

Well Construction and Field Development in Mexico

The way of doing business in Mexico's oil and gas industry is changing. The results are high gains in efficiency and production as project scopes evolve from single-service contracts for logging, cementing or stimulation to full-scale field-development projects. This article highlights projects in two regions of Mexico—Burgos basin and Chicontepec paleochannel.

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CMR (Combinable Magnetic Resonance), MDT (Modular Formation Dynamics Tester), PowerSTIM and ProCADE are marks of Schlumberger.

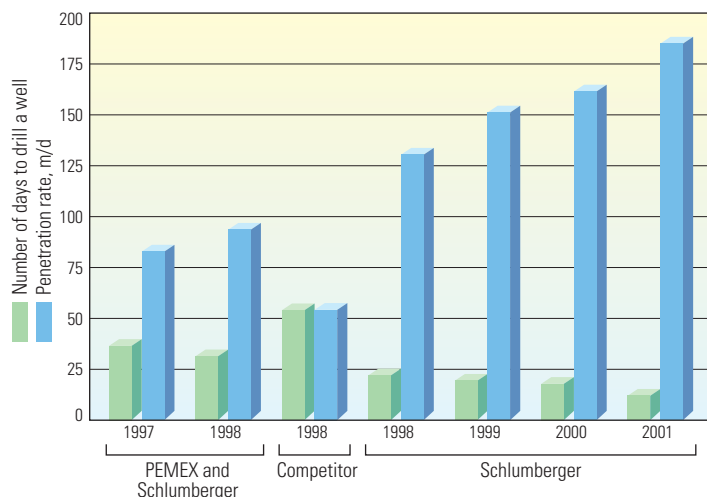
When national oil companies and resource holders need to increase activity in a field, they usually have three alternatives: They can invest in personnel and expertise; they can partner with another oil and gas company; or they can team up with an integrated-services provider.

Each option has advantages and disadvantages. Hiring expertise, while appropriate for

some companies and some projects, may not suit every situation. Partnering with other companies can be successful in many cases, but is not allowed in some countries. Working with an integrated-services provider may allow operating company staff to concentrate efforts on more complex problems, but often requires learning a new way to operate.



^ Burgos basin in northern Mexico, covering 3706 sq miles [9595 km²]. Gas fields in the Burgos basin could contain up to 18 Tcf [515 billion m³]. They currently produce around 1 Bcf/D [29 million m³/d] of nonassociated gas. The Chicontepec paleochannel lies near Poza Rica.



▲ Improvement in Burgos basin drilling performance with introduction of Schlumberger IPM integrated services. Average penetration rate more than doubled between 1997 and 2001. During the same period, the average number of days required to drill a well decreased from 36 days to 12 days. Labels across bottom indicate companies responsible for drilling.

Several oilfield services companies offer integrated services. At Schlumberger, the business segment charged with organizing and managing integrated-services projects is known as Integrated Project Management (IPM). The IPM organization offers a variety of project-management solutions, including development of new fields, rehabilitation of mature fields, well construction, production management and integration of well and production services.

In this article, we describe how Schlumberger IPM is working with Petr leos Mexicanos, or PEMEX, the national oil company of Mexico, to enhance production from fields in the Burgos basin and in the Chicontepec paleo-channel. Over the lifetime of these projects, the scope and commercial models have evolved to meet new challenges and to satisfy the project objectives of both operator and service provider.

Burgos Basin

Gas was discovered in the Burgos basin in 1945. Of the four basins in Mexico that produce non-associated gas, Burgos, covering 3706 sq miles [9595 km²], produces the most (previous page).¹ Recent geological studies conducted by PEMEX indicate the Burgos fields could contain up to 18 Tcf [515 billion m³]. Today, the basin produces around 1 Bcf/D [29 million m³/d], and PEMEX Exploraci n y Producci n is moving aggressively to double that production level.

The Burgos basin contains sediment thicknesses up to 30,000 ft [9000 m] of Upper Mesozoic- and Tertiary-age strata, and are

geologically equivalent to the Queen City, Vicksburg, Wilcox and Lobo sandstones that are productive just to the north, in the Gulf Coast basin of southern Texas, USA.

Reservoirs in these low-permeability siliciclastic sediments are small and compartmentalized by faulting. Each compartment must be considered separately, with different petrophysical and depth-dependent properties. In this complex geology, formations with lost circulation and high pressure present drilling challenges. Most wells are drilled to depths of 9500 to 9800 ft [2900 to 3000 m], completed, and then hydraulically fractured. Initial well productivity is high, but declines quickly.

Project Evolution

In January 1994, faced with decline in production of nonassociated sweet gas from the Burgos basin, PEMEX established a small team of professionals to estimate the remaining production potential and recoverable gas reserves in the Burgos basin.² The group outlined the necessary steps the company would have to take to continue working profitably from its center in Reynosa, Mexico.

The task force members produced a vision that many considered overly ambitious. However, through innovative contracting strategies, teamwork and the selective use of technology, implementation of their vision resulted in a sixfold increase in the rate of production from the basin—from 183 MMcf/D [5 million m³/d] in December 1993 to

1030 MMcf/D [29.5 million m³/d] in January 2003.³ During the course of the revitalization project, more than 74 new fields were discovered, and more than 3 Tcf [86 billion m³] of new reserves were added. Development and exploratory drilling activity increased from 10 wells completed in 1994, to 343 wells completed in 2002. In all, 1313 wells were completed during that time.

This extended period of success began with small-scale contracts and simple improvements to the well-construction process that evolved to encompass larger projects with greater impact. To increase production from wells in the central area of the Burgos basin, PEMEX awarded Schlumberger IPM a first contract to acquire 650 sq miles [1680 km²] of 3D seismic data, perform two integrated reservoir studies, drill 31 wells and construct a gathering station and four gas-compression plants. This work was completed in 11 months starting in mid-1997.

PEMEX awarded the second Burgos contract to a Schlumberger IPM competitor to construct, complete and connect 18 wells in a 10-month period ending in early 1999. After a few months of deficiencies in performance, PEMEX voided the contract and opened a new bid. Schlumberger IPM was awarded the drilling of 18 additional wells. By the end of the second contract, IPM had improved drilling performance in this part of the basin from an average drilling time of 36 days in 1997 to a new average of 22 days per well in 1999 (above left). This downward trend in drilling times continued through all subsequent stages of the Burgos projects.

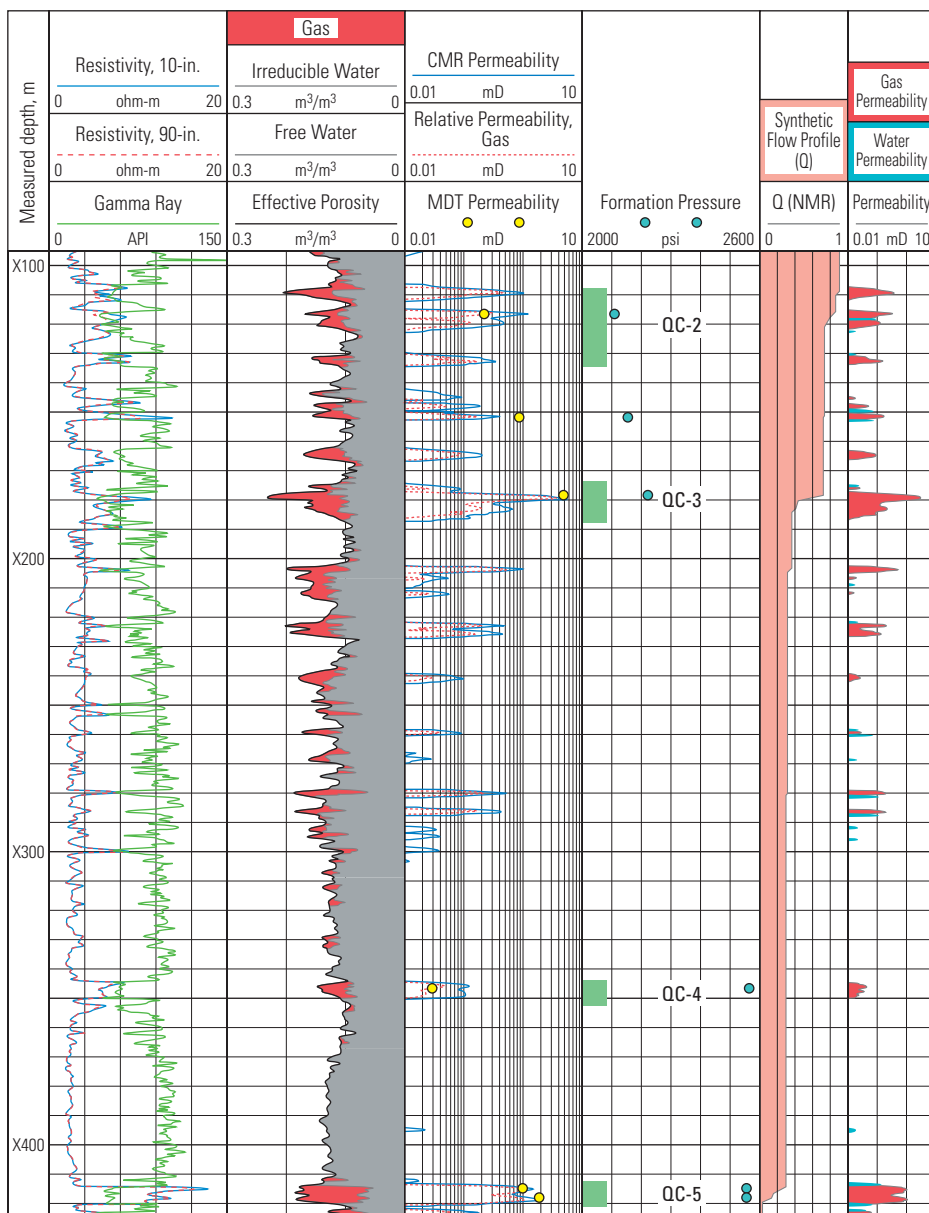
In the next phase, PEMEX awarded IPM a contract to prepare 40 wellsites, drill 54 wells, and complete and connect 50 wells. The project, which was to take 18 months beginning in March 1999, took only 16 months.

By the middle of 2000, a drop in crude-oil prices motivated PEMEX to reduce oil exploration and production activities and invest in gas projects. More rigs were mobilized to continue the aggressive drilling program in the Burgos basin. Schlumberger IPM won the new bid with another integrated-services solution, this time one that included supplying and managing rigs, supervising and providing all necessary services, and utilizing PEMEX personnel. Drilling times in this area decreased from 25 to 15 days per well. Schlumberger directed management, engineering and operational issues for the preparation of locations, drilling and completion of all wells.

1. Nonassociated gas is natural gas that accumulates alone, without oil.

2. Sweet gas refers to gas containing no hydrogen sulfide.

3. Palomo R, C ron A and Ramisa L: "Un Nuevo Modelo de Negocios," *Burgos Review* (Primer trimestre de 2003): 14-23.



Identifying candidate zones for stimulation by combining petrophysical information with pressures from wireline formation testers and permeabilities from magnetic resonance logs. Permeabilities from MDT Modular Formation Dynamics Tester station measurements (Track 3, yellow dots) correlate with permeabilities derived from continuous CMR Combinable Magnetic Resonance logging. Of the four most promising intervals containing gas with little free water, two of them, QC-3 and QC-5, contribute 70% of the gas flow estimated for this well. Green bars in Track 4 indicate locations of perforations. Only QC-3 and QC-5 were stimulated.

The original contract included 40 wells. Novel approaches compounded the success of the project; for example, using production tubing as drillpipe resulted in cost savings that allowed 14 additional wells to be drilled. Over the course of drilling the 54 wells, 90 drilling-rig days were saved.

The next integrated-services project included preparation, drilling, completion and

connection of 60 wells, to be completed by June 2001. Because of the efficiency of the PEMEX-Schlumberger cooperation, the contract was extended to a total of 190 wells by February 2002.

In the most recent contract, the scope of the integrated-services project, which initially included 100 more wells, was amended to increase the number of new wells to 210.

Schlumberger responsibilities were expanded to include the following:

- construction of access ways and wellsites
- design of drilling programs
- management and execution of operations
 - wellsite supervision
 - drilling fluids
 - directional drilling
 - logging
- completion
 - perforating
 - well testing
 - fracturing
- installation of flowlines
- provision of drilling rigs
- all logistics
- waste management.

Since January 2003, Schlumberger has completed 72 wells in this contract, with a collective initial production rate of 189 MMcf/D [5.4 million m³/d]. Average initial production per well exceeded 2.6 MMcf/D [74,500 m³/d], which is 5% higher than the past initial rate average. While completing these wells, Schlumberger performed 93 fracturing operations, perforating and testing 122 intervals.

Advances in well construction and improved drilling efficiency are not the only factors responsible for this dramatic production increase in the Burgos basin. New methods that help identify gas zones and improve understanding of reservoir properties are increasing completion efficiency and boosting production.

Production Enhancement

Production from the Burgos formations has been enhanced by more accurate methods of characterizing gas-bearing reservoirs and by using this information to optimize well completions.⁴ An integrated approach to identifying productive zones combines dynamic reservoir information, obtained from wireline formation testers, with high-resolution porosity and permeability data obtained from nuclear magnetic resonance tools. These formation properties also contribute to better stimulation modeling and hydraulic-fracture design.

This strategy, known as the PowerSTIM well optimization service, can reduce operating costs and increase efficiency by allowing completion of only the most productive gas layers in every well.⁵ The PowerSTIM method, introduced in North America in 2000, has a current activity level of 150 projects per month, and has been successful in Russia, the Middle East, Europe, Africa, China and Southeast Asia. Examples

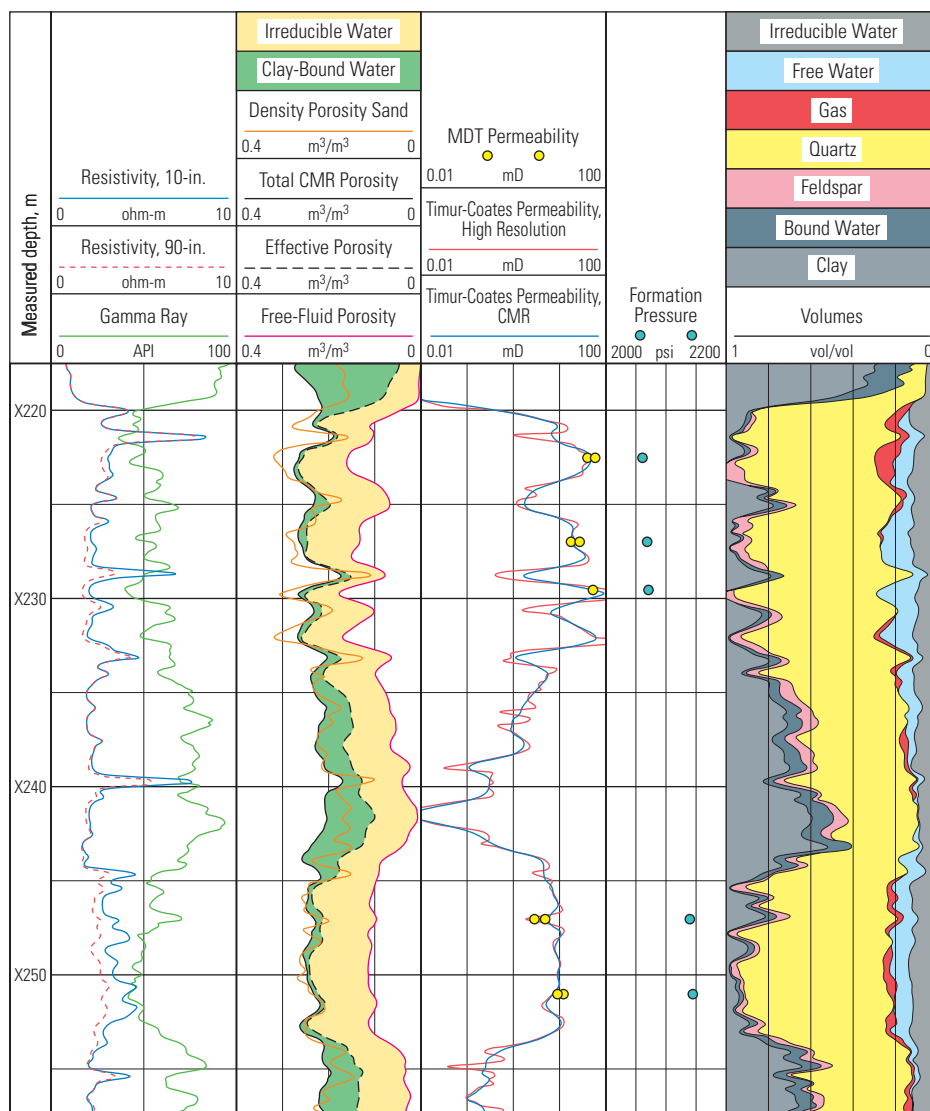
from three wells in the Burgos basin show how this integrated approach distinguishes zones worth completing from poor candidates.

The first Burgos candidate in which this methodology was used was a development well that encountered multiple layers of gas-bearing sandstones. Lithologically, the reservoir units are shaly sandstones with fine to very fine grains of quartz and feldspar, igneous rock fragments, clays and micas. The low permeability of these sandstones—0.05 to 5 mD—makes it necessary to hydraulically fracture them if they are to produce at economic rates. Permeability is so low that conventional production testing can take more than four days at each zone of interest to acquire sufficient buildup pressure for permeability analysis. Typically, in such a well, five or six layers would be tested, with unproductive results. Completion takes an average of 35 days per well, including testing, stimulating and plugging the unproductive zones, which are often in the majority.

In this well, the comprehensive formation evaluation facilitated by a full suite of petrophysical logs, plus measurements from CMR Combinable Magnetic Resonance and MDT Modular Formation Dynamics Tester, helps identify the zones most suitable for completion (previous page). Analysis of gamma ray, resistivity, CMR and MDT measurements points to the Queen City formation QC-5 and QC-3 intervals as the best performers. Pressures and permeabilities derived from the MDT tool are highest in these zones. The match between high-resolution permeabilities inferred from the CMR results and those from the MDT measurements brings confidence in the ability of the CMR tool to produce reliable permeability values at all well depths.

A synthetic flow profile computed from the CMR measurements indicates how much each level will contribute to overall well production. While numerous gas-bearing sands were detected in this well, two sands would deliver 70% of the potential gas production: 30% from the QC-5 zone at the bottom of the well and 40% from the QC-3 zone.

By ranking the most productive intervals, engineers can select the best candidates for hydraulic fracturing, thus drastically improving completion efficiency. In this case, only intervals QC-5 and QC-3 were stimulated. This optimization process cut 65% off the completion time required in comparable wells, accelerating production by 20 days and saving 20 days of completion time.



▲ Burgos development well in which logs detect high volumes of free water in potential completion intervals. While resistivity logs (Track 1) indicate typical low-resistivity pay zones, the CMR estimates of bound and free water (Track 2) show most of the logged interval contains high volumes of free water. This well was not completed over the logged section due to the computed high water cut, saving rig time and termination costs to PEMEX.

In another development well, the integrated approach to completion design involving interpretation of CMR, MDT and other log data helped to rule out some shallow zones that were being considered for completion (above). Again, permeabilities from the CMR tool matched those calculated from the MDT data at the five levels tested. Interpretation of petrophysical logs showed two sand-rich intervals. However, in the few zones that had the potential for gas, the CMR tool also indicated high volumes of free water. The well was not completed over the logged section, saving PEMEX time and expense that could be better spent on a more productive well.

The final Burgos example comes from an exploration well. Conventional log interpretation and formation evaluation based on high resistivities and crossover of the neutron-porosity and density-porosity log curves had limited value

4. Mengual J-F, Saldungaray P, Artola P and Riaño JM: "Reducing Completion Costs and Enhancing Productivity Using Nuclear Magnetic Resonance Logs and Formation Tester Data," paper SPE 74362, presented at the SPE International Petroleum Conference and Exhibition, Villahermosa, Mexico, February 10–12, 2002.
5. Al-Qarni AO, Ault B, Heckman R, McClure S, Denoo S, Rowe W, Fairhurst D, Kaiser B, Logan D, McNally AC, Norville MA, Seim MR and Ramsey L: "From Reservoir Specifics to Stimulation Solutions," *Oilfield Review* 12, no. 4 (Winter 2000/2001): 42–60.

when trying to identify productive reservoir within thin-bedded gas-filled sandstone (below). Since the CMR tool responds primarily to pore space, it gives a more reliable indication of gas-filled volumes than do other measurements. In this example, the CMR tool identified thicker continuous zones of pay than indicated by the crossover technique. The thickest of these, at 10-ft [3-m] thickness, was tested with the MDT tool. Permeabilities calculated from the MDT measurements correlated closely with permeabilities derived from averaging the high-resolution CMR results, and averaged 10 mD throughout the zone. The good correlation between CMR and MDT permeability

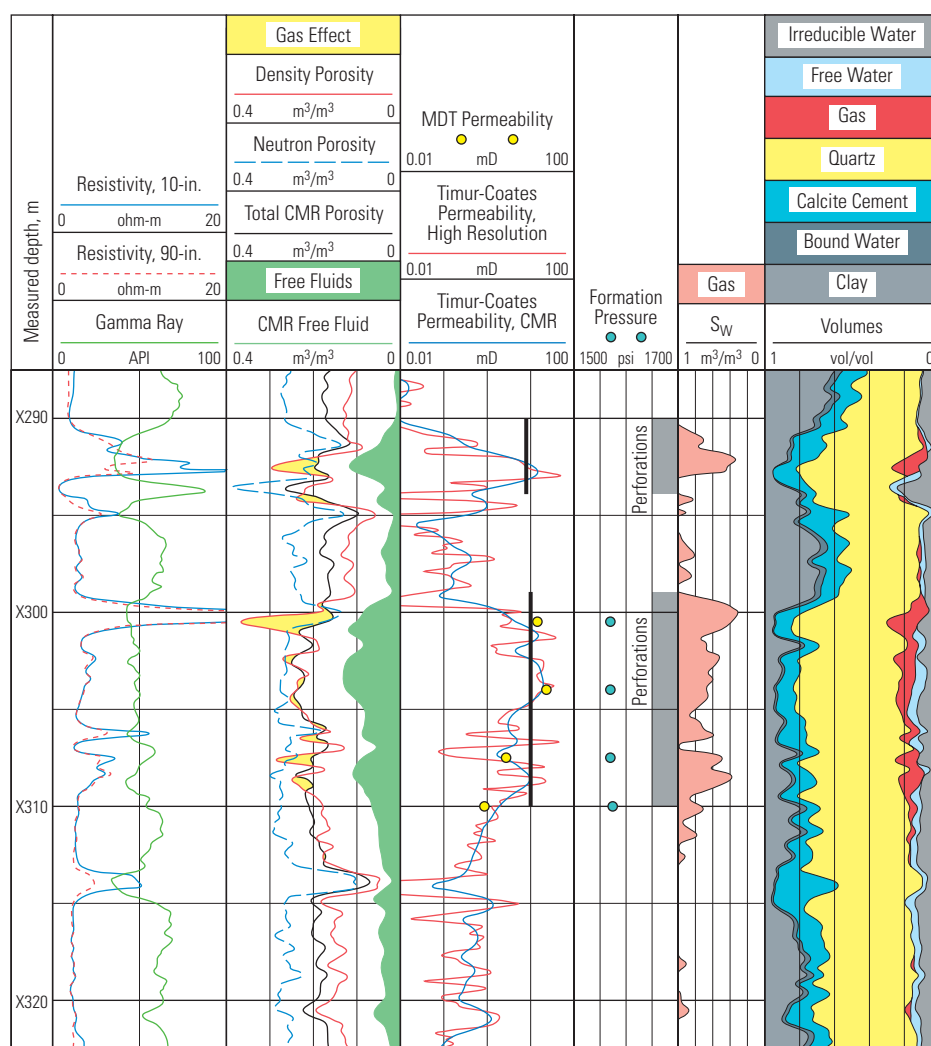
estimates in this zone gave engineers confidence that the 6-mD permeabilities measured by the CMR tool alone in a shallower zone were real and reliable.

At 6 and 10 mD, the two zones were permeable enough for the well to produce without being hydraulically fractured, according to production simulation results. Simulations from ProCADE well analysis software estimated production at 2653 Mcf/D [75,982 m³/d]. The interval was perforated and produced 2571 Mcf/D [73,633 m³/d] without stimulation.

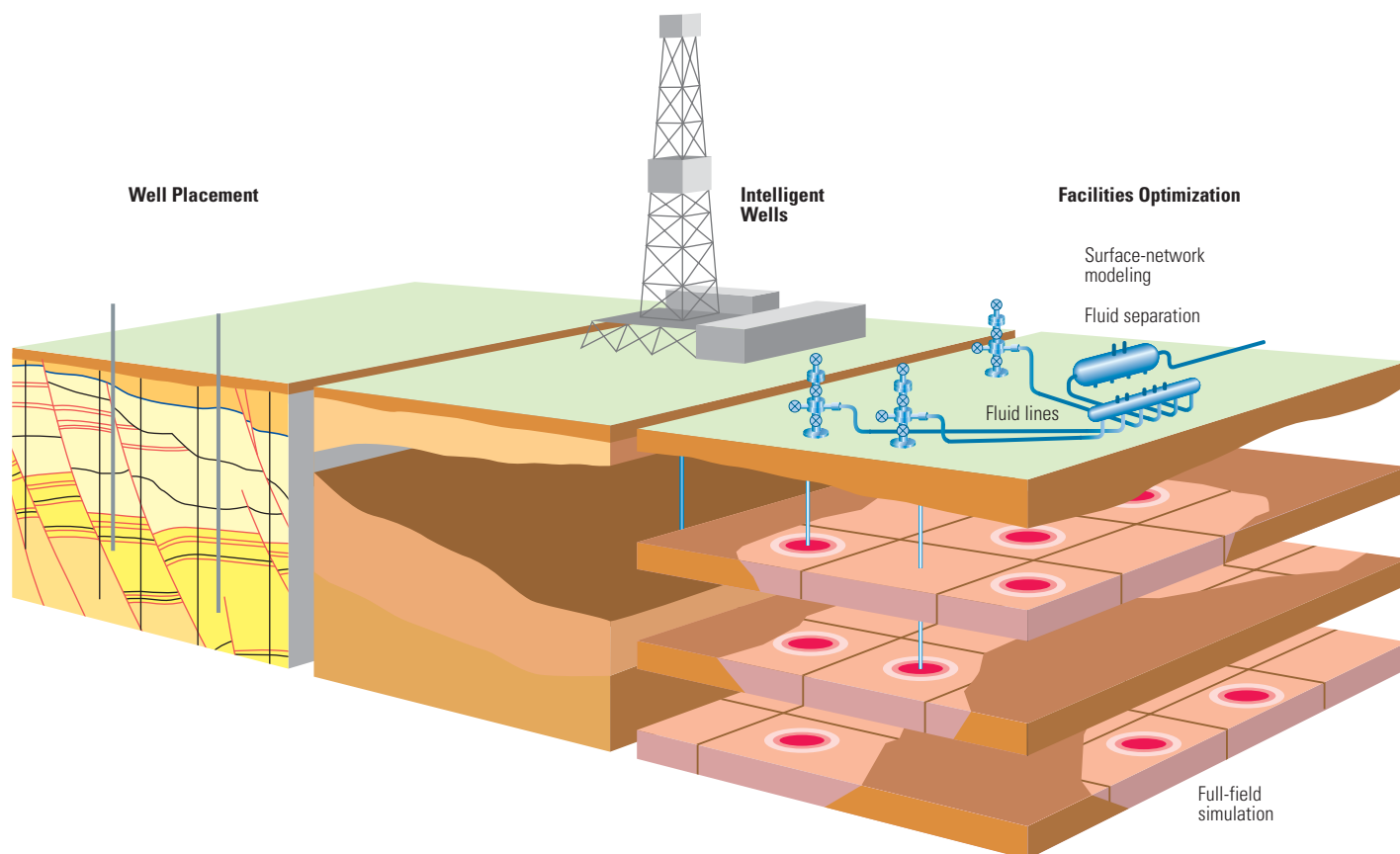
PowerSTIM methodology, which integrates petrophysical and reservoir knowledge with completion design, execution and evaluation, was applied to more efficiently select sands with high

productivity potential and to design more efficient fracturing programs. Before implementation of this methodology, the average Burgos well produced 1 MMcf/D [29,000 m³/d]; now the average is 4.5 MMcf/D [129,000 m³/d]. The PowerSTIM process reduced completion times by an average of 60% in the Burgos basin. Completion costs have dropped by a similar percentage.

Today, the Burgos contract between PEMEX and Schlumberger calls for the construction of wells at a given price and location. Schlumberger, however, has proposed that it can bring additional value to PEMEX by taking more responsibility in the selection of well locations, designing the completions and optimizing production.



^ Exploration well in which conventional log interpretation underestimates production potential. High resistivities (Track 1) and neutron-density crossover (yellow shading, Track 2) identify some thin streaks of gas-filled sandstone. Permeabilities derived from CMR measurements are high across thicker continuous zones (Track 3). Average permeabilities (vertical black bars, Track 3) in the two thickest zones are high enough to perforate and produce without stimulation.



^ Future evolution of integrated services in the Burgos basin. As the integrated-services concept matures (*left to right*), PEMEX and Schlumberger could jointly participate in selecting well locations, designing and constructing intelligent wells, optimizing surface production facilities and simulating reservoir behavior.

Selecting optimal well locations will require reservoir characterization and integrated geological studies. Advanced seismic techniques such as amplitude variation with offset (AVO) analysis, inversion, sequence stratigraphy and attribute analysis will help interpreters choose well locations based on a geological model, maximizing productivity and minimizing the risk of drilling uneconomical holes. Technology to detect gas in low-resistivity pays will help tap more gas zones. Simulating field performance and including the effects of surface facilities will help optimize production. Adding high-, medium- and low-pressure lines in production systems will help optimize individual well performance and eliminate bottlenecks in surface facilities ([above](#)).

Chicontepec Production Enhancement

The Chicontepec region is another mature area with potential for production enhancement. Oil was discovered there in 1926, and first commercial production began in 1952. The current fields all lie within a geological feature called the Chicontepec paleochannel, located in northern Veracruz state, 250 km [153 miles] from Mexico City and 5 km [3 miles] from Poza Rica. The paleochannel is a 3815-km² [1473-sq mile] accumulation of Paleocene-age sediments. This thick, low-permeability deposit contains 139 billion barrels [22 billion m³] of original oil in place and 50 Tcf [1.4 trillion m³] of gas. About 12 billion barrels [2 billion m³] and 31 Tcf [888 billion m³] are recoverable, making it the largest PEMEX asset.⁶

From 1952 to 2002, 951 production wells were completed. On average, the wells were modest producers, with initial production rates on the order of 70 to 300 BOPD [11 to 48 m³/d].

By 2002, total field production averaged 2500 BOPD [397 m³/d] and 12 MMcf/D [344,000 m³/d]. In its first 50 years, the field had produced just 111 million barrels of oil [18 million m³] and 195 Bcf [5.6 billion m³] of gas.

In 2002, PEMEX initiated an aggressive strategy to increase field production over the next four years. The production goal for 2006 is to reach 39,000 BOPD [6200 m³/d] and 50 MMcf/D [1.4 million m³/d], increasing oil production by a factor of more than 10, and boosting gas production more than fourfold. Central to the success of this project is the construction of wells whose productivity is significantly higher than the historical average.

6. Williams P: "Mexico," *Oil and Gas Investor* (July 2003): 26-37.



^ Chicontepec paleochannel drilling rig, built to optimize drilling times and logistics on multiwell pads in this environmentally sensitive area.

To make this vision a reality, Schlumberger IPM, in partnership with ICA Fluor and Drillers Technology de México, has signed a contract with PEMEX to develop the Coapechaca, Tajín and Agua Fría fields of the Chicontepec asset. Building on the Burgos contract performance, PEMEX has contracted Schlumberger to take greater responsibility in the Chicontepec project. The Schlumberger IPM role is to deliver the field-development plan, including reservoir-characterization studies, optimization of subsurface well locations, drilling and completing all wells, rig management, a pilot test for water injection, construction and upgrade of gas-compression stations, pipeline construction and all logistics.

The project began with bid preparation and submission at the end of 2002 and reached full mobilization by mid-2003, with the first well spudding in May. Project timing allows 1400 days for 200 wells. Key project goals for 2003 included updating the sector reservoir studies to better identify the most suitable locations to place higher productivity wells; drilling 59 wells and completing 46 wells before year-end; building 8 multiwell pads; constructing 50 km [30 miles] of pipeline; and constructing and upgrading 6 production- and compression-facility modules.

The environment surrounding the Chicontepec area is sensitive, and home to many protected plant species. Wellsites have been designed for minimal environmental impact. Fit-for-purpose drilling rigs have been built to optimize drilling times and rig moves on multiwell pads (above). Wells are drilled directionally, with 3 to 18 wells from each pad. State-of-the-art rigs with topdrives and telescoping masts keep pipe in the derrick when moving between wells on the same pad. Rigs are equipped with skidding mechanisms to reduce move time from three days to less than 12 hours. Perforating, fracturing, coiled tubing operations and testing are performed without a rig.

Stimulation Strategies in the Chicontepec Paleochannel

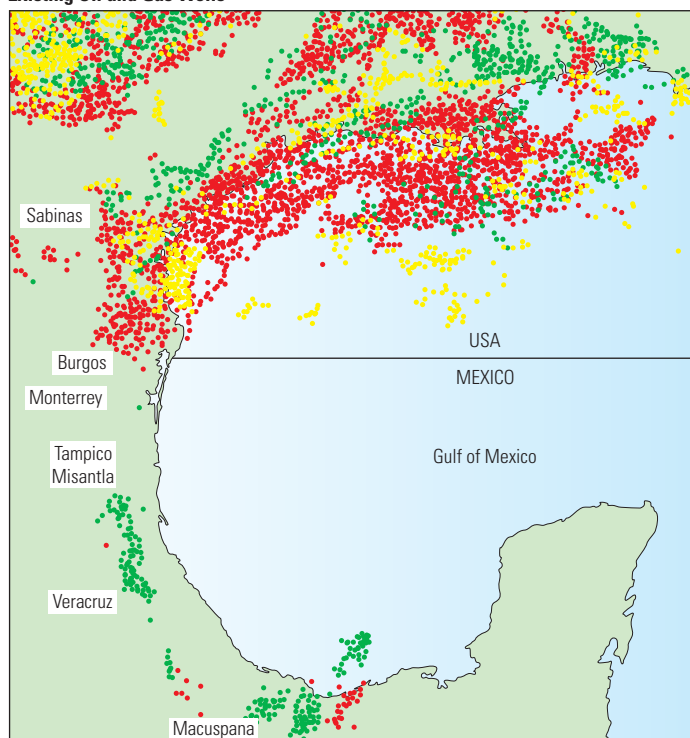
To help PEMEX further improve production from the Chicontepec area, Schlumberger stimulation specialists are evaluating the potential to increase production through the application of the PowerSTIM methodology that has proved so successful in Burgos projects. However, instead of applying the technique on individual wells, engineers and interpreters are developing a stimulation strategy to optimize the overall performance of the fields in the Chicontepec

paleochannel. This large-scale study encompasses the area bounded on the west by the Sierra Madre Oriental and on the east by the Faja de Oro reef.

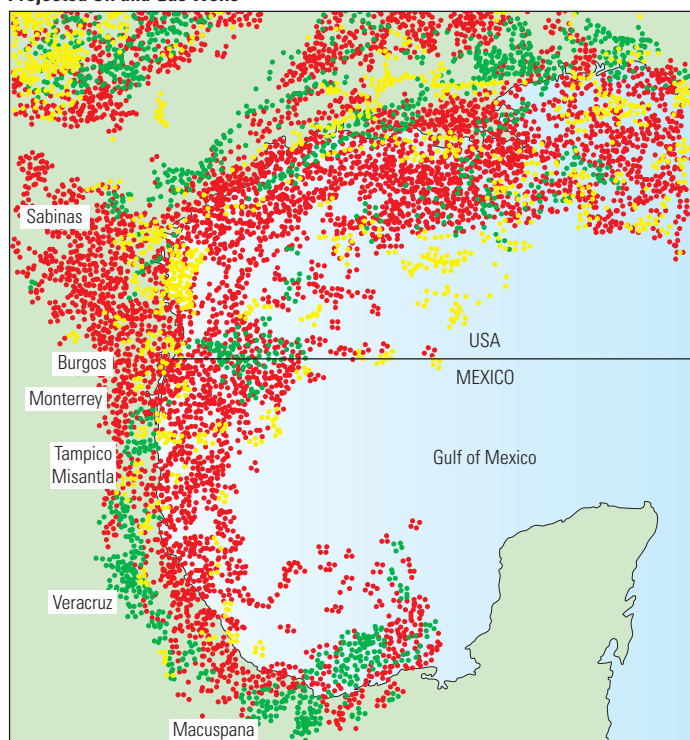
The first step in the study was to evaluate the current development plan and to validate well locations proposed by PEMEX Exploración y Producción (PEP) asset teams. This required complete reevaluation and integration of 3D seismic, geological, production, core and log data. Analysis of the stimulation history of each sandstone layer indicated that cost-effective production improvements could be realized by selectively stimulating higher quality zones.

Candidate selection and stimulation-treatment design using the PowerSTIM method helped achieve higher production per fracturing job and at lower cost compared with production levels and costs achieved on previous drilling campaigns.

Existing Oil and Gas Wells



Projected Oil and Gas Wells



^ Vision of Gulf of Mexico oil and gas exploration and production activity. Currently, the vast majority of oil and gas fields are in the US sector of the Gulf of Mexico (*top*). One vision of future production shows a similar level of activity spread across the Mexico sector within ten years (*bottom*). Red and yellow dots are gas wells. Green dots are oil wells. [Adapted from "México at a Glance: The MCA Story," *México Interchange* (November 11-14, 2003): 21.]

Further Growth in Chicontepec Production and Beyond

The enhanced candidate-selection techniques and fracturing practices encompassed by the PowerSTIM approach have been shown to improve the cost-effectiveness of stimulation in the Chicontepec paleochannel. Further improvements will focus on optimizing the productivity of the highest potential zones. New logging and imaging services are already being introduced to increase understanding of the reservoir and to aid the stimulation process. As in the Burgos basin, the CMR-MDT combination is helping Chicontepec reservoir engineers improve the completion process for each well. The next steps will introduce new fracturing fluids and technologies to this high-potential asset, increasing the ability of stimulation treatments to enhance production from each well and to increase profitability for PEMEX.

Properly exploited, Chicontepec reserves constitute one step toward overcoming Mexico's current oil production decline. Efficient development of other fields and discovery of new accumulations are required to reverse the decline and replace reserves. So far, Mexico's reservoirs have mostly undergone only primary recovery, and are now experiencing varying degrees of depletion. Developing strategies for enhanced recovery will become important to maintaining production goals.

One area likely to see expanded activity is the Mexican sector of the Gulf of Mexico. As of 2001, more than 20,000 wells had been drilled targeting natural gas in the US sector of the Gulf of Mexico, while only 400 wells were drilled in the Mexico sector (*left*). This vision of the future predicts an increased number of integrated projects and dramatic growth in drilling activity and hydrocarbon production in the next five to ten years.

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