Facies identification by Fuzzy Inference

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Abstract

This work aims to present a modified fuzzy inference system able to identify one particular facies of interest in the well logs recorded in uncored boreholes. Input variables are the natural gamma ray log (GR) and the parameters N and M, which are defined from the density log, the neutron porosity log and the sonic log. The database of this inference system is built from the natural gamma ray log and parameters M and N taken from depth intervals defined from core information in reference boreholes in the oilfield with evidence of occurrence of the facies of interest. The output of this inference system indicates the depth interval of occurrence of the facies of interest in uncored boreholes in the same oilfield. The proposed methodology was applied in synthetic well log data and real well log data recorded in two boreholes in the Namorado's oilfield (Campos basin, Brasil).

Introduction

The formation evaluation needs to several information, which are particular characteristics of each reservoir in an oilfield, to produce a realistic estimative of hydrocarbon volume. These information, commonly, are not given by well logs itself and reflects the geologic characteristics of the reservoir layers, which in the end determine its qualification as a hydrocarbon reservoir. Important part of these geological information about the reservoir rock can be resumed by the facies concept (SELLEY, 1976) and are usually produced by core analysis.

In many practical cases, particularly in offshore oil exploration, the absence of outcrops combined with limited number of cored wells collaborate for the insufficient geological support to identify the facies of interest to all boreholes in the oilfield to supply the geologic information needed for formation evaluation and to improve the stratigrafic knowledge of the field.

Considering that all boreholes in an oilfield are logging, this work presents a computational method based on fuzzy inference able to produce a mapping among the geological description of the facies of interest and its physical properties registered in conventional wireline logs. Moreover, this method can transport the mapping acquired in a cored borehole to the all uncored boreholes in the oilfield. This procedure allow the use of all geological information to improve the formation evaluation in uncored wells and may permit the determination of the lateral continuity of the facies of interest.

The present method was applied in synthetic well log data and real well log data recorded in two boreholes in the Namorado's oilfield (Campos basin, Brasil).

Methodology

The mapping among description of the facies of interest (geological information) and its physical properties (wireline logs), both acquired in a cored well assumes the existence of a realistic correlation between the geological characteristics of a layer and its physical properties recorded on well logging. Thereby the correlation between the description of the facies of interest and the natural gamma ray, density, neutron porosity, and sonic logs is established, this correlation remains valid if the last logs are codified according to M and N parameters (BURKE et al, 1969).

The construction of the fuzzy inference system proposed here locates the facies of interest in an uncored borehole considering that:
•The correlation among physical properties and geologic characteristics is established in a cored well;
•There are similarities between this correlation (established in the cored wells) and the correlations established in the uncored wells in the same oilfield.

This methodology can be divided in the following steps. The first step is performed the recognition of the depth interval of occurrence of the facies of interest in a cored well and selected the depth points in this interval in the natural gamma ray log (ELLIS,1987) and in the M-N plot (BURKE et al, 1969). On the second step, the membership functions (KOHAGURA, 2007) which characterize the facies of interest are generated based on histograms built with the selected natural gamma ray log and the parameters M and N. To solve the problem of identifying the facies of interest in an uncored well, the result generated by the fuzzy inference system is binary, in words, 1 (one) when the depth point corresponds to the faces of interest and 0 (zero) otherwise.

This work adopted a single rule which is written in the equation (1) as,

$$\mu_F(u_i) = \max\left[\, \min\left[\, \mu_N(u_i)\,, \mu_M(u_i)\,\right], \mu_{RG}\,(u_i)\,\right] \qquad (1)$$

where , $\mu_F(u_i)$ is the membership function related to the facies of interest, $\mu_N(u_i)$ is the membership function determined by parameter N in the cored well,$\mu_M(u_i)$ is the membership function determined by the M parameter in the cored well, $\mu_{GR}(u_i)$is the membership function determined by the natural gamma ray log in the cored well, and u_i is the i-th depth point in the uncored well, in which we want to obtain information whether the facies of interest occur or not as identified in the cored well.

The solution of the problem of the identifying of the facies of interest in an uncored well corresponds to the output signal produced by the fuzzy inference system. The fuzzy membership function ($\mu_F(u_i)$) is evaluated or transformed in one integer number on the interval ([0, 1]) by the function of evaluation depicted on Figure (1).

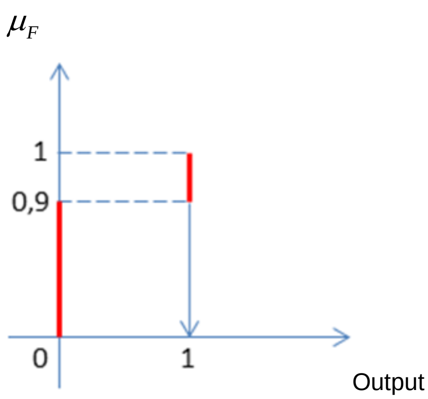

Figure1: Evaluation function: Transformation of the membership function in an integer number ([0,1]).

Results

The evaluation of the methodology presented here is performed with synthetic data and real data. The synthetic data satisfy the general equation of the log and the real data are made up by the natural gamma ray logs and by the porosity logs measured in two wells Namorado's oilfield, located at Campos basin. The core information of the well which is taken as a test well (B) is not used by the fuzzy system and server only for results validation.

a - Synthetic Data

Figure 2 represents the set of logs measured in the reference well (well A). The first trail represents gamma ray log (GR), the second density log (RHO), the third neutron porosity log (PHI), the fourth sonic log (DT). The fifth trail represents core's description. Also in Figure 2 is made the selection of the facies of interest (facies A) in the well A, being its description given in table 1, along with description of the others facies.

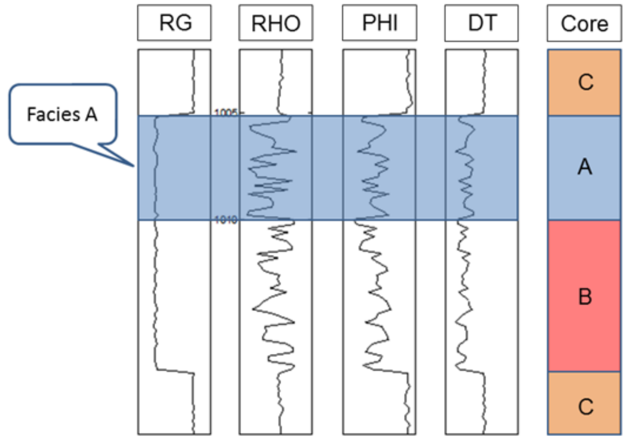

Figure 2: Synthetic data - the selection of the facies of interest (facies A) in the reference well (well A).

Table 1: Synthetic data: Facies description in the well A.

Facies	Description
A	Lime-sandstone (60% quartz + 40% calcite)
B	Limestone (100% calcite)
C	Shale

Figure 3 represents the M-N plot of well A, the crosses in red the identification of facies of interest, and the crosses in black the remaining points in depth of the well A.

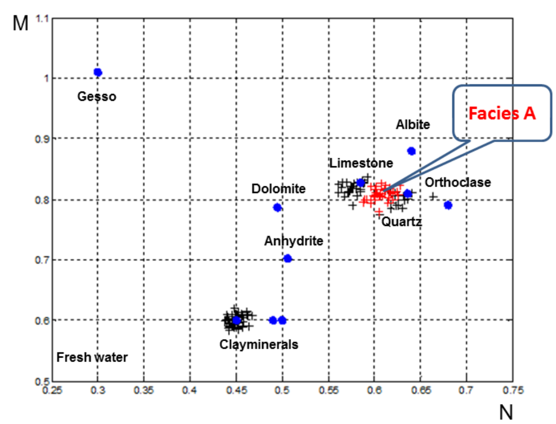

Figure 3: Synthetic data - Identification of facies A in the M-N plot of well A.

Figure 4 shows histograms created from the data of natural gamma ray logs (GR) and the data of the parameters N and M of well A, and beside each histogram the membership functions corresponding to them.

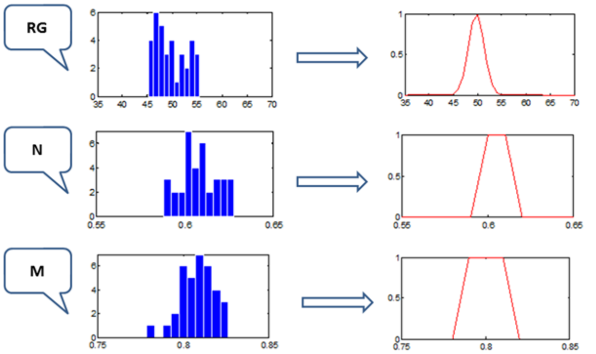

Figure 4: Synthetic data – Creation of evaluation functions related to well A, from the data of natural gamma ray logs (GR) and the data of the parameters N and M.

Figure 5 is similar to Figure 2, but, in this instance, is shown the set of logs measured in the test well (well B). Importantly, the well B is cored, but we depart from the assumed not to is to prove the methodology used in the work. It is noticed the presence of one more layer (layer D). Table 2 shows the facies description of well B.

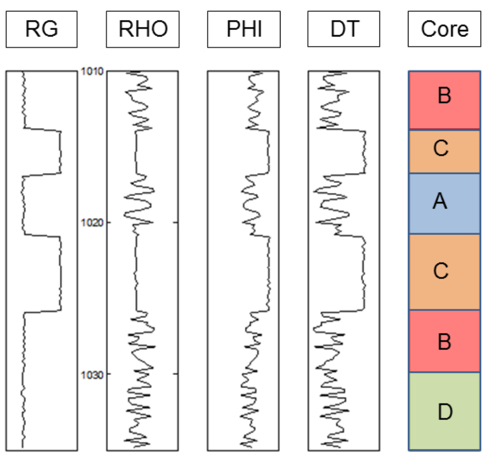

Figure 5: Synthetic data - Presentation of the logs of the well B (uncored well).

Table 2: Synthetic data: Facies description in the well B.

Facies	Description
A	Lime-sandstone (60% Quartz + 40% Calcite)
B	Limestone (100% Calcite)
C	Shale
D	Sandstone (100% Quartz)

Figure 6 represents the M-N plot of the well B. It is noticed the impossibility of making a direct visual interpretation in this graph, because it is possible to interpret the presence of two or three layers, though in fact there are four layers in this interval of the well B, according to the description of the core.

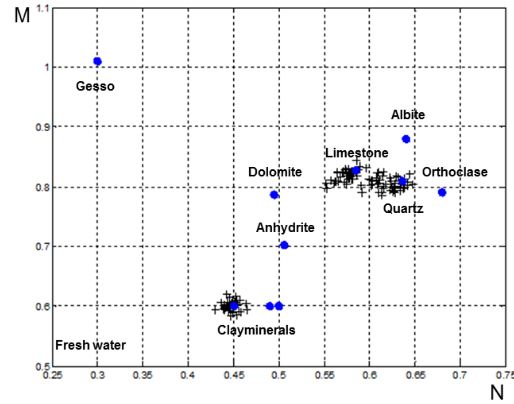

Figure 6: Synthetic Data - M-N plot of the well B.

Figure 7 shows schematically the operation of the fuzzy inference system presented in this paper. Applies to the rule of inference proposed here, eq. (1), in a point of the well B which was chosen randomly in the membership functions created from data well A. After the application of the inference rule is done an evaluation, in which the values corresponding to the facies A are in the interval between 0.9 and 1 and outputs value 1. The 0 output correspond to the values outside this interval (binary output). It is noticed that the point at depth chosen as example belongs to the facies A found in well A.

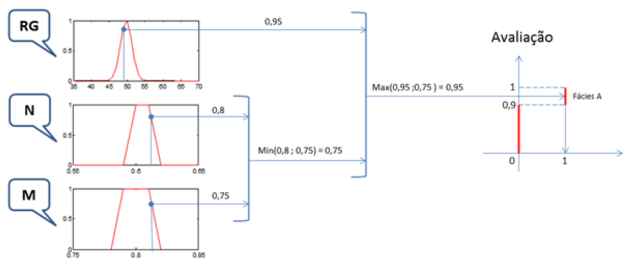

Figure 7: Synthetic data - Scheme of the application of the methodology proposed in this work in the well B.

Figure 8 shows the identification in the M-N plot of facies A in the well B.

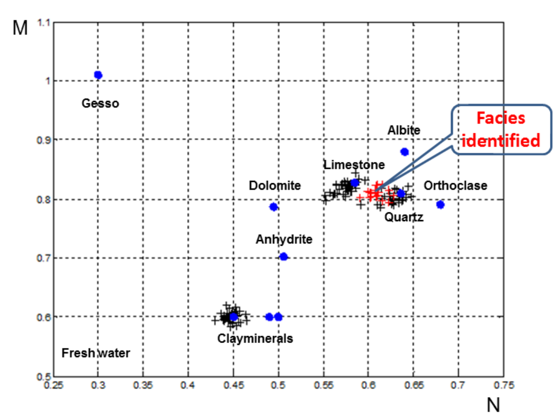

Figure 8: Synthetic data -Identification of facies A in the M-N plot of the well B

Figure 9 shows the identification of the facies A in function of depth in the well B, taking natural gamma ray log as reference.

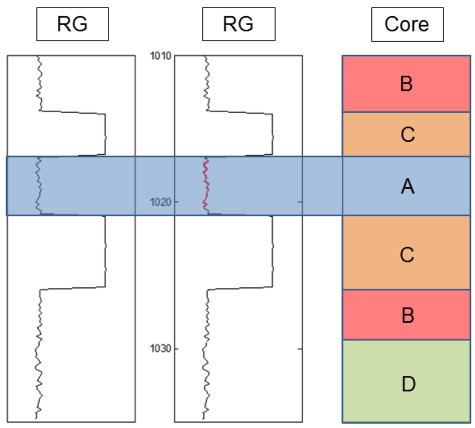

Figure 9: Synthetic Data - Identification of the facies A in function of depth in the well B.

b - Real Data

The Figure 10 represents the set of logs measured in the reference well (well A), similar to the Figure 2. The difference between Figure 2 and Figure 10 is which on the first are used synthetics data and on the second are utilized real data and real cores. The same way as was done in Figure 2, in Figure 10 is made the selection of the facies of interest (facies A) in the well A, being its description given in table 3.

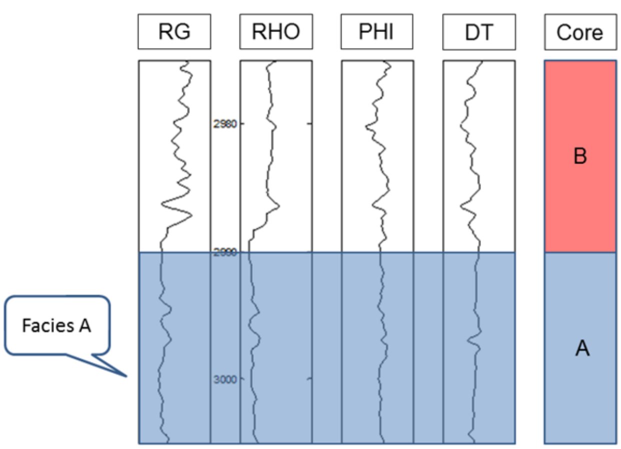

Figure 10: Real data - the selection of the facies of interest (facies A) in the reference well (well A).

Table 3: Real data: Facies description in the well A.

Facies	Description
A	Well sorted, medium sandstone
B	Inter laminated silt and shale bioturbated

The figure 11 represents the M-N plot of well A, the crosses in red the identification of facies of interest, and the crosses in black the remaining points in depth of the well A, similar to Figure 3.

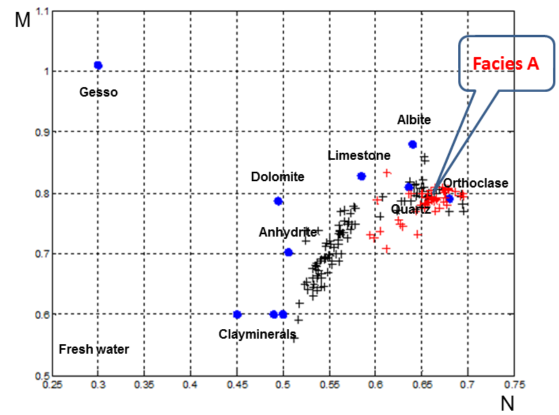

Figure 11: Real data - Identification of facies A in the M-N plot of well A.

Figure 12, similar to Figure 4, shows histograms created from the data of natural gamma ray logs (GR) and the data of the parameters N and M of well A, and beside each histogram the membership functions corresponding to them. it is important to emphasize that, for example, could have been used one trapezoidal membership function to represent the gamma ray log, but was used a Gaussian function, being it built in a way that helps remove values with high natural gamma ray, above 60 (values most probably related to the clay). The membership functions created here were selected in order to try to attenuate to the maximum the effect of the clay and emphasize the matrix parameter.

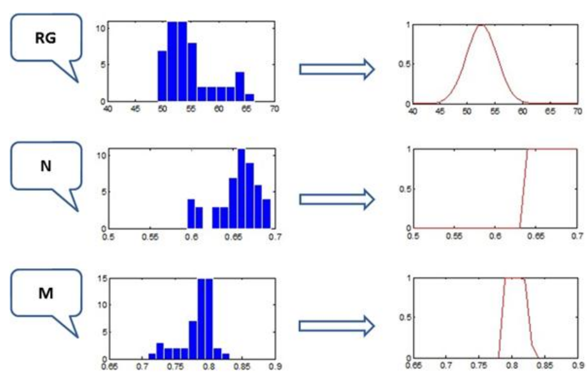

Figure 12: Real data – Creation of evaluation functions related to well A, from the data of natural gamma ray logs (GR) and the data of the parameters N and M.

A Figure 13 is similar to Figure 2, Figure 5, and Figure 10. It represents the set of logs measured in the test well (well B). Importantly, the well B is cored, as well as in Figure 5, but we depart from the assumed not to is to prove the methodology used in the work. It is noticed the absence of the layer B found in the well A and the presence of other layers unidentified by the core of the well A (layer C, layer D, and layer E). Table 2 represents the description of the facies of well B.

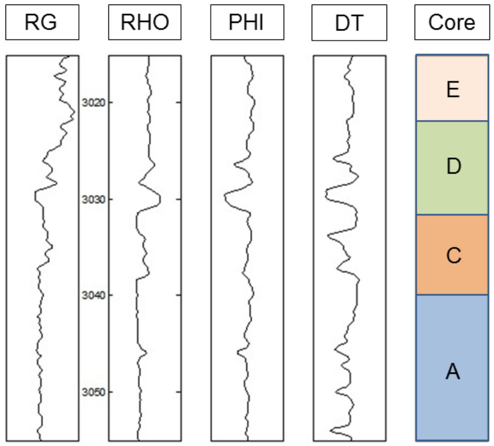

Figure 13: Real data - Presentation of the logs of the well B (uncored well).

Table 4: Real data: Facies description in the well B.

Facies	Description
A	Well sorted, medium sandstone
C	Inter laminated sandtone-shale bioturbated
D	Gray shale bioturbated
E	Inter laminated silt and shale deformed

Figure 14 represents the M-N plot of the well B, similar to Figure 6. It is noticed the impossibility of making a direct visual interpretation in this graph, because it is possible to interpret the presence of two or three layers, though in fact there are four layers in this interval of the well B, according to the description of the core

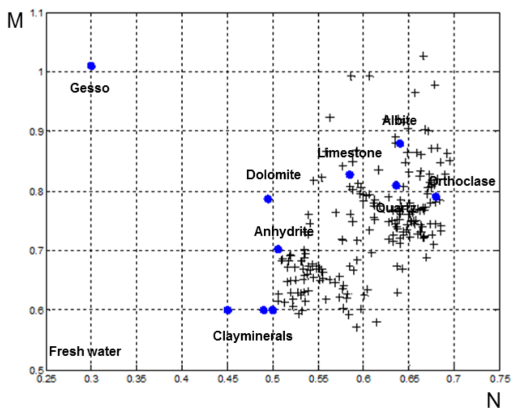

Figure 14: Real Data - M-N plot of the well B.

Figure 15 shows schematically the operation of the fuzzy inference system presented in this paper, similar to Figure 7. What was previously done in the well B shown in Figure 7 is made in Figure15. It is noticed that the point at depth chosen as example belongs to the thefacies A found in well A.

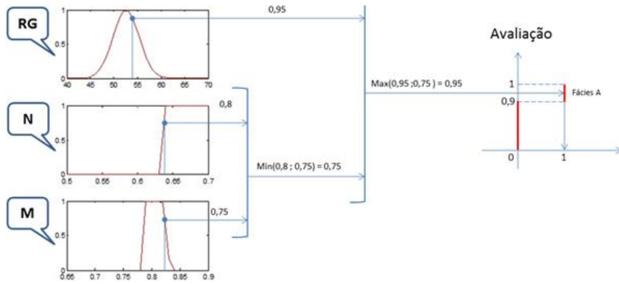

Figure 15: Real data - Scheme of the application of the methodology proposed in this work in the well B.

Figure 16 shows the identification in the M-N plot of facies A in the well B.

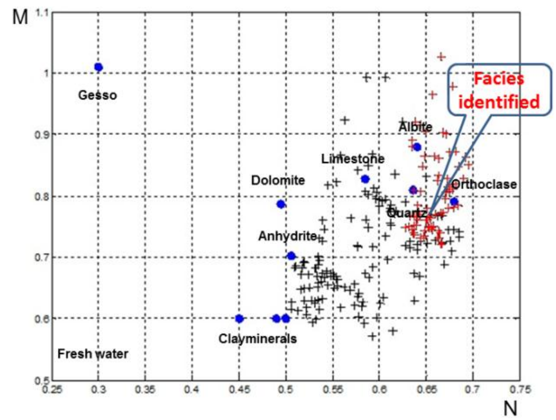

Figure 16: Real data - Identification of facies A in the M-N plot of the well B

Figure 17 shows the identification of the faciesA in function of depth in the well B, taking natural gamma ray log as reference, similar to Figure 9.

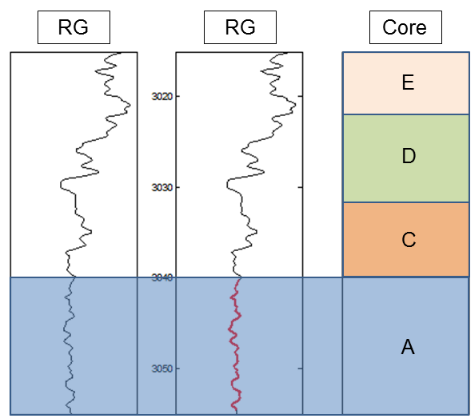

Figure 17: Real Data - Identification of the facies A in function of depth in the well B.

Conclusions

We presented a fuzzy inference system for the identification of one facies of interest directly on the recorded logs in an uncored well. The inference system builds your database around the recorded logs in a core well, where the facies of interest is identified in the core analysis. It has been shown that the identification of the facies of interest in an uncored borehole occurs independently of the depth and thickness of the layer the cored borehole that produced the database of this fuzzy inference system. This fact permit us to propose the application of this method for mapping a reservoir layer along oilfield, even at complex geologic scenarios which cause the thickness variations and of the depth of the layer of interest.

References

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