Predicting porosity, permeability frequency and hydrocarbon saturation using cuttings gas logs

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INTRODUCTION

The aim of this project is predict the porosity, permeability and hydrocarbon saturation of reservoir rocks during drilling using advanced techniques to analyse the cuttings gas measurements. Success in such a venture would reduce the necessity for LWD or traditional wireline data as well as enabling the characteristics of the subsurface rocks to be better understood extremely early in the exploration. Previous work, especially that of Cuddy has indicated that low resolution hydrocarbon shows during drilling may be used to predict porosity and hydrocarbon saturation. Three parameters show promise. These are the hydrocarbon wetness ratio, the hydrocarbon balance ratio, and the hydrocarbon character ratio. Each of these is calculated from the first five cuttings gas measurements (i.e., C1 to C5). The relationship of these hydrocarbon ratio to specific rock properties is complex: advanced analysis techniques such as the use of genetic algorithms and/or fuzzy logic needs to be used. An anonymous but typical well from the UK Sector North Sea has been analysed in the standard manner for porosity and hydrocarbon saturation using conventional well log data. This data was then used together with the cuttings gas ratios to calibrate a genetic algorithm. The software to do this combines the advantages of both the genetic algorithm approach and the fuzzy logic analysis technique. The resulting calibrated genetic algorithm can be used to predict the porosity, permeability and hydrocarbon saturation from cuttings gas ratios in other associated wells in the same field with a high degree of accuracy.

WHAT ARE CUTTINGS GASES?

The log of the different hydrocarbon gases evolved from drilling cuttings. They are done in every well during drilling and often included in the mudlog. Because they are a statutory obligation on the grounds of safety, they are "free" and immediately available.

However, cuttings gas logs have an extremely poor vertical resolution and have not, until recently, been successfully linked to useful reservoir properties such as porosity and saturation

Commonly the lighter alkanes are analysed. These are:

C1, C2, C3, iC4, nC4, C5, C5+

Which are sometimes expressed as the cuttings gas ratios:

Hydrocarbon Wetness (W_h)

$$Wh = \frac{(C_2 + C_3 + C_4 + C_5)}{(C_1 + C_2 + C_3 + C_4 + C_5)} x\,100$$

Hydrocarbon Balance (B_h)

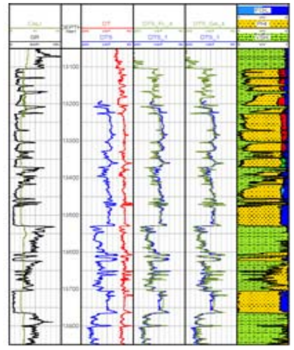
$$Bh = \frac{(C_1 + C_2)}{(C_3 + C_4 + C_5)}$$

Hydrocarbon Character (C_h)

$$Ch = \frac{(C_4 + C_5)}{C_3}$$

PREDICTION OF THE GAMMA RAY LOG, POROSITY AND FLUID SATURATIONS

Prediction test: Sonic travel time with GAs and fuzzy logic



Input (Calibration Data) in Tracks 1 and 2

- CALI — Caliper
- GR — Gamma ray
- DT — Sonic travel time

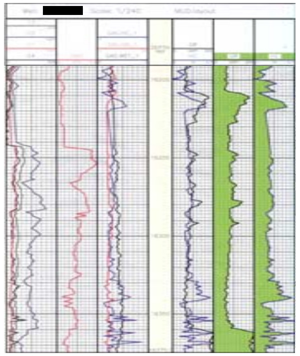
Output (Predicted Data) in Tracks 3 and 4

- DTS_GA_4 — Predicted travel time (GAs)
- DTS_FL_4 — Predicted travel time (fuzzy logic)

Test (Comparison Data) in Tracks 3 and 4

- DTS and DTS_1 — Comparison travel times

Relationship of Hydrocarbon Character to the gamma ray log



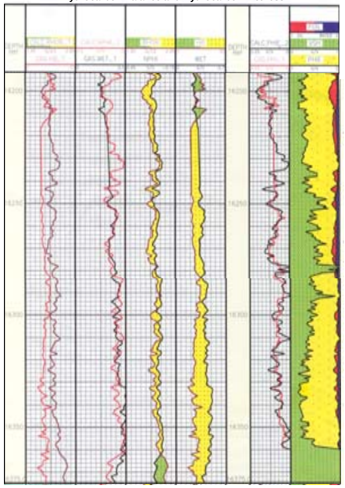
Gas Data

Track 1: Individual cuttings gas measurements
Track 2: Total gas
Track 3: Cuttings gas ratios:
Hydrocarbon Character (HC)
Hydrocarbon Balance (HB)
Hydrocarbon Wetness (WET)

Comparison of Hydrocarbon Character with Gamma Ray

Track 4: GR & HC Ratio
Track 5: GR alone (filled)
Track 6: HC alone (filled)

Prediction test 1: Porosity and Fluid saturations from Hydrocarbon Balance and Hydrocarbon Wetness



Track 1: Comparison of HB with Density Log
Hydrocarbon Balance (HB)
Density Log (RHOB)

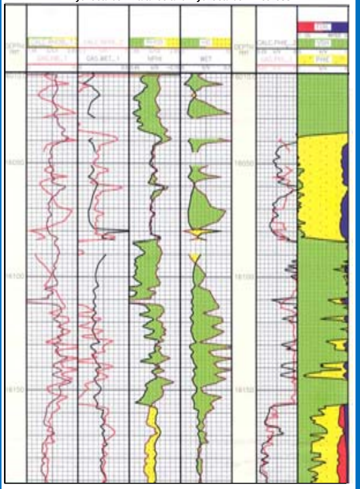
Track 2: Comparison of Hydrocarbon Wetness with Neutron Porosity Log
Hydrocarbon Wetness (Wet)
Neutron Porosity Log (NPHI)

Tracks 3 & 4: Comparison of NPHI/RHOB Combination with Hydrocarbon Balance/Wetness Combination
Green = Shaly
Yellow = Sandy

Track 5: Comparison of Porosity
From Gas Ratios using GAs
From Conventional Logs

Track 6: Final Rock Analysis from the Gas Ratio Data
Shale
Sand
Oil
Water

Prediction test 2: Porosity and Fluid saturations from Hydrocarbon Balance and Hydrocarbon Wetness



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Cuttings gas measurement (Haliburton) is routinely carried out on site as the well is drilled.

Clearly, there is some relationship between:

1. Gamma Ray Log and Hydrocarbon Character Ratio
2. Density Log and Hydrocarbon Balance Ratio
3. Neutron Porosity Log and Wetness Ratio

Genetic Algorithms can find this relationship, and use it to predict porosity

The conventional logs are:
Expensive
Take many extra days to do

The gas log/GA method is:
Free
Available during drilling

WHAT ARE GENETIC ALGORITHMS ?

Genetic algorithms are computer-based programs that take a general form of an equation then evolve the coefficients and operators until a best fit to some calibration data is found. The evolution may include random changes, cloning, sexual reproduction etc. Hence, the program finds the appropriate equation for the data not at random or in a user-defined manner, but by gradual evolution towards its goal. In this respect it is like biological evolution, and, like biological evolution, it may produce a result that one might imagine as an evolutionary dead-end. That is, and equation that provides a good fit to the data, but not the best fit; the best fit occurring in another part of the evolutionary tree.

Ideally, the evolved equation uncovers the mathematical relationships hidden in the calibration data and the equation can then be used to predict any desired parameter.

The general form of the equation may be

$$Y(A, B, C, D\ldots) = aA^b ❖_1 cB^d ❖_2 eC^f ❖_3 gD^h ❖_4 \ldots$$

where:
$❖_i$ = Either + , - , ÷ or ×
a, b, c, d, e, f ... are variable coefficients
A, B, C, D ... are variables in the calibrating data set
Y(A, B, C, D…) is the parameter that is required

The advantage of genetic algorithms include their ability to discover the mathematical relationship linking complex patterns. Hence, they can be used to predict the porosity and saturations in the sub-surface from well-log data, but also from any data that contains information about porosity and saturation no matter how complex or slight the relationship.

If cuttings gas logs contain information, GAs will find it - then porosity and saturation can be predicted

CONCLUSIONS

1. The sonic travel time can be predicted effectively by either genetic algorithms of by using fuzzy logic. Here the test has been done to ensure that the methods were working effectively.
2. Three hydrocarbon gas ratios can be calculated from the cuttings gas measurements.
3. The Hydrocarbon Character is clearly a proxy for the gamma ray log: High hydrocarbon character ratios are generally associated with high shale volumes.
4. The Hydrocarbon Balance is clearly a proxy for the density log: High hydrocarbon balance ratios are generally associated with high densities.
5. The Hydrocarbon Wetness is clearly a proxy for the neutron porosity log: High hydrocarbon wetness ratios are generally associated with high neutron porosities.
6. Two tests have been carried out to test the ability of the genetic algorithm technique to predict the porosity, the water saturation and the hydrocarbon saturation from cuttings gas ratios.
7. Both tests have successfully predicted the porosity and fluid saturations in each well.
8. This method is extremely inexpensive, uses data that is already routinely measured, and that is available during drilling.

For additional information, please contact:
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