Technology Drives Evolution Of Pemex’s Operations In Perdido Fold Belt

By Víctor Gerardo Vallejo Arrieta, Aciel Olivares Torralba, Octavio Saavedra, Juan Ramon Lopez Morales and Manuel Ernesto Torres Villalobos

MEXICO CITY–Petróleos Mexicanos, the national oil company of Mexico, has developed significant deepwater expertise over the past decade from the 30-plus wells it has drilled in water depths up to 9,500 feet. As a result, the company has evolved to innovate and adopt new technologies and processes to optimize investment, reduce costs, and drive project success.

Pemex is applying this knowledge to optimize its activities in the ultradeepwater Perdido Fold Belt region of the Gulf of Mexico. The company has made three discoveries on the Mexican side of the Perdido Fold Belt, including one less than 25 miles from U.S. territorial waters, where significant discoveries have been made since the first Perdido Fold Belt test in 2001 in Alaminos Canyon. Those fields include Trident, Great White and Shell’s Perdido, which holds the world water-depth record for a drilling and production platform, and produces from the deepest subsea well (Tobago at 9,627 feet).

To date, the Perdido Fold Belt’s reserve discoveries have been made within the Tertiary geological system, specifically the Middle Oligocene Frio, Lower Eocene, and the Lower Paleocene sandstones. The area’s geology is complex, and is surrounded by large canopies of allochthonous salt and hydrocarbon accumulations on the crests of regional anticlinal structures.
Located about 200 miles off the Texas Gulf Coast and 155 miles from Matamoros at the U.S. border, the Perdido Fold Belt is well known for the technical challenges it presents to operators: Project spread rates are expensive and rigs are forced to operate at the limits of their capabilities far offshore in water depths approaching 10,000 feet and reservoir target depths up to 26,250 feet. This is in addition to highly variable exploration geology, narrow mud weight windows, shallow geohazards, subsalt drilling, and complicated pore pressure models derived from surface seismic velocities, low-resistivity pay, and highly laminated reservoirs.

Regardless, the Perdido Fold Belt is considered to have high reserve and oil production potential. Pemex has drilled three oil reservoir discoveries successfully: Supremus-1 and Trion-1 in 2012, and Maximino-1 in 2013. An important element of the evolution and development of the company’s working practices in the Gulf over the past decade has focused on drilling and formation evaluation.

Figure 1 illustrates the increasing water depths of drilling projects offshore Mexico between 2003 and 2013, with 30 deep- and ultradeepwater wells drilled in water depths ranging from 1,680 to 9,514 feet. The green lines indicate wells that were spudded in 2013, but still were being drilled in the first quarter of 2014.

Pemex uses a front-end loading methodology that is based on project management stage gates and clearly defined milestones to optimize well construction design and control capital expenditure. Five stages—visualization, conceptualization, definition, follow-up and evaluation—characterize the approach.

During visualization, all possible options are identified and validated in relation to strategic business goals. The team uses a systematic approach to digitally simulate different design scenarios to find an optimal configuration, with contingencies and mitigation options. Conceptualization sees the selection of the best option, which is followed by the definition stage when the project scope is developed in depth, and an execution plan and cost estimates are produced. In the follow-up stage the well is constructed, and in the final evaluation stage, the project is evaluated and lessons learned are documented.

The exploration team is steered by a project leader, who brings in each multidisciplinary element required to progress through the design stages: geophysics, geology, petrophysics, geomechanics, reservoir, drilling, completion, productivity, risk assessment and technical limits. This process is further supported with international service companies that leverage their wider global knowledge bases and improved application solutions of their technologies.

**Drilling Considerations**

An important design consideration is the specification of the subsea wellhead, given the stresses caused by environmental marine-current lateral forces and high hydrostatic pressures in deepwater wells. The wellhead system must support numerous casing strings of different diameters to reach deep geological targets, as well as resist the ongoing presence of hydrogen sulfide and carbon dioxide.

For example, in its first ultradeepwater well drilled in 2009 in a water depth of 5,570 feet and that reached a total depth of 11,030 feet, Pemex used an 18 5/8-inch subsea wellhead system with a maximum pressure capacity of 15,000 psi, and a bending moment limit of 5.2 million foot-pounds. This arrangement allowed suspension of 36 x 20 x 13⅞ x 9⅞-inch casing strings, allowing liner options of 16, 11⅝, and 7⅞ inches.

For the subsequent deeper wells drilled in 2012 and 2013 (in water depths up to 9,514 feet and final depths up to 21,326 feet), the company used a different system with an increased bending moment limit of 7 million foot-pounds, and 36 x 28 x 22 x 13 3/8 x 9⅞-inch casing strings, with liners of 18, 16, 11⅝ and 7⅞ inches. This is a good example of how the company has evolved and adapted its approach in line with lessons and experiences from the field.

Pemex used the pump-and-dump system for drilling riserless sections. Here, the surface section is drilled without fluid returns to the rig. Once an expected increase in pore pressure is confirmed with real-time indicators, a heavy fluid is used to drill an interval between 150 and 200 meters, and to optimize setting the 20-inch surface casing. The large fluid volume must be in constant supply during the 24-hour window of operation because of the high rate of penetration.
The drilling fluid must provide proper rheology for hole cleaning and chemical properties to minimize destabilizing shales. The high fluid volume quickly exceeds available rig storage capacity and mixing capabilities, thus the pump-and-dump system is utilized to mix the drilling fluid in real time. To produce it consistently and with homogenous properties, mixing on the fly is undertaken to ensure the correct blend at high work flow rates. High-density bentonite fluid volume is prepared onshore, and a supplying vessel ships it to the rig and a mud boat for pumping. The following variables should be considered for pump-and-dump planning: rate of penetration, flow rate, interval length, and fluid volumes needed to ensure proper hole cleaning.

During the drilling campaign, jetting practices include controlling the string slack-off weight while jetting, and reciprocation of the conductor in relation to the weight on bit. After the first ultradeepwater well (Supremus-1) was drilled in the Perdido area, the team reviewed the surface conductor setting procedure with data to optimize the relevant parameters. The minimum ROP for jetting was determined to be 17 meters/hour in order to ensure the team could jet the casing to the desired depth.

Pemex applied the best practice of maintaining the well’s verticality while drilling surface sections to minimize lateral forces, prevent casing wear and maximize wellbore quality for better cementing operations.

**Redesigned BHA**

For the next Perdido wells, Trion-1 and Pep-1, a redesigned bottom-hole assembly incorporating rotary steerable, hole-opener tools was used to enlarge the hole to 33 inches to set 28-inch casing. The system included an under-reamer positioned above the motor to reduce the rat hole length and improve the measure point of the logging-and measurement-while-drilling tools. This BHA proved very successful with Trion-1, delivering a maximum inclination of 0.18 degrees. The Pep-1 well assembly entered with an inclination of 1.02 degrees and ended with 0.09 degrees. The maximum inclination obtained was 0.26 degrees, and the 28-inch casing was run and cemented successfully.

Well design possibilities have evolved to include tandem hole openers with BHAs of $12\frac{1}{4} \times 17\frac{1}{2} \times 22$ inches, $12\frac{1}{4} \times 16\frac{1}{2} \times 20$ inches, or $12\frac{1}{4} \times 14\frac{1}{2} \times 17\frac{1}{2}$ inches. These new assemblies incorporate the rotary steerable system with mechanical and hydraulic hole openers, plus a complete set of LWD measurements to support real-time formation and geomechanical evaluation (Figure 2).

The hole, therefore, can be drilled, evaluated and enlarged in one run, reducing wellbore stability risk and saving rig time. The team used a comprehensive approach to protect against accidental side-tracking using hydraulics analysis, torque and drag modeling, and shock and vibration simulations with varying drilling parameters to optimize the BHA design. A bull-nose, tandem hole-enlargement BHA design was selected and validated with drilling simulation software.

New technologies and techniques were used in Pemex’s deepwater and Perdido wells to better meet well objectives. This included caliper data for confirming good wellbore quality in enlarged hole sections for evaluating shallow and deeper targets, integrating a multi-activation circulating sub above the BHA to solve lost circulation issues, and using simulation software to model and optimize complex BHAs. A dual-tandem under-reamer assembly eliminated a subsequent rat hole enlargement trip, saving a full BHA trip and any subsequent wellbore stability risk.

LWD tools allowed evaluation decisions based on petrophysical and geomechanical data, and quadrupolar sonic tools improved source strength and protected against reamer attenuation. A BHA with a special hydraulic opener was designed to completely remove the cement inside 22-inch casing during drill-out, ensuring that a cement ring was not left behind that could lead to stuck pipes, casing damage and potential circulation losses during cementing.

**Technological Advances**

Figure 3 shows the techniques and tech-

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**FIGURE 2**

Wellbore Geometry Evolutions According to Water Depth (Hole Enlargement with Multiple Under-reamers in BHA)

<table>
<thead>
<tr>
<th>Water Depth</th>
<th>Hole Size</th>
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<tbody>
<tr>
<td>500 m &gt; Water Depth &lt; 1,500 m</td>
<td>26-in hole size, pump and dump</td>
</tr>
<tr>
<td>30 in</td>
<td>Jetting</td>
</tr>
<tr>
<td>16 in</td>
<td>Pilot hole 12(\frac{1}{4})-in, then hole enlargement to 17(\frac{1}{4})-in x 20-in hole size</td>
</tr>
<tr>
<td>13(\frac{1}{2}) in</td>
<td>Pilot hole 12(\frac{1}{4})-in, then hole enlargement to 12(\frac{1}{4})-in x 14(\frac{1}{4})-in hole size</td>
</tr>
<tr>
<td>9(\frac{1}{2}) in</td>
<td>10(\frac{1}{2})-in x 12(\frac{1}{4})-in hole size</td>
</tr>
<tr>
<td>7(\frac{1}{2}) in</td>
<td>8(\frac{1}{2})-in x 9(\frac{1}{2})-in hole size</td>
</tr>
<tr>
<td>5(\frac{1}{2}) in</td>
<td>6(\frac{1}{2})-in hole size</td>
</tr>
</tbody>
</table>

| > 1,500 m Water Depth | 26-x 33-in hole size |
| 30 in | Jetting |
| 28 in | 26-in hole size, pump and dump |
| 22 in | 12\(\frac{1}{4}\)-in x 22-in hole size |
| 18 in | 12\(\frac{1}{4}\)-in x 20-in hole size |
| 16 in | 12\(\frac{1}{4}\)-in x 17\(\frac{1}{2}\)-in hole size |
| 13\(\frac{1}{2}\) in | 12\(\frac{1}{4}\)-in x 14\(\frac{1}{4}\)-in hole size |
| 11\(\frac{1}{2}\) in | 10\(\frac{1}{2}\)-in x 12\(\frac{1}{4}\)-in hole size |
| 9\(\frac{1}{2}\) in | 8\(\frac{1}{2}\)-in x 9\(\frac{1}{2}\)-in hole size |
| 7\(\frac{1}{2}\) in | 6\(\frac{1}{2}\)-in hole size |
nologies introduced in deep- and ultra-deepwater operations in Mexico since 2004.

Modern downhole sensory equipment and streaming data network technology have allowed Pemex project teams to benefit from real-time measurements, automatically updating and optimizing drilling plans and models. Digital workflows were used to validate and update predrill geological, geomechanical and pore pressure models to reduce uncertainty and improve decision making.

Part of the real-time drilling process methodology defined clear communication processes between the operator and service company using a color-coded risk classification system and notification protocol. Potential drilling events and risks were communicated to decision makers along with recommended contingencies and mitigation steps.

This was made possible through a dedicated drilling visualization center in Poza Rica-Veracruz, which was inaugurated in 2011. The center receives real-time LWD data from the rig and is staffed with a multidisciplinary team of specialists—petrophysicists, geomechanics engineers, geologists, geophysicists, reservoir engineers, drilling fluids engineers, cementing engineers, completion engineers and drilling optimization engineers—who undertake interpretation and analysis. Figure 4 shows the monitoring center supporting the ability to employ a number of real-time optimization processes and logistics decisions during project execution.

Since 2009, seismic-while-drilling (SWD) technology has been used to acquire real-time seismic velocities and reduce uncertainty in formation compression data that are derived from surface seismic. It also has allowed downhole seismic sensors to improve the accuracy of seismic velocity acquisition with accurate depth control. SWD data are used to acquire depth-velocity information to calibrate and update predrill models.

The value of this capability was demonstrated on the Kabilil-1 well for a 16-inch casing hole interval between 1,500 and 2,200 meters to accurately define a fault plane. Real-time, look-ahead-of-the-bit check shots and vertical seismic profile (VSP) information led to a revised casing point location. SWD measurements also were used to conduct a salt proximity survey in the 13½-inch section that allowed geosteering under the salt dome structure.

Real-time drilling geomechanics have allowed Pemex to make pore pressure and wellbore stability decisions during drilling to provide up-to-date information about the wellbore condition, right up to setting casing. This service aggregates all available data, including LWD sonic, through constant monitoring and ensures any deviations from the plan are flagged for immediate action. It provides continuously updated pore pressure and wellbore stability forecasts to validate predictions for drilling ahead.

**High-Resolution Logging**

Modern high-resolution logging tools...
have improved reservoir characterization and reserves estimation. For the Trion-1 well, preliminary estimates from conventional resolution tools resulted in a net pay of 103 meters. After the petrophysical analysis that incorporated high-resolution, tri-axial resistivity and lithology (from spectroscopy, which more accurately captured the rock’s thinly laminated nature), the net pay was adjusted to 142 meters (a net pay increase of about 128 feet, or 37 percent).

The left-hand image in Figure 5 shows the evolution of the LWD sonic in the deepwater environment. The center image shows a real-time LWD monopolar sonic log and tandem BHA configuration. The image at right shows a new generation of LWD quadrupole sonic log in real time and tandem BHA optimized, with the DeltaT compressional and DeltaT shear sonic logs from the LWD quadrupole sonic tool.

The process of identifying independent or compartmentalized reservoirs was improved by using an in-situ fluid analyzer. Pressure gradient analysis is not conclusive if two sands interconnect. However, in situ composition and density data revealed a homogeneous fluid column in the upper sand and a compositionally graded bottom column, which clearly demonstrated that the two reservoirs were not connected, which assured clear flow consequences for future production.

Data processing techniques illuminated subsalt structures, accurately defining surface seismic velocity information and overcoming imaging challenges from shallow gas accumulations. Generalized surface multiple prediction, a leading-edge algorithm, was used to remove the multiples generated by the water bottom that could mask underlying reflective events completely. High-end, prestack, depth migration techniques were combined with anisotropic compensation for optimal seismic imaging and velocity model fidelity.

Advanced interactive velocity modeling that used localized seismic imaging allowed interpreters to modify the geometry of a salt body to obtain new depth-migrated images in close to real time, providing an advantage during salt interpretation scenario testing. Ray-based Q tomography also was used to mitigate the effects of shallow gas absorption, or other similar amplitude attenuators.

Evolution Through Experience

Lessons from earlier Gulf projects have shaped the evolution of Pemex’s deepwater operations. The subsea wellhead has evolved to cope with very high pressure and significant loads that are created by long risers and sea currents (15,000 psi pressure and 7 million foot-pounds bending moment capacity in the Perdido area). The pump-and-dump method that is used for riserless sections takes advantage of specially weighted and engineered drilling mud to improve hole integrity, minimize geohazard effects, and provide enough hydrostatic pressure to drill surface sections deeper for optimal casing setting depths.

The importance of maintaining verticality—achieved through specialized BHA designs using RSS technology—when drilling surface sections has been noted as crucial for protecting against casing wear. Drilling and under-reaming operations must consider real-time data acquisition (LWD/MWD) requirements in the drilling assembly design, and hole size and wellbore quality must be addressed in the wireline evaluation program to allow optimal data acquisition for reservoir characterization.

BHA designs were engineered as part of a wellbore quality assurance approach that maximized LWD and subsequent wireline data acquisition and optimized cementing operations for zonal isolation. Tandem drilling boosted deepwater performance and efficiency because it improved hole quality and allowed real-time data acquisition. Accurately modeling the complex and varied BHA designs has proven central to ensuring reliability and performance, as well as reducing shocks, vibrations, torque and drag.

These best practice lessons were employed during exploration evaluation activities for the Perdido wells, with both shallow and deep zones evaluated to identify pay intervals and qualify expected reserves. In order to provide accurate volumetrics, physical rock samples and fluid samples, the evaluation programs have considered real-time data from wireline logging tools with tri-axial resistivity, elemental capture spectroscopy, nuclear
magnetic resonance, VSPs, and mechanical sidewall coring, as well as formation testing services for pressure and fluid sampling.

The ability to employ a number of real-time optimization processes during project execution—supported by a dedicated monitoring center—gave the team the agility for critical decisions during drilling based on the best possible information. It also provided the basis for informed decisions that fine-tuned the more comprehensive wireline evaluation if a particular zone warranted further attention.

Future Pemex deepwater projects will benefit from the important lessons the company has learned and best practices it has co-developed with its service providers. These key insights from current and future projects will reduce nonproductive time and improve the formation evaluation and drilling performance in many well types and conditions.

Editor’s Note: The preceding article was adapted by the co-authors from OTC 25030, a technical paper on the evolution of Pemex’s ultradeepwater drilling campaign in the Perdido Fold Belt, which was presented at the 2014 Offshore Technology Conference Asia in Kuala Lumpur.

VÍCTOR GERARDO VALLEJO ARRİETA is the leader of the well engineering multidisciplinary group in Pemex. He is responsible for the overall design and well intervention of the exploration wells that are drilled offshore (deep, ultradeep and shallow waters) and onshore wells in Mexico’s oil and gas basins. Under his leadership, Pemex has designed, engineered and provided real-time surveillance on 34 of Mexico’s 37 deep- and ultradeepwater wells. Vallejo holds a bachelor’s and a master’s in petroleum engineering from the Universidad Nacional Autónoma de México, and a doctorate in petroleum engineering from Louisiana State University.

ACIEL OLIVARES TORRALBA is part of Pemex’s group of deepwater drilling specialists. He joined Pemex in 1987 as an operations engineer assigned to marine assets, and was the leader of well completion and workover operations. He is the 2012 recipient of the Mexican Petroleum Engineering Association’s Juan Hefferan Prize. Before starting his career as a reservoir specialist in geothermal engineering for the Electricity Commission of Mexico, he received a bachelor’s in petroleum engineering from Universidad Nacional Autónoma de México. He also holds a diploma in project management and a master’s in business administration.

OCTAVIO SAAVEDRA is the well design coordinator for Pemex’s northern exploration and production asset group, responsible for the multidisciplinary well engineering group. He started his career as a project engineer in Pemex’s drilling group. From 2003 through 2012, his responsibilities included well design, engineering and well construction within the company’s drilling and well intervention group. Saavedra holds a bachelor’s and a master’s in petroleum engineering from the Universidad Nacional Autónoma de México.

JUAN RAMON LOPEZ MORALES is a Schlumberger senior drilling engineer for deepwater projects in Mexico and Colombia. He joined Schlumberger in 2004 as a logging-while-drilling and directional drilling engineer. Lopez holds a mechanical and electrical engineering degree from Tec of Monterrey.

MANUEL ERNESTO TORRES VILALOBOS is the principal geomechanics domain champion at Schlumberger Drilling & Measurements for deepwater operations and exploratory drilling in Mexico and Central America. He has been working with the geomechanics consulting group since 2002. Early in his career, he worked as a petroleum geologist for international and national oil companies in Colombia, and has worked in petroleum rock mechanics for the past 15 years. He holds a degree in geology from National University of Colombia, a degree in civil engineering from the Catholic University in Colombia, and an M.S. in geotechnical engineering from National University in Colombia.