

## Combining Modern and Vintage Log Data to Evaluate Conventional and Unconventional Formations in the Eagle Plain of Northern Yukon

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### Summary

A petrophysical interpretation study to characterize both conventional and unconventional hydrocarbon bearing formations in Northern Cross Limited's Eagle Plain region of Northern Yukon was successfully performed. The vintage of available petrophysical log data ranged from the most modern types of logs (quad-combo, spectroscopy, magnetic resonance and dielectric) in a few wells to the most basic types of logs (gamma ray, deep induction and compressional slowness) in majority of the wells. By using the basic logs, core, strip logs and correlations between the elemental volumes and the basic logs in the wells with modern logs, a robust and rigorous workflow was developed for evaluating all of the wells in a consistent manner. This paper describes the workflows that was employed and the results obtained. Results showed very good agreement with core measurements in wells where they exist.

### Introduction

The Eagle Plain of Northern Yukon is an intermontane basin bounded on the east by the Richardson Mountains, and on the north, west and south by the Keele, Nahoni and Taiga ranges respectively, of the Ogilvie Mountains. The basin covers an area of approximately 20,608km<sup>2</sup>, and is bisected by the Arctic Circle. The area is characterized by lightly forested low rolling hills with elevations ranging between 400 and 800 meters.

Northern Cross Yukon Limited is the majority working interest owner and operator of three (3) Significant Discovery Licenses (SDLs) located in the Eagle Plain. There are a total of four (4) suspended oil and/or natural gas wells on these properties and recently, Northern Cross recently drilled and evaluated additional wells with modern logging and core analysis techniques. Northern Cross identified a number of prospective conventional and unconventional hydrocarbon bearing zones within the wells and had a number of analyses performed on the log and core data with the aim of integrating this analysis, along with additional regional work, into a cohesive three-dimensional interpretation that allows for the visualization of the properties and an assessment of the reserves.

The first step in this analytical process was the petrophysical characterization of the prospective zones in the primary area of interest utilizing vintage petrophysical log data. This was made all the more challenging by the varying number of petrophysical logs available in the candidate

wells. The vintage of available petrophysical log data ranged from the most modern types of logs (quad-combo, spectroscopy, magnetic resonance and dielectric) in a few recent wells to the most basic types of logs (gamma ray, deep induction and compressional slowness) in majority of the vintage wells.

A workflow was developed that utilized all the modern logs to establish correlations between certain elemental volumes and the vintage logs found in the wells with sparse logs. These correlations were used in conjunction with the available logs, core and strip logs in these wells to produce petrophysical results consistent with those in the wells with the modern logs.

## **Method**

As a first step, performing an inventory of the log types and core available in all the wells drilled in the Eagle Plain gave an accurate indication of data availability. The gamma ray log (GR), deep resistivity log (ILD) and compressional slowness log (DT) were common to all the wells and as such dictated that these logs form the primary inputs to the petrophysical model.

The wells with modern logs were designated as the key wells and a main model was created that utilized all of the available log types. This main model resolved the ten dominant elemental volumes in the conventional and unconventional formations and these were illite, chlorite, quartz, orthoclase, calcite, dolomite, pyrite, kerogen water and hydrocarbon. Since majority of the wells only possessed the GR, ILD and DT logs, an attempt would have to be made to reproduce as best as possible the results of the main model while using only these three logs as the inputs.

However, using any of the available mineral solvers, it is mathematically impossible to accurately solve for these many volumes with only three input logs. This is because mineral solvers are based on resolving a system of linear equations and a system of equations generated under this condition (three inputs and ten outputs) is severely under-determined. To improve this situation, more logs were required and to this end, auxiliary logs were created from regressions between either the elemental volumes derived from the main model or specific core derived petrophysical attributes to any of the three the logs (GR,ILD,DT). Crossplots of DT vs. clay volume, DT vs. total porosity, DT vs. carbonate volume and GR vs. kerogen volume were made and used to create auxiliary clay volume (VCL), total porosity (PHIT), carbonate volume (VCAR) and kerogen volume (VKER) curves that, in conjunction with the GR, ILD and DT curves, increased the number of input logs from three to seven. A system of linear equations that seeks to solve for ten volumes by using seven equations (logs) though still slightly under-determined can be solved if adequately constrained to arrive at an acceptably accurate result. The constraint is provided by the use of core data and cuttings to guide the result.

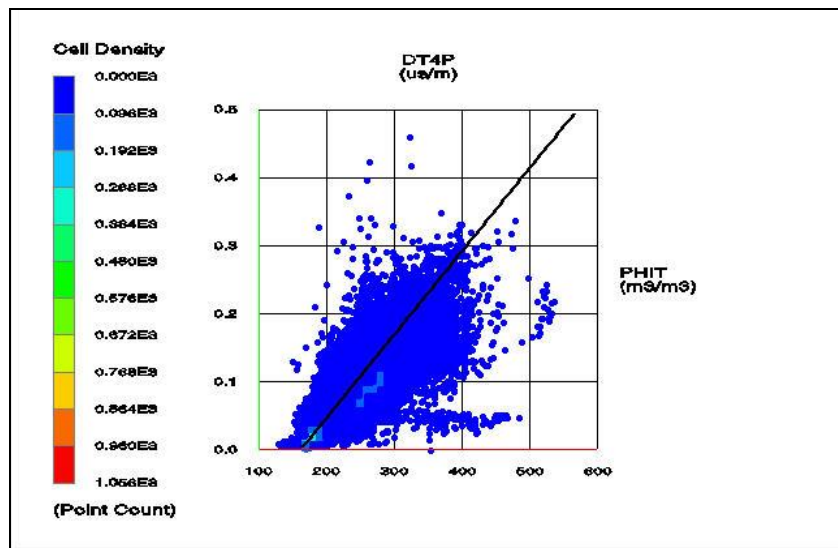


Figure 1 : PHIT from the main model vs. DT. The regressed porosity will be used as one of the inputs to the model with a reduced set of input logs.

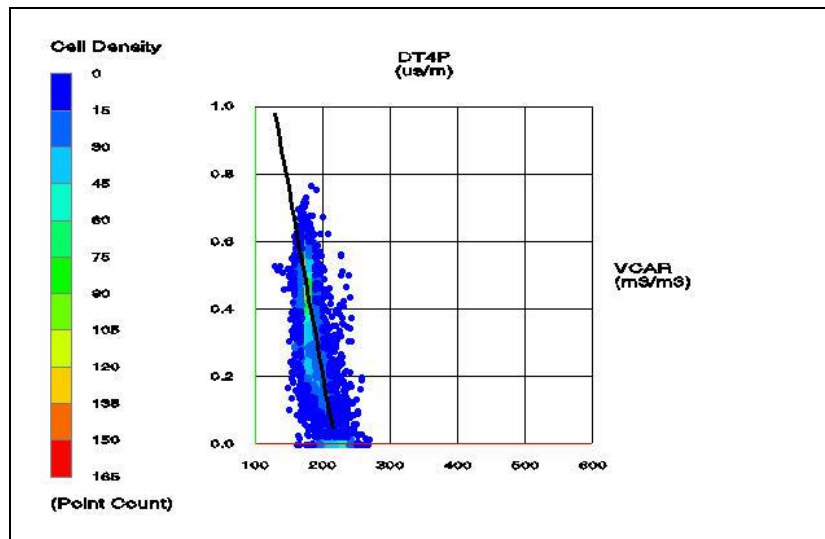


Figure 2 : Volume of carbonate from the main model vs. DT.

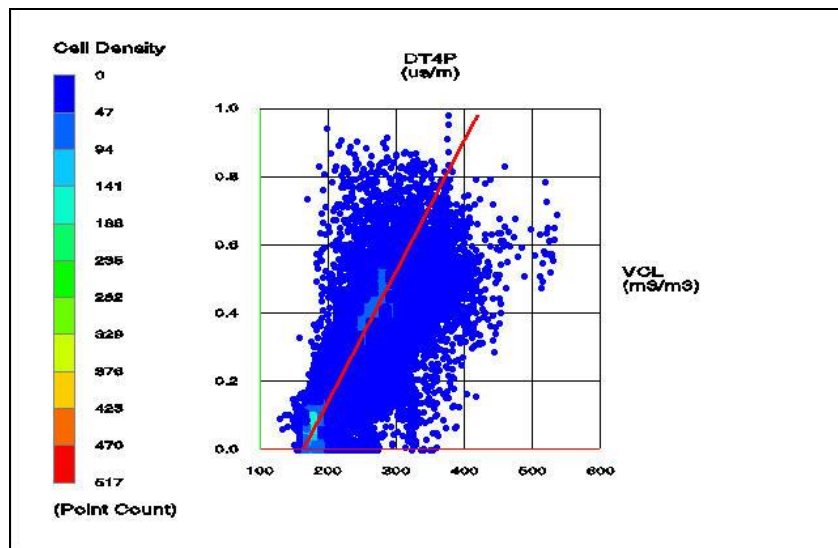


Figure 3 : Volume of clay from the main model vs. DT.

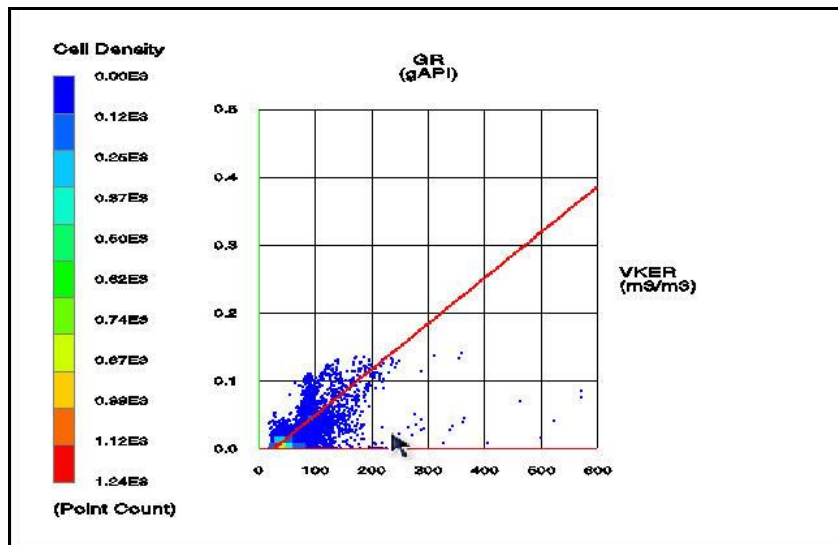


Figure 4 : Volume of Kerogen from the main model vs. GR

Clay typing was not critical so no attempt was made to distinguish between illite and the other clay type (chlorite) determined in the main model. In addition, the volume of dolomite was eliminated from the streamlined model.

The GR, ILD, DT, auxiliary VCL, VKER, VCAR and PHIT curves were used as inputs in the mineral solver model. The auxiliary curves were heavily de-weighted because of the sometimes high regression errors (high uncertainty).

In the main model, the TOC was derived from the volume of kerogen by the relationship:

$$\text{TOC} = \varnothing_{\text{ker}} \times \rho_{\text{ker}} / \rho_b \times \kappa \text{ ----- (1)}$$

Where:

TOC = total organic carbon

$\varnothing_{\text{ker}}$  = kerogen volume

$\rho_{\text{ker}}$  = kerogen density

$\rho_b$  = bulk density

$\kappa$  = kerogen conversion factor

Equation 1 above can also be written in the form

$$\text{TOC} = \mathbf{C} \times \varnothing_{\text{ker}} \text{ ----- (2)}$$

Where  $\mathbf{C} = \rho_{\text{ker}} / \rho_b \times \kappa$

C is the slope of the straight line in a crossplot of the TOC from the main model and the volume of kerogen from main model. So in the absence of a bulk density log, the regression equation of the volume of kerogen and the TOC from the main model was used to convert the volume of kerogen from the streamlined model to TOC.

## Examples

A comparison of the mineralogy, porosity, saturation and TOC derived from the main SGA model and the model with the reduced set of input logs shows an acceptably close match.

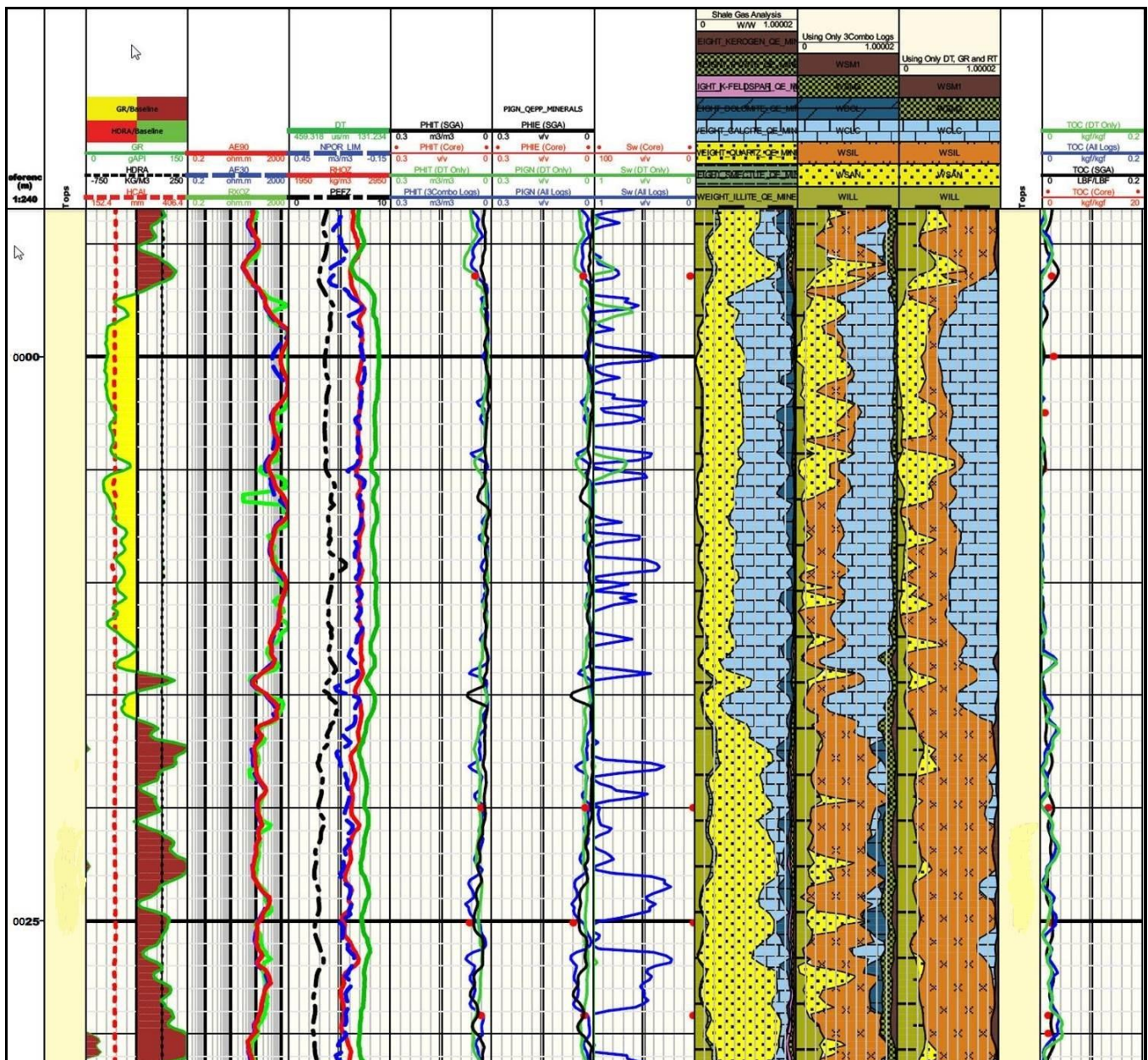
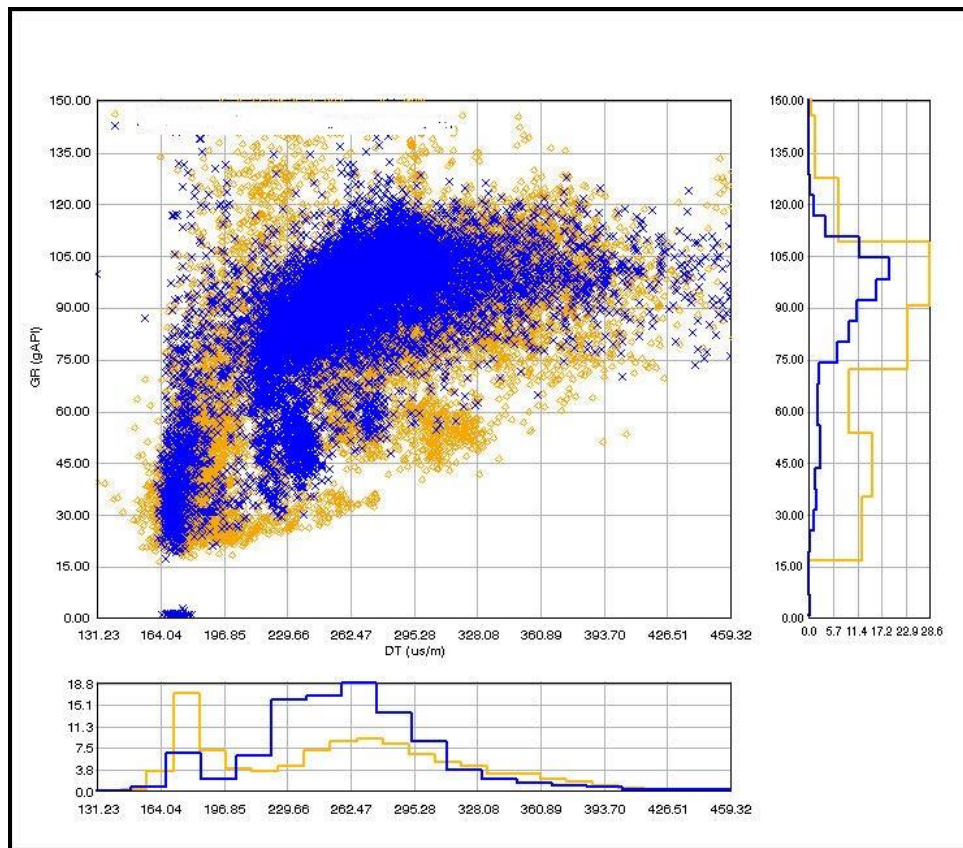


Figure 5 : A comparison of the results from the main model and the auxiliary logs model. Tracks 9, 10 and 11 respectively show the elemental volumes from the main model that utilized all the basic and high tech logs, the volumes from a model that utilized only triple combo logs and the volumes from a model that utilized only the GR, ILD, DT and the auxiliary logs. The porosities and TOCs from these models are also shown in black, blue and green respectively.

In Figure 5, the volumetrics from the main model are shown in the fifth track from the right while in the fourth and third tracks from the right are the volumetrics from triple-combo-only and GR-ILD-DT-only models respectively. There is also an acceptably close match between the porosities and TOCs from the three model types.

The GR-ILD-DT variant of the main model was confidently applied to other wells in the field as long as the GR and DT logs from those wells were statistically consistent with the same logs in

the key wells. Figure 6 shows the crossplot used to check the statistical consistency of the key and target wells.



**Figure 6 : A crossplot was used to check for statistical consistency between the GR and DT in the target (blue) and key (gold) wells.**

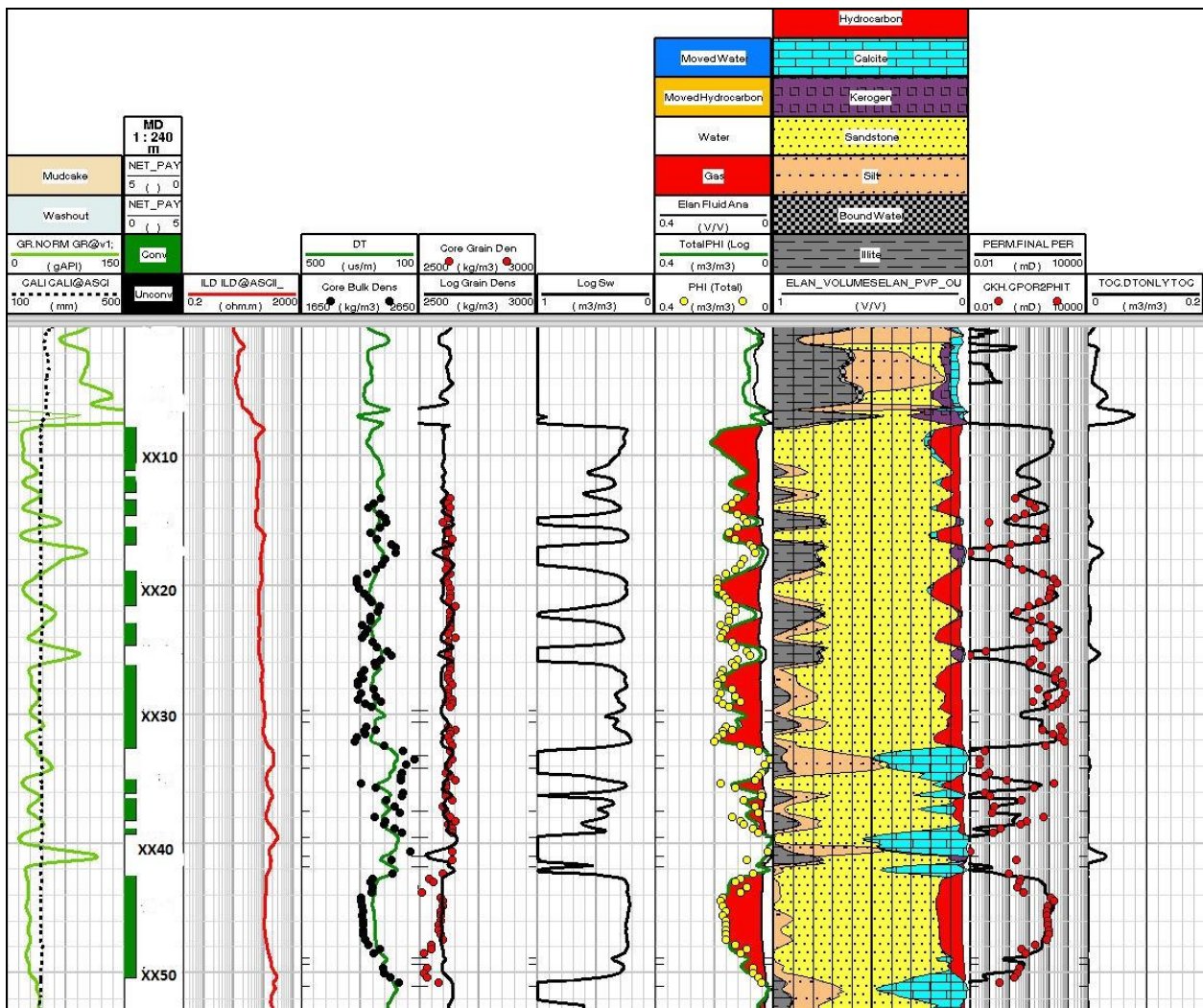


Figure 7 : Acceptably accurate results were derived over the conventional reservoir sections in wells with a minimum set of logs using this workflow.



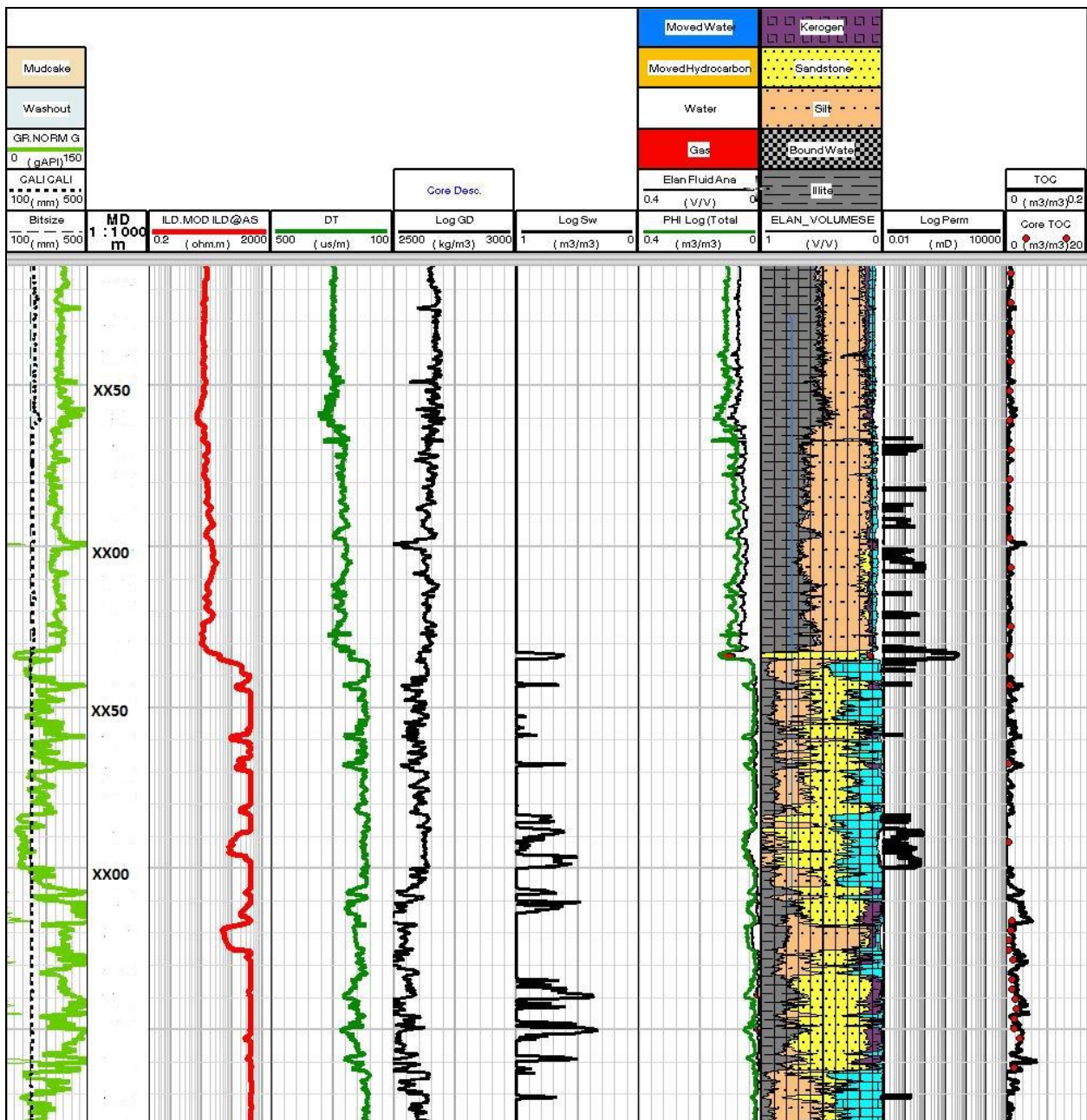


Figure 8 : An acceptably accurate match between core and log derived TOC was also derived over the unconventional reservoir sections in wells with a minimum set of logs using this workflow.

## Conclusions

By utilizing a workflow that extends the value obtained from modern logs acquired in one well to other wells in the basin, petrophysical results that are acceptably close to the core derived petrophysical properties in both conventional and unconventional reservoir rocks have been obtained in the wells with limited petrophysical logs. However, the areal variability sometimes

encountered in most plays limits the applicability of this method and this makes it necessary that adequate log data is acquired for the proper characterization of hydrocarbon plays.

### **Acknowledgements**

We would like to thank the management of Northern Cross Yukon Limited for their support in the development of this workflow and for allowing us to share our work with the Petrophysics community.