The deepwater region east of the state of Tamaulipas, Mexico, remains effectively unexplored. Pemex launched an initiative to develop a deepwater-exploratory strategy, assess risks, and classify hydrocarbon types by area. Comprehensive geological modeling enabled identifying several key play elements including reservoir presence/quality and hydrocarbon-source rocks, -migration patterns, and -trapping mechanisms. The shale/sand section from 2900 to 3400 m has low unconfined compressive strength (UCS), but engineers wanted to drill out the 18-in.-casing shoe without tripping for a bottomhole-assembly (BHA) change out while retaining adequate clearance to run the subsequent 16-in. string without nonproductive time (NPT). This technique would eliminate an extra 12¼-in. pilot hole, significantly reducing the number of rig days. The challenge was to build a tandem-reamer/directional BHA.

Introduction
The BHA provider recommended a 12¼×16½×20-in. tandem-reamer BHA including a rotary-steerable-system (RSS) -driven 12¼-in. polycrystalline-diamond-compact (PDC) bit, a 12¼×16½-in. fixed-blade hole opener, and an expandable reamer. The BHA would prevent internal damage to the 18-in. casing and allow the operator to set 16-in. casing in the next run, while the 20-in. hydraulic opener would create adequate clearance for cementing. Real-time measurement-/logging-while-drilling (MLWD) data would be used for formation evaluation and well placement. A finite-element analysis (FEA) was performed to balance the cutting structures, minimize the vibration potential, and set the optimum operating parameters. On the basis of the simulations, a 716-type PDC bit was selected.

Deepwater Exploration
The operator’s deepwater-exploration strategy included regional geochemical modeling that identified source rocks and the types of expected hydrocarbons. The study identified a strong relationship between abundant natural hydrocarbon seeps and discovered fields to identify prospects in the subject area. A 2D-/3D-seismic-acquisition program focused on the most-prospective areas. The initial drilling phase will concentrate on areas with the greatest potential to produce high volumes of light oil (28–37°API) and natural gas.

Deepwater-Drilling Challenges
Deepwater drilling presents challenges that the operator has not encountered. The most critical in the area of interest include:

- Time/cost efficiency while maintaining safe operations. Rig costs, including associated services, may exceed USD 1.2 million/D.
- Directional control in extremely soft formations and hole enlargement while drilling in nonconventional scenarios that can include a high probability of BHA shock and vibration.
Recording and collecting as much high-quality information as possible from downhole lithology and in-situ fluids for regional and reservoir characterization.

Extreme-weather environments and conditions such as hurricane season.

Narrower mud-weight windows compared with traditional wells.

**Hole-Enlargement.** The customary process for enlarging a well section begins by drilling out with a smooth BHA and then drilling the section with a $12\frac{1}{4} \times 8\frac{1}{2}$-in. reamer, creating a pilot hole while running LWD tools to capture data in real time. Next, an additional trip is required to enlarge the predrilled hole to accommodate the next casing string. The goal of this study was to optimize the process to reduce rig-time usage and NPT as much as possible by eliminating one trip in the hole.

From experience, the cutters on an expandable reamer’s cutter blocks (Fig. 1) and the shearing elements on the PDC pilot bit (Fig. 2) show excessive dulling after drilling and enlarging a predrilled section. Improving the dull condition of these tools became an additional objective for a new BHA.

**Directional Plan**

The exploratory well, Caxa-1, approximately 150 km offshore Tamaulipas (Fig. 3) in 1820-m water depth, presents unique challenges. The plan called for a vertical wellbore to penetrate a thick section of Pliocene/Miocene shale overburden to evaluate two sequences of Miocene sands before reaching total depth. Most of the difficult shale/sand section between 2900 and 3400 m has a relatively low UCS of 2–5 ksi, but the tubular program would make it particularly difficult to drill and case the section efficiently.

**Engineered Approach**

To address these issues, a holistic approach was implemented that included collaboration between the operator and the service provider’s drilling group. Rather than the use of trial and error for drillstring and BHA adjustments, a dynamic FEA-based modeling system was used to design a fit-for-purpose BHA before drilling commenced. The exercise included:

- Extensive multidisciplinary risk assessment in the planning stage, paying special attention to drilling parameters used in previous wells
- Dynamic BHA modeling to select the most appropriate configuration, considering stability and shock/vibration avoidance

**Fig. 2**—12¼-in. PDC bit in poor dull condition after attempting to enlarge the 12¼-in. pilot hole on a 14½×17½-in. BHA.

**Fig. 3**—Location of exploration Well Caxa-1.

**Fig. 4**—Staged opener would be positioned directly below the expandable reamer at the top of the BHA for a balanced tandem-reamer configuration.

**Fig. 5**—Expandable reamer at the top of the BHA.
Fine tuning operations on the basis of downhole and surface high-frequency measurements and correlations between drilling parameters

The service provider recommended a 121/4 × 161/2 × 20-in. tandem-reamer BHA with a 121/4-in. PDC bit, an RSS, a 121/4 × 161/2-in. fixed-blade staged hole opener (Fig. 4), and an expandable reamer (Fig. 5) with a maximum opening diameter of 20 in. The BHA would prevent internal damage of the 18-in. casing and allow setting the 16-in. casing efficiently in the next run, while the 20-in. hole opener would create adequate clearance for cementing.

To ensure acquisition of high-quality log data for formation evaluation and accurate well placement, the operator wanted to use real-time MLWD tools. An in-depth engineering analysis and modeling study would be required to balance the cutting structure on the bit and two reamers to minimize vibration and allow the sophisticated suite of logging tools to function properly.

**BHA Modeling.** A team of field and design engineers analyzed the dynamic effects of the two-reamer BHA by studying four PDC bits. The objective was to determine the best cutting-structure configuration and operating parameters for dynamically stable drilling. An existing rock-strength analysis from an offset well in Tamaulipas was used to determine the appropriate rock samples to simulate field formations. On the basis of gamma ray and sonic log data, the Lower Pliocene shale between 3100 and 3400 m was selected as a suitable case for the bit/reamer/reamer modeling analysis.

Dynamic BHA comparisons were used to determine the degree of bit/reamer vibration and the response to applied downhole/surface torque. The four 121/4 × 161/2 × 20-in. BHAs were modeled to determine bending stress, build-rate capabilities, and walk tendency. To optimize operating parameters, a series of 20 simulations was run to observe how four weight-on-bit (WOB) and rotation revolutions/minute (RPM) values would affect vibration and torque levels.

**Simulation Results.** Simulations were run to determine lateral, axial, and torque response between the PDC bit, the staged hole opener, and the expandable reamer. Simulations were also run to analyze surface torque, bending stress, and BHA steering tendencies. To determine drilling-parameter sensitivity, a series of simulations was performed to observe how different WOB and RPM values would affect lateral vibration and torque at 3100 m and at 3400 m during transition drilling.

**Recommendations.** On the basis of the analysis at 29,000 lbf WOB and 140 RPM, only two bits (713 and 716) displayed acceptable behavior in terms of delivering low values of torque and vibration. However, additional analysis revealed that PDC Bit 713 would be more stable in the parameter combination analysis, but Bit 716 would provide better rate-of-penetration (ROP) potential. Also, Bits 713 and 716 showed the lowest surface-torque values of the four designs. The 121/4-in. 716 bit was recommended because of its higher ROP potential when used in combination with the balanced tandem-reamer-BHA configuration and the recommended operating parameters.

**Caxa-1 BHA Solution.** The tandem-reamer BHA kicked off from 3.67” and built angle to 6° inclination, drilling tangent for approximately 382 m at an average ROP of 18.6 m/h. No vibration issues were recorded, resulting in high-quality MLWD data with the entire operation completed in one trip. The 18-in. casing was undamaged, enabling the 16-in. casing to be run successfully on the first attempt. The BHA configuration eliminated an additional trip to drill out the 18-in. casing shoe, while efficiently delivering all directional objectives and allowing the use of advanced MLWD tools (i.e., resistivity, gamma ray, density, neutron, and sonic) in the surface section. Finally, use of these tools and the operational technique eliminated the requirement of the additional 121/4-in. pilot hole, saving many days of rig time. This was the first directional 121/4 × 161/2 × 20-in. tandem enlargement recorded. The BHA was pulled at section total depth and found to be in excellent dull condition, with essentially no wear on any of the three tools’ cutting structures.

**Conclusion.** Use of the dynamic modeling program enabled engineers to predict the drilling systems’ behavior accurately in the problematic wellbore sections. The modeling program demonstrated the ability to predict bit/reamer interaction during hole-enlargement-while-drilling applications. The quantitative measurement provided the operator with valuable data to make the final bit/reamer selections.

Balancing the two reamers’ cutting structures with a stable PDC-bit design eliminated vibration while producing high average ROP, even while transitioning from shale to sandstone during hole-enlargement-while-drilling operations. Controlling drilling parameters, particularly WOB and weight-on-reamer, had a significant effect on increasing stability of the entire BHA. Stable drilling enabled the sophisticated suite of logging tools to deliver reliable high-quality data for accurate formation and wellbore measurements. The dull condition of the three cutting structures was very good, and a quality full-gauge hole section was achieved. JPT