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Elemental spectroscopy yields ultimate answer

TOC combined with matrix-corrected porosity directly determines accurate hydrocarbon saturation.

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As the industry expands to increasingly complex reservoirs, accurate understanding of the elemental composition and mineralogy of a formation is an essential factor in completion decisions. The ability to determine both the matrix mineral composition and total organic carbon (TOC) can be invaluable to the geoscientist, the petrophysicist, and the reservoir engineer. A new application of neutron-induced gamma-ray spectroscopy provides these critical data in a single logging pass.

Neutron-induced gamma-ray spectroscopy is not new in wireline well logging. Traditionally, wireline spectroscopy tools have focused on two types of gamma-ray measurements. Cased-hole spectroscopy tools obtain ratios of carbon to oxygen from high-energy neutron inelastic scattering interactions to help petrophysicists evaluate formation hydrocarbon saturation. Openhole spectroscopy tools exploit low-energy neutron capture interactions for quantifying the abundance of rock-forming elements and interpreting matrix composition.

The new Litho Scanner high-definition (HD) spectroscopy service uses a pulsed neutron generator (PNG) to characterize both the inelastic scattering and neutron capture processes in a formation. High-energy neutrons produced by the PNG collide with and excite the nuclei of certain elements to produce signature gamma-ray spectra. As the neutrons penetrate the formation, their energy dissipates, and they are subsequently captured by the nuclei of other elements that also emit characteristic gamma-ray signatures that can be interpreted in terms of formation composition. This comprehensive array of elemental concentrations, some of which could not be measured by previous tools, can be used to interpret formation mineralogy and other formation parameters.

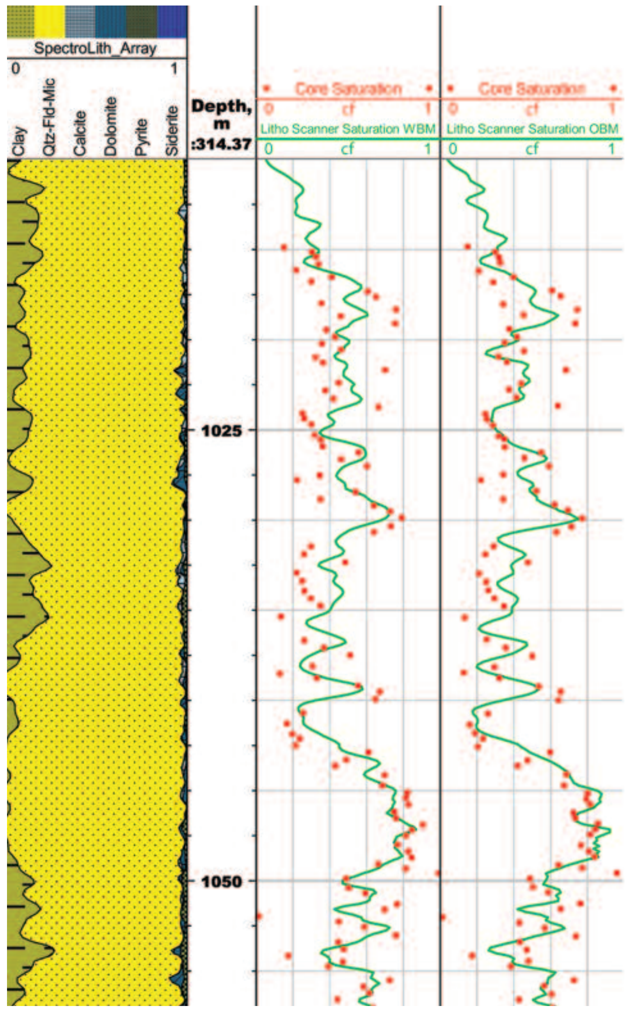

FIGURE 1. Hydrocarbon saturation based on TOC as determined by the HD spectroscopy service logging in both water- and oil-based mud in a complex formation in Canada closely matches core measurements. (Images courtesy of Schlumberger)

More accurate measurements

The new HD spectroscopy service has two important technological advantages over previous-generation openhole spectroscopy measurements. The first is the implementation of the PNG neutron source, which enables the acquisition of both inelastic and capture gamma-ray spectra. Only half of the 12 rock-forming elements analyzed by this new service produce both capture and inelastic gamma rays, and many of the inelastic reactions are too weak to measure with sufficient accuracy and precision. However, with the inclusion of inelastic gamma-ray spectroscopy, the measurement of carbon and an improved measurement of magnesium, another critical element, are possible. Furthermore, the neutron output from the PNG is a factor of seven higher than a standard neutron logging source, which significantly improves the precision of all of the elements measured. Finally, the PNG source can be used where nuclear logging with a chemical source is not an option.

The second unique feature of this new service is the cerium-doped lanthanum bromide (LaBr3:Ce) detector, which has superior intrinsic spectral resolutions and count rate capability and thus delivers accuracy and precision for elemental quantification while providing high-temperature performance and faster logging speed.

Together, the PNG and LaBr3:Ce detector deliver greater measurement precision, improved accuracy, and a broader spectrum of quantifiable elements at higher formation temperatures.

A broad suite of applications

The technological advances of the new service support robust mineralogy and lithology interpretation in formations with complex mineralogy, including the determination of TOC, which is a key indicator of reservoir quality for unconventional resources.

In conventional reservoirs, the TOC determined is used to evaluate hydrocarbon saturation by converting its value (expressed as the weight fraction of organic carbon per unit mass of matrix components) into a volume fraction of hydrocarbon. The workflow combines a porosity estimation involving other wireline logs with multiple spectroscopy inputs, including the carbon elemental concentration, formation mineralogy, and matrix density. This approach provides enormous advantages where the traditional openhole resistivity method does not work because the formation water salinity is either too fresh or is unknown as a result of historical production, steam- or waterflooding, or other EOR techniques.

Case studies

Two examples from challenging conditions illustrate the accuracy of the new spectroscopy service for petrophysical interpretation. For both examples, laboratory core data, presented as dots in the figures, verify the accuracy of the log values.

In the first example, a Canadian operator routinely performs detailed Dean-Stark analysis on core for an accurate determination of the hydrocarbon content in a bitumen-rich sandstone. This extensive program of core retrieval and laboratory measurement is both time-consuming and costly to the operator. The measurements provided by the HD spectroscopy service quantified the formation mineralogy, grain density, and TOC. The grain density was combined with a bulk

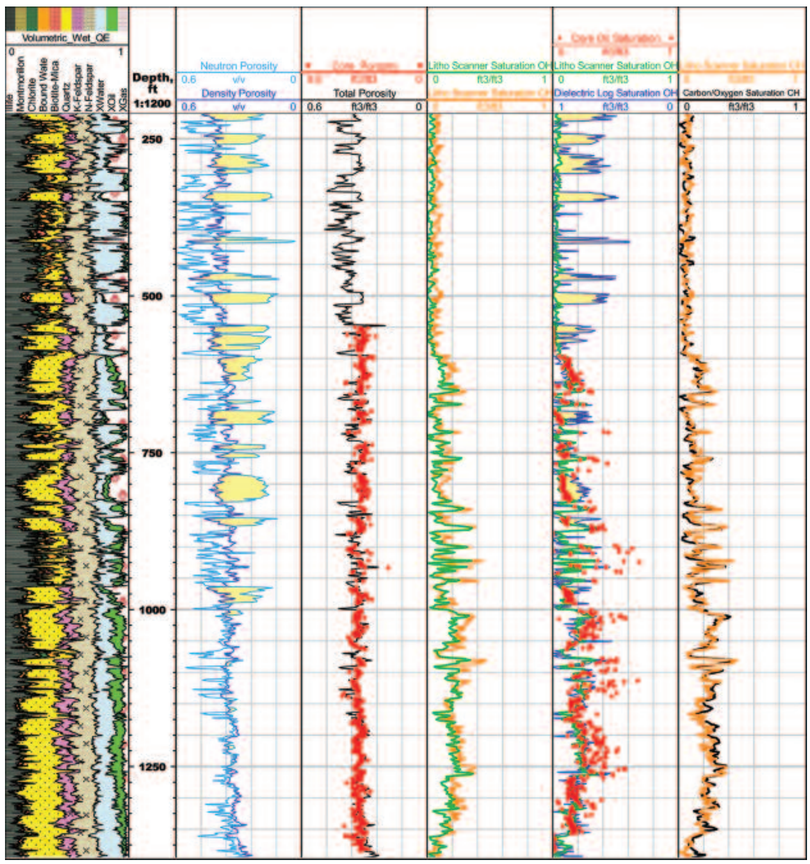

FIGURE 2. Hydrocarbon saturation is difficult to determine with conventional approaches due to residual effects of EOR involving steam injection. However, saturation determined from the Litho Scanner service in both open- and cased-hole conditions yields accurate results, as confirmed by core and other log measurements.

density log to more accurately determine the formation porosity, which was found to be constant at about 30 µ as confirmed by the close match to core data. The TOC was then combined with porosity to calculate the formation hydrocarbon saturation. As shown in Figure 1, the log-derived saturation results also closely matched the core data, demonstrating the accuracy of the saturation interpretation by the spectroscopy service in a well that was logged in both water- and oil-based mud.

The second example is a heavy oil sandstone in California that is under enhanced recovery by steamflood (Figure 2). Assessing the remaining oil saturation in the formation by using traditional openhole methods is challenging because of the effects of the steamflood on the unknown and variable water salinity. The HD spectroscopy service was selected with the objective of evaluating the heavy oil zones independent of the water salinity for an accurate interpretation.

In this example, the hydrocarbon saturation was computed from spectroscopy measurements in both open and cased hole. Track 1 on Figure 2 displays a volumetric interpretation of both the mineralogy and fluids. Track 2 is the neutron and density porosity, with the steamflood zones clearly visible in the shaded crossover zones. Track 3 is the density porosity computed using the derived matrix density from the spectroscopy service, which closely matches the core data. Track 4 shows the agreement of the hydrocarbon saturations logged in both open and cased hole. Two additional pieces of information are added to the openhole interpretation in Track 5. The first is the water saturation measured by the Dielectric Scanner multifrequency dielectric dispersion service, which consistently overlays the hydrocarbon saturation from the spectroscopy service except in the crossover zones. Also added to this track are the core hydrocarbon saturations, which closely match both logs in zones where they overlay but match only the hydrocarbon saturation in the crossover zones.

This example highlights the complementary nature of the two saturation estimates: The spectroscopy service provides the hydrocarbon saturation, while the multi-frequency dielectric dispersion service provides the water saturation. The difference results from the presence of gas or in this case steam saturation. The spectroscopy service was subsequently run after the well was cased. The service produced behind-casing results that closely matched saturation estimated by the RSTPro reservoir saturation tool (Track 6), demonstrating the versatility and accuracy of the new spectroscopy measurements.

Applications include complex lithology and mineralogy interpretation, kerogen estimation, matrix properties for petrophysical evaluation and, as demonstrated here, hydrocarbon saturation. The newly introduced saturation estimation is especially valuable where traditional resistivity-based methods fail because of unknown formation conditions following EOR procedures. E&P

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