GeoNeurale

Mixture of Gaussian fitting of NMR spectra for retrieving fluid distributions

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Summary

The de-convolution of low field NMR spectra, especially those obtained from borehole logging tools, is a very important procedure that can unveil information hidden in the T1, T2 or Diffusion. This information is associated with the determination of the spectral components present in the distributions that can be used to identify reservoir rock quality and fluid types. The fitting method presented in this paper uses as input only spectral data already available after inverting the NMR echo trains; it identifies the bins where the spectral components are located and quantifies them in terms of height, mean and variance corresponding to the selected fitting curves. The method has been tested with simulated T2 distribution data, considering combination of different amounts of heavy oil, clay-bound water, capillary-bound water, movable water and oil-based mud filtrate.

The versatility of the method relies on its applicability to any kind of spectral distribution whether coming from lab measurements or from the borehole.

The results shown in this paper reveal that individual components could be detected down to two-percent porosity unit and the spectral resolution is about one unit more than the standard deviation when fitting with a Standard Gaussian curve.

Simulations

The simulation procedure for generating T2 distributions is based on a step-like reservoir profile, having oil saturation at irreducible water saturation conditions at the top and a gradual decrease of oil saturation down to the water zone. The reservoir should have shale boundary at the top. T2 distributions from three depth levels have been analyzed: one in shale, above the reservoir layer; one at the top of the reservoir, at irreducible water saturation; and one at one intermediate level above the water leg, with approximately sixty five-percent water saturation.

The developed code is based on detecting slope variations of the T2 envelope curve. For the so-called key points the initial values of amplitude, position and standard deviation of the T2 component are detected or calculated. In a second stage, the fitting procedure is started and run until the convergence is reached. At the end, the curve parameters of the detected T2 components are extracted.

To honor the displacement of the wetting phase (water) by the non-wetting phase (hydrocarbon), the simulation of the T2 distributions consider the presence of pendular water as described by the pore-scale modeling, Romero, (2008). In this simulation, the pendular water, which is part of the irreducible water, generates its peak at bin 16.

Figure 1 shows the original T2 components along the T2 axis in bin number units.

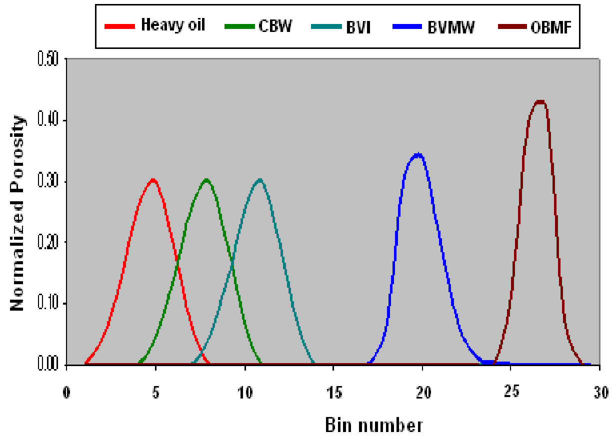

Figure 1 Original T2 components

For simplicity, the theoretical reservoir layer should have a linear decrease of the oil saturation down to the water leg, as shown in Fig. 2.

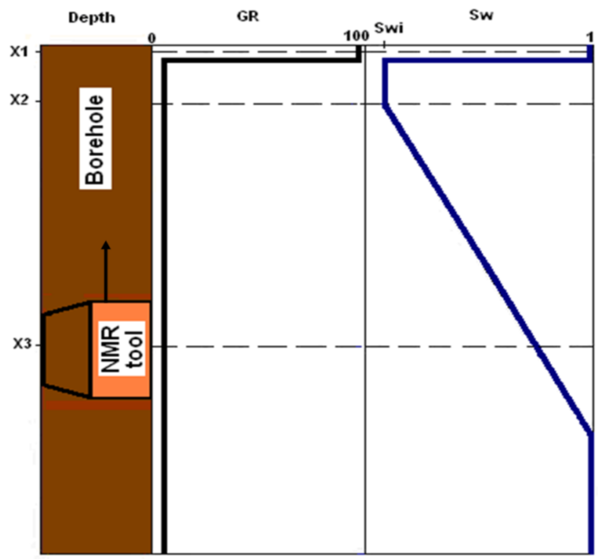

Figure 2 Gamma ray and water saturation profile in the idealized reservoir. A NMR side-looking tool senses the formation acquiring data as sets of echo trains.

A variety of fitting curves can be selected, e.g. Standard Gaussian, Split-Gaussian, Gamma Incomplete, Voigt and others.

Results

Spectral resolution: The fitting method applied on two Gaussian curves of 1 bin standard deviation allows the separations of the signals when the maxima are no closer than two bins from each other, as shown in Fig. 3.

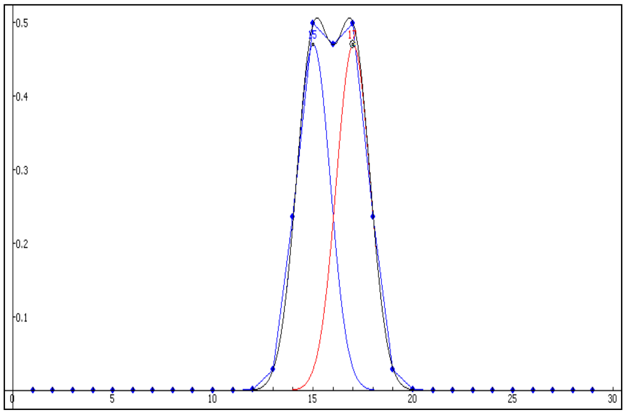

Figure 3 Spectral resolution for Gaussian Peak of 1 bin stdev.

For a Gaussian peak of standard deviation is equal to 2 bins, the peaks can be resolved when they are no closer than 3 bins, as shown in Fig. 4.

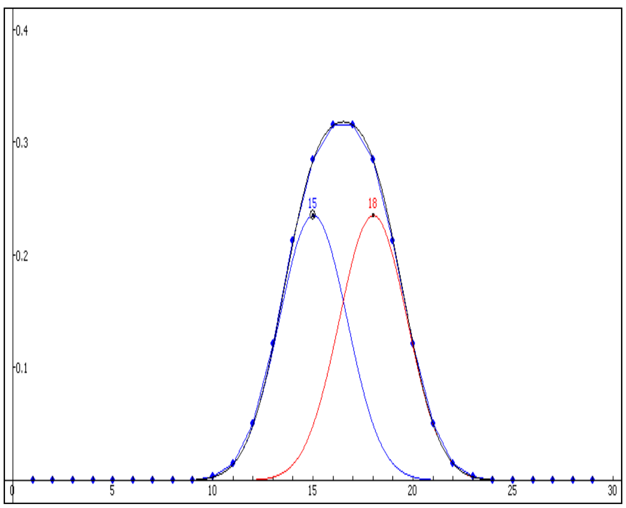

Figure 4 Spectral resolution for Gaussian Peak of 2 bins standard deviation.

<u>Simulations of T2 distributions:</u>

The first layer should contain only CBW and BVI corresponding to a shale interval, Sw equals 100-percent, above the reservoir. The results of the fitting procedure are shown in Fig. 5.

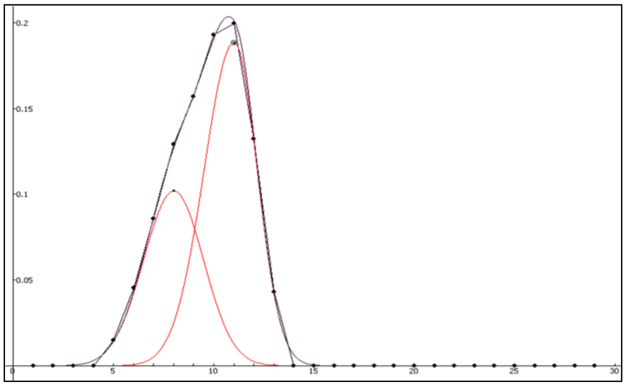

Figure 5 T2 distributions of a simulated shale section. Depth x1.

The volumetric bar analysis of this fitting is shown in Fig. 6. It demonstrates that a spline interpolation of the T2 distribution does not improve the results.

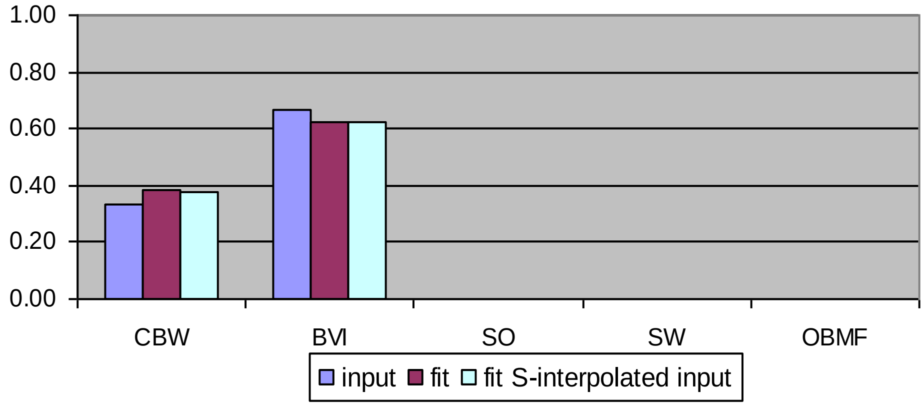

Figure 6 Volumetric results of the fitting for a simulated shale section.

Below the shale layer we should expect the reservoir at irreducible water saturation conditions. Figure 7 displays the corresponding T2 distribution where some OBMF contribution is allowed.

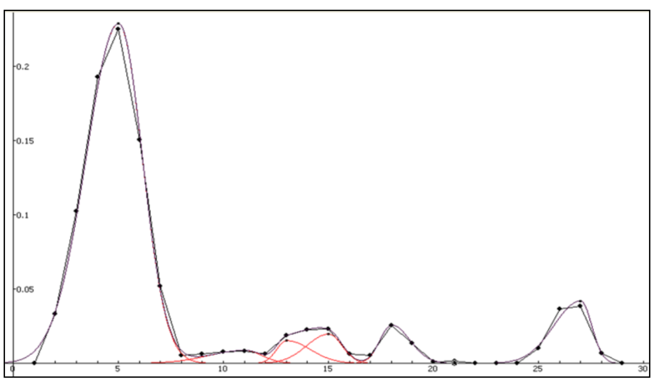

Figure 7 Fitting T2 components of a reservoir layer at Swi. Depth x2.

The volumetric results of the fitting shown in Fig. 7 are shown below in Fig. 8.

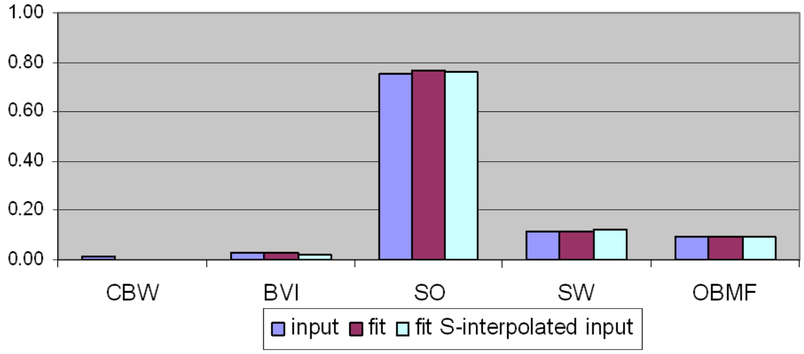

Figure 8 Results of the volumetric analysis of the fitting of a T2 distribution at Swi.

In this case we note that the CBW is not detected as it amount is below two-percent, an indicator of the limit of the volumetric resolution of this procedure.

Finally, Fig. 9 shows the fitting of a T2 distribution corresponding to a layer with hydrocarbons and movable water.

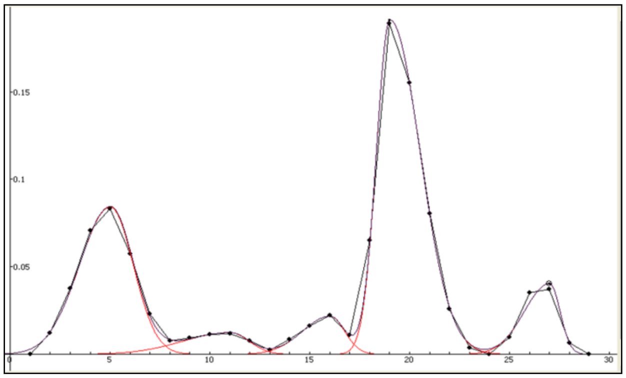

Figure 9 Fitting f T2 components of a reservoir layer containing oil saturation and also movable water. Depth x3.

The corresponding results of the volumetric analysis are shown below in Fig. 10.

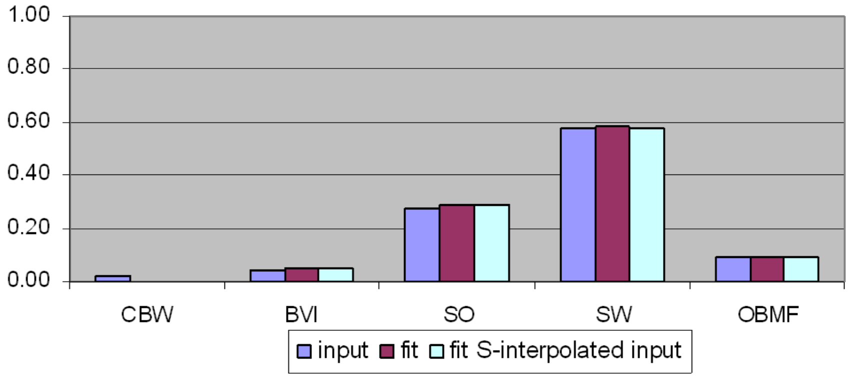

Figure 10 Volumetric results of fitting a T2 distribution containing oil and movable water.

Figure 10 shows that the missing amount of CBW in this particular layer is detected as a part of the BVI and SO.

Conclusions

The fitting algorithm developed for analyzing the T2 distributions based on the curve profile is effective in detecting components above two-percent in magnitude.

The spectral resolution when fitting with standard Gaussian curves is equal to σ +1, where sigma (σ) is the standard deviation of the fitting curve.

The algorithm allows fitting with different types of functions such as Standard Gaussian, Gamma Incomplete, Voigt and others.

The fitting is not restricted to T2 distributions. It can also be used for T1, and Diffusivity curves obtained in the presence of gradient fields.

The fitting algorithm does not depend on the type of T2 inversion procedure used for generating the distributions from the time-domain data or the echo trains.

Nomenclature

BVI: bound-volume index (capillary irreducible water)

CBW: clay-bound water

OBMF: oil-based mud filtrate

So: oil saturation

Sw; water saturation

Swi: irreducible water saturation
T2: transversal relaxation time

References

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Gomez, Sebastian, 2009, Determinación de componentes espectrales de tiempos de relajación magnética transversal o T2, B.Sc. Tesis, Universidad de Antioquia, Colombia.

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