analyses are delivered for geological correlations and gas ratio detection during drilling operations.
RELIABLE COMPLETIONS FOR MAXIMUM PRODUCTION

Deepwater completions pose a range of technical and operating challenges, from well planning, to cementing, to providing flow management.

A properly designed completion helps achieve a successful end to the drilling process, and is vital to reservoir ultimate recovery, field life, and the economic performance of the asset.

Ensuring a clean wellbore prior to beginning a completion or new drilling interval facilitates every operation that follows. Halliburton offers a broad selection of mechanical wellbore cleaning solutions (CleanWell®) for riser and casing, and for debris removal. These tools can improve efficiency throughout the well construction process by reducing mechanical risk and saving rig time.

A SIMPLER, FLEXIBLE TRSV

As water depths increase, the limited capability of conventional subsurface safety valves has posed a challenge. Higher control system pressures often exceeded the capacity of the subsea umbilical, requiring additional seals and/or the long-term retention of gas-charged chambers to reduce operating pressures.

Halliburton's solution is a new tubing-retrievable safety valve design, the DepthStar® TRSV, which provides placement freedom and improved operating characteristics. Setting depth is not constrained and the valve operates at a consistently low control system pressure regardless of depth or well pressure.

The tool eliminates the need for a high-pressure surface-controlled subsea valve (SCSSV) line and system. Its non-elastomeric, metal-to-metal seal construction meets the demands of deepwater and high-pressure/high-temperature (HP/HT) environments. A magnetic coupler reduces the operating pressure required, because interaction between the hydraulic operating piston and the internal tubing-wellbore pressure is independent.

Completion design is simpler, more flexible, and more reliable with this new SCSSV design because it has a minimal number of body connections and moving parts, and has no moving seals exposed to the tubing wellbore. Maximum valve opening capability is 4,000 to 5,000 psi (27.58 to 34.47 MPa).
EXPANDABLE LINER HANGER

In deepwater operations a failed liner hanger operation can cause unwanted NPT or create difficulties that will be encountered when drilling ahead. Halliburton’s solution is an expandable liner hanger (ELH). The industry leader in expandable liner hanger technology provides field proven advanced liner hanger designs such as VersaFlex® Standard and VersaFlex® Big Bore liner hanger systems for offshore deepwater applications. These systems are designed for reliable deployment, setting and sealing of the liner hanger while maintaining compatibility with conventional liner tubulars and float equipment for cemented liner applications.

Our ELH makes liner hanger installations less complex, reduces potential leak paths, and offers multiple redundant sealing (packer) elements. Field proven in more than 2,600 installations, it offers these benefits:

- Integral liner top packer
- No external moving parts
- Standard wash and ream capabilities
- Rotation and reciprocation prior to and during cement job
- Handles higher pumping pressures and increased flow rates
- Smooth external radial flow path lowers ECDs

Both VersaFlex systems offer all the benefits as described; however the newest ELH system, VersaFlex Big Bore system steps up to overcome the issues seen by operators in deepwater applications where well head casing suspension systems in the larger casing strings have failed to operate properly. The VersaFlex Big Bore system offers operators the ability to set the top of the liner at any depth within the previous installed casing string and at high degrees of deviation.

VersaFlex® ELH has no moving parts which gives a greater chance for higher reliability over conventional liner hangers.
CEMENT JOB PLANNING

Predictive models of how operating variables can affect a cementing job makes a significantly positive difference when making technical decisions for safe and successful operations. With a design tool based on computation fluid dynamics and finite element analysis, Halliburton's iCem® service provides customers with the ability to evaluate the effect of changes to the cement sheath over the life of the well from a wide number of variables. These variables include mud displacement, cement slurry properties, casing/pipe movement and centralization, fluid volumes, pump rates, and temperature and pressure differentials.

The service can interactively run prognostic models to simulate fluid-flow interaction, displacement phenomena, and stresses in set cement. This enables us to work collaboratively with customers on the analysis, design, and optimization of primary cementing, a reverse-circulation cementing job, a balanced plug cementing job, or a post-cementing operation evaluation.

The service helps predict the risk of cement failure during various stress-inducing operations and then generates thermal and mechanical properties required to retain zonal isolation through the producing life of the well. Among the nearly 30 specific available results from the service are a rheological hierarchy plot to optimize fluid rheologies by assessing the likelihood of fluid bypass based on pressure drop versus flow rate for each successive fluid, the industry’s only three-dimensional spacer and cement placement simulation, and a cement sheath stress analysis.
**INFLOW CONTROL**

Unbalanced inflow from a deepwater reservoir can result in premature water or gas breakthrough, leaving valuable reserves in the ground. Because no two reservoirs are alike, access to a variety of inflow control options is needed to achieve the highest ultimate recovery.

Halliburton's solution is an array of inflow control devices (ICD) in the EquiFlow® family that offer a variety of flow balancing options. Standard passive ICDs come in fixed or adjustable pressure drops. Both are designed to improve completion performance and efficiency by balancing inflow throughout the length of the wellbore's exposure to the producing zone.

The EquiFlow autonomous valve is Halliburton's next generation ICD, which utilizes innovative dynamic fluid technology to differentiate between fluids flowing through the device in order to maximize oil production. The valve works like a passive ICD during oil production, yet greatly restricts the production of water and gas at breakthrough. This enables higher ultimate recovery and may significantly reduce the cost and risk of managing unwanted fluid production at the surface. This technology uses no moving parts, does not require downhole orientation and utilizes the dynamic properties of the fluid to direct flow.

Both the EquiFlow passive ICD and autonomous valve are designed to be simple, reliable and cost-effective solutions to maximize reservoir performance, minimize undesired fluid production, and increase reliability through design simplicity.

**SAND CONTROL**

For sand control applications where a more efficient filtration medium is required, our solution is a complete suite of screen products which provides effective solids filtration.

PetroGuard® Mesh screen consists of a perforated base pipe and a non-bonded mesh filter cartridge. The perforated outer shroud protects the mesh filter during deployment, while the unique shroud design lends stability to the mesh and ensures filter integrity downhole. The inner wire wrapped drainage layer provides additional mesh stability and improves flow into the base pipe. PetroGuard Wrap screen is a direct wrap filtration system which provides extreme strength, close tolerance slot gauge, and unsurpassed reliability in deepwater completions.

Any PetroGuard screen can be used as a standalone system or in conjunction with gravel or frac pack applications. When used with our other technologies, such as our inflow control devices and zonal isolation tools, the screen is the heart of a total sand control solution.
WEIGHTED FLUIDS

A growing number of wells in the Gulf of Mexico are being drilled to depths greater than 19,685 ft. (6,000 m) and have bottomhole pressures exceeding 20,000 psi (138 MPa).

Because of the high fracture gradient and friction in the wellbore tubulars, a conventional 1.0 to 1.04 specific gravity (SG) fracturing fluid would require surface treating pressures greater than psi (103 MPa). This pressure is the current limit of the flexible treatment line that transmits fluid from the stimulation equipment to the wellhead.

To solve this challenge, Halliburton developed the DeepQuest® service, a borate cross-linked high-density fracturing (HDF) fluid with a specific gravity up to 1.38. The fluid uses gravity to reduce the surface treating pressure required to achieve adequate fracturing pressure. In numerous wells, we recorded a minimum of 20 percent reduction in surface treating pressure compared to a 1.04 SG fluid.

This weighted fracturing fluid service was used in performing the industry’s deepest frac pack treatment, a deepwater Gulf of Mexico well that also held the Gulf’s deepest successful well test.

SPE 90721

SPE 112859 MS

“Proactive breakthrough prevention: Improving openhole completions with inflow control devices and swellable zonal isolation can be the means to avoiding problems associated with early water and gas breakthrough and resulting reduced oil production.” Article By Geirmund Saetre, Halliburton, E&P Magazine, January 5, 2009.

SPE 116007-MS
**HALLIBURTON VESSELS**

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<tr>
<th>VESSEL</th>
<th>Falcon Tide</th>
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<th>Skandi Fjord</th>
<th>Stim Star Angola</th>
<th>Stim Star Borneo</th>
<th>Stim Star II</th>
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**STORAGE**

| | Acid (gal/bbl/min) | Proppant (lb) | Gel/completion Fluid (bbl) | Frac (bbl) | Water (bbl) | Watermaker | Gel or Frac on Fly | Blender (bbl/min) | Blender (bbl/min) |
| | | | | | | | | | |
| Acid (gal/bbl/min) | 250,000/50 | 14,800/15 | 67,288 | 31,000 | 180,000 | 25,000 | 8,400 | 60,000 | N/A |
| Proppant (lb) | 240,000 | 150,000 | n/a | n/a | 2,000,000 | 450,000 | 350,000 | 668,000 | 668,000 |
| Gel/completion Fluid (bbl) | 2,450 | n/a | n/a | 1,628 | 19,750 | 8,051 | n/a | n/a | 6,040 |
| Frac (bbl) | 2,450 | 3,988 | 2,200 | 1,628 | 23,810 | 8,051 | 4,000 | 4,850 | 5,465 |
| Water (bbl) | 2,588 | 5,085 | 5,085 | 1,770 | 7,140 | 5,661 + Watermaker | 5,100 | 4,850 | 10,486 |

**TANKAGE**

| | | | | | | | | | |
| Gel or Frac on Fly | YES | N/A | N/A | N/A | YES | YES | YES | YES | YES |
| Blender (bbl/min) | 50/50 | 25/18 | 35/35 | 40/35 | 60/60 | 70 | 30 | 50 | 50 |

**BLENDER**

| Line pressure Cap (psi) | 10,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 |
| Number of Pumps | 5 | 6 | 4 | 4 | 6 | 6 | 8 | 7 |
| Total Hydraulic (hp) | 7,500 | 7,200 | 6,750 | 6,750 | 10,400 | 8,250 | 8,250 | 10,150 |
| Max rate (bbl/min) | 50 | 35 | 35 | 40 | 100 | 62 | 25 | 75 |

Newest addition to the Halliburton Vessels is the Stim Star Arabian Gulf, designed for Saudi Aramco’s dedicated use.
EXTENDING THE ASSET'S ECONOMIC LIFE

After completing a deepwater well, the focus is on ensuring that flow all along the path from reservoir to production facilities is optimized. Challenges include providing sand control, minimizing water flows, and cleaning and testing pipelines to prepare for commissioning.

Halliburton’s holistic approach to deepwater development and its ability to bring reliable equipment, resourceful people and innovative technology to bear across all phases of the asset’s life cycle provide solutions to these challenges.

CONSOLIDATION

Our (SandTrap® ABC) formation consolidation service is an in-situ process that uses an aqueous-based emulsion of curable epoxy resin. Because it is an internally catalyzed consolidation mixture, no overflush of external catalyst fluid is required.

A pre-flush fluid conditions the formation to readily accept the consolidation fluid, a low-viscosity fluid that can penetrate and displace deep into formation matrix to provide an effective treatment.

The consolidation fluid is over-displaced into the formation with a post-flush fluid to maximize the depth of consolidation away from the wellbore and regain permeability.

Because the treatment is internally catalyzed, it has a limited pumping time. Pumping time depends on the time of exposure and the temperature to which the consolidation fluid is exposed. Exposure begins when the hardener and resin components are mixed, and continues during the pumping into the well and into the formation.

The SandTrap ABC service is designed for wells with temperatures ranging from 70°F to 180°F (21°C to 82°C) and can be used in oil wells, gas wells, water wells, and injection wells. Injection wells should be evaluated on a case-by-case basis until a best practice can be established.

SandTrap ABC service can be applied in:

- Cased and perforated completions
- New completions
- Remedial applications
- Open hole completions with stand-alone screens or perforated liners
- Remediation to stop sand production from a damaged or failed sand-control completion

SandTrap ABC service offers key advantages over conventional solvent-based systems; including very low viscosity, high flashpoint, and no volatile solvents. It does not require spacer fluids, and can be commingled or foamed with nitrogen to improve placement and load-fluid recovery. Acid can be used to stop the resin from curing.

The service is not recommended for low-permeability formations. In general, sand consolidation treatments are not applicable in reservoirs with permeability of less than 300 mD. Lab testing is required (using competent formation cores) with formations that contain relatively high concentrations (greater than 4 percent) of swellable clays. All successful lab testing to date was performed in sand packs/cores with permeability greater than 100 mD.
CONFORMANCE CONTROL

Halliburton's H₂Zero® environment-friendly, organically cross-linked polymer system to control unwanted water production can be prepared at the well site.

The simple preparation requires only the dilution of two liquid components in the mixing brine, and avoids lumping problems that can occur with dry polymer.

An initial viscosity of less than 30 cp keeps pumping friction pressure at a minimum. Extensive laboratory characterization of the polymer system enables precise and reliable formulation to meet specific job requirements.

CASE HISTORY: First H₂Zero® LT System used for Pemex in Deepwater is a Success

Our first H₂Zero® LT system job in Mexico was performed in a deepwater well, Labay 1, with an original perforated interval between 10,879 and 10,925 ft (3,316 and 3,330 m) in a 5 1/2 in. (13.97 cm) liner. Production was 55 percent water, and it was decided to permanently abandon this interval with a cement retainer at 10,499 ft (3,200 m) and produce another interval a few meters higher.

An additional challenge was bad cement behind the 5 ½ in. (13.97 cm) and 7 5/8-in. (14.29 cm) liners. To avoid communication between the old and new intervals behind the liner, it was decided to perforate at 3,115-3,125 m using a casing puncher. Then a 25-bbl H₂Zero LT job, tailed in with 25 bbl of cement was performed. Radioactive tracers mapped out H₂Zero LT and cement injection behind the liners.

Pemex considered the operation a success and planned to perforate the new interval at 9,902 and 9,974 ft (3,018 and 3,040 m).

CASE HISTORY: H₂Zero® Treatment in Deepwater GOM

A gas well in the deepwater Mississippi Canyon field was shut in due to excessive water production. Production logs indicated 61 percent of the gas and all of the water came from a section of the gravel pack in the upper two-thirds of the top perforation in the shaly sandstone reservoir. Halliburton recommended H₂Zero service to shut off water entry from the upper sand lobe and maintain gas production.

Two critical challenges was to control placement of the solution and ensure that none of the polymer gel migrated through the screen and gravel pack during the treatment. Our H₂Zero system reduced the water-to-gas ratio by 96 percent.

Laboratory testing results demonstrate the superior penetration capabilities and performance of the H₂Zero system. Top image shows a typical chromium-based polymer system. Penetration was about 0.5 ft (15.2 cm), and regained permeability about 0.28 percent. Bottom image shows the H₂Zero system penetration was over 4.5 ft (137.16 cm) into the formation and regained permeability was less than 0.001 percent.
PIPELINE AND PROCESS SERVICES

Halliburton Pipeline and Process Services offers pre-commissioning, commissioning, maintenance and de-commissioning services.

The skills, experience and technology provide effective solutions to deepwater pipeline commissioning and maintenance challenges. Among these resources are the largest mobile pumping fleets in the world, and an extensive range of specialized pipeline and process services equipment.

The global track record has been built over more than 40 years of ensuring the integrity of systems and helping to maximize production. The experience includes, among others, these successes:

- Performed the world's first unmanned deepwater pipeline hydrotest operation
- Pre-commissioned pipelines in water depths exceeding 6,561 ft (2,000 m)
- Dried a number of the largest gas export pipelines in the world
- Cleaned large, complex systems before operation in many locations across the globe
- Performed bulk material excavation projects at water depths to 6,561 ft (2,000 m)
- Pre-commissioned and commissioned the world's longest subsea pipeline to date—1,200 km of 42/44 in. (1.07/1.11 m)
- Laid the longest thermoplastic umbilical in the world to date—33.5 mi (54 km)
- Leak tested a number of the largest process systems and plants

Halliburton's commitment to quality, safety, risk management, and operational excellence includes our compliance with industry standards such as ISO 9001-2008, ISO 14001-2004, and OSHA 18001-2007.

SPE 143248

SPE 139197
MEETING BRAZIL’S DEEPWATER PRE-SALT CHALLENGES

Oil and gas development offshore Brazil has always been daunting: ultradeepwater, deep wells and long distances from shore. But in the face of these challenges, Halliburton has a lengthy record of success in optimizing deepwater drilling in Brazil’s Campos Basin and adjacent areas.

Deepwater drilling, evaluation, and completion in Brazil’s waters became even more complex with the discovery of highly productive formations under a layer of salt.

UNDERSTANDING PRE-SALT RESERVOIRS

Brazil’s offshore pre-salt reservoirs consist of a series of marine rocks up to 3,002 ft (915 m) thick, containing high quality oil with low acidity and low sulfur content and located below a salt formation as thick as 6,562 ft (2,000 m) that serves as a reservoir seal. However, some of the reservoirs contain oil with a CO₂ content ranging from 2 to 12 percent which can cause corrosion conditions. These highly prospective formations cover almost 57,915 m² (150,000 km²), and may contain recoverable reserves of as much as 50 billion BOE.

Heterogeneous, hard microbialite carbonate reservoirs under the thick salt layer contain waxy oil (24-30°API, 80-240 GOR, gradational composition). Reservoir temperatures are as high as 260° F (126° C) and pressures can reach 10,000 psi (69 MPa). Well depths can exceed 19,029 ft (5,800 m) TVD subsea.

From better deepwater imaging, to innovative well and fluids designs, to special cements, Halliburton offers a range of solutions to the unique challenges of Brazil’s pre-salt development that can help increase safety, efficiency, and asset value.

One of the biggest of those challenges is reservoir imaging. Pre-stack depth imaging data acquired through 2D and 3D seismic surveys and interpreted through Halliburton’s SeisWorks® and GeoProbe® applications helped lead to discoveries beneath the salt. Now, our solutions are providing the necessary understanding to develop these discoveries.

Our special RockStrong™ coring equipment has no pressure or temperature limits and has been demonstrated to provide high core recovery in the Campos Basin.

Halliburton’s innovative GeoTap® formation pressure-while-drilling technology is used in pre-salt drilling to indicate formation pressure changes that can influence safety, drilling efficiency, and ultimate recovery.

With better, quicker fluid samples, the GeoTap IDS sensor’s formation-testing-while-drilling capabilities will be able to further help optimize wellbore placement for maximum ultimate recovery.
ACQUIRING, PROCESSING DEEPWATER SEISMIC

Halliburton technology and expertise generate reliable, high resolution seismic imaging of structure and stratigraphy under salt layers and process the data in a way that optimizes the asset's value in the decision making process.

Our solutions include software to help design wide-azimuth seismic acquisition programs that meet the challenges of complex pre-salt structures. Wave-equation-based migration algorithms deliver high resolution seismic images of these reservoirs.

For large data volumes, Landmark's next generation of seismic-processing software, (SeisSpace®, ProMAX®, and LDI™) combines ease of use with effective analysis tools, superior geophysical algorithms, and optimized parallel processing infrastructure.

The technology uses visualization tools that allow rapid viewing of pre- and post-stack data to help better understand the subsurface. Our workflows facilitate construction of the optimum seismic image of the geologic target.

To put it all together, Landmark's DecisionSpace® Desktop module is leveraged across workflows and modules, giving asset teams the ability to share data and collaborate more effectively. The module allows a choice of Landmark, proprietary, and other applications that enables easier adoption of new technologies and workflows.

RESERVOIR GEOMETRY

To accurately interpret and model reservoir geometry near complex salt features, our 3D GeoProbe® multi-volume interpretation and visualization solution allows geoscientists to identify geologic structures and potential hydrocarbon trends much more intuitively.

GeoProbe® Reservoir Model

The software can accelerate workflows from basin scale exploration through detailed prospect and reservoir analysis. Tightly integrated with our SeisWorks®, Well Seismic Fusion™, and OpenWorks® tools, the GeoProbe® software lets interpreters simultaneously analyze multi-attribute/multivolume seismic, well and cultural data, and reservoir models.
PRESSURE WHILE DRILLING
A challenge in Brazil’s Campos Basin, where pore pressure prediction is difficult and there is a slim margin between pore pressure and fracture gradient, was downtime—most of which resulted from hole problems. Sperry Drilling’s solution was the use of pressure-while-drilling (PWD) sensors that provide real-time data on annular and internal pressure and temperature.

PWD data are an important part of the optimization programs we have created for the Campos Basin area. The PWD capability is at the core of hydraulics management and ensuring wellbore integrity and it also has applications in other aspects of the drilling process.

In the Campos basin, we used PWD to:

- Make a variety of drilling practices more efficient, including pipe and casing running, circulation, wiper trips
- Improve hole cleaning
- Indicate the effect of low mud rheology, hole problems, surge/swab effects
- Prevent lost circulation
- Monitor circulating hydraulics
- Monitor mud motor performance
- Validate a hydraulics program and the influence of temperature and pressure on fluid properties

INTEGRATING PRESSURE DATA
Rock strength characteristics, salt creep, the tight window between pore and frac gradient, and ensuring wellbore stability all pose significant drilling challenges in deepwater pre-salt environments.

Halliburton’s approach to dealing with these challenges is to integrate accurate pore pressure, fracture and overburden pressure prediction to improve well planning/design and drilling efficiency.

From prospect evaluation, to pre-drill, to real-time drilling analysis, our Drillworks® software provides an integrated pore pressure and geomechanical solution.

Tightly integrated with Drillworks software is our Pressworks™, OpenWorks® and EDM™ database system. The software allows project development to be streamlined through an integrated family of software for pore pressure and geomechanical analysis. Pressworks results can also connect to proprietary data stores, ESRI® SDE databases, and commercial data vendors.

CUSTOMIZED PRE-SALT DRILLING FLUIDS
Salt has low mechanical strength and can flow—creep—either vertically or horizontally; salt becomes semi-plastic at 220° F (104° C) and plastic at 400° F (204° C).

Brazil’s deepwater salt layer is composed of different types of salt—primarily halite and anhydrate, but also layers of carnallite and tachydrate—with different creep rates. And creep can vary significantly from top to bottom of the interval, making monitoring torque and drag important.
Halliburton specialists have defined these important pre-salt drilling fluids issues and solutions:

**Lost Circulation.** Treatments that can increase the hoop stress around the wellbore to reduce lost circulation are characterized by a low gel-breaking pressure, lower equivalent circulating density (ECD), and less cold water rheology effect.

**ECD Management.** During the planning stage it is important to model downhole conditions relating to hydraulics; while drilling, conditions should be monitored in real time.

**Cold Rheology Effect.** High down-hole pressure loss and high ECD caused by cold temperatures can be reduced by use of a High Performance Invert Emulsions (HPIE).

**Barite Sag.** Increasing the concentration of clay to control barite sag may cause elevated rheology and ECD. Because the HPIE system does not rely on organophilic clays for suspension, circulating/conditioning the fluid is no longer necessary.

**Hole Cleaning.** The cuttings bed should not exceed 3%, and it is important to monitor cuttings to ensure the openhole circulating pressure does not exceed the fracture gradient.

**Rate of Penetration.** Organophilic clay and lignite should be replaced with a low colloidal solid content based on polymers and surfactants.

**Stuck Pipe.** In drilling the salt layer, the risk of stuck pipe can be reduced by displacing with seawater pills and operating a drilling jar.

**Wellbore Stability.** In pre-salt drilling in anhydrite, cuttings integrity should be monitored, and the fluid systems for this interval should have strong emulsion and salinity properties.

**Shallow Hazards.** Large volumes of high density fluids can help prevent flows and help achieve hole stability.

**Lubricity.** Preventing high torque and drag and vibration while drilling the salt and carbonate layer requires the excellent lubrication properties of an HPIE fluid.

**High Temperature.** The HPIE provides excellent rheology in temperature and pressure conditions likely to be encountered.

Additional challenges facing fluids used in Brazil’s pre-salt drilling include resistance to contaminants; avoiding formation damage; mitigating corrosion; enhancing well control capabilities, and drilling gas hydrates.

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**TESTING AND EVALUATION**

Halliburton’s Large Bore Sampling System (Armada*) and the SurgePro™ dynamic perforating system are key components of the full large bore testing string. These superior testing capabilities were used to evaluate a key discovery well in Brazil’s pre-salt area. Based on a well-proven 5 in. (12.7 cm) sampling system, this new system features a larger-bore configuration designed for deepwater applications.

This bottomhole sampling system is ideally suited for extreme HP/HT (400°F (204°C) and 20,000 psi) cased-hole environments. Samplers are inert to facilitate a representative hydrogen-sulfide analysis, and together, the multiple samplers can deliver 3,600 cc of single-phase reservoir fluid. The sample carrier can accommodate memory gauges that measure the sampler’s representative status during recovery.

Our large bore sampling system has demonstrated its superior performance in deepwater field applications, and has had a significant impact on the ability to collect representative bottomhole samples in demanding environments. Its large-volume capacity and reliability can improve field development efficiency and reduce costs.

The DynaLink* Telemetry System improves efficiencies in well testing by providing real-time data to surface. DynaLink can save rig time, prevent wasted time, and prevent incomplete reservoir data collection. The system has demonstrated reductions in buildup duration by as much as 60 percent by recognizing when the buildup objective is met, achieving significant savings in rig time and associated costs. DynaLink Telemetry System has also provided information to prevent the need to repeat a well test due to incomplete reservoir data because the planned buildup (based on duration) was not long enough to meet test objectives. This is quality assurance for the job, assuring that the testing objectives are complete before demobilizing.
INNOVATIVE STIMULATION SOLUTIONS

Halliburton’s SurgiFrac® service—the answer to the need for a cost-effective method to boost production from openhole horizontal completions—provides unprecedented control of fracture initiation and propagation.

In the process, sand-laden fluid pumped through a Hydra-Jet™ tool creates a cavity in the formation. As the cavity is formed, pressure on the bottom of the cavity increases, eventually initiating a fracture. Annular fluid is pulled into the fracture, helping to extend it.

The technique can boost production from existing assets by re-entering open-hole horizontal wellbores with coiled tubing or jointed pipe to create fractures in bypassed or under-performing zones.

Customized for specific well conditions, the SurgiFrac service can optimize reservoir drainage and can add new production quickly because multiple fractures can be created in only hours with no sealing required between zones. The service can also reduce fracturing costs by requiring less equipment and lower viscosity fluids.

The service has been applied successfully in open-hole intervals, deviated cased holes, a horizontal slotted liner, and other applications.

CO₂ SOLUTIONS

The significant CO₂ content of Brazil’s presalt production poses an additional challenge for well construction and completion. As more projects use CO₂ to enhance oil recovery, new reservoir monitoring devices and specialized cement formulations that resist carbon dioxide degradation have emerged. A low-cost monitoring technology can acquire micro-deformation data in near real time that allows NRT geomechanical inversion analysis to provide 3D reservoir flow images.

A new approach to acquiring reservoir flow measurements and patterns in these projects could also be applied to CO₂-rich reservoirs in Brazil.

One of Halliburton’s CO₂ solutions is the CorossaCem™, a special cement designed for a wide variety of corrosive wellbore environments.
SurgiFrac® service enables placing fractures with surgical precision using no downhole mechanical isolation.
DELIVERING RELIABLE SERVICES IN THE GULF OF MEXICO

Impressive discoveries in the deep water of the US Gulf of Mexico have led to the development of impressive technology to develop these prolific finds.

To fully exploit this resource requires innovative solutions to drilling, completion and production challenges posed by water depths to 10,006 ft (3,050 m), thick salt layers, drilling depths to more than 29,856 ft (9,100 m) TVD subsea, reservoir pressures that can exceed 25,000 psi (172 MPa), and temperatures to 300° F (149° C).

Among Halliburton’s suite of tools designed for this extreme environment are:

- An advanced single-trip multizone completion system that helps lower costs and provides access to more intervals
- Innovative fluids designs, including a cost effective packer fluid to minimize annulus pressure buildup and a system that helps optimize drilling efficiency
- Reservoir evaluation and sampling tools designed for the rigors of deepwater
- A robust, reliable intervention tool for setting wellbore devices such as plugs and packers

An important target in the Gulf of Mexico are large, thick reservoirs of Lower Tertiary age stretching 300 miles (483 km) across federal waters offshore Texas, Louisiana and Mississippi that could ultimately yield 3 to 15 billion bbl of recoverable oil.

CUTTING COMPLETION COSTS

As well depths increase and subsurface conditions become more hostile, the challenge has been to develop new completion systems that are more cost effective.

Halliburton’s answer to this need is the Enhanced Single-Trip Multizone (ESTMZ™) system, a proven cased-hole single-trip sand control completion technology. Earlier generations of our Single Trip Multizone (STMZ™) systems were first deployed in the early 1990s, and now have been installed in over 1,000 intervals in hundreds of wells.

The ESTMZ system was specifically developed for the Lower Tertiary formations and offers additional benefits over conventional stacked multizone completion:

- Reduces rig time by reducing the number of workstring trips required to complete multiple zones
- Provides complete zonal isolation of all zones, thereby reducing the potential for fluid loss or well flow
- High pump rate and proppant volume allows optimized frac designs for each reservoir interval
- Allows long reservoir intervals to be separated for optimum fracturing design
- Provides access to smaller reservoir intervals that would normally be bypassed
- Takes a single workstring trip to deploy
- Has Has a 10,000-psi (69-MPa) differential pressure rating to increase the operating envelope for deeper wells

Halliburton’s ESTMZ system was designed and qualified to meet the requirements of a major deepwater operator. The system is pump rated to 45 bbl/min, with a proppant volume of 400,000 lbs of 16/30 HSP per interval for up to 5 intervals.

The system was also set up with a 4 3/4 in. (12.065 cm) ID. The 4 3/4 in. (12.065 cm) for 9 5/8 in. (24.4 cm) casing provides maximum fracture rates, reverse rates, and production rates, and is compatible with SmartWell® zonal flow control equipment that can be installed adjacent to each interval.
**SINGLE TRIP ADVANTAGE**

Tight, low-permeability formations and long intervals can prove difficult to complete the Gulf’s Lower Tertiary wells in a way that achieves production rates capable of making the project economically viable.

A traditional stacked multizone gravel-pack completion treats each zone independently, requiring perforating runs, clean-up runs, and sand face completion runs for each interval. The single-trip multizone completion approach results in significant cost savings by reducing the number of workstring trips to install.

This latest generation meets today’s frac pac demands: higher pressures, higher pump rates, higher proppant-placement rates, and the ability to segment intervals to optimize fracture design.

The ESTMZ system is designed for 9 5/8 in. (12.4 cm) 47 to 53.5 ppf casing; a system for 7 in. (17.8 cm) 29 to 32 ppf casing is available. Isolation packers are rated at 10,000 psi (69 MPa), and can be retrievable/testable, retrievable/non-testable, or permanent.

The ESTMZ system eliminates the need for a concentric workstring and the need for a wash pipe as required with the previous Single-Trip Multizone system (STMZ). When the sand face completion is in place, all zones are isolated by the modular screen and interval isolation packers.

Individual intervals are opened for treatment and then closed after the treatment. Because the intervals are isolated after the treatment, there is no restriction on zone length; the limiting factor becomes the limitations of the gravel-pack treatment design.

ESTMZ™ solution goals are twofold: reducing rig time while maximizing each reservoir intervals full drainage capability.
COST-EFFECTIVE PACKER FLUIDS
In the deepwater and ultradeepwater of the Gulf of Mexico, a well’s annulus can be cooled or heated as the well is started up or shut down. If the fluid is not bled off as the well heats up, then pressure in the annulus can increase enough to cause damage.

Halliburton’s solution is the high-performance N-SOLATE® aqueous-based insulating packer fluid that helps save costs and time compared with other insulating options.

Designed to keep heat away from the outer casing strings, the fluid can dramatically reduce annular pressure buildup to extend the life of the well under high production rates and mitigate the risk of damage.

CASE HISTORY: Insulating Packer Fluid Saves $2 Million in GOM
Murphy Exploration sought a solution that would prevent well failure caused by annular pressure buildup in three of its deepwater Gulf of Mexico wells.

A vacuum insulated tubing (VIT) system would require larger production casing, increased volumes of drilling fluid, larger-diameter bits, and extended drilling times.

Based on its reliability and robustness in deepwater applications—and its cost and time savings—Halliburton’s solution was N-SOLATE® insulating packer fluid instead of a VIT system.

The solution for these wells was required to be:
- Aqueous-based and solids-free
- Thermally conductive (less than 0.17 BTU/hr/ft)
- Easily pumped and removed
- Low toxicity
- Hydrate inhibitive to 8,500 psi (59 MPa) at 40°F (4°C)

Halliburton completion fluid design specialists formulated this fluid as a delayed cross-linking system until placed in the wellbore; following placement, full gelation of the system would occur.

Even after placing the high-performance insulating packer at a depth of about 21,982 ft (6,700 m), it took almost 12 fewer hours of rig time than the VIT system would have taken to install to 10,006 ft (3,050 m).

After comparing all operational costs, the N-SOLATE® system saved nearly $2 million compared with the VIT option.
ENVIRONMENTALLY SAFE, COST-EFFECTIVE DRILLING FLUIDS FOR LOWER TERTIARY

Synthetic-based fluids have helped reduce overall well costs on many deepwater projects while providing an environmentally friendly alternative to oil-based fluids.

Our ester/internal olefin-blended mud adds a combination of esters—the most biodegradable and least toxic base fluids—ensuring that the system passes regulatory requirements.

Our high performance fluids have been used by major operators in the Gulf of Mexico where Baroid drilling fluids specialists customize the fluid to optimize wellbore value by providing stable viscosities through a wide range of temperatures, high resistance to contaminants, and low equivalent circulating densities (ECD).

Our synthetic-based fluid solutions include:

- ACCOLADE® fluid technology, an organophilic, clay-free fragile gel fluid system, is an ester blend for temperatures to 300° F (149° C) that has proven drilling performance and excellent environmental properties
- ENCORE® synthetic-based fluid system is used for Gulf of Mexico service in bottomhole temperatures greater than 300° F (149° C) that utilizes organophilic, clay-free ACCOLADE fluid technology

FLUID SYSTEM SAVES TIME, MONEY

Since Lower Tertiary well temperatures may vary over a wide range, ACCOLADE and ENCORE fluid systems can provide an organophilic, clay-free drilling fluid solution to cover a range of temperatures.

An ACCOLADE drilling fluid system was used for a deepwater well in the Gulf of Mexico with a planned deviation of 56° F (13.3° C) to achieve the most efficient drilling practices.

Baroid designed a drilling fluid system that allowed Sperry Drilling to pump at the maximum allowable flow rate with minimum equivalent circulating densities. The objective was to drill this well as quickly as possible while maintaining good hole-cleaning conditions.

Time spent on this well, including drilling, directional work, tripping, logging, and running casing, was 21 days fewer than planned.

Based on rig days saved, the economic value to the operator of this fluid design and its application was $1,050,000.

Lowest Downhole Losses

107 Well Study: Losses of Conventional Technology vs. Clay-Free Fluids

Consistent high performance of the clay-free fluids prove less downhole losses and better economics on the operator.
CASE HISTORY: Clay-Free Synthetic-Based Fluid Helped Eliminate Wiper Trips, Saving $1.2 M

The challenge on a well in Mississippi Canyon Block 248 was to evaluate the formation for a number of days and run casing without making a wiper trip in an S-shaped hole at more than 20,095 ft (6,125 m).

Baroid’s solution was to recommend clay-free ENCORE® synthetic-based fluid. An 11 5/8 in. (29.5 cm) hole was drilled with maximum mud density of 12.6 lb/gal to casing depth at 16,362 ft (4,987 m) measured depth. At casing depth, the well was wireline logged for 94 hours.

Then the 9 7/8 in. (25 cm) liner was run to bottom without a time-consuming wiper trip. The casing was run and cemented with full returns.

Using the ENCORE fluid again, the operator drilled the 9 1/2 in. (24.1 cm) section to 20,105 ft (6,128 m) measured depth, with maximum mud density of 14.4 lb/gal. The section was wireline logged for 101 hours. After logging for 101 hours, a wiper trip was not performed and the 7 5/8 in. (19.4 cm) liner was run to bottom and cemented with full returns.

The 24 hours of rig time savings—trip to bottom, circulating out, and trip out of the hole—was achieved on each hole section. At the daily spread rate in effect at the time, the estimated savings to the operator was $1,200,000.

CLEAN SAMPLES

A recent application of Halliburton’s reservoir fluids sampling technology in deepwater Gulf of Mexico wells involved well depths greater than 18,996 ft (5,790 m) and water depths greater than 3,900 ft (1,200 m).

The system utilized Halliburton’s Oval Pad technology originally developed for laminated sand shale sequences. Due to the larger contact area, we were able to maintain the precise pressure differential that would collect the heavy oil while minimizing the production of mud solids and other contaminants.

By using our new density meter and MRILab® analysis, we were able to determine fluid contamination during pump-out and clean-up. Post job Lab tests confirmed that samples taken had contaminations below 3 percent. As a result of a 20 percent reduction in testing time, according to the client, our RDT™ tool saved $104,000 in rig time cost for the pressure program. An additional $400,000 worth of rig time was saved in the sampling operation.

In addition to saving over $500,000, the operator obtained better samples more efficiently in an area where it previously had not been possible to obtain samples.

Benefits of the Oval Pad design include:

- Facilitates fluid extraction, minimizing the time in contact with the borehole wall and mitigating the risk of stuck pipe
- RDT pump design allows for up to 42 percent solids to be processed through the tool, reducing plugging when sampling unconsolidated formations
- Full bore fluid density sensor that uses first principle approach to solving for density provides better data and reduces the chance of plugging
- Largest DOT-approved sample chambers of 1,000 cc reduce the number of samples that must be acquired, minimizing HSE risk

The Oval Focused Probe was developed specifically for this type of formation. Simulations have shown up to a 10-fold decrease in sampling time versus a standard probe.

In early 2012, Halliburton introduced a 25,000-psi (172-MPa) Reservoir Description Tool (RDT™) and Oil Mud Reservoir Imager (OMRI™) tools designed specifically for Gulf of Mexico ultradeepwater service.
**A ROBUST INTERVENTION TOOL**

Halliburton's nonexplosive electromechanical DPU®-I setting tool, Downhole Power Unit—Intelligent series, provides reliability and quality assurance when setting wellbore devices such as plugs and packers. It is a fully controlled set that provides full compression of the elements.

The tool provides these features in well environments up 400 °F (204° C) and 30,000 psi (207 MPa). Its 100,000 lb shear-force capability and slow, precisely controlled linear force with real-time feedback help optimize setting and completion in even the most hostile well environments.

It was recently applied in a plug-and-abandonment in which the casings had earlier been cut, cast-iron bridge plugs (CIBP) set, and the 7 in. (17.8 cm), 9 5/8 in. (24.4 cm), and 11 7/8 in. (30.1 cm) strings cemented. The 16 in. (40.6 cm) CIBP was set on e-line with a #20 setting tool and cemented with 299 ft (91 m) of cement.

Two months after the P&A operation, pressure began to increase in the well, and it was necessary to perform another P&A. It was determined that the CIBP in the 16 in. (40.6 cm) casing allowed pressure bypass due to leaking seal elements. The CIBP required a shear force of 47,000 lb to set, and the #20 setting tool, utilizing an explosive power charge and capable of 55,000 lb setting force, applies the force in a nonlinear manner and in a short time.

The uneven application of setting force and quick set time may not have allowed the elastomers seals to fully compress and then expand to form the required seal. Had the CIBP been set using the DPU-I setting tool, the slower application of force would have allowed a uniform expansion of the elements. With up to 100,000 lb of setting force, a higher shear could have been planned to ensure the CIBP remained at the set depth.

The force applied, the stroke length to set, and other measurements to indicate a quality set could also have been observed real time. To reduce costs, the operator mobilized a lift boat instead of a jackup rig for the remediation. The lift boat crane with a swivel was used to pick up 3.5 in. (8.9 cm) drill collars and drill pipe to drill enough cement so a second CIBP could be set in the 16 in. (40.6 cm) casing with the space to put 151 ft (46 m) of cement on top of it.

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**CASE HISTORY: DPU® Tool Mobilized Quickly, Saves Rig Time Worth $1,375,000**

When Halliburton was asked to set our EZSV-B plug on a competitor’s electric line unit in a deepwater well in the Gulf of Mexico, the first challenge was to mobilize in two days, instead of the normal one-week preparation time.

The objective was to use a 3 3/8-in. (8.6 cm) DPU-I tool to set the plug in 9 7/8-in. (25 cm), 62.5-lb casing at 31,975 ft (9,691 m) measured depth on a drill ship in 4,114 ft (1,354 m) of water. Bottomhole temperature was 252° F (122° C) and bottomhole pressure was 25,440 psi (175.4 MPa). A 15.9-lb/gal mud system was used.

The time planned for setting the plug on jointed pipe was 42 hours, but Halliburton only required nine hours from rig up to rig down, saving 33 hours of rig time. At a daily rig rate of $1,000,000/day, savings in rig time alone was $1,375,000. Because of the performance of our crew and DPU-I technology, Halliburton was called back two weeks later to set another EZSV-B plug in the same well at 7,263 m.

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**SPE 116245**


**SPE 135177**


**SPE 113806**

SOLUTIONS FOR AFRICA’S DEEPWATER

In some ways, offshore West Africa deepwater reservoirs are similar to those of Brazil and the US Gulf of Mexico.

But West Africa deepwater exploration also presents some unique challenges, including unconsolidated sands, multiple producing zones, and variable water and gas flows in the reservoir.

Halliburton has also met other challenges faced by an operator in deepwater off Africa’s southeast coast, where exploration is ongoing and the remote location lacks needed infrastructure. To better serve the area’s deepwater activity, we are deploying modular equipment to deliver the service and support the operator needs to complete the project.

East Africa countries are an emerging deepwater plays. Offshore Africa is seeing an increased focus from several operations for exploration drilling and evaluation.

PROSPECTS AND ENVIRONMENT

The primary deepwater exploration targets along the West African Transform Margin (Sierra Leone to Ghana) are turbidite fan sandstones in rotated fault block traps, stratigraphic traps, or combinations of the two.

In the Niger Delta and Lower Congo Basins, deepwater targets are thick, early Tertiary (Oligocene-Miocene) turbidite sands deposited in deepwater slope channel systems and basin-floor fans.

There is also renewed interest in the potential for a deepwater extension of the presalt play offshore Angola and Gabon.

Most West Africa deepwater discoveries have been in water depths from 1,000 ft to 6,562 ft (305 m to 2,000 m), but prospects exist in water depths to 3,000 m. Two recent deepwater discovery wells in the Sierra Leone-Liberian Basin were drilled to TD of 15,951 ft and 18,500 ft (4,862 m and 5,639 m).

Representative West Africa deepwater fields include:

- **Tano Basin (Jubilee field, Ghana)**—Water depth is 4,100 ft (1,250 m); oil gravity is 37°API; reservoir sandstones are very hard and abrasive.

- **Niger Delta Basin (Bonga field, Nigeria)**—Water depths range from 3,100 ft and 3,800 ft (945 m and 1,158 m; primary reservoirs are unconsolidated sands between 6,004 ft and 10,500 ft (1,830 m and 3,200 m) TVD subsea. Average gravity and viscosity are 30° API and < 1 cp; porosity ranges from 20 to 37 percent and core permeability reaches 5,000 md.

- **Lower Congo Basin (Gimboa field, Angola)**—Water depth is 2,300 ft (700 m). Reservoirs are unconsolidated sands in stacked lower-slope channel systems and basin-floor fans at depths from 5,003 ft to 6,224 ft (1,525 m to 1,900 m). Oil gravity and viscosity are 22 to 27° API and 2.3 to 5.3 cp, respectively.
MAINTAINING HOLE STABILITY
One deepwater operator faced a drilling challenge when unstable shale in the pay zone caused the wellbore to collapse, resulting in unplanned non-productive drilling time that cost an estimated $13.2 million.

Halliburton’s solution was to integrate the AquaLinear® drill-in fluid, completion tools, and the gravel packer fluid service, which is based on a viscosified fluid system used to gel a wide range of water-based brines to make them shear thinning and efficient in static sand suspension.

The AquaLinear service fluid provides very high viscosity under low shear conditions. This service can be designed so the gelled fluid’s sand suspension capability is similar to that of a cross-linked gel. The fluid can also be used to control fluid loss with less damage to the formation during workover and completion and at lower polymer levels. The AquaLinear fluid can produce a “slick brine” consistency, giving reduced pumping friction pressures. In addition to gravel packing, the AquaLinear service brings efficiency to sand washing and coiled tubing cleanout operations.

INNOVATION AND RELIABILITY
In deepwater wells offshore Africa, Sperry Drilling overcame concerns about LWD battery life and memory fill, and used the Geo-Pilot® rotary steering system to save rig time.

In one well in 4,396 ft (1,340 m) of water, a reliable 8 1/2-in. (21.6-cm) drilling BHA Hexa-combination run was drilled with Halliburton’s 7600 Geo-Pilot system, and a package of sensors was used to measure pressures and rock properties and gather other downhole data. The hole was opened to 9 1/2 in. (24.1 cm) with the XR™800 reamer in one run from 9,898 ft (3,017 m) to TD at 11,319 ft (3,450 m)—within the AFE requirements and without incident. No wireline logging was required and the completion screens reached bottom on the first pass.

In another West Africa well in 3,862 ft (1,177 m) of water, we executed a 12 1/4-in. (31.1 cm) triple-combo LWD run. Because of problems pulling casing in an existing wellbore, the operator planned to make a traditional motor kickoff at 87° F from 6,870 ft (2,094 m), drill 328 ft (100 m), and then pull out of the hole and run a rotary steerable system to total depth of 16,595 ft (5,058 m).

This 9,724-ft (2,964-m) long tangent raised operator concerns about drilling the section. The desire was to drill as quickly as possible to minimize potential hole problems. Halliburton dispelled those concerns by drilling the section to TD in one run with the 9600 Geo-Pilot system within the AFE, saving 36 hours of rig time. Torque and drag readings while pulling out of the hole indicated the hole was in excellent condition and no problems were experienced in subsequent operations running logs and casing.
OPTIMIZING RECOVERY
In deepwater wells offshore West Africa, Halliburton’s reliable, SmartWell® intelligent well-completion (IWC) technology helps operators collect, transmit, analyze downhole data and remotely control selected reservoir zones.

IWC technology:
- Increases production—Co-mingling production from different zones accelerates and enhances production
- Increases ultimate recovery—Selective zonal control helps effectively manage water injection, gas and water breakthrough, and individual zone productivity
- Reduces capital expenditure—Producing multiple reservoirs through a single wellbore reduces the number of wells needed, lowering drilling and completion costs, and surface facilities are reduced by managing water with remote zonal control
- Lowers operating expenditure—Remote configuration of wells optimizes production without costly well intervention

Well Completion Benefits
In Chevron’s Agbami field offshore Nigeria in about 5,000 ft (1,525 m) of water, the three major reservoirs are divided into 5 or 6 main producing areas. Each major reservoir is vertically subdivided into three or more zones.

The field is being developed with 20 producers, 12 water injectors and 6 gas injectors over 3 development stages.

Agbami wells are typically completed in multiple zones in the same reservoir. Since vertical and lateral/cross fault connectivity under dynamic conditions is still uncertain, water- and gas-flood fronts are likely to advance at different rates.

A key challenge in Agbami was to optimize field performance and ultimate recovery.

Halliburton’s innovative solution was to install intelligent completions with downhole control valves to provide zonal information, control production and injection. We deployed over 25 work flows and 17 SmartWell® IWC systems, boosting well availability to 95% from an estimated 65% at project startup.

Our IWC solution for Agbami provides these tangible benefits:
- Flowback testing and cleanup
- Remote control of individual zones from FPSO for zonal pressure build-up and production testing
- Timely diagnosis of well problems, and re-configuration without intervention
- Accelerated ramp-up of production to maximum rate
- Offstream wells act as observation wells
- Reduced completion impairment
- Virtual metering for improved flow allocation
- Balancing of production from zones
- Accurate data for quick decision making

Halliburton WellDynamics provides the intelligent well data gathering, pre-processing and management system. All the data are handled and archived from subsurface sensors and streamed in real time through the FPSO to the operator’s office. Data can be visualized with Landmark’s DecisionSpace® Desktop module.

The SmartWell® system consists of a tailored combination of zonal isolation devices, interval control devices, downhole control systems, permanent monitoring systems, surface control and monitoring systems, distributed temperature sensing systems, data acquisition and management software, and system accessories.
OTC 20191

SPE 127691

SPE 140640

SmartWell® completion technology systems and the real-time center enable greater recovery and improved economics for deepwater fields.
QUICKER FIRST OIL IN THE ASIA PACIFIC THEATER

A number of recent discoveries promise that significant deepwater petroleum resources exist in the Asia Pacific region. One of the many geological areas within the Asia Pacific petroleum theater with similar types of challenges is Malaysia.

In Malaysia’s Sabah basin, the US Geological Survey has estimated mean undiscovered reserves are 4.3 billion bbl (683.6 thousand m³) of oil and 26.4 Tcf (747 1012 m³) of gas. The country’s Sarawak basin is also prospective.

The shelf offshore northwest Borneo is dominated by thick middle Miocene–Holocene pro-grading shelf-slope sequences and complex slope topography of intraslope basins and anticlinal structures. Promising discoveries have been made in the deepwater of the northwest Sabah Basin in these Miocene channel and fan turbidites.

Primary plays in the area involve multiple stacked sandstone reservoirs in structural traps formed in hanging-wall folds above toe-thrusts; most prospects are defined by four-way closure of the anticlines.

Seismic imaging is severely affected by the presence of shallow gas hydrates and complex crestal faulting. The presence of shallow hazards—methane hydrates and overpressure—create drilling risks.

The Sabah deepwater reservoirs were thought to be gas prone until the discovery of the Kikeh field, currently the country’s only producing deepwater development. Instead, the field’s seven Miocene-age deepwater turbidite sandstone reservoirs are believed to contain estimated recoverable reserves of more than 400 million bbl of light, sweet crude oil.

Kikeh is located in the Sabah basin 75 miles (120 km) offshore northwest Borneo, in water depths averaging 4,300 ft (1,310 m). Reservoir depth is about 16,500 ft (5,030 m). Pressure data indicate long hydrocarbon columns ranging from 1,607 to 2,067 ft (490 to 630 m). Pore pressure in deeper sections is equivalent to mud weights of 12 to 13 lbm/gal.

Though Malaysia serves to highlight the challenges facing operators in the Asia Pacific region, there are many other geological environments in the area with unique properties. Following are examples of Halliburton’s ability to provide specific solutions for these deepwater challenges.
MEETING DEMAND FOR FLUIDS EXPERTISE

In recent years, Baroid has dramatically expanded its ability to provide drilling and completion fluids, and expertise, to deepwater operators in the Asia-Pacific region. Our broad experience now counts deepwater successes in the Philippines, Brunei, Indonesia, Australia, and Malaysia.

In Asia-Pacific, Baroid has steadily expanded application of its fluids services and built new support facilities in Australia, Indonesia, and Brunei. In 2010, we used ENVIROMULT™ and INNOVERT® systems on 25 wells in Asia-Pacific and significantly expanded our facility capabilities in Indonesia. In 2011, we are constructing a full service fluids facility specific to the deepwater market in Brunei.

Our deepwater portfolio continues to provide innovative solutions to Asia Pacific challenges that improve drilling efficiency, enhance safety, and increase reservoir performance.

CASE HISTORY: Efficient Acquisition, Processing Expertise Deliver High Quality Data

The challenge to Sperry Drilling Services in a high profile South China Sea deepwater exploration well was to acquire as much data as possible as quickly as possible after drilling, as hole conditions would not permit more wireline runs.

Our solution was to obtain petrophysical data from seven main sensors simultaneously. The BHA comprised a Geo-Pilot® rotary steering system followed by the package of logging sensors, including our QBATTM sonic sensor, GeoTap® formation pressure tester, and the MRIL®-WD magnetic resonance tool.

With excellent real-time detection, data were used to make timely decisions while drilling. Important input to this process came from the GeoTap tool. It allowed frequent “on-the-fly” pressure tests in the previously unexplored formations to help optimize well stability and drilling parameters.

At one point, the GeoTap tool indicated an unusually high pressure that exceeded the maximum pressure set to avoid an unwanted well control situation. Based on this real-time input, mud weight was increased and drilling continued safely.

After drilling to TD, the MRIL® tool was switched from T1 acquisition mode to sliding mode to be used while pulling out of the hole. Potentially productive zones were wiped with the MRIL tool to gather T2 NMR data for further evaluation of rock properties and for fluid typing.

When the BHA was on the surface, it was clear that because of the high quality of the LWD real-time data, most of the planned wireline runs could be cancelled. Only a formation fluid-sampling tool run was needed.

The challenge posed by processing the resistivity and sonic data was met by the ability of our M5™ compensated multiple-frequency resistivity tool to minimize the polarization effects at bed boundaries.

Slow shear data also presented a challenge, but the wide band receivers of the QBAT tool delivered high-quality sonic data that could provide input for further rock studies.

In addition to the standard formation-evaluation data, Azimuthal Lithodensity Sensor Animation (ALD™) image data helped geologists to better understand the subsurface.

Our performance and support capability during this job has resulted in Sperry Drilling being the preferred drilling and LWD supplier for this operator’s future deepwater exploration wells.
TESTING AND SUBSEA

To provide the safety and reliability required in the demanding deepwater environment, Halliburton incorporates the latest advances in subsea safety system design and technology.

Testing deepwater wells calls for a reliable disconnect capability to deal with rig positioning or well control issues when drilling with either a semisubmersible or dynamically positioned vessel.

Our solutions provide operating efficiency that results from significant design advances, including dual-sealing elements for well isolation.

Mechanically-locked tool joints eliminate the possibility of backoff in the well and facilitate preassembly and pressure testing of the subsea safety tree. A quick union provides a robust alignment feature for assemblies and prevents damage to its dual sealing elements. The valves of the subsea safety tree have a fail-safe closed design.

An emergency release module facilitates a quick system disconnect, allowing the well to be shut in with dual barriers and the riser work string to be isolated from the riser annulus—all within 15 seconds.

The system also enables safe intervention operations. If wireline or coiled tubing is in the well when it must be shut in at the seabed, the system can cut the wireline or coiled tubing and still provide a seal, helping to ensure that the well can be controlled during an emergency closure.

Halliburton's solution to deepwater test tool challenges is a full-opening annulus pressure response (APR®) system of tools operated by annulus pressure that allows a well test to be performed with the BOP rams closed and without pipe manipulation or rotation.

We applied this solution in an Asia Pacific well that required tools to withstand a 450° F (232.2° C) bottomhole temperature, 10,000 psi 10,000-psi (69-MPa) gas surface pressure, and a high-pH completion brine. Key testing equipment components included:

- Select Tester® Valve for downhole closures and flow
- OMNI™ Circulating Valve, a multi-cycle recloseable circulating valve
- A rupture disk (RD) safety circulating valve that can serve as both a safety valve and circulating valve

These tools have demonstrated their capabilities by performing a DST in a well that was 18,504 ft (5,640 m) deep, with a pressure of 14,500 psi (100 MPa), bottomhole temperature of 433° F (222.8° C) and a mud weight greater than 14.5 lb/gal. Test duration was 16 days.

These tools are rated for use in wellbores with up to 20,000 psi (138 MPa) pressure. Future development and testing will qualify them to 30,000 psi 30,000 psi (207 MPa) and 500° F (260° C).

An important challenge of deepwater completions is met by our large bore Subsea Safety Tree. It provides two fail-safe ball valves for well control, as well as a latch for emergency release.

This system has the required BOP interfaces for landing the completion in a horizontal production tree and provides well control if required. It has a 2-million-lb 2,000,000-lb (907,185-kg) tensile rating with lock-tight tool-joint design. It also has the highest number of hydraulic ports for completion equipment control, and a passive orienting and debris-tolerant latch system. A pump-through design facilitates well-kill operations. The system has a valve that retains landing string contents in the event of disconnect or shear.
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.