Drilling Evolution of the Ultra Deepwater Drilling Campaign in Mexico, Perdido Fold Belt
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Abstract
The Mexican National Oil Company (NOC), PEMEX, increased its ultra-deep-water exploration investment in the North Tamaulipas region of the Gulf of Mexico after four major oil deposits were discovered during 2012 and 2013. The new ultra-deep-water Perdido fold belt exploration region has a high potential for commercial production. The hydrocarbon reserves from the Perdido region were found in the Tertiary geological system that includes the Middle Oligocene Frio sandstones, Lower Eocene sandstones, and the Lower Paleocene sandstones. This region has challenged the ultra-deep-water semisubmersible rigs to work at their operational technical limits. The technical challenges include ultra-deep-water depths (more than 1,500 m < 2,900 m); narrower drilling mud weight windows; shallow geohazards; subsalt drilling; deeper target depths (7,000 m to 8,000 m); high-pressure, high-temperature (HPHT) conditions; and uncalibrated pore pressure models derived from seismic velocities obtained from surface seismic. Accurate reservoir evaluation is challenged with known low resistivity pay and highly laminated reservoirs, complex geology that consists of high angle dips and faulting. Operating conditions are impacted by remote offshore operations with complex logistics. The NOC has successfully drilled three wells in the Perdido area with oil reservoir discoveries: Supremus-1 and Trion-1 drilled in 2012, and Maximino-1 drilled in 2013. Currently, the operator is drilling one appraisal well and another exploration well in the Perdido area, applying the lessons learned to reduce nonproductive time (NPT) and improve drilling performance in every hole section. The cross-functional drilling group comprising of drilling engineers and Geologist and Geophysicist (G&G) members utilized the front-end-loading methodology to define stage gates and well-defined milestones within the project's lifecycle to ensure the important lessons learned were communicated and applied on subsequent wells.

The project's economic priority to optimize investment and reduce costs requires a comprehensive approach to the design and operational requirements. The process starts with good planning and testing multiple design scenarios with specialized software that can help recreate possible operational conditions. The well design may include multiple contingencies that may increase the number of casing strings, thus the importance of performing efficient simultaneous formation evaluation, drilling, and hole enlargement activities. Drilling and undereaming operations must consider the real-time data acquisition that requires complex drilling assembly designs that include logging-while-drilling (LWD) and measurement-while-drilling (MWD) tools. Hole size and wellbore quality are considerations for the wireline evaluation program in acquiring the data needed for reservoir characterization. Acquiring wireline pressure and fluid samples is more difficult in shallower geological targets where a hole size of 12⅝ in is considered the optimum size for achieving best results.

Introduction
During the ten-year period between 2003 and 2013, Mexico drilled 30 deep and ultra-deep-water wells in water depths ranging from 512 m to 2,900 m (Figure 1). During this exploration period, the learning curve has improved with each subsequent level of difficulty and increased well depth. In order to reach water depths greater than 1,500 m, both the wellbore geometry and the real-time data acquisition strategy has changed. Figure 2 shows how wellbore geometry evolved to reach geological targets, and how the various hole diameters changed to meet exploration objectives. As seen on the left of the figure, a conventional drilling and data acquisition approach was applied: drilling a 12½-in pilot hole for data acquisition and thereafter enlarging the hole to 17½ in or 14¼ in to set the casing. This enabled the real-time LWD data acquisition and provided a 12½-in maximum hole size for wireline data acquisition. However, as water depth increased (right side of Figure 2), the hole size requirements for the mechanical well design increased accordingly. In some cases, with shallow geological
targets, the required hole size of 22 in was needed for the casing. This required a strategy to drill an appropriate hole size for LWD and wireline evaluation with minimal dedicated drilling and hole enlargement trips. The evaluation programs considered real-time data needed to make decisions during the drilling phase and also support decisions for a more comprehensive wireline evaluation program if the zones warranted more extensive evaluation. The comprehensive evaluation logging suites included wireline logging tools with tri-axial resistivity, elemental capture spectroscopy, nuclear magnetic resonance, vertical seismic profiles, mechanical sidewall coring, and the complete suite of formation testing services for pressure and fluid sampling. The ultimate goal of the program was to provide accurate volumetrics, physical rock samples, and fluid samples for the booking of hydrocarbon reserves.

Figure 1. Deep water and ultra-deep-water drilling campaign in Mexico between 2003 to 2013. Green lines are the current wells being drilled at the time of this paper’s writing.
Figure 2. Wellbore geometry evolutions according to water depth. Hole enlargement in tandem drilling for drilling optimization. If a zone of interest is identified in a large hole section, the BHA will drill a 12¼-in pilot hole to improve the logging and formation fluid and rock sampling.

Another challenge faced by operations in the Perdido area in the Gulf of Mexico is the complexity of operational logistics; namely, the timely sending of tools and crew to the rig. These activities are impacted by two extremely important risk factors: the remoteness of the operator’s port facilities from the well locations, and dependency on weather conditions particularly during the hurricane season.

The purpose of this paper is to describe the drilling and formation evaluation evolution that occurred with Mexico’s deep-water and ultra-deep-water drilling campaign in the Gulf of Mexico. The paper will cover elements of well design, lessons learned, drilling practices, and formation evaluation strategies.

**VCDSE or Front-End Loading (FEL) Methodology**

This NOC incorporates the VCDSE (Spanish acronym for FEL) methodology to manage their exploration projects and achieve their objectives. It follows the FEL method of optimizing well construction design by capital project planning, based on the concept of stage-gates; formal gates at well-defined milestones within the project's lifecycle where each milestone/decision for the next stage is properly planned and approved (go/ no go). This methodology fosters multidisciplinary team collaboration of expertise and provides a rigorous and more robust analysis process to define an improved project management approach for the well.

The VCDSE methodology is defined by five stages: visualization, conceptualization, definition, follow-up and evaluation (Figure 3). The stages ensure a detailed definition of the project’s scope, a subsurface-surface and reservoir-well integrated vision. The exploration VCDSE design team, the operational teams, and service companies participate in the process as the progress level advances. The activity that forms each stage if outlined as follows:

- **Visualization**: Identification stage of options aligned to the business strategies. Used to validate the opportunity of the well project.
- **Conceptualization**: Conceptual engineering stage which allows for the analysis and selection of the best option among the previous stage’s proposals with the objective of selecting one alternative and making progress in its definitions.
- **Definition**: Detailed engineering stage where the scope is developed with greater depth, the execution plan is created by means of the documentation of the best choice through the drilling program and a more finite final cost estimate.
- **Follow-up**: Well project construction and operational follow-up stage. This is the stage where the most time and money are invested. Its success is partly determined by the quality of the previous stages.
- **Evaluation**: Documentation and evaluation stage of lessons learned during the execution of the well. A final total cost determination is delivered.

The VCDSE design multidisciplinary teams are led by a project leader charged with coordinating the work and the participation of each discipline throughout the design process: geophysics, geology, petrophysics, geomechanics, reservoir, drilling, completion, productivity, and technical limits. The work teams are further supported by other specialists in different disciplines including international service companies that have access to a wider global knowledge base (Figure 4).
The major technical and engineering challenges posed by the new deep-water and ultra-deep-water projects are greatly influenced by narrower operational drilling windows and by operation costs that can exceed more than USD 1 million spread rates. Technologies available in the international market that meet technical–economic analysis requirements have been adopted throughout the Mexico deepwater evolution. Since 2004, the new implemented technologies have achieved more efficiency with step change improvement in ROP compared to the older conventional technologies and methods (Figure 5).

Figure 3. VCD SE Methodology.

Figure 4. Discipline participation in the design and execution process.

Figure 5. Techniques and technologies introduced in deep and ultra-deep-water in Mexico since 2004.
The subsea wellhead is one of the most important components of deep and ultra-deep-water wells. It provides the structural support, pressure seal, casing string isolation, and a profile to latch the subsea blow out preventor (BOP). The burst limit and bending stresses caused by environmental marine-current lateral forces and high hydrostatic pressures of water depths from 1,500 m to 2,900 m are key technical considerations in the selection of a proper subsea wellhead system. The well design must consider a wellhead system that can support numerous casing strings with different diameters needed in the casing design to reach deep geological targets. Other considerations include the presence of H₂S and CO₂ that can affect the integrity of the subsea wellhead system over time.

In 2009, Mexico drilled its first ultra-deep-water well in a water depth of 1,698 m reaching a total depth of 3,362 m. This well used an 18½-in subsea wellhead system with a maximum pressure capacity of 15,000 psi, and a bending moment limit of 5,200,000 ft-lb. This arrangement allowed suspension of the following casing strings: 36-in x 20-in x 13½-in x 9½-in. This system had the option of using liners of 16 in, 11¼ in and 7½ in. As new exploration well locations were identified in deeper water depths, the engineering design challenges increased. This necessitated the operator to select a different subsea wellhead system with an increased bending moment limit of 7,000,000 ft-lb and pressure capability of 15,000 psi. The new well design considered the following series of casing strings: 36 in x 28 in x 22 in x 13½ in x 9½ in and liners of 18 in, 16 in, 11¼ in and 7½ in. In 2012, the new wellhead system was implemented on three wells in water depths ranging from 1,802 m to 2,900 m and final depths from 4,500 m to 6,500 m (Figures 6).

![Figure 6. String configuration, hanging capacity.](image)

**Pump and Dump**

The pump and dump system is used in deepwater wells for drilling riserless sections, but requires large volumes of bentonitic fluid during the drilling of the surface stages. As the name implies, the surface section is drilled without fluid returns to the rig with no riser or BOP. Using a weighted mud system improves the certainty that the surface casings are placed at the designed depth and also mitigates pore pressure that might exceed normal pressure regimes. Technical challenges during these operations include the use of large volumes of drilling fluid in wide-diameter surface holes, high rates of penetration that necessitate high flow rates to assure hole cleaning, the risk of encountering reactive formations that ball-out the drilling bits and decrease the hole diameter, and shallow water influxes that may dilute the drilling fluid and cause instability in the wellbore.

The surface stage is drilled with seawater and bentonite to a predetermined depth, where an increase in pore pressure is expected as per geo-pressure predictions. This is confirmed with real-time indicators such as torque and drag detected with the drilling string. The abnormal pressure requires the use of a heavy fluid to drill an interval between 150 m and 200 m, and to allow reaching greater depths to optimize the setting of the 20-in surface casing. The large fluid volume must be in constant supply during the 24-hr window of operation due to the high ROP that will be experienced in the short operational period. The following variables are considered for planning: ROP, flow rate, length of interval to be drilled, and volumes needed to ensure proper hole cleaning until the stage is completed. Additional fluid volumes are needed with high mud weight (slugging pills) and volumes for filling casing string during running in the hole. The fluid properties must provide proper rheology for hole cleaning and chemical properties to minimize destabilizing shales. The large quantity of fluid volume of over 3,000 m³ quickly exceeds the available rig storage capacity and mixing capabilities, thus the pump and dump system is utilized to mix the drilling fluid in real time. In order to produce it consistently and with homogenous properties, the “mixing on the fly” mixer is used as it provides an accurate blend at high workflow rates. Logistics preparation includes a
high-density bentonite fluid volume prepared onshore and shipped by a supplying vessel to the rig, and a mud boat for pumping. Given the high density of the fluid and the high viscosity conditions of the blend, the concentrated fluid density is prepared at 1.70 g/cc with a maximum limit of 450 m$^3$ transported per vessel in order to minimize any vessel instability.

Jetting Practices Prompt Improvements in the Perdido Field.

During the deep-water drilling campaign, the operator utilized established jetting practices according to international experiences. They include controlling the slack-off weight of the string while jetting and reciprocation of the conductor a set amount of times based on weight on bit that was applied (Figure 7). After the first ultra-deep-water well was drilled in the Perdido area (Supremus-1), the procedure for setting the surface conductors was reviewed and the data suggested an optimal set of parameters for maximizing these operations (Figure 8). It was determined that a minimum ROP while jetting should approach 17 m/hr, anything less would jeopardize the ability to jet the casing to the desired depth.

Drilling 26-in X 33-in Section to Set the 28-in Casing and Keep the Well Trajectory Vertical

The challenge faced when drilling surface sections in ultra-deep-water wells with conventional BHAs or motor BHAs that have a straight bend housing is to keep the well trajectory as vertical as possible. Maintaining the verticality of the well in the surface sections is mandatory to minimize lateral forces created with the casing and subsea wellhead and to prevent future casing wear spots. Lesson were learned from a previous well, Caxa-1, that had a BHA configured with a straight bend housing in the motor plus 28-in drilling bit and where the verticality was not maintained. Mitigation measures were employed like reducing weight on bit, controlling rate of penetration, and changing rotary speed, but were unsuccessful in maintaining verticality. Although no geological targets were compromised, the correction to well inclination was
implemented on subsequent hole sections, this problem would be unacceptable for other deepwater wells. The next two Perdido wells, Trion-1 and Pep-1, did not have any room for error due to the expected zones of interest at shallow and deeper depths. In order to ensure verticality, the newly re-designed BHA incorporated a rotary steerable, hole opener tools to enlarge the hole to 33 in to set a 28-in casing.

After the initial jetting, the new BHA assembly performed the drill-ahead operations that performed drilling and LWD logging of the section. The hole section was enlarged to 33 in with a dedicated BHA (Figure 9) that consisted of a rotary steerable system powered by motor, an underreamer positioned just above the motor to reduce the rat hole, and LWD and MWD tools. This BHA proved very successful with Trion-1 well having a reported maximum inclination of 0.18 deg, and the PEP-1 well’s assembly entering with an inclination of 1.02 deg and ended with an inclination of 0.09 deg. Once the well was vertical, the maximum inclination obtained was 0.26 deg. The 28-in casing was successfully run and cemented with no problems.

**Evolution of Drilling with Tandem Reamer**

Economic factors that highly impact the cost of a deepwater well relate to drilling time and data acquisition. Engineering groups have focused on seeking ways to optimize the well design to reduce this impact. The evolution of BHA designs for real-time acquisition resulted in a learning curve which is described in Table 1. The drilling team has evolved their methodologies from traditional drilling with a 12½-in pilot hole and subsequent enlarging from 17½ in x 20 in, or 12¼ in x 14½ in to more complex drilling assemblies that incorporate tandem hole openers. The new BHA arrangements include tandem hole openers with BHAs of 12¼ in x 17½ in x 22 in, 12¼ in x 16½ in x 20 in, or 12¼ in x 14½ in x 17½ in. These new assemblies incorporate the rotary steerable system with mechanical and hydraulic hole openers, plus a complete set of LWD measurements for supporting the real-time formation and geo-mechanical evaluation. This combination assures that in one run, the hole is drilled, evaluated, and enlarged; thereby reducing wellbore stability risk, and saving costly rig time.

In the shallow sections of the well, there are unique challenges that require an approach to meet multiple stake holder requirements. The potential shallow geohazards require a unique directional well trajectory where the build section traverses through the reservoir and the formation evaluation data acquisition requires a maximum hole size of 12¼ in to provide a complete set of wireline logs with a modular pressure and fluid sampling tool, mechanical sidewall cores, and other measurements that are hole-size dependent. After the pilot hole was drilled and evaluated, the subsequent hole enlargement operation presented a considerable risk with accidental sidetracking. A comprehensive approach was employed using hydraulics analysis, torque and drag modeling, and shock and vibration simulations using varying drilling parameters which resulted in an optimum BHA with a bull nose tandem hole enlargement BHA design validated with drilling simulation software tools. This design resulted in a successful operation with reduced risk and meeting the design objectives.
Some of the different well scenarios to ensure the well objectives are met for better drilling performance and operations drilling reliability. The deepwater and Perdido wells have allowed the operator to utilize newer technologies and methods to address different well scenarios to ensure the well objectives are met for better drilling performance and operations drilling reliability. Some of the new innovative technologies and methods are described below:

- **Wellbore quality** in the enlarged hole sections was a major concern on the four Perdido wells (Trion-1, Supremus-1, Maximino-1, and Pep-1) when the objective of the well was to evaluate shallow and deeper targets. After programs were designed with simultaneous drilling and evaluation tools, the caliper data and good wellbore quality was confirmed. This gave the drilling engineers confidence in delivering good hole quality for the wireline acquisition program and cementing operations.

- **Mitigation in lost circulation zones.** The integration of a multiactivation circulating sub above the BHA allows the contingency to cure lost circulation problems. The valve allows the circulation of high concentrations of lost circulation material (LCM) and minimizes the potential to plug the downhole drilling and logging tools.

- **Better simulation produces better field results.** The Finit Element Analysis simulation software allows complex BHAs to be modeled and optimized against different well conditions and lithology to ensure performance and reliability. The new BHAs have dramatically improved drilling times and have resulted in fewer trips into the well.

- **Efficiencies with drilling and underreamer operations achieved**, but in some cases the +40 m of ratohole was not acceptable for running the casing to bottom. A dual tandem underreamer assembly was employed to drill the pilot hole and enlarge the open hole, and the lower underreamer (dynamic activated) was used to enlarge the ratohole and eliminate a subsequent dedicated trip resulting in one full trip of rig time savings.

- **Longer and more complex LWD strings introduce new challenges with signal-to-noise.** The ability to drill and acquire petrophysical and geomechanical data with LWD logs in zones of interest allows the operator to make proper decisions regarding whether to employ a more comprehensive wireline logging evaluation. Different stabilizer types and change in reamers to LWD sonic tools were considered. The use of LWD quadrupolar sonic tools improved the source strength and proved strong enough against reamer attenuation. Figure 10 shows two drilled wells in the same formation at different locations. These logs were acquired with the same reamer configuration, but with different stabilization configuration and LWD tool. Well 1 (to the left) was drilled with the LWD that included the use of the quadrupolar source. In this log, the compressional wave (DTCS) is coherent and is not attenuated, while Well 2 (right) has an incoherent compressional wave that gets lost with the noise caused by the reamers and the drilling fluid used.

- **Cement ring buildup.** The 16-in landing sub installed in the 22-in casing generates a restriction to completely remove the cement inside 22-in casing when during the drill out operation causing a cement ring. This cement ring cause problems when drilling the 20-in hole section generating stuck pipe situations, casing damage when trying to eliminate it with the complex BHAs (Figure 11), and loss of circulation when cementing. This issue was addressed with a dedicated BHA including a special hydraulic hole opener designed to ensure the cement ring is completely eliminated without damaging the 22-in casing, the MWD and APWD tools for the leak off test (LOT), and the 18 1/8-in roller cone bit. Figure 12 shows how was the evolution of the BHAs for drilling out of the 22-in casing.
eliminating the cement ring due bit size.

Figure 10. Left: logs and bottomhole assembly configurations to improve sonic quality measurements. Right a): sonic log comparison with BHA not optimized. Right b): BHA optimized and the quadrupole sonic tool.

Figure 11. Left: metal shavings during drilling out with 12\(\frac{3}{4}\)-in x 18\(\frac{1}{4}\)-in x 22-in BHA. Right: FEA simulation showing hole opener behavior inside casing during drill out.
Real-Time Surveillance

After vetting of the well design, it was necessary to define an operational execution process that integrated the design to execution process. This requirement was successfully met with an industry-proven drilling and geomechanical real-time operational process, referred as “No Drilling Surprises” or NDS. The workflow process incorporates information from the design stage to define operational steps for identifying and mitigating potential drilling risks along with contingency measures produced with the DrillMap* drilling engineering and operations plan. This process allowed a cohesive approach to the operation that integrated the various operation team members from the geomechanics team, Drilling Optimization Engineers (DOE), and the drilling engineers (DEs) to finalize predrill well models and create the DrillMap forecast using new software technology. These DrillMap plans include preventive actions (best practices and lessons learned) and mitigation measures (contingencies) in order to optimize drilling during the execution phase. The Perdido project wells have created 33 DrillMap plans through an integrated team effort for the Perdido exploration area.

During the drilling phase, real-time drilling monitoring (No Drilling Surprise Service*) (Figure 3) and real-time Geomechanics monitoring processes were important contributors to the successful execution of these projects. The real-time monitoring was enabled through a dedicated state-of-the-art Drilling Visualization Center located in Poza Rica-Veracruz and inaugurated in 2011 (Figure 13). The center received real-time LWD data transmitted from the rig and was staffed with specialists (petrophysicist, geomechanics engineer, and drilling optimization engineers) to interpret and analyze the received data. Several workflows were used to validate and update predrill geological, geomechanical, and pore pressure models to further reduce the uncertainty in the next sequence of the well, validating the expected drilling results versus the predicted. The NDS process defines a clear communication process between operator and service company that uses an agreed drilling risk color-coded classification system and notification protocol system. Drilling events and potential risks are communicated to decision makers with pre-conceived contingencies and/or mitigation recommendations.
Real-Time Seismic While Drilling (SWD)

After the drilling of the Kabilil-1 deepwater exploration subsalt well in 2009, this technology proved its usefulness in acquiring real-time seismic velocities for reducing uncertainty in formation compression data derived from only surface seismic data. The use of SWD technology allowed seismic downhole sensors with surface airgun sources to acquire more accurate seismic velocities with accurate depth control. Engineers used the SWD data to acquire depth-velocity information, calibrate the geomechanical and geological models, and provide real-time surveillance in order to adjust the model against the predrill model.

An example application during the Kabilil-1 well utilized the real-time look-ahead-of-the-bit check shot and vertical seismic profile (VSP) on the 16-in casing hole interval between 1,500 and 2,200 m to accurately define a fault plane. This 16-in casing hole section was expected to cross the nearby salt flank; however, the look-ahead VSP station measurement confirmed that the trajectory would pass some distance from the salt flank, but identified an unexpected fault plane. This information led to an informed decision on where to set the casing 16-in casing point. For the remaining part of the well, the SWD measurement was used to conduct a salt proximity survey in the 13\(\frac{3}{8}\)-in section, determining that the well was actually closer than expected to the salt dome, a minimum distance of approximately 163 m (535 ft). (Vallejo 2013, 2012; Aguilera 2011; Sanchez 2010). The SWD technology will be very useful when drilling subsalt structures to minimize the risk setting the casing in a place where the subsequent operation may be compromised.

Real-Time Drilling Geomechanics: Approach and Workflow

The conventional approach of pore pressure prediction and wellbore stability provides safe mud weight window between pore pressure and fracture gradient and a stable mud weight window between the collapse and fracture gradients. However, borehole enlargement, or breakout, is significantly influenced by the drilling process. The predrill wellbore stability study cannot model the effect of the drilling process, therefore cannot predict wellbore degradation.

Real-time drilling geomechanics (RTDG) allows the operator to make pore pressure and wellbore stability decisions during drilling by providing the most current information about the wellbore condition, right up to setting casing. Hazards identified for a specific well trajectory and geological setting are identified and consolidated through the overburden and into the reservoir with a predrill mechanical earth model. The service collects and aggregates all available data, which may include drilling measurements, logging while drilling (LWD), mud logging, seismic, and hydraulics. Through continuous, 24/7 monitoring it ensures that any deviations from the plan are quickly recognized so that immediate action can be taken by the operator. RTDG provides continuous updated forecasts of pore pressure and wellbore stability through real-time-enabled software to validate predictions for drilling ahead. On completion of the well, a final end-of-well summary of the pore pressure and wellbore stability analysis is prepared and submitted to the operator for capturing lessons learned and input for future well planning and drilling operations.

Accurate Velocity Field for Well Design and Drilling Enhancement

The offshore geology of the Perdido area is complex and surrounded by large canopies of allochthonous salt that poses challenges to illuminating structures below salt and accurately defining surface seismic velocity data for and use with geomechanic and pore pressure prediction (PPP) modeling. Away from the salt bodies, the area is also characterized by
shallow gas accumulations on the crests of the regional anticlinal structures which frequently cause serious absorption problems when imaging the targets deeper within the same anticlines with surface seismic. Some of the key data processing techniques that have been tested or used to maximize the potential of the surface seismic data are as follows:

- Generalized surface multiple prediction (GSMP). A leading-edge algorithm to combat the strong multiples generated by the water bottom that, if not correctly modeled and removed, can completely mask the underlying reflective events.
- High-end pre-stack depth migration (PSDM) techniques such as RTM (reverse time migration) and various beam migrations, combined with anisotropic compensation for optimal seismic imaging and fidelity of the resultant velocity model.
- Advanced interactive velocity modeling using LSI (localized seismic imaging) where interpreters can interactively modify the geometry of a salt body and obtain new depth migrated images in close to real time—a huge advantage in scenario testing of different potential salt interpretations.
- Q-Tomography. This application creates a depth and spatially variant field that is inversely proportional to the degree of energy attenuation that the data suffers. The ‘Q’ field is fully ray traced in the depth domain and can be subsequently applied during the process of depth or time migration to mitigate the effects of shallow gas absorption, or other similar amplitude attenuators.
- Maximization of the available data through innovative high-resolution velocity solutions. The integration of the geomechanics project helped to derive the final velocity model obtained through a combination of available narrow-azimuth (NAZ) seismic data migrated using a velocity field obtained from an overlapping wide-azimuth (WAZ) survey, and then manually refined using offset well logs and horizon information prior to a constrained dense velocity analysis as input to geomechanics and PPP work.

**Real-Time LWD Quadrapole Sonic Tool for Larger Hole Sizes**

The execution phase included real-time geomechanics, petrophysics and updates of the geological model using LWD tools. Quality log data in real-time is essential for validating pre-drill models that will be used to drill with more certainty and safety. Potential detection of geohazards and setting casings at appropriate depths are key uses of the data. The real time geomechanics monitoring has proven very useful for drilling these wells and the data acquired from LWD sonic monopolar and quadrupolar tools as a major input for the model validation. As the LWD BHA’s have evolved and problems of sonic signal to noise issues have arisen from the use of single and tandem hole openers, the quadrapole LWD sonic logging tool has proved to be the best technology when drilling with these conditions and ensures the best chance of acquiring the best sonic logging data.

The new LWD Sonic tool for 8” collar size was introduced in Mexico with the Perdido project. This tool was specifically developed to deliver an excellent Real-Time compressional slowness for use in pore pressure models, as well as a recorded mode quadrupole shear measurement and Stoneley measurement for geomechanics, fracture detection and Petrophysics uses. On previous wells using the older generation sonic tool it was extremely difficult to deliver quality Real-time Sonic data in BHA’s with dual under reamers, where most of the formation signal was adversely affected by the large noise signal generated by the under reamers. During the Maximino-1 well, the 12 ¼"x16 ½"x22” and the 12 ¼"x16 ½"x20” hole sections were successfully drilled, logged and under reamed while transmitting the real-time sonic and density data to the Real Time Data Center to update the real-time pore-pressure model. The subsurface team was able to use the real time data to determine the casing point by correlating with offset wells and the surface seismic data. The LWD log quality was determined to be of good quality and the decision was made not to further acquire wireline logs and no additional hole opening of the rathole was needed. After processing the tool memory data, the shear data was successfully acquired in very slow formations near the mud line with shear slowness as low as 700 us/ft.

**Formation Evaluation Using Real-Time Data**

Real-time update of the geological and reservoir models has improved with good application of the data to achieve the well objectives. The conventional coring points have been determined with good accuracy using real-time interpretation and petrophysical analysis using the LWD data with correlation offset well data.

Reservoir characterization and reserves estimation are key objectives with any exploration well program. In the case of the Trion-1 well, the value of the latest-generation logging tools with much higher levels of resolution resulted in an increased estimate of reserves. The preliminary estimates after the petrophysical interpretation using conventional resolution logging tools resulted in a net pay of 103.47 m. The petrophysical analysis was re-analyzed using the high-resolution tri-axial resistivity and lithology from spectroscopy which captured the thinly laminated nature of the rock more accurately, resulting in net pay of 141.72 m or a 36.7% increase in net reservoir quantity. Apply the net pay over the structure extent and this equates to millions of additional barrels that may have been overlooked.
Another example of good application of new technologies involves the identification of independent or compartmentalized reservoirs. Using a pressure gradient analysis is not conclusive if two particular sands are interconnected. The further analysis using an in-situ fluid analyzer demonstrated very clearly that the two reservoirs were not connected. The in-situ fluid analyzer composition and density data revealed a homogeneous fluid column in the upper sand and a bottom column that was compositionally graded. These conclusions have clear flow assurance consequences when producing these reservoirs in the future. The consequences of not recognizing these different fluids and omitting the flow assurance strategies could have proved very costly.

**Project Results**

The operator PEMEX has created a complete database of lessons learned using the team’s input to accelerate the learning curve. These lessons learned have been part of the success of drilling deepwater projects including those in the ultra-deep-water of the Perdido area.

- The VCDSE methodology used to optimize the well construction and design and manage the planning and execution of the deepwater drilling campaign highly contributed to the success of the NOC projects.
- The subsea wellhead is in evolution. In the Perdido area, the NOC has been using 15,000 psi pressure and 7,000,000 ft-lbs bending moment capacity due the high pressure at the subsea wellhead and high loads applied to it caused by the huge length of riser interacting with the water currents and rig motion.
- The pump and dump system for the riserless section delivers two important functions. 1) the use of an engineered weighted drilling fluid provides improved wellbore stability either to improve hole integrity or to minimize geohazard effects 2) the weighted engineered mud provides the hydrostatic to drill the surface sections deeper, thereby allowing deeper setting depths for the surface casings.
- Drilling the surface section vertically is a must to ensure the casing will not suffer wear while drilling. It was achieved with specialized BHA designs with rotary steerable systems.
- Tandem drilling has significantly impacted the drilling performance and cost reduction by improving hole quality, allowing real-time data acquisition by eliminating an extra dedicated run to enlarge the hole.
- Finite Element Analysis simulation is a very important engineering application to model the complex BHA designs, and to ensure that the performance for a specific objective is achieved delivering proper drilling parameters to reduce shocks and vibrations, torque and drag increasing the reliability of the tools string.
- For project execution, real-time geomechanics and drilling optimization processes were employed and supported by a dedicated 24/7 monitoring center, meaning that data could be received in real time and be used to enable real-time decisions.
- For the Perdido wells, the exploration evaluation objectives included shallow and deeper zones of interest. The primary outcome of the evaluation was to enable the identification of pay intervals and qualifying the expected reserves. BHA design configurations were engineered to maximize the acquisition of the LWD data and the subsequent wireline data. This required a wellbore quality assurance approach to ensure good hole quality for evaluation and for the subsequent cementing operations to achieve zonal isolation.

**References**