An Innovative Approach for Estimating the S_W and Porosity Using Gas and Mud Logging Data in Real Time*

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Abstract

In recent years, many papers/studies have been presented describing the multiple uses of gas data in supporting electrical wireline log (eLog) analysis, hydrocarbon phase/quality determination and reservoir characterization, thus showing the added value of mud logging data for early formation evaluation and fluid characterization. However, conclusions reached from the quantitative interpretation of mud logging and gas data are often viewed skeptically due to the uncertainties inherent in data acquisition.

This paper describes a new methodology, developed by Repsol, of interpreting mud logging data to provide quantified real-time information about porosity and water saturation. The technique uses the real-time mud-logging data from the gas chromatograph and from drilling parameters such as rate-of-penetration (ROP), weight on bit, etc. First, the real-time data is critically examined by a stringent QC check. Then the methodology involves cross-plotting the various parameters to determine the intermediate variables and calibrate these against the available well data.

To develop real time water saturation (S_W) data, Repsol has developed two protected algorithms (known as the Gw equation and the Beda & Tiwary equation). Results to date show that Sw calculated by this methodology have similar values to those obtained by petrophysical analysis and that Sw can be predicted prior to wireline data being acquired.

Total porosity is obtained by converting the basic drilling data into a Perforability Index (PI) and this is translated into porosity by either of two methods. When well log data is available the PI can be directly calibrated. In the absence of well data, an equation developed by authors is used. The porosity derived from this methodology has a satisfactory correlation with the log derived porosity. To date the integration of gas and petrophysical data by this methodology has provided significant results to aid both real-time and post-drill evaluations. Further refinements and additional calibration of this methodology is on-going and the authors believe that further uses of gas and drilling data will be developed.

Overview

The methodology developed is an integration of petrophysics and mud log data. To achieve this integration, the mudlog data is visualized as "homologous log curves". The concepts and interpretation techniques of petrophysical evaluation are extrapolated to these "mudlog curves" for calibration and quantification in terms of reservoir parameters. This methodology has become routine for all Repsol exploration wells and, so far, has been used successfully in more than 20 wells from different continents.

This paper presents the results of applying this methodology to 3 wells. The wells are from the same geologic province but vary in stratigraphy, reservoir and fluid type. Wells A and B were used to develop the approach. Well C was the first application of the methodology in real time. The reservoir parameters developed by this methodology were highly consistent with the subsequent wireline log evaluation.

Methodology

A minimum data set of resistivity, porosity and gamma ray (GR) is needed for a formation evaluation from wirelines logs. In the mud logging domain, these direct physical measurements are replaced by drilling and gas data. Methane (C1) has been selected as the primary input from the gas data and ROP from the drilling data. Generally speaking, high gas shows correspond to the presence of hydrocarbons (high or higher resistivity with respect to the formation water) and low gas shows are recorded mainly in presence of water bearing or a shaly zone (characterized by low resistivity) (Figure 1).

Variations in rate of penetration are generally linked to porosity and lithology. In particular low ROP is normally recorded in tight lithologies (low porosity), while high ROP is generally registered in the presence of porous zones.

Calculation of the Water Saturation (S_W_Gas)

Normally, gas shows are considered a possible indicator of a presence of hydrocarbon; at present the only possible "quantitative" analysis is related to a fluid characterization (gas-while-drilling (GWD) or equivalent methods). The innovative approach presented here is aimed to derive "quantitative curves" that can be used to measure the volume of the hydrocarbon in the formation. The proposed technique is considered to be a watershed between the current qualitative approach and a future industry accepted quantitative methodology.

The derived S_W_Gas from gas data is a curve comparable to the S_W calculated by electric logs. The calculation of the S_W_Gas can be carried out without "calibration/reference wells" or existing interpretative models.

The calculation of S_W_Gas commences with complex mathematical operations involving cross-plotting various mud logging and drilling data. This process gives the factor Gw which is the volume of gas in 100% water saturated reservoir of a given porosity. Then S_W_Gas is obtained using a further equation (B&T) which is a function of Gw and actual gas data (C1). The formulas and methodologies for obtaining the Gw and S_W_Gas cannot be disclosed as patents are pending.

It should be mentioned that not all the gas shows represent hydrocarbon bearing reservoirs. It is emphasized that the absolute magnitude of gas needs to be integrated with the analysis of other parameters such as gas composition and, if available, by calibration with nearby wells.

Derivation of Porosity (PHI)

If allowance can be made for all the variables inherent in drilling conditions, the mud logging data are essentially dependent on lithology and porosity. While drilling, the lithology is known by cuttings, GR/MWD (measurement-while-drilling) or by reference wells, so the remaining unknown variable is porosity. Thus, without large variations in the reservoir properties on a short vertical scale, mud log data can theoretically be used to predict the magnitude of the porosity. The objective of this technique is not to get a precise quantification of porosity but to have a porosity profile in real time, which is comparable in terms of trend and magnitude to the porosity derived by eLog.

Two methodologies have been developed to achieve this:

Methodology 1 (PHI_LOG): Calibration well available

This methodology uses a calibration well (at field or basin scale), where a full set of logs is available. The ROP is normalized using Dex equation and is then converted into a function called Perforability Index (PI). A patent is pending on the mathematical conversion of Normalized ROP into PI. The PHI_LOG is obtained by correlating the PI with the total porosity derived from Neutron/Density logs.

Methodology 2 (PHI_ML): No calibration well

This methodology is employed in the absence of suitable calibration log data. The PHI_ML is mathematically derived from the so called B&T_PHI equation (patent pending). In this case the calculated porosity curve usually over-estimates slightly the porosity as derived from eLog.

Case Studies

The case studies presented in this paper are from offshore wells located in shallow water. The sequence is comprised of sands and shales deposited in shelf margin to deep water environments. The reservoirs are in a hydrostatic pressure regime.

Well A

Four gas zones were recorded while drilling, three of these have been confirmed to be hydrocarbon bearing by eLog formation evaluation (Figure 2).

Only two of these zones were tested: one tested gas and condensate, the other flowed mainly formation water and is considered to be a failed test due to a poor cement bond. The upper reservoir recovered oil by wireline formation tester (WLFT). Figure 3 shows a triple combo plot and a comparison of the S_W and PHI derived from petrophysical evaluation with that derived from ML data using the methodology described in this paper: GR-ROP is shown in track 1, Resistivity in track 2, Neutron/Density in track 3, S_W in track 4, PHI_LOG in track 5 and PHI_ML in track 6.

For clarity, the three hydrocarbon bearing zones are presented as zoomed images in Figure 4, Figure 5 and Figure 6. In track 4, the S_W calculated by petrophysical evaluation using eLog data is overlain with the S_W_Gas calculated by the presented methodology. It is evident that the two S_W curves match each other and are consistent in both magnitude and trend. Hydrocarbon/water contacts defined by Formation Evaluation at the depth of X137.8 m and X146.0 m are also clearly delineated by the quantitative gas analysis.

In track 5 of Figures 4 to 6, the total porosity (PHIT) defined by Density/Neutron is compared to PHI_LOG (calculated by Methodology 1). In track 6 the PHIT is compared to PHI_ML (Methodology 2). These plots clearly show that the ML-derived porosity (both Methodologies 1 and 2) are in agreement with the eLog-derived porosity in both trend and magnitude. This is proof for the applicability of the ML approach, especially considering the range of uncertainty in the PI curve derived from petrophysical data. As to be expected, the PHI_ML derived without any calibration well is less accurate than the calibrated PHI_LOG, but PHI_ML is still generally comparable with the petrophysical-derived data.

The input parameters used for well A have been applied in well B, both for the S_W and the porosity calculation. The fact that the same parameters can be used for both wells confirms the reliability of the gas and mud logging data and hence the applicability and robustness of this quantitative methodology. Figure 10 plots the correlation between the derived reservoir parameters (S_W_Gas, PHI_LOG and PHI_ML in track 4, 5 and 6, and the calculated S_W and porosity by eLog formation evaluation. The results obtained for both the ML derived S_W and porosity curves are remarkably similar, with the two curves virtually overlying each other. Moreover, there is agreement as to the determination of the OWC derived from the two S_W methodologies.

Well C - Application in Real Time

Wells A and B were analyzed as a “post-mortem evaluation” - the results of which were used to further develop and consolidate the methodology. The next step was to use the methodology in a predictive mode, i.e. prior to eLog evaluation. Well C was the first real time application performed to validate the technique and the results were used to support the final formation evaluation. Only one interval was found interesting based on the eLog analysis (Figure 11). The WL bottom-hole sample taken within this interval proves the presence of formation water with traces of oil (max 10-20%). The same input parameters for the equations used in well A and B were also used for well C, confirming again the robustness of the methodology and its applicability for quantitative purposes. The S_W and porosity derived by gas and mud logging data are in line with the petrophysical evaluation as shown in track 4, 5 and 6 of Figure 11. The results clearly demonstrate the effectiveness of the methodology, in predicting S_W and porosity in real time, using only gas and mud log data.

Applications and Limitations

The application of this methodology adds important supporting data to petrophysical interpretations, resulting in less uncertainty in reservoir and fluid characterization. The methodology has particular use in those situations in which:

a) The conventional eLog formation evaluation is not conclusive, e.g. removing ambiguity in determining low resistivity pay, definition in low contrast formations and in shaly sequences;
b) Logs are difficult to acquire (HT, horizontal wells);
c) Operational problems result in an absence of eLogs;
d) In mature fields where S_W and porosity are well known and calibrated, reducing costs as a full log suite is not required.

Conversely, the methodology is not effective:

a) With mud losses;
b) In fractured reservoirs;
c) During special drilling operations such as coring, turbine drilling;
d) In over/under pressured reservoirs.

Conclusions

The innovative methodologies proposed in this paper permit an early evaluation of the potential hydrocarbon intervals with a real time estimation of S_W and total porosity. This method will allow preliminary well-site reservoir evaluation that can be useful in selecting the appropriate logging suite and determining if a zone should be tested. The one proviso is that care is required in assessing the quality of the data from the mud logging domain.

The case studies detailed in this paper show that this methodology is a reliable and effective tool for formation evaluation - the trends and magnitude of the derived parameters are within +/- 10% of the eLog results. The techniques are applicable to both exploratory and development wells. The big „selling point" is that its application involves no modification to basic mud logging practices and therefore important real time data comes at no additional cost. The technique is being further evaluated and additional applications are under development. In this regard, a close cooperation is necessary between oil and service companies. Continued improvement in the quality and reliability of mud and gas data will undoubtedly lead to the development of other applications and improved algorithms for the quantitative evaluation of gas and mud log data.

Acknowledgements

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Glossary

B&T: Beda & Tiwari
C1: Methane
Dex: Dexponent
eLog: Electrical Wireline Log
GR: Gamma Ray
Gw: Gas in 100% water saturation
GWD: Gas While Drilling
ML: Mud Logging
MWD: Measurement While Drilling
PHIT: Total Porosity from eLog
PHI_LOG: Porosity from Methodology 1
PHI_ML: Porosity from Methodology 2
S_W: Water saturation from eLog
S_W_Gas: Water saturation from Repsol methodology
WLFT: Wireline Formation Tester

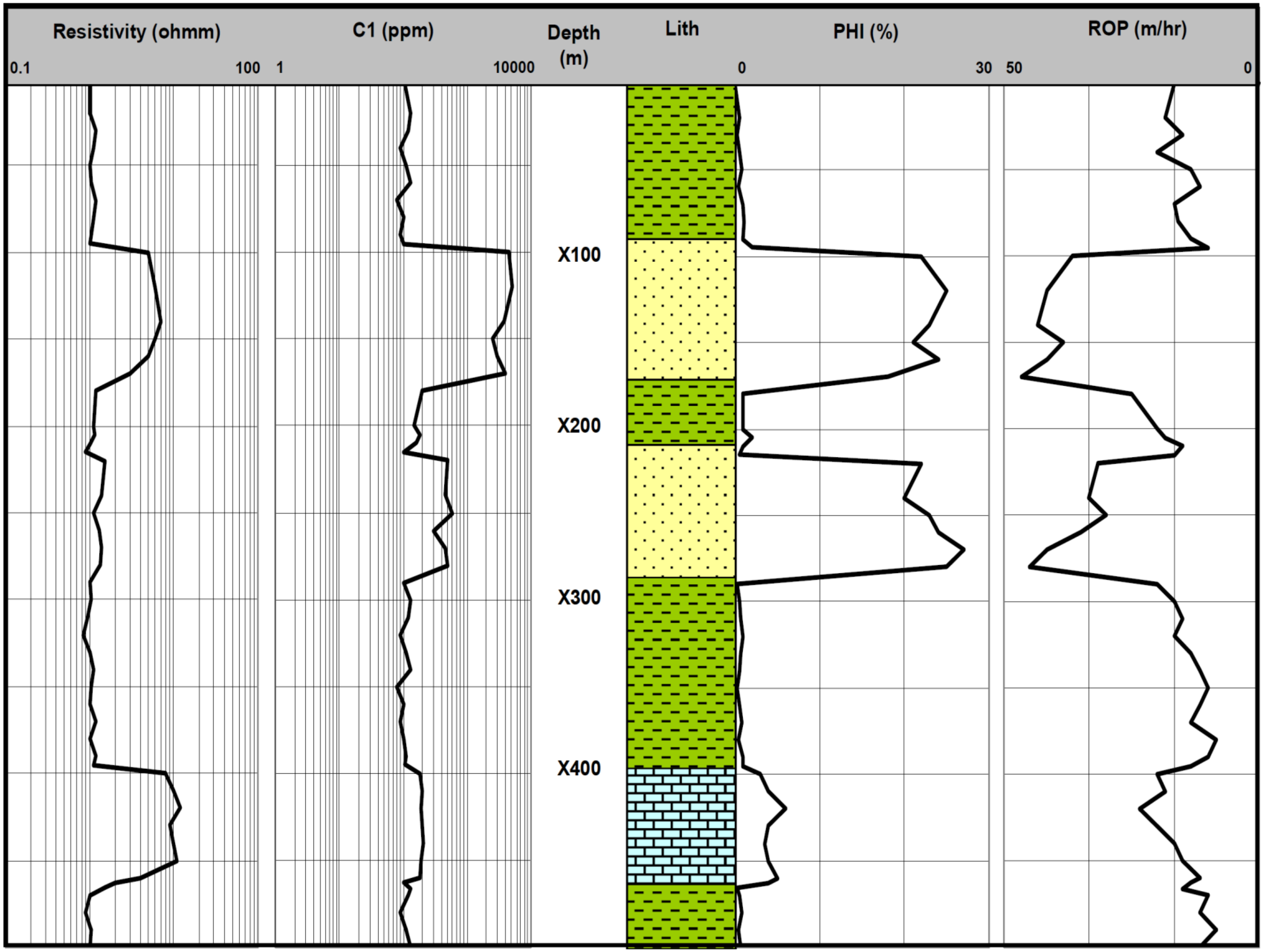

Figure 1. Resistivity/Porosity versus Gas/ROP model.

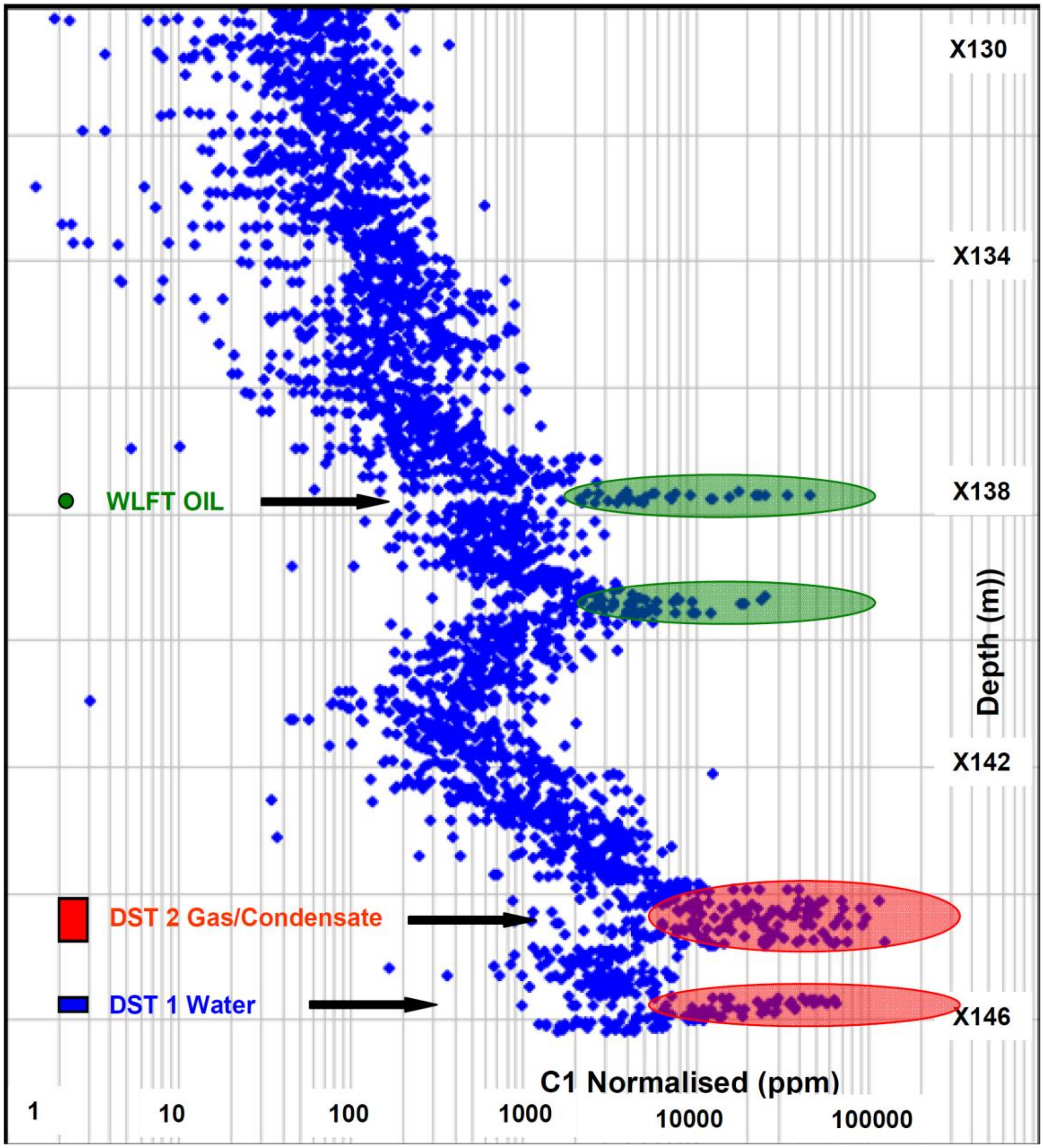

Figure 2. Well A, C1 Normalized versus Depth with test results.

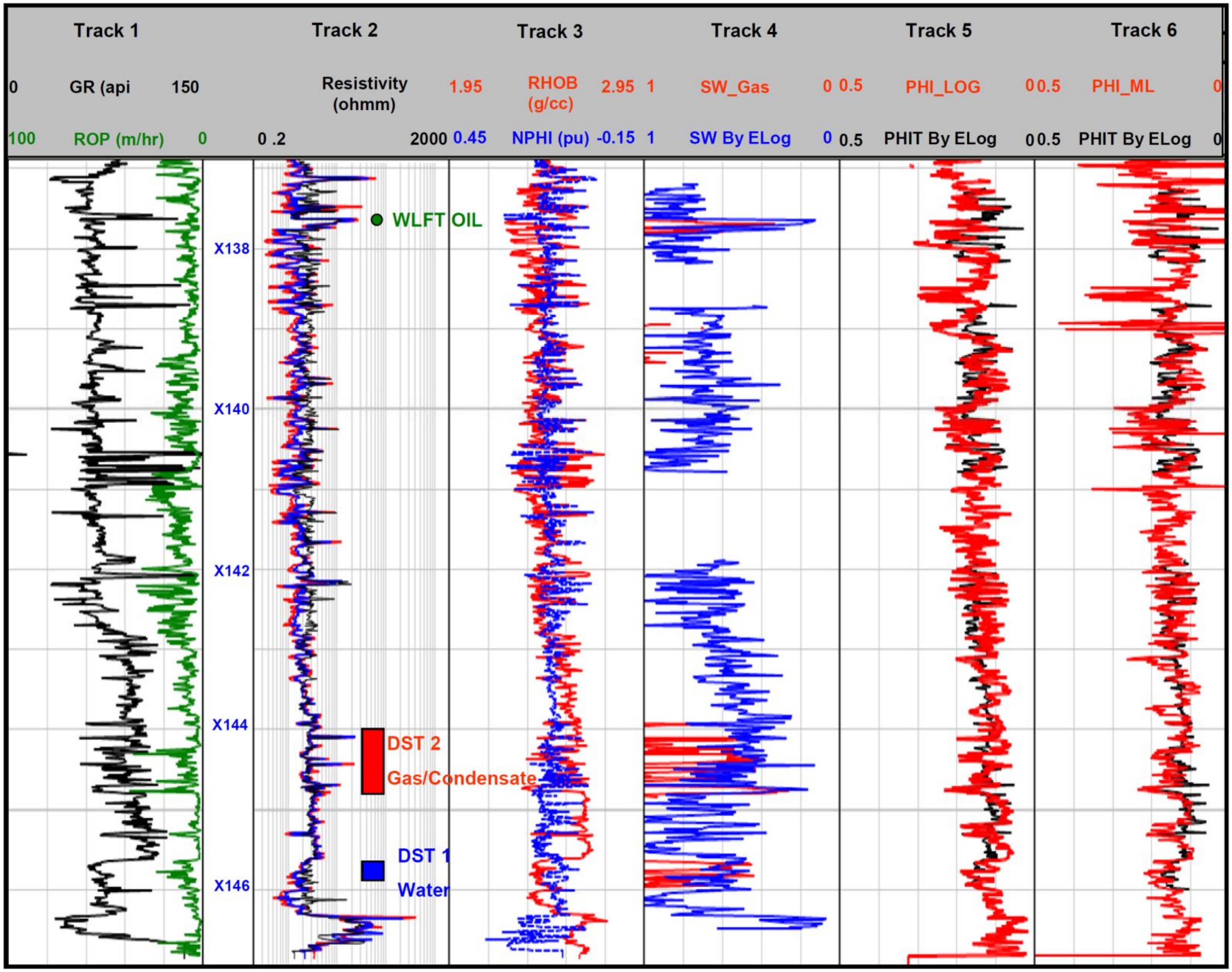

Figure 3. Well A Triple Combo plot with test results and comparison between the conventional eLog analysis and the innovative approach by Mud Logging data.

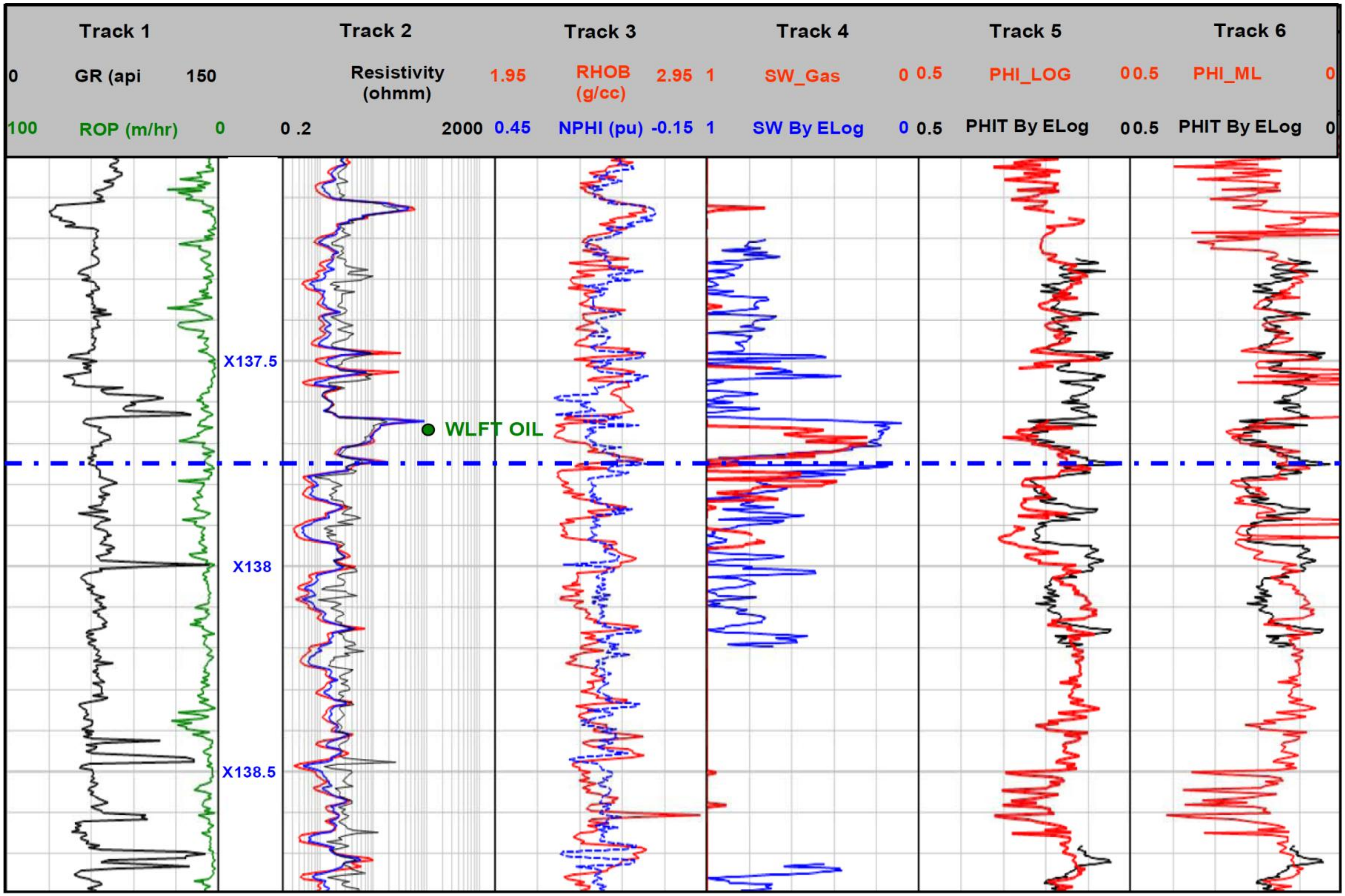

Figure 4. Well A Triple Combo plot with test results and comparison between the conventional eLog analysis and the innovative approach by Mud Logging data in the oil zone.

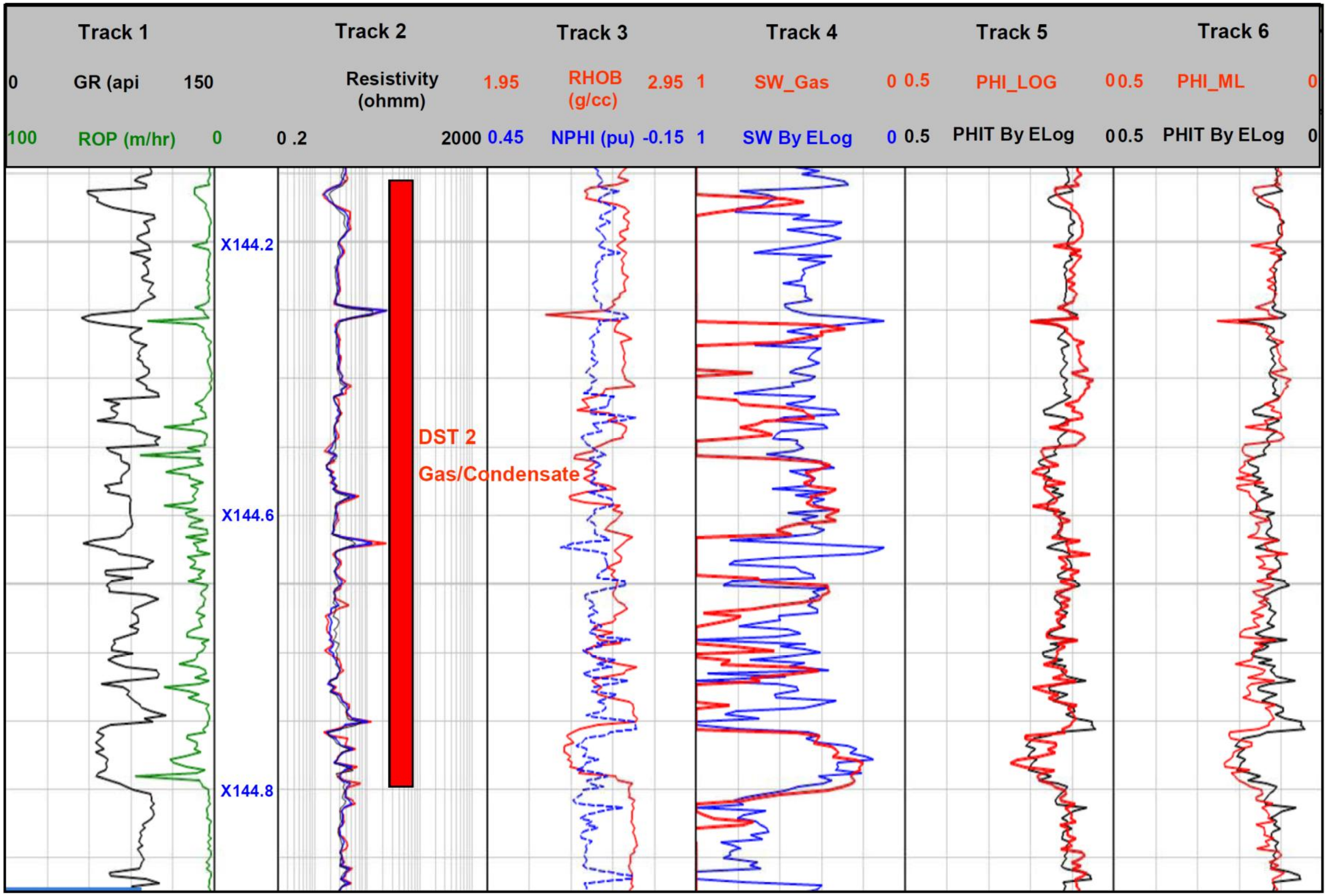

Figure 5. Well A Triple Combo plot with test results and comparison between the conventional eLog analysis and the innovative approach by Mud Logging data in the Gas/Condensate zone.

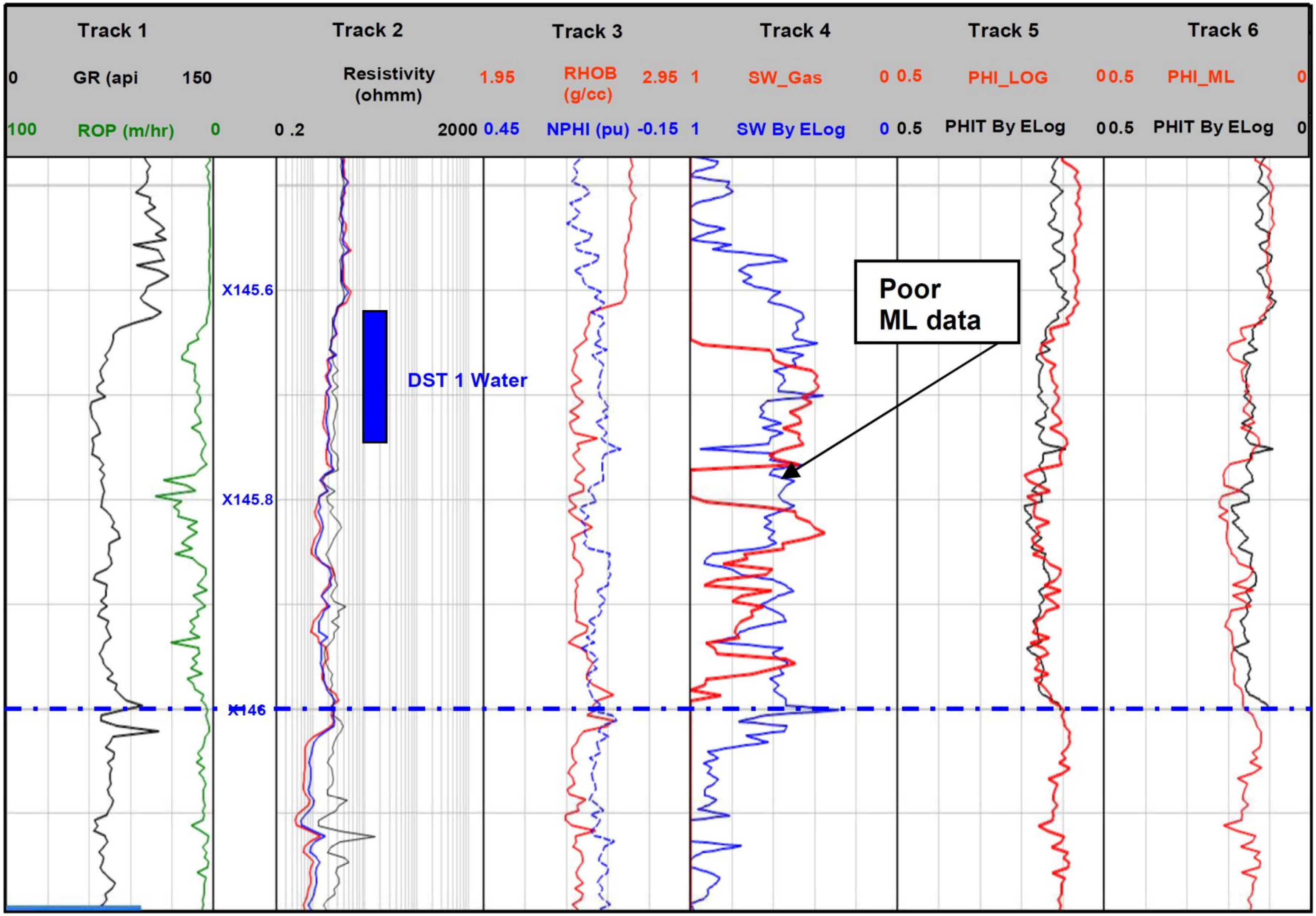

Figure 6. Well A Triple Combo plot with test results and comparison between the conventional eLog analysis and the innovative approach by Mud Logging data in the tested water zone (considered gas bearing).

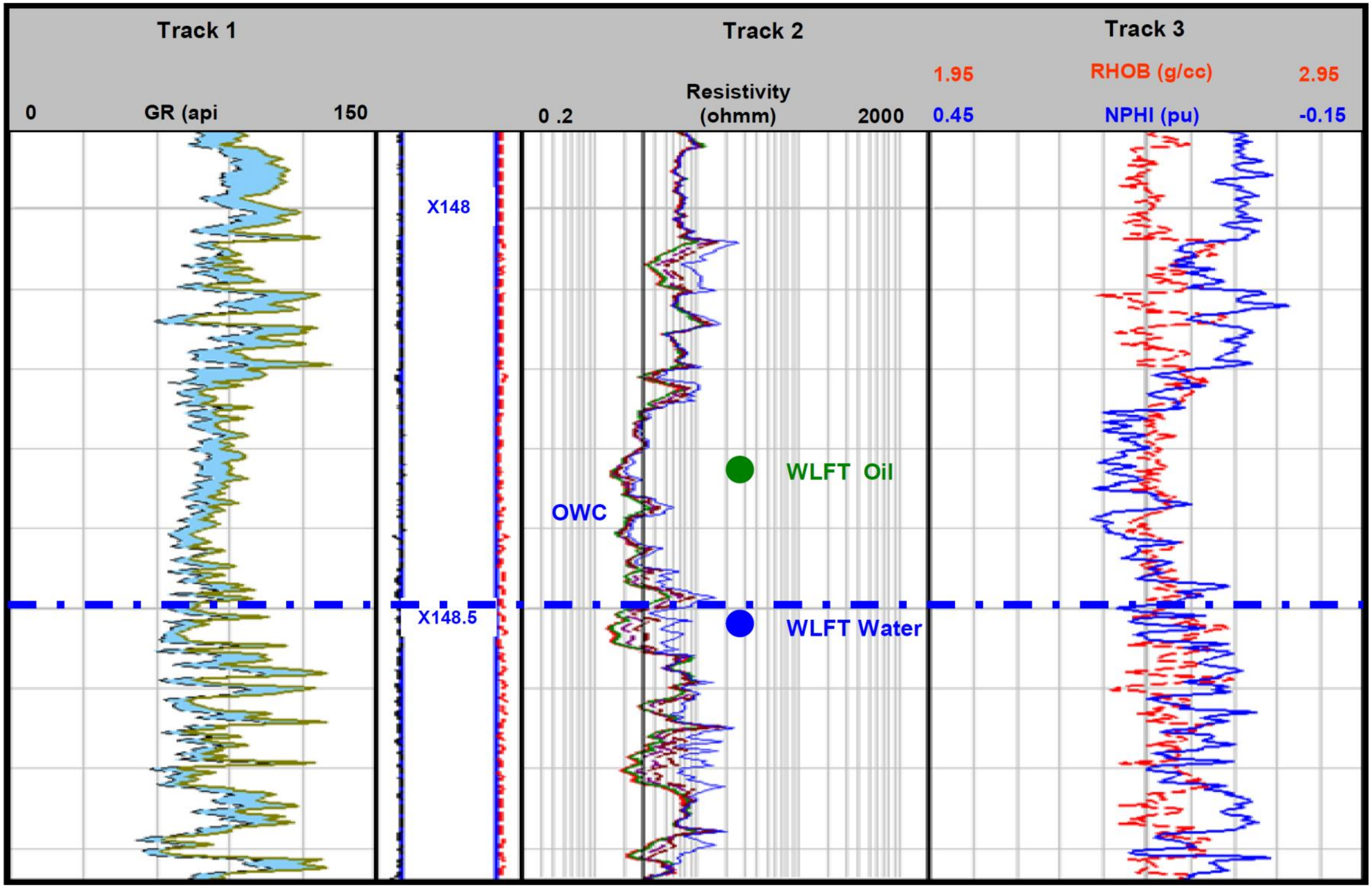

Figure 7. Well B Main eLog with WLFT results.

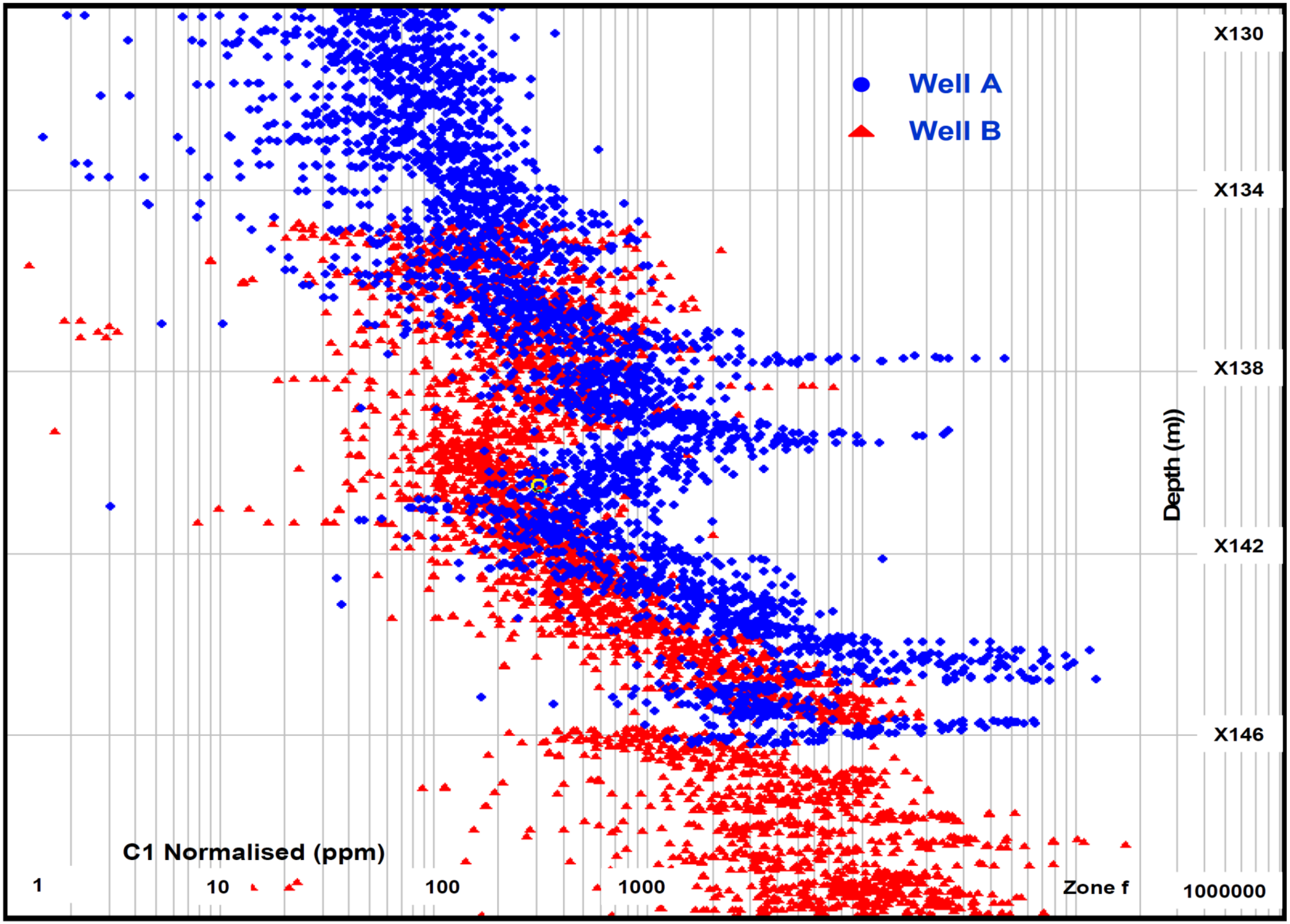

Figure 8. Wells A and B, C1 Normalized versus Depth.

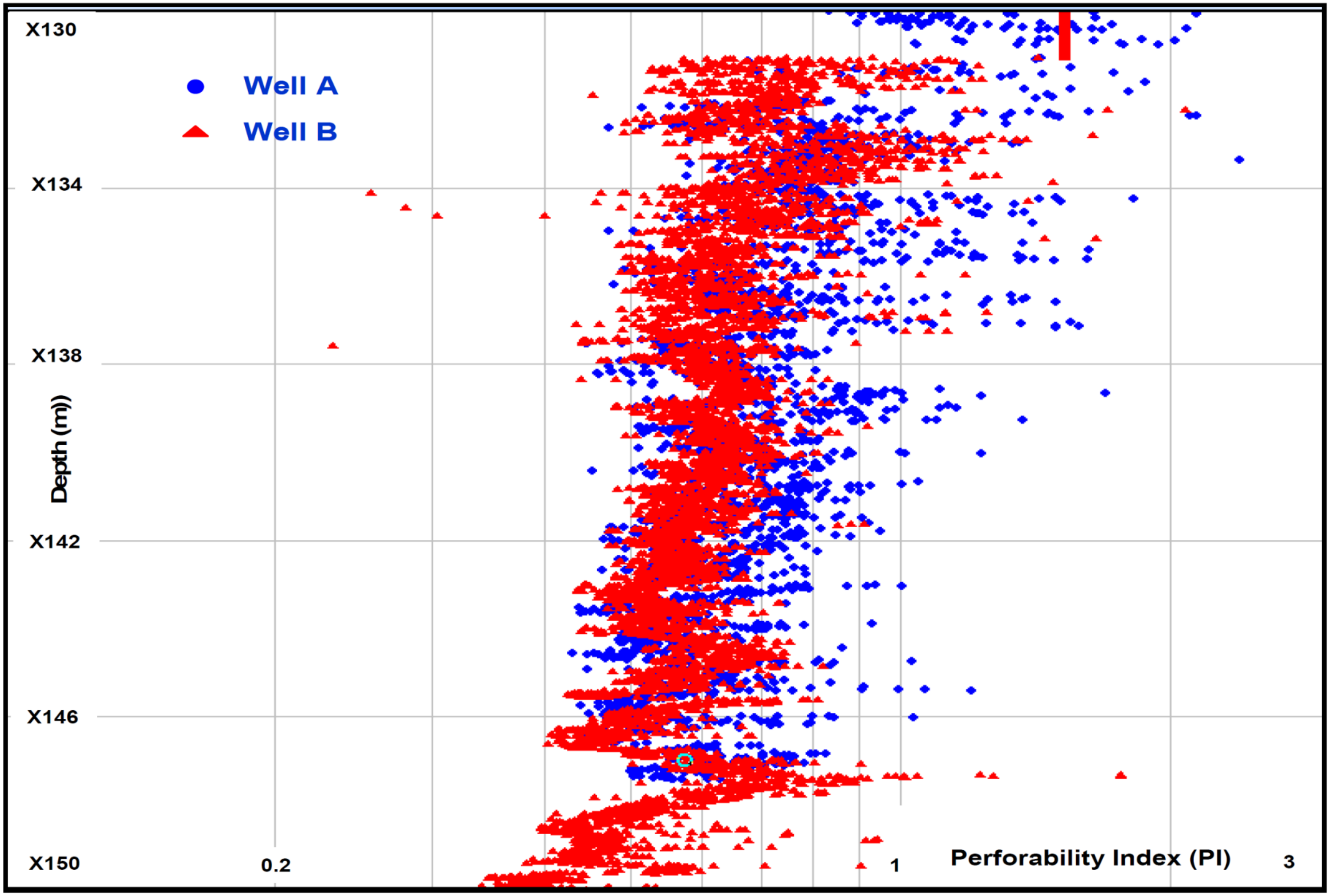

Figure 9. Wells A and B, PI versus Depth.

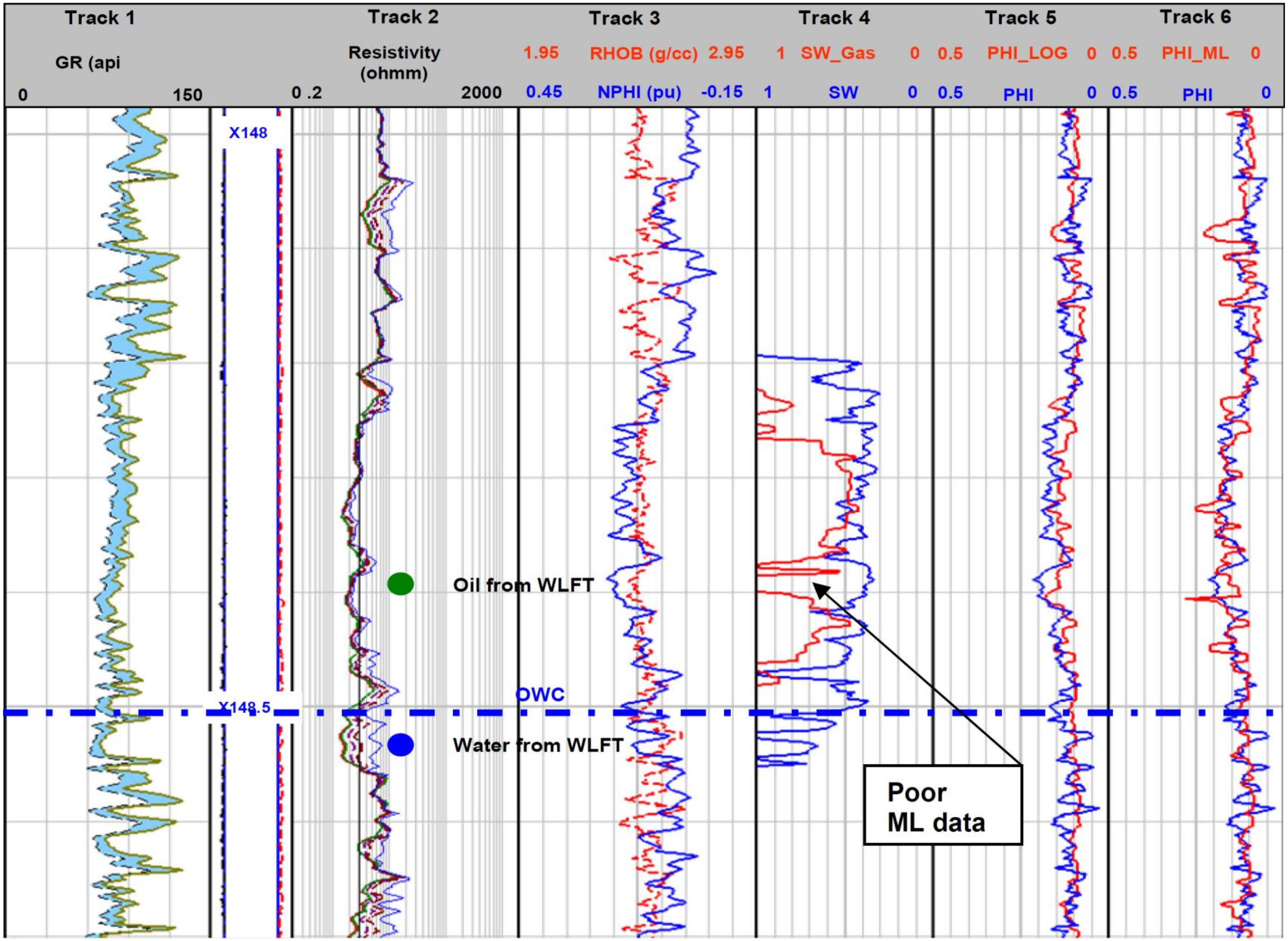

Figure 10. Well B Triple Combo plot with test results and comparison between the conventional eLog analysis and the innovative approach by Mud Logging data in the hydrocarbon bearing zone.

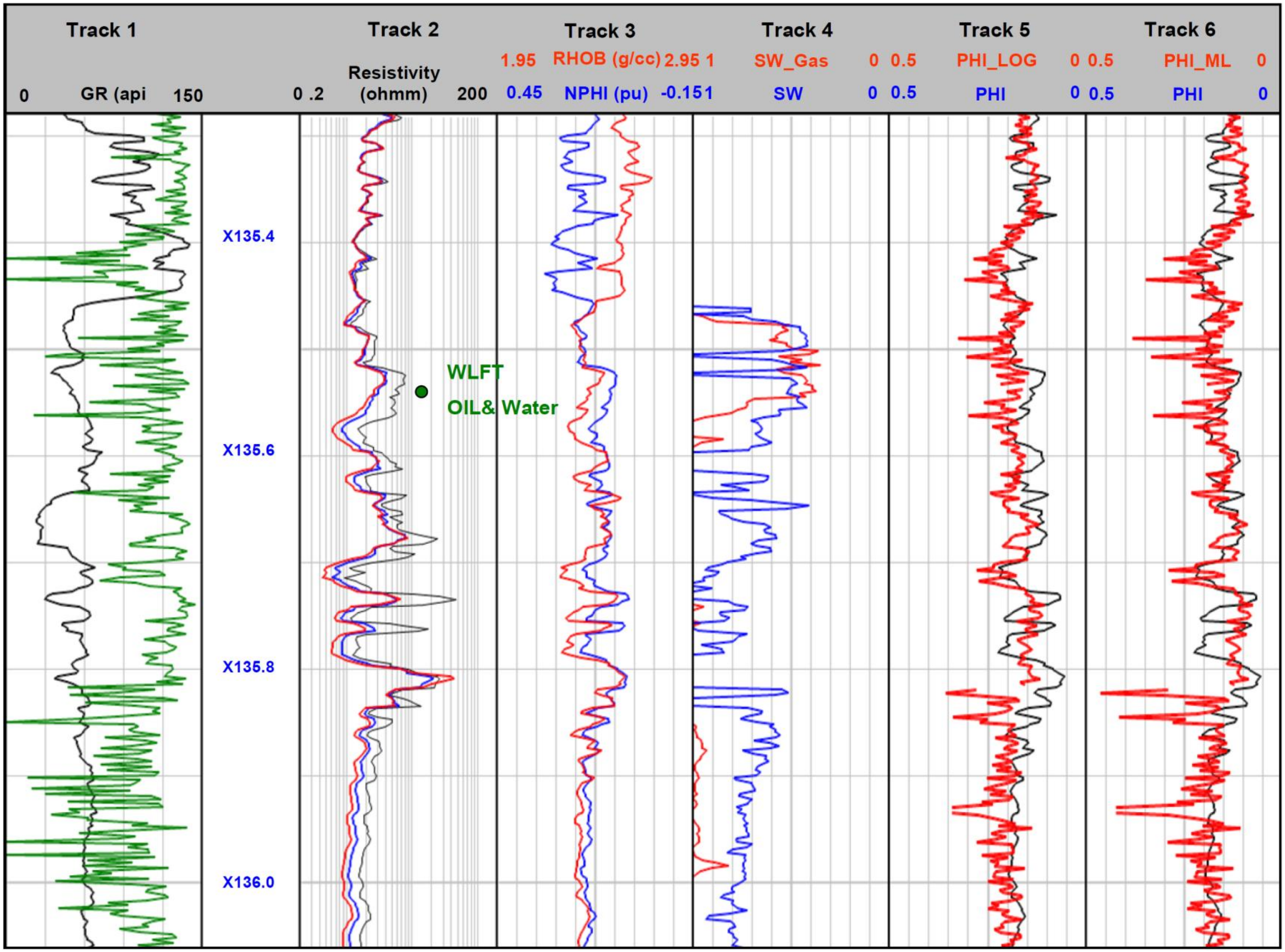

Figure 11. Well C Triple Combo plot with test results and comparison between the conventional eLog analysis and the innovative approach by Mud Logging data in the hydrocarbon bearing zone.