Determination of Duvernay Formation Reservoir Properties through Probabilistic Petrophysical Analysis calibrated to Core Studies.

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Summary

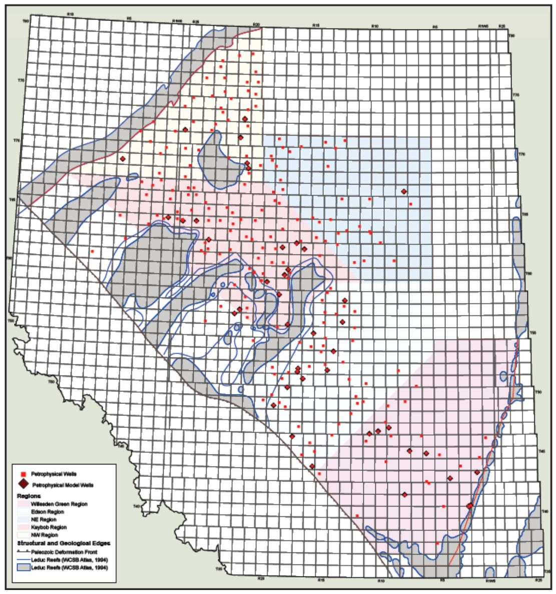
The petrophysical analysis of low porosity unconventional plays is a major challenge for the oil and gas industry as the application of conventional petrophysical techniques has proven to be generally unsatisfactory for several of these plays, including the Duvernay. This talk will present an overview of a workflow designed to determine reservoir properties in unconventional reservoirs using probabilistic petrophysical techniques. A regional study of the Duvernay Formation in Alberta incorporating sample analysis data guided by sedimentological understanding is used as an example of this methodology.

The analytical model developed was designed to allow calculations of mineralogical components, effective porosity, and fluid saturations using the minimum possible number of log curves. After the initial modelling, a second iteration calibrated the model for pyrite content and allowed for enhanced TOC calculations. The results of the model were in general agreement with the static analyses. Petrophysical models developed in this fashion may be applied to unconventional reservoirs with similar characteristics throughout the world.

Introduction

Various petrophysical methodologies were refined and new concepts were implemented in the exploration and development of unconventional plays. The nature of unconventional reservoirs together with unique porous media modeling requires that petrophysical studies integrate data and results of analysis from other disciplines such as stratigraphy, sedimentology, hydrogeology, geochemistry and geophysics. In 2014, Canadian Discovery Ltd together with partners Graham Davies Geological Consulting Ltd. and Trican Geological Solutions Ltd., completed an integrated study of the Duvernay resource play from developing a regional stratigraphic framework of petrophysical reservoir characteristic for future drilling and completion optimization.

The Study Area, as shown in Figure 1, is bounded to the east by the Rimbey-Meadowbrook Leduc Barrier Reef trend, to the west by the Deformation Belt, to the northwest by the Peace River Arch Leduc Fringing Reef and to the northeast by the onset of Duvernay organic thermal maturity. This study area was further divided into analysis regions.

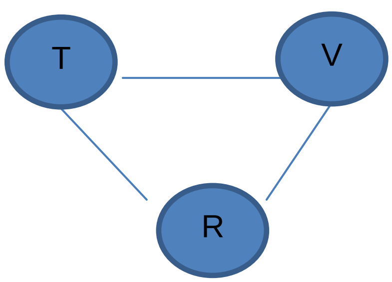


The stratigraphic framework for the Duvernay was established though detailed sampling and analysis of 29 cores (Total described core = 896m) and detailed correlations. The Duvernay was divided into three members: the basal, variably shaley Duvernay “A”, the middle carbonate-rich Duvernay “B”, and the upper shaley Duvernay “C”. Duvernay C was further divided into subunits from C1 through C5.

This paper provides a general overview of the work flow, methodologies, results and conclusion of the petrophysical component of the study.

Theory and Methodology

The probabilistic petrophysical modeling was facilitated through the Geolog™ Multimin™ software developed by Paradigm™. The basic concept of almost all probabilistic methods can be defined through the example shown in Figure 2



Where T is the tool, V is the volume of minerals and fluids, and R is the log response in mineralogically pure rocks (e.g. limestone that is pure calcite with a density of 2,750 kg/m^3). Several equations will then be combined to form a comprehensive petrophysical model. The mathematical representation of these is:

$T_1 = V_1R_1 + V_2R_1 + V_3R_1 \ldots\ldots\ldots V_mR_1$
$T_2 = V_1R_2 + V_2R_2 + V_3R_2 \ldots\ldots\ldots V_mR_2$
$T_3 = V_1R_3 + V_2R_3 + V_3R_3 \ldots\ldots\ldots V_mR_3$
-
-
$T_n = V_1R_n + V_2R_n + V_3R_{3n} \ldots\ldots\ldots V_mR_n$

The objective function used in Multimin™ analysis required that the number of answer Log curves computed need to be equal to number of input curves.

A set of 240 wells were selected, based on data suitability and spatial distribution, for inclusion in the study. The model was developed through the detailed analysis of 45 wells screened for log quality and presence of a combination of the following: integrated core descriptions/analysis, X-Ray Diffraction (XRD), Source Rock Analysis and/or specialty logs (NGS, Flex, ECS, GEM, NMR/ CMR).

Within each of the five sub-areas, the model wells were developed so that the remaining wells in the sub-area could be analyzed in a batch process. The greater the availability of specialty logs, the more sophisticated the mineralogical determination that can be derived. Conversely, lower resolution of the mineralogical content is expected when wells are limited to a “triple combo” (i.e. GR, Resistivity, Neutron, Density and Sonic) log suite or a Formation Density log as opposed to a Litho-Density log.

It is a common practice to calculate the supplemental curves required for mineralogical analysis through such as artificial neural network or nearest neighbor analysis. These processes are complex, time consuming and are generally poorly accepted by industry. The supplemental curves for the Duvernay model were derived through the calibration of the original well logs.

The XRD Data available to the study display the following ranges (expressed as a volume percent): quartz - 2-65%, illite (predominant dry clay mineral): 2-37%, carbonate 8-50%, feldspar 0-15%, pyrite 0-6%. The data of Source Rock analysis ranges TOC values from 0-6%.

Basic QA/QC steps to prepare logs for the deterministic analysis used to determine clay volume (V_{sh}) and effective porosity, or non-clay bound porosity (Φ_{eff}) included: environment corrections, temperature/pressure calculations. The V_{sh} curve was constrained by total clay volume derived from XRD data, estimated clay volume from core descriptions and thin sections. The Φ_{eff} was computed through neutron, density and sonic crossplots calibrated with core porosity data. Calibration adjustments were applied to compensate for variations in measurements between RCA (Routine Core Analysis and SCAL (Special Core Analysis data). The V_{sh} and Φ_{eff} curves were included with other available curves as inputs for the determination of Illite, quartz, calcite, dolomite, pyrite, along with Φ_{eff} and water saturation (S_w).

During the evaluation of other resource plays, CDL has determined that the pyrite content has a significant effect on the petrophysical logs. This effect is particularly the case with the resistivity and density logs. An investigation into the effect on the abundance and distribution of pyrite on the log responses in the Duvernay Formation was, therefore, presumed to be necessary. Using the analogy of a parallel circuit, correction of the resistivity logs were performed by assuming that the conductive path through pyrite is in parallel with the conductive path through saline water (from Crain, 2011 The level of pyrite was determined to be relatively low and was not observed to have a significant effect on the resistivity and density logs.

In normal cases, if a formation contains clay minerals, the measured resistivity is often less than expected from a mineralogically pure formation. The petrophysical analysis developed for this study utilizes a Dual Water Saturation Model (Clavier et al., 1984) to account for the increase in water conductivity through the Cation Exchange Capacity (Waxman and Smits, 1968) of the shales. After the Dual Water model S_w was calculated, a second iteration was computed using pyrite-corrected deep resistivity. The application of the pyrite-corrected deep resistivity does not indicate a significant difference in water saturations due to the low volume pyrite and, to a lesser extent, the generally high resistivity values in the Duvernay Formation.

TOC was derived through the Passey-Schmoker method (Passey et al., 1990) calibrated to SRA values. The Level of Maturity (LOM) values applied range from 10 to13. These values were calculated from SRA values, and appear to provide the best fit between measured TOC and calculated TOC. The corrected deep resistivity was also used to calculate corrected TOC as shown on an overlay of example log. Using this deep resistivity corrected method improves the TOC calculation.

An effective porosity cut-off of 0.5% was applied to the Duvernay C1 to C5 and A Shale intervals to compensate for kerogen hosted porosity. In the Duvernay B interval, the porosity level is proportional to the carbonate content, and a 3% cut-off was. An S_w cut-off of less than 50% was used for calculation of net reservoir, resource calculations and other dependent parameters

Examples

Example 1: Comparison of V_{sh} and Φ_{eff}

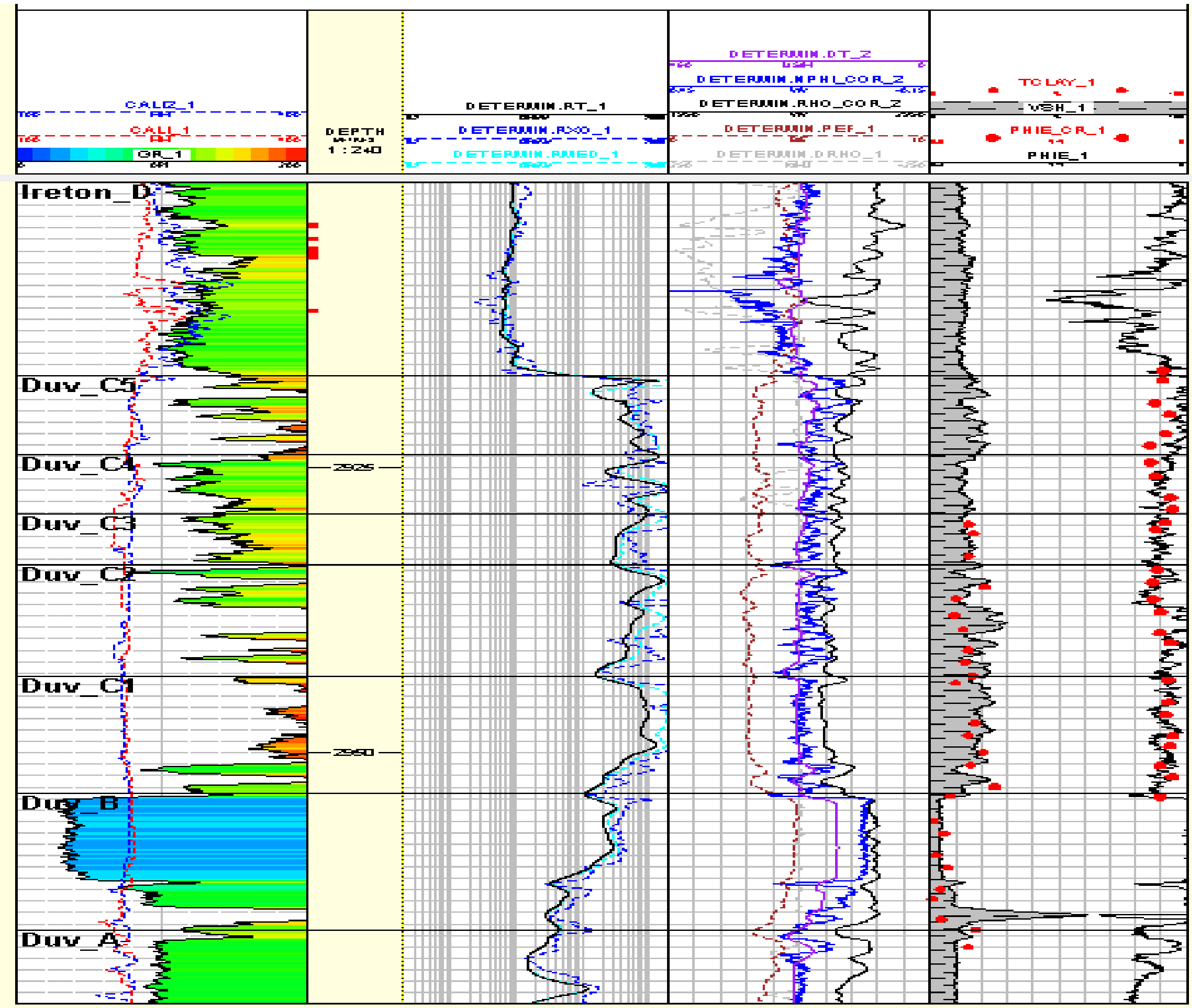


Figure 3 (Example 1). Calculated V_{sh} and Φ_{eff} showing good correlation with XRD Total Clay Volume and effective core porosity

Example 2: Comparison of Probabilistic Petrophysical Analysis with XRD and Core

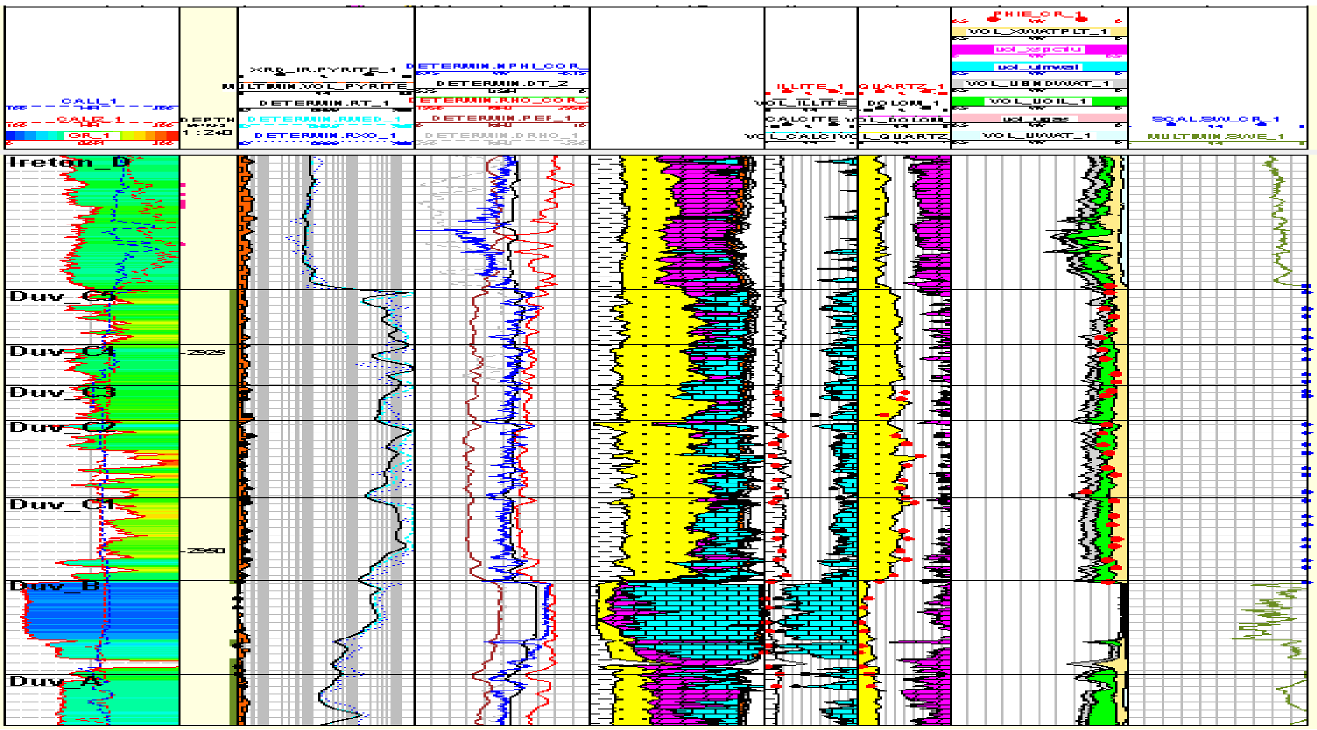


Figure 4 (Example 2). Evaluated Probablistic Petrophysical Parameters Dispalying a Good Correlation Between XRD derived mineralogy,Core Φ and S_w

Example 3: Comparison of Passey-Schmoker TOC and SRA TOC

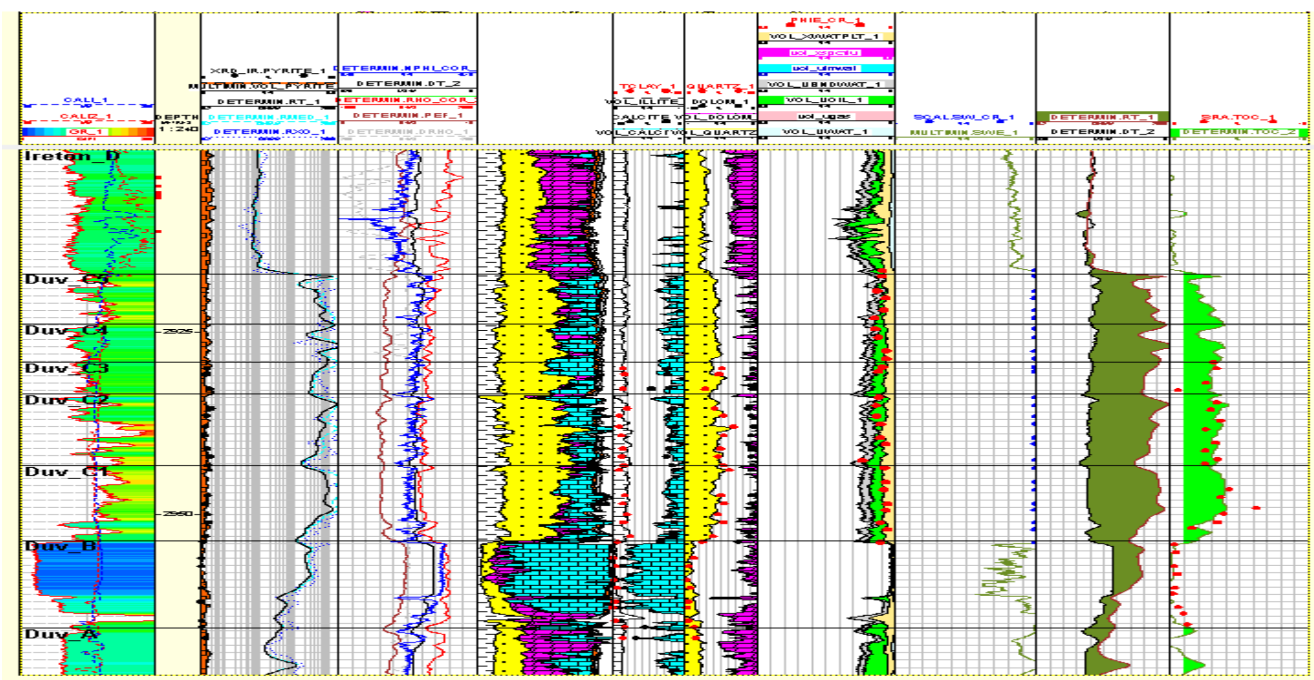


Figure 5 (Example 3). Calculated TOC through Passey-Schmoker Shows Good Correlation with SRA TOC.

Example 4: Final Interpretation from Probabalistic Petrophysics Analyis and TOC Calculation

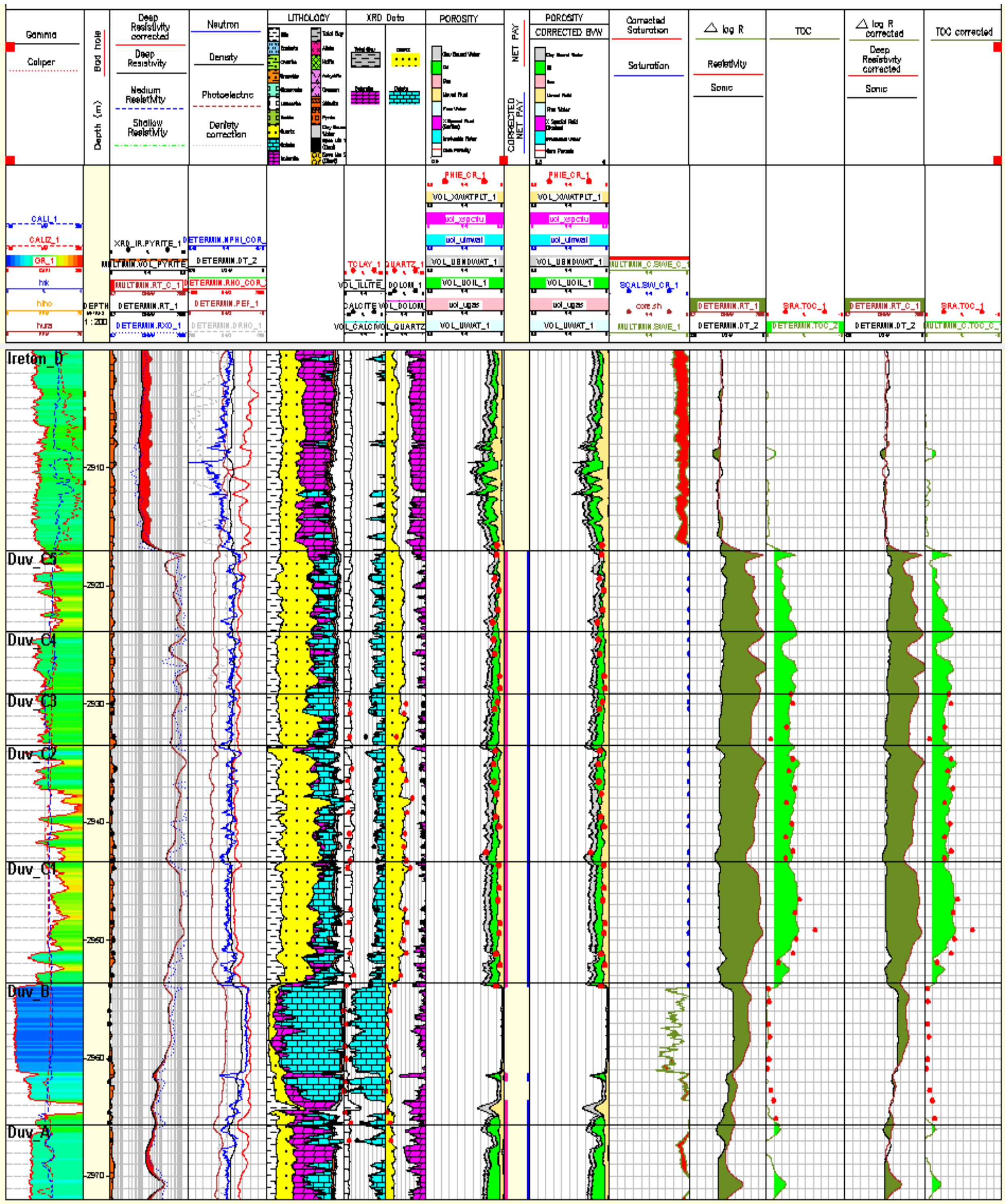


Figure 6 (Example 4).. Duvernay: Probabilstic Petrophysical Analysis and Passey Schmoker TOC displaying good correlation with XRD mineralogy and SRA TOC. Comparison of analyzed S_w and TOC after pyrite correction.

Results

A frequency distribution analysis was applied to the dataset to determine the variation between stratigraphic units in the study. Linear regression analysis demonstrated strong correlations between of the probabilistically determined parameters for 53 wells to core analysis data as shown in Figure 7 and 8.

The finalized analyses were used for regional mapping of net reservoir thickness (h), volume percent of the following minerals and the associated formation properties: illite, quartz, calcite, dolomite, pyrite, TOC, and associated formation properties, such as : Φ_{eff}, and water saturation as shown in Figure 9 and 10.

Conclusions

Detailed petrophysical analysis offered a unique contribution to the understanding of the regional geological, geochemistry and geomechanics of an important resource play. The detailed study of 240 wells in study area with extensive data sets shows strong correlations between core and evaluated probabilistic petrophysical parameters, which proved useful in distinguishing specific intervals reservoir characteristics in Duvernay.

Acknowledgements

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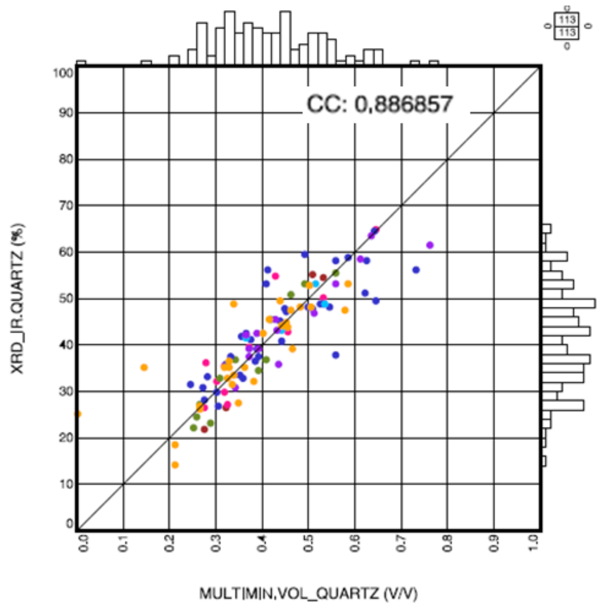

Figure 7. Linear regression analysis of Quartz demonstrated strong correlations between of the probabilistically determined parameters for 53 wells to core analysis data. R2 =0.89

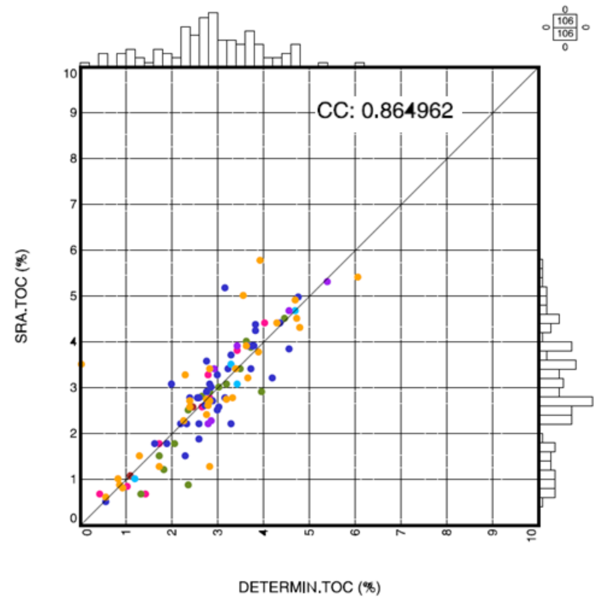

Figure 8. Linear regression analysis of TOC demonstrated strong correlations between of the Passey-Schmoker determined parameters for 53 wells to SRA analysis data. R2 =0.86

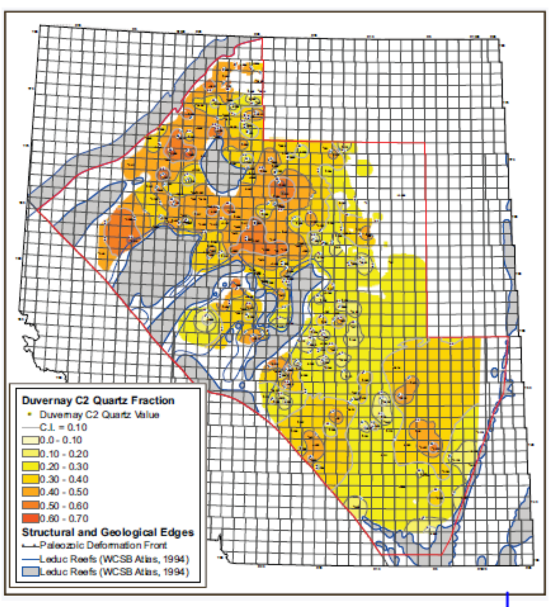

Figure 9. Regional net reservoir map displaying quartz volume percent of Duvernay C2 interval of the study area.

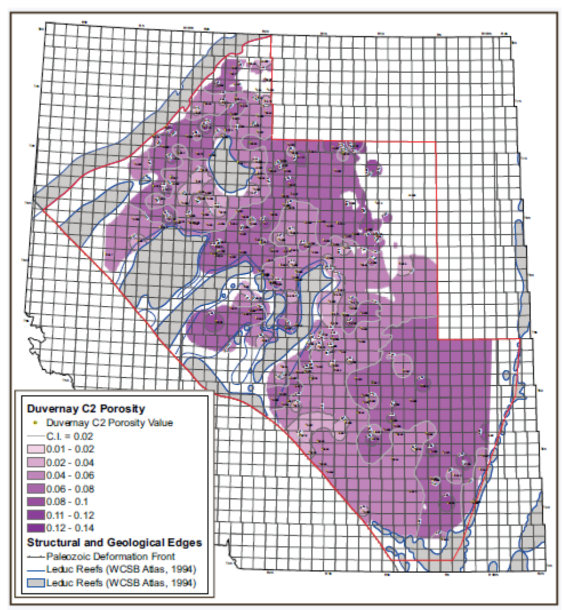

Figure 10. Duvernay Regional net reservoir map displaying Φ_{eff} of Duvernay C2 interval of the study area.