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Exploring new petrophysical possibilities off West Africa

As the search for deepwater resources off West Africa continues, an operator and a service company have paired two rock and fluid characterization technologies to identify hydrocarbon-bearing zones in laminated reservoirs. Jennifer Pallanich describes how the technology yielded a better description of the reservoir in a Chevron field.

Chevron, based on previous knowledge of the geology of turbidite deposits, and coring during a deepwater exploratory well, knew that it had potential in thin beds in an offshore West Africa play. A core showed laminations as thin as 10mm, well below the resolution of logging instruments. Armed with knowledge of the thin beds’ existence, Chevron wanted to use wireline technology that would help delineate, evaluate and assess these resources.

‘Some prospects in West Africa have combinations of massive sands . . . and some of what people call marginal reservoirs,’ says Jean-Baptiste (‘JB’) Clavaud, team leader of Chevron’s formation evaluation interpretation products group. ‘We knew we would have some thin bed issues and we knew we would have some bed dipping issues.’

An additional pressure was the need to accurately assess the resources in the deepwater turbidite Miocene sand. Properly assessing the hydrocarbons in place can be tricky because evaluating thinly bedded formations calls for different methods from evaluating thick formations.

‘One way to achieve that is to use the right tools.’ Clavaud says. He collaborated with the Chevron West Africa business unit to use a pair of new formation evaluation tools from the Schlumberger portfolio, the MR Scanner and the Rt Scanner.

The MR Scanner provides continuous fluid characterization and lithology-independent porosity at multiple depths of investigation within the reservoir. Based on the medical industry’s nuclear magnetic imaging technology, it makes a magnetic image scan of the rock to see what kind of fluids reside within the rock. The Rt Scanner is a multi-component array induction instrument that directly measures resistivity anisotropy (namely the resistivity parallel and perpendicular to the beds) to evaluate the thin-bed or laminated-sand reservoirs while also measuring structural dip of the beds. An enabling interpretation technique used in West Africa was the Schlumberger modified Klein cross-plot, which graphically portrays vertical and horizontal resistivity, then provides a direct shale fraction, sand resistivity and saturation, enabling hydrocarbon identification and quantification.

When the Rt Scanner shows hidden pay in thin sands when used with other formation evaluation techniques, the question becomes one of closer inspection and confirmation, Chanh Cao Minh, Schlumberger fellow, director of measurements, says.

‘The MR Scanner is handy – it scans the fluid near the wellbore, and if it’s water, it says water. If it’s oil, it says oil,’ Minh says.

Because the MR Scanner service can identify fluid type independent of the lithology, and the Rt Scanner tool can identify anisotropy and quantify saturation, integrating the two datasets allows a company to identify commercial hydrocarbon deposits that previously might have been missed, Minh says.

‘Each tool has its own limitations,’ he notes. The two scanners can work from 6in to 20in diameter boreholes to 20,000psi and 150°C in standard form. The Rt Scanner, Minh says, can be limited by salty mud, and the MR Scanner can be limited by small borehole sizes. ‘Very salty mud could be a showstopper for the MR Scanner as well,’ he says. Understanding oil-based mud invasion, taking it into account in the inversion of the raw measurement and in the petrophysical analysis can be challenging, Minh adds.

Petrophysical model of laminated shale-sand formation. When $R_{\text{sand}}$, $R_{\text{shale}_h}$, $R_{\text{shale}_v}$ and $F_{\text{shale}}$ are 20ohm-m, 2.0ohm-m and 0.4 respectively, the equivalent horizontal conductivity are 2.3ohm-m and 12.8ohm-m, respectively.
‘We started seeing new petrophysical possibilities that we did not see before.’

JB Clavaud, Chevron

As with using any tool for the first time, there were some initial concerns about how the tools would perform, Clavaud says; the company chose to supplement the acquisition using the scanner data with core samples and other logging tools.

Chevron wanted to ensure the first generation of hardware and software was behaving as expected, he adds. ‘We knew we would have a lot of other information to validate or invalidate from the Rt Scanner,’ Clavaud says.

On the first job, in 2005, the Rt Scanner combined with the MR Scanner and other porosity logs showed ‘a good chunk of that prospect was thinly laminated hydrocarbon-bearing sands,’ Clavaud says. The MR Scanner and density logs were necessary to eliminate the possibility that the high $R_v/R_h$ ratios were due to tight carbonate streaks.

The company knew from core data the hydrocarbons were in the area within thinly laminated and porous shaly-sand intervals; the Rt Scanner confirmed the presence of hydrocarbons, allowing Chevron to identify and quantify a larger amount of oil-bearing formation, he says. Using the Rt Scanner compared to measuring pay through classic induction showed an increase in hydrocarbon thickness by about 40% in that particular instance, Clavaud says. Core analysis later confirmed the presence of hydrocarbon in the thinly laminated sand layers.

The West African business unit reviewed the results from the first well, which led to Chevron’s use of the Rt Scanner in additional jobs within the same business unit. Chevron has acquired data in five wells in the region and in other wells around the world using both the Rt and MR scanners. The five West Africa wells, drilled one after the other in about 1000m of water, were similar in that core data was available at all sites. ‘We picked them carefully so we could extract the maximum amount of information,’ Clavaud says. While looking at the scanner results, he adds, he realized there was more information to be extracted. ‘We started seeing new petrophysical possibilities that we did not see before. Doors were opening and we started to look at shales to better understand the behavior of laminated shaly-sand reservoirs.’

Wriggle room

The Rt Scanner obtained both vertical and horizontal resistivity data, and new processing methods allowed more precise information about bed boundaries and structural dip. Most people are used to seeing ‘wriggles’ on log data, Clavaud says, and ‘that’s not the way the tool and the inversion of the raw data work’. Instead, it generates square logs that display the horizontal and vertical resistivities in a given bed as well as its upper and lower bed boundaries.

The square logs can be smoothed into wriggles, depending on personal taste. ‘I realized there might be some value in the square logs,’ he says, adding the bed boundaries make sense when compared to core data. ‘We can extract even more information about the bed boundaries.’

These boundaries often correlate to stratigraphic events and are not random, Clavaud says. The Rt Scanner ‘raised a lot of questions about our understanding of structural dip, about stratigraphic dip, and about square logs versus squiggly logs,’ he says. Square logs, Clavaud believes, translate into increased pay because they provide a benchmark to help correct other logs from some of the shoulder bed effect. ‘With a square log, you can tell the geologist precisely, “here is the top of the bed”. It’s very specific,’ he says.

Application

In the deep waters off West Africa, an accumulation of fine sand and shale laminations overlies the thick Miocene channel sands. Operators, historically seeking large pay haven’t spent too much time thinking about the thin channel-
levee sands despite the potential for good porosity and hydrocarbons in place in the thin sands.

Minh says these channel sands are often seen as interesting but unimportant. But failing to include the laminates in the in-place estimates at the field means an incomplete tally of the reservoir’s potential value. While the intention may not be to produce these ‘hidden’ or unconventional resources at the time of discovery, there will likely come a time when they will become a focus, Minh says. When the main sands eventually dry out, he says, the thin sands above and below will produce. The right time to evaluate those thin sands, Minh says, is during the drilling process before pipe is set to protect the wellbore, as pipe affects the ability to measure what’s behind the casing.

Historically, resistivity measurements were sensitive to only one direction, perpendicular to the borehole, Minh notes, and it was cumbersome to compensate for thin laminations and anisotropy and shoulder bed effect with conventional measurements. A fundamental flaw with resistivity interpretation historically was the industry’s typical assumption that the dip was perpendicular to that wellbore, Martin Isaacs, Schlumberger wireline marketing communications manager, says. This was fine for vertical wells. But with deviated or horizontal wells, realistically the dip of the bed could be at any angle to the wellbore, Isaacs adds.

It came down to having a tool that could measure resistivity in rock in three orthogonal directions. ‘Before the Rt Scanner, we did not account for anisotropy or dipping beds very well,’ Minh says. The Rt Scanner, which has collocated tensor resistivity measurement, ‘gives us a measure directly down the bedding plane and perpendicular to it at multiple depths of investigation.’

‘We have a fully resolved 3D model that gives us a measure directly down the bedding plane and perpendicular to it. That is absolutely unique. Nobody else has that.’

In the past, a 1ft-2ft layer of hydrocarbons may have been overshadowed by shale layers over and below it. A conventional resistivity tool would make environmental corrections, Minh says. These would amount to tool location in the borehole, resistivity of the mud in hole, resistivity of beds adjacent to the bed being measured, the dip of the bed, and others, Isaacs says. This becomes more challenging as sand beds thin down to 10mm or less.

‘That was one of the challenges that have always existed with resistivity logging.’ Minh says. If the layer was too thin for the tool’s resolution, Minh says, it could be difficult to distinguish a good sand from a shale.

It took over a decade, Minh says, to be able to eliminate the corrections that have to be made and a tool sleeve design to manage the borehole signals. The interpretation system computes sand fraction and sand porosity from nuclear magnetic resonance (NMR) data. Crossplotting conventional porosity data with the shale fraction calculated from MR Scanner logging allows the interpreter to identify potential hydrocarbon-bearing thinly laminated shaly sands. The Rt Scanner provides the vertical and horizontal resistivity data to calculate sand resistivity, free of shale effects. Sand, which holds hydrocarbons contrary to most shales, is resistive, so the readings and Rv/Rh ratio that emerge from shales differ from thinly laminated sands. Called a low-contrast pay, Schlumberger says intrinsic shale layering anisotropy is needed.

It is possible to calculate water saturation for the sand using shale-corrected inputs, which addresses how much hydrocarbon is present. The NMR data also identify the type of fluids occupying the sand laminations: oil, gas, filtrate, or water.

In one Chevron example, Schlumberger supplied regarding the evaluation of a 400ft interval of conventional and laminated sands, traditional techniques identified 23ft of oil bearing formation. Using the service company’s Scanner family technologies bumped the figure up to 38ft, and an additional 3ft was identified from NMR data.

Clavaud says additional information and interpretation technique advances mean ‘we started seeing new petrophysical possibilities that we did not see before. Doors are opening, and we have started to look at shales to better understand the behavior of laminated shaly-sand reservoirs.’