The primary goal of this project was to maintain the well in the sweet spot of the reservoir to improve productivity. As a final delivery, the structural map of the top of the M1 Sandstone enabled the customer to adjust the seismic information in the zone of influence of the well. A major drilling company assumed the challenge by using a rotary steerable system, proactive logging-while-drilling azimuthal resistivity sensors, and 3D geosteering techniques to place the well in the sweet spot of the reservoir and to ensure the permanence in the sandstone reservoir.

The azimuthal deep resistivity sensor can provide a broad quantity of curves with various depths of investigation (D0Is). Having this information as an entry, the geoscientists applied the three logical geosteering phases of model, measure, and optimize. At the modeling stage, the geosteering team selects the appropriate proactive set of variables to transmit in real time, including compensated resistivities at various ranges of investigation, images, and geosignals according to the geology in the area, reservoir thickness, and existing resistivity contrast. The measuring stage begins by obtaining the selected variables in real time with average resistivities that enable the calculations of the distance-to-bed boundary (DTB) using a forward-modeling technique, while real-time images are compared against modeled information for stratigraphic positioning. During landing, the drilling and geology departments agreed that the reservoir top was 35 ft (10.7 m) shallower than expected. At this point, the directional drilling plan needed to be changed, beginning the optimization stage even before the horizontal section began.

The appropriate combination of reactive and proactive logging-while-drilling sensors enabled the well to be placed parallel to the top of the reservoir, maintaining an optimal distance of 1 to 3 ft, with 100% reservoir exposure in the pay zone and no exits.

The main objectives of geosteering were achieved. The well produced 6,800 BOPD after an initial estimate of 800 BOPD. The top of the reservoir was mapped, thereby improving knowledge of this zone for future study.
Abstract
A campaign to successfully drill and geosteer fourteen horizontal wells was performed in the Orinoco heavy-oil belt of eastern Venezuela. This campaign used the latest logging-while-drilling (LWD) azimuthal deep-resistivity tools in conjunction with specialized modeling and wellbore positioning techniques for a full geosteering service. Two simultaneous clusters (YA and SD), located in the southern part of the field, were the subject of this complete solution. The application of a full, real-time geosteering technique that combined the real-time responses of the tool and a model, measure, and optimize workflow enabled the flawless wellbore placement within a reservoir with a challenging stratigraphy and complex sedimentological environment and having notorious operational difficulties.

All of the wells were drilled in a deltaic depositional environment with average sand thickness ranging from 10 to 15 ft. Lateral facies changes, heterolitic beds, thickness variations, and pinch-outs were observed in this environment. The use of azimuthal tools made it possible to define the origin (relative to the wellbore) of these stratigraphical variations, which decreased the while-drilling uncertainty in the decision-making process. From a drilling perspective, extremely high rates of penetration (ROPs) of up to 1,000 ft/hr were achieved, which is common for these largely unconsolidated, highly permeable, heavy-oil sands. These fast operations required an efficient and reliable geosteering solution that enabled swift reaction to maintain the well path within the reservoir boundaries. Our solution proved to be very valuable, as we helped in reducing frequent sidetracking performed when drilling these deltaic units, thus minimizing NPT.

The outcome, including optimized well placement, reduced uncertainties in decision-making, and improved rig-time effectiveness, were possible by operating with an integrated approach. Under this approach, geoscientists and drilling engineers from the operating company and the service company shared information on a real-time basis and worked as a multi-disciplinary team to make the best wellbore trajectory decisions.
Abstract
The drive for rational exploitation of oil and gas resources has raised the bar on the accuracy of well placement. Thinly layered reservoirs represent a particular challenge as the opportunity to exit the reservoir is always present. This challenge is met using a suite of LWD instruments, including azimuthal deep resistivity, together with flexible forward modeling software. A new class of sensors sends to the surface in real time a variety of measurements and images with which to navigate. In the middle of the process is the geoscientist who must digest in real time the flow of information and synthesize it into clear and accurate instructions for the direction of the well.

When it comes to real-time information, the simple rule "more is better" applies. However, a robust workflow is required to integrate and process the complex stream of data and to convert it immediately into actionable instructions. Because of the limited bandwidth of mud pulse telemetry, downhole data must first be integrated into higher-level intelligence. For the wells in this study, resistivity measurements indicating an up or down direction for an approaching boundary were determined to be the most valuable information. In addition, a series of parameters named Geosignals gave early warning of approaching boundaries, allowing for timely and accurate corrections to the well path. A real time deep resistivity image was also sent to the surface to help visualize the geology several feet away from the wellbore.

Of the three wells discussed, the more recently drilled wells brought about significantly longer reservoir contact as geoscientists learned how best to use and interpret the azimuthal data. Similarly, experience gained from drilling problems encountered in earlier wells, coupled with close communications between operator and service provider, resulted in steadily improved drilling performance.
Abstract
Deep azimuthal wave resistivity sensors yield a new type of electrical images. Although traditional micro-electrical images are limited to the surface of the wellbore, the new deep resistivity images span a volume of several cubic feet around the borehole. This new window on the geology helps to geosteer with more confidence than a series of discrete non-azimuthal curves.

Deep azimuthal images feature frowning and smiling patterns similar to their micro-images counterparts, except for two important distinctions. First, they make it possible to recognize approaching boundaries long before they intersect the well path. Because they emanate from several feet away from the wellbore, deep electrical images effectively enable proactive geosteering. They guide proper and timely evasive actions before the well exits the reservoir into shale or an underlying water-bearing interval. Second, the deep propagation images feature a characteristic bright spot that appears when drilling through a reservoir and approaching an exit into a less resistive formation. Various spacings and frequencies generate images with differing depths of field that provide a sense of 3-dimensional view away from the wellbore. This important information is unavailable from micro-images limited to the wellbore surface.

New interpretation methods specific to deep electrical images are illustrated on modeled data and on real logs where the primary objective is often to steer near a boundary, while staying clear of it. To quantify the distance to nearby beds, deep images are supplemented by Geosignal, a new real-time electromagnetic log that is very sensitive to the distance to the nearest boundary. By integrating multiple deep images with multiple depths of field, electrical Geosignals, and quantitative azimuthal resistivity data, a real-time inversion software helps the geosteering engineer to locate the well precisely with respect to the geological layers.

**Abstract**

The challenges presented by a field in Ecuador included placing the wells in the cleanest, most permeable portion of the reservoir, in the middle of the structure, without penetrating an overlying kaolinitic bed or the caprock shale above the reservoir or penetrating the water bearing zone. These objectives could not be optimally achieved with traditional wellbore imaging sensors or with deep non-azimuthal wave resistivity. Wellbore imaging instruments identify the relative dip and azimuth of geological events intersecting the wellbore, but the information is clear only after leaving the reservoir. Non-azimuthal wave resistivity predicts the impending intersection with a reservoir boundary, but does not predict the azimuth of approach. In the first instance, a proper decision can be made only after exiting the reservoir; in the second instance, a proper decision requires other knowledge about the probable direction of the approaching boundary.

A newly deployed azimuthal deep resistivity while-drilling sensor produces a vast array of azimuthal measurements. When mapped into an image, deep resistivity behaves for the most part like traditional images in which "smiling" patterns indicate that the wellbore is going up stratigraphically and "frowning" patterns indicate that the wellbore is going down stratigraphically. One exception is the newly discovered phenomenon of the "bright spot" that appears when approaching a low resistivity shale or water bearing interval from a high resistivity reservoir. The bright spot clearly indicates an impending reservoir exit. Because it is keyed to the low side of the well, the bright spot indicates the direction of the required evasive action to remain within the desired interval. This visual indicator is complemented by a novel quantitative measurement, the Geosignal, which features a strong exponential dependence on the distance to the boundary of the reservoir. In the examples shown, the visual information from the bright spot is combined with the quantitative information from the Geosignal measurement to properly guide real-time geosteering decisions.