

## **Petrophysics Designed to Honour Core – Duvernay & Triassic**

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### **Summary**

**A Log Interpretation Method, not commonly available, designed to incorporate and be calibrated by core measurements.**

**Many Log interpretation packages are available that use log input only and the results may subsequently be compared to core. If the log interpretation does not agree with the core, what do you do?**

**Our interpretation starts with the most basic inputs that can be correlated to core measurements every step of the interpretation. For example, we start with measurements of the elements, (Ca, Fe, Si, S, etc.) by Nuclear Spectroscopy. These measurements must compare with core element measurements such as x-ray fluorescence (XRF). The next step is to use an element to mineral model to derive the common minerals from the input elements. While this may seem an obvious strategy, there are more ‘unknowns’ than ‘knowns’ involved. It is accomplished by a normalization procedure using the elements as constraints. Alternatively, a normalization procedure has also been developed that uses the core minerals as constraints. If core is not available, mineralogical analysis from cuttings can also be used to calibrate the method. However, as cutting samples generally correspond to a mixing of grains from different lithologies, the average mineralogy of each litholotype must be extracted from the bulk composition of the sample.**

**Once the mineralogy is obtained, elements and minerals including kerogen can be compared to valid quantitative mineral measurements. The core-calibrated log-derived-mineralogy attributes can be used to derive cation exchange capacity, grain density and permeability vs. valid quantitative core measurements.**

**When corrections are made so that core and log minerals agree, water saturation porosity and permeability are computed and compared to core. Of course, the validity of the core analysis must be ascertained for comparisons.**

**Examples are shown using analysis of core or cuttings and well logs from the Duvernay and Triassic formations of Alberta.**

## **Introduction**

This article is designed to explain the methods of mineralogy determination from logs. The process involves a normalization method to convert elements to minerals. We use attributes of the minerals to obtain preliminary estimates of water saturation, permeability and porosity. These preliminary estimates and the log-derived minerals are constrained by whatever core measurements are available.

Why involve mineralogy? We can use the mineral attributes such as cation exchange capacity, grain density and surface area to compute  $S_w$ , porosity and permeability. However, this analysis may still be incomplete as diagenesis may modify the attributes.

Why use core? Log interpretation without using core must be based on a model of previous interpretations. When diagenesis changes the attributes of the rocks, especially in shale resources, previous models may not be appropriate. Consequently, we respond with changes of the parameters of the model. We have designed this interpretation program to be very flexible so that appropriate, logical changes to parameters can be made.

Is core always valid? No, and we provide some checks to see if it is valid or not. One must be vigilant to include only valid, quantitative core measurements.

Why not use core and not logs? Logs have the advantage of better vertical resolution and depth control. Using both core and logs combines their advantages.

In summary, valid mineralogy from logs and core or cuttings can improve interpretation of porosity, water saturation and permeability, provided the interpretation program is flexible so that checks and balances can be made at each step of the process.

## **Method**

We have to prepare reliable data before entering the calculation programs:

- a) correct for washouts affecting the density,
- b) predict missing log curves,
- c) determine  $R_w$  from the SP and
- d) calculate the total organic carbon (TOC).

The above data can be interpreted to obtain porosity, permeability and mineralogy of the formations.

The Method uses:

- A. First Program: Element prediction program when nuclear spectroscopy is absent; reconstruction can substitute for lack of core; otherwise, X-ray fluorescence core measurements are used to check our predictions
- B. Second Program: Nuclear Spectroscopy for mineralogy to be compared with core mineralogy. When core is not available or is limited, we connect the dots with a “synthetic” core made from the results of the first program.
- C. Third program: Nuclear Spectroscopy with core or cuttings mineralogy and XRF chemistry - all are combined in a separate program called Robust Element to Minerals. (Ref 2).

There are several sections involved in the calculations prior to entering the calculation programs:

Prepare the log data for the first program

1. Fix the density log for washouts using clustering. In this method one nulls bad data and predicts the nulled data from the good hole.
2. Find the  $R_w$  from the SP and a known  $R_w$  at any zone in the borehole. The SP propagates the known  $R_w$  to all the other depths in the well.
3. Predict any missing curves from offset wells: such as nuclear magnetic resonance (NMR) free fluid porosity, Spectral GR, Nuclear Spectroscopy elements and Total Organic Carbon (TOC); you usually start with neutron, density, and resistivity, GR, SP, Pe and DT logs. You might have many core-XRF values *instead* of the nuclear spectroscopy log curves or you could have both the log and core or cuttings measurements. (Ref 1 & 2).

The Elemental Capture Spectroscopy (ECS) tool has been around for some time; 99% of our interpretations on previously logged wells use measured or offset ECS logs. The other logs available are the LithoScanner (Schlumberger<sup>TM</sup>), the GEM (Halliburton<sup>TM</sup>) and the FLEx (Baker<sup>TM</sup>) tools.

The main difference between the older ECS and the newer nuclear Spectroscopy tools is that ECS measures iron + 0.14\*Aluminum, whereas the iron spectrum of the other tools is not contaminated by aluminum. In addition many more elements are measured.

Calculations in the second program

4. Solve for clastics as a group, carbonates as a group, and clays as a group.
5. Solve for porosity and permeability using the Herron formulas (Ref 3) involving the measured elements and the calculated carbonate, clay and siliclastics groups.
6. Normalize by constraining with the elements, to convert the clastics to quartz, ksp, plagioclase and muscovite; carbonates to dolomite, calcite and anhydrite; clays to illite, smectite, kaolinite and chlorite. Note that we assume a core laboratory is capable of separating illite and muscovite in X-ray diffraction (XRD) but know some can't...yet. So,

we need to either get a set of logs with little muscovite or do some guessing, or farm out the XRD to another company, who can do the separation.

7. Calculate a grain density from the elements, based on Dr. Herron's paper (Ref 4) and some empirical modifications made to the program.
8. Calculate a porosity which can be verified by core.
9. Calculate a permeability also verified by core,

#### Calculations in the third program

10. In this program, we constrain the results with mineral input from core or cuttings and sometimes minerals from the previous program when core is sparse. Our checks for valid quantitative core mineralogy are based on:
  - Comparison of XRF to the log elements.
  - XRD chemistry compared to the log elements.
  - Separation of illite from muscovite so the clay fraction only contains clay.
11. In addition to XRF and XRD, we enter any core or cuttings analysis of Sw, porosity, grain density, cation exchange capacity, surface area, kerogen and TOC that are available.
12. Create a cluster of the input log curves to provide a lithology description of sands, silts, clay, limestones, dolostones, anhydrites and ankerites. This cluster is a key component of the interpretation process. The rock is divided into as many modes as necessary to provide an automatic 'zonation' of the well.
13. Now we can compute the porosity, water saturation and permeability since we have a valid core-calibrated mineralogy.
14. Compare the results of porosity to core: is the core porosity in the range between the free fluid and total porosities? If so, that is where we expect it to be since the core measurement is extremely dependent on how much drying and fluid purging took place before the measurement.
15. Compare the results of permeability to core: is core permeability several times higher in magnitude to log-derived permeability? If so, the core measurement is suspect. On the other hand, is the core permeability less than the log permeability? If so, it is likely that the core is correct and severe diagenesis has taken place which was not accounted for in the mineral model. In this case we can increase the diagenesis factor for the clay contribution, reducing the permeability, until a match is obtained.
16. Compare the results of water saturation to core: is core water saturation greater than log water saturation? If so, the diagenesis has affected the cementation and tortuosity factors, 'm' and 'n'. The 'm' and 'n' we used originally was the best obtainable from a relationship of grain density and surface area. However a change is needed when core Sw is higher than log Sw and we apply a diagenesis factor to increase both 'm' and 'n' until a saturation match is obtained.

The result of program three is a mineralogy that *must* fit core mineralogy in a probabilistic sense, since core was directly involved in the computation.

Now we have a core or cuttings calibrated core-log calculation that can be relied upon to provide a good hydrocarbon pore volume to use in reserve calculations.

## Examples

We have several examples. They illustrate:

1. Comparison of core and log mineralogy.
2. Comparison of core and log permeability.
3. Comparison of core and log water saturation.
4. Comparison of core and log porosity
5. Comparison of core and log total organic carbon.
6. Comparison of quartz from program 2 and program 3 (core XRD not released).
7. Comparison of mineralogy from cuttings with mineralogy of log interpretation when a *predicted* nuclear spectroscopy log was used.

Example 1a. Comparison of log and core mineralogy.

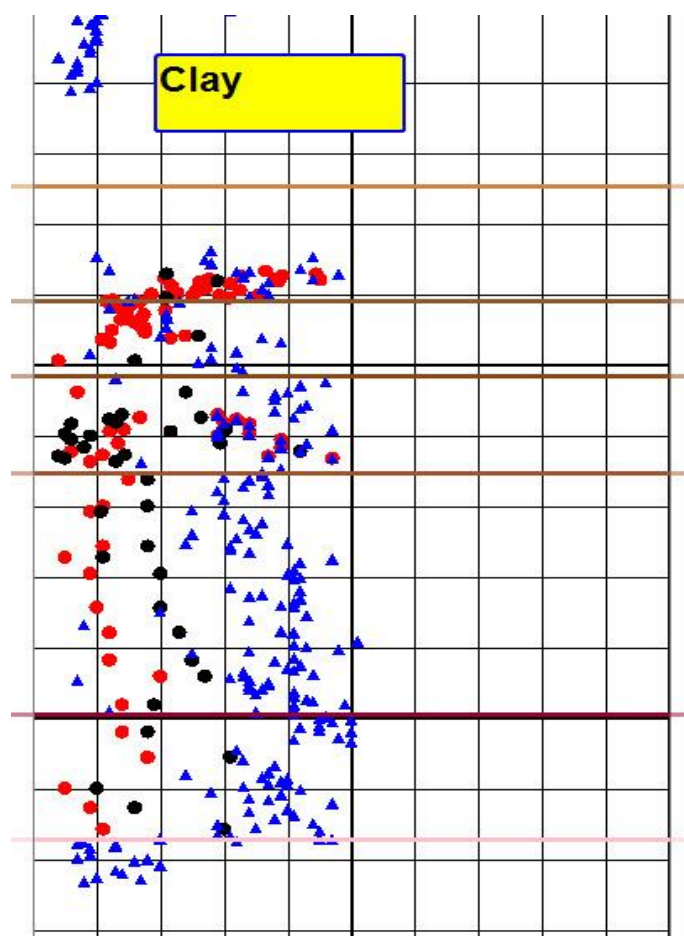


Fig. 1. Barnett: There are 2 XRD (red and black) and FTIR (blue) evaluations of clay content. Depth interval is 10 m between each horizontal line. Obviously they do not agree. So we have to be selective in the core measurements we choose to use.

Example 1b. Comparison of log and core mineralogy. Different well than Fig. 1.

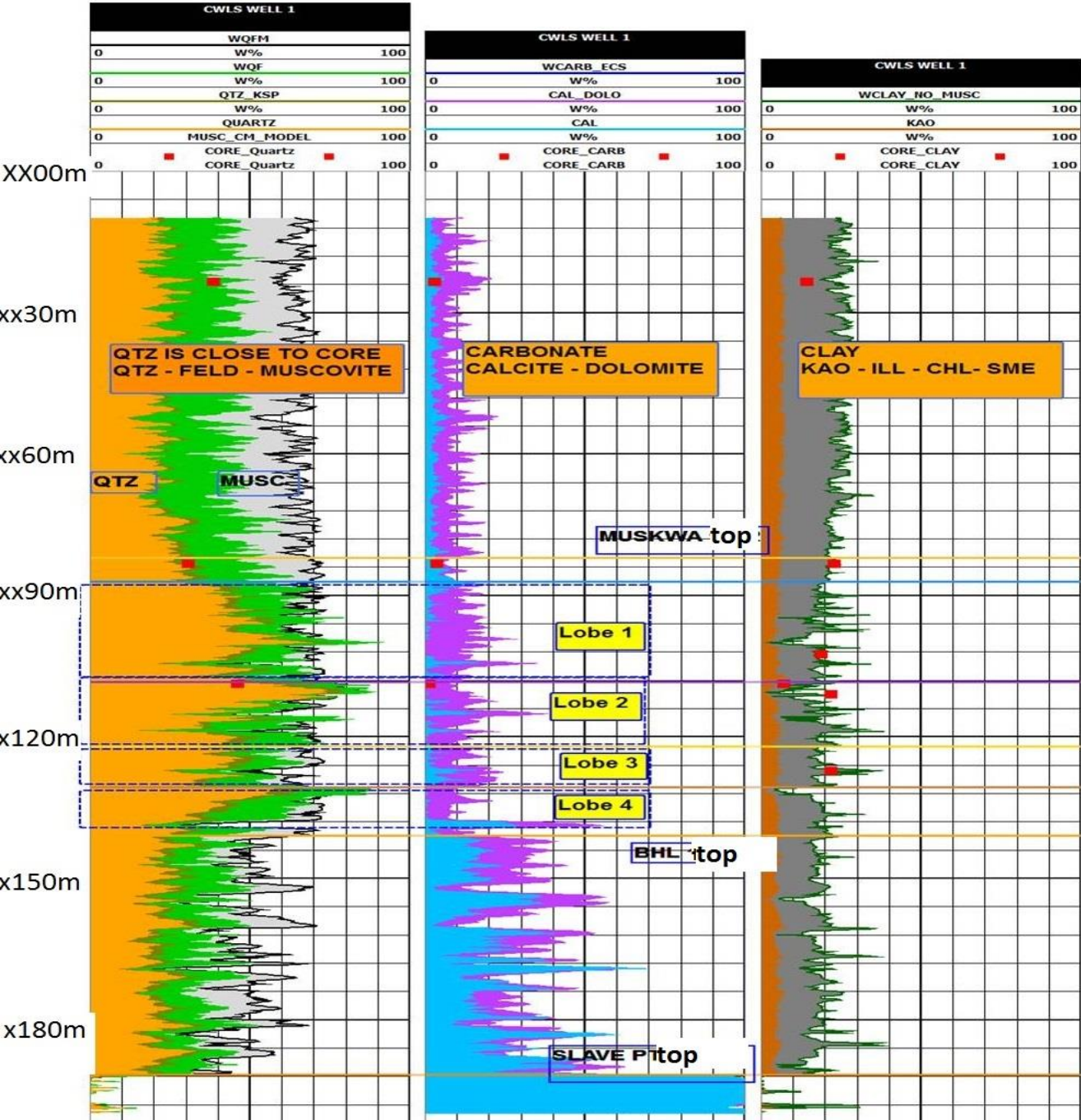


Fig. 2. Muskwa: We chose to use this data set, in which muscovite was separated from illite and find a nice match of core and log-derived mineralogy.



Example 1c. Comparison of log and core mineralogy.

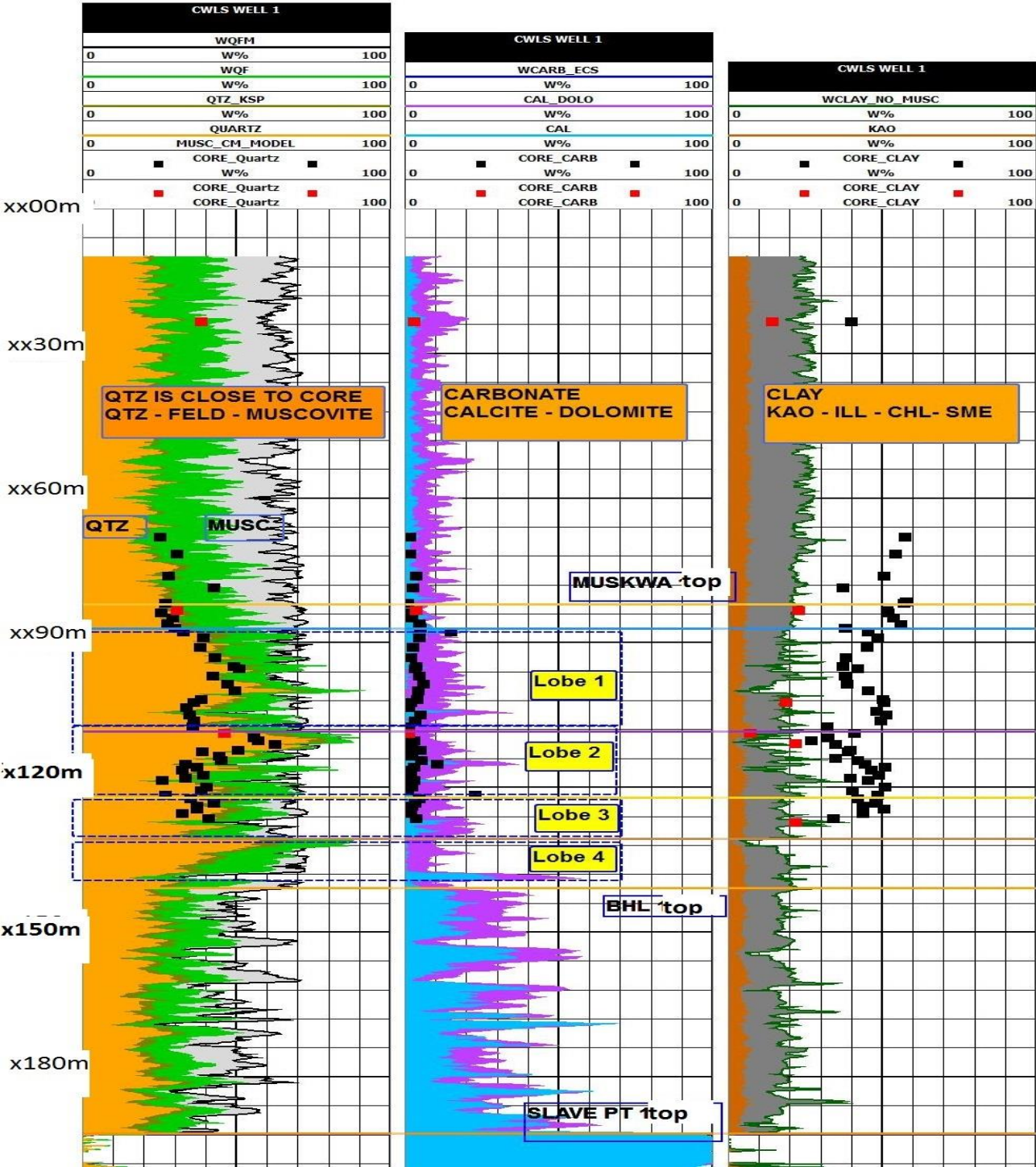


Fig. 3. Muskwa: Plotting all the data shows good correlation for quartz but poor for clay and carbonates as a direct result of not separating illite and muscovite.

Example 2a. Comparison of core and log permeability, Duvernay, Alberta

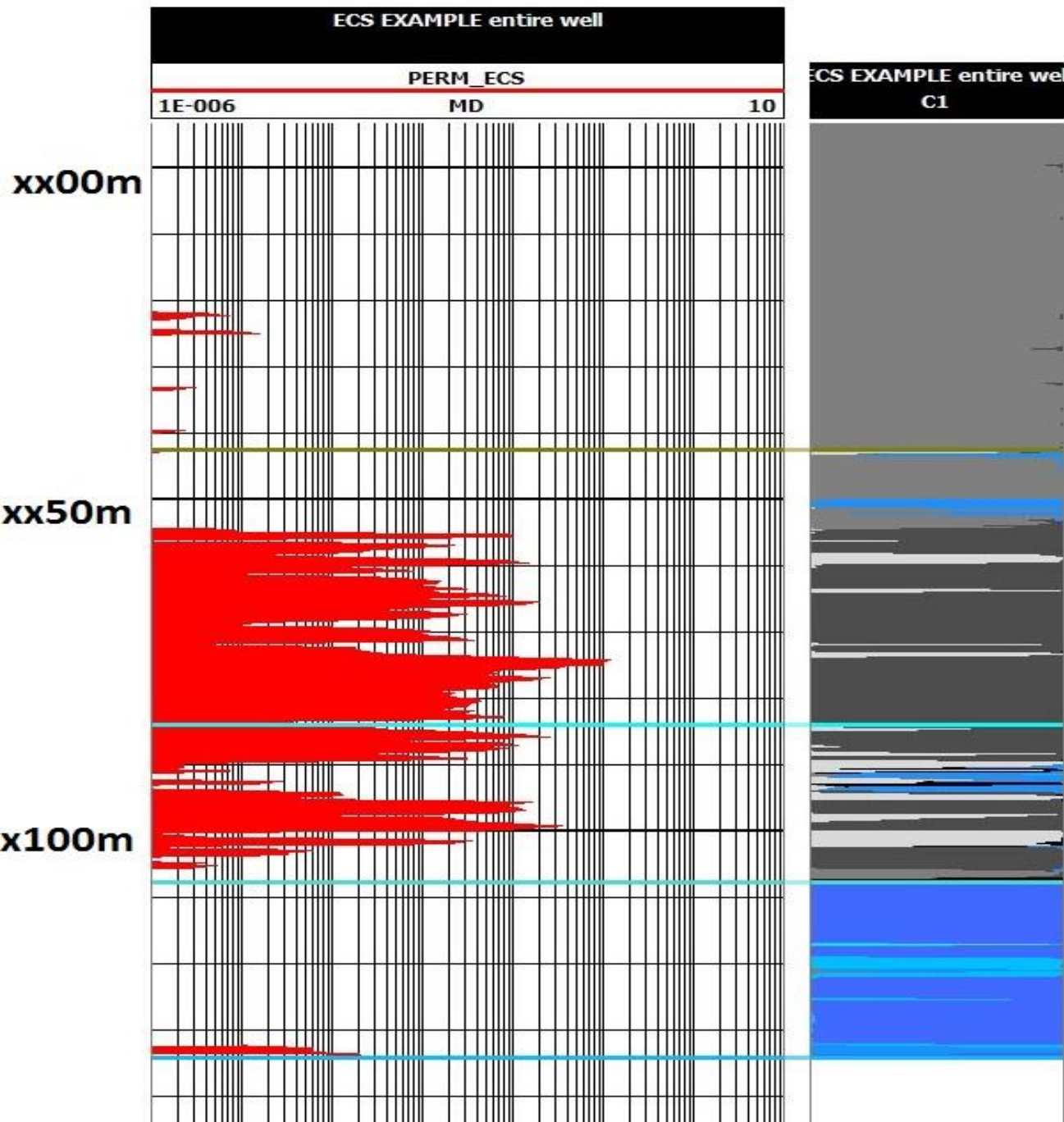


Fig 4. Duvernay: Calculated permeability



Example 2b. Comparison of core and log permeability, Duvernay, Alberta

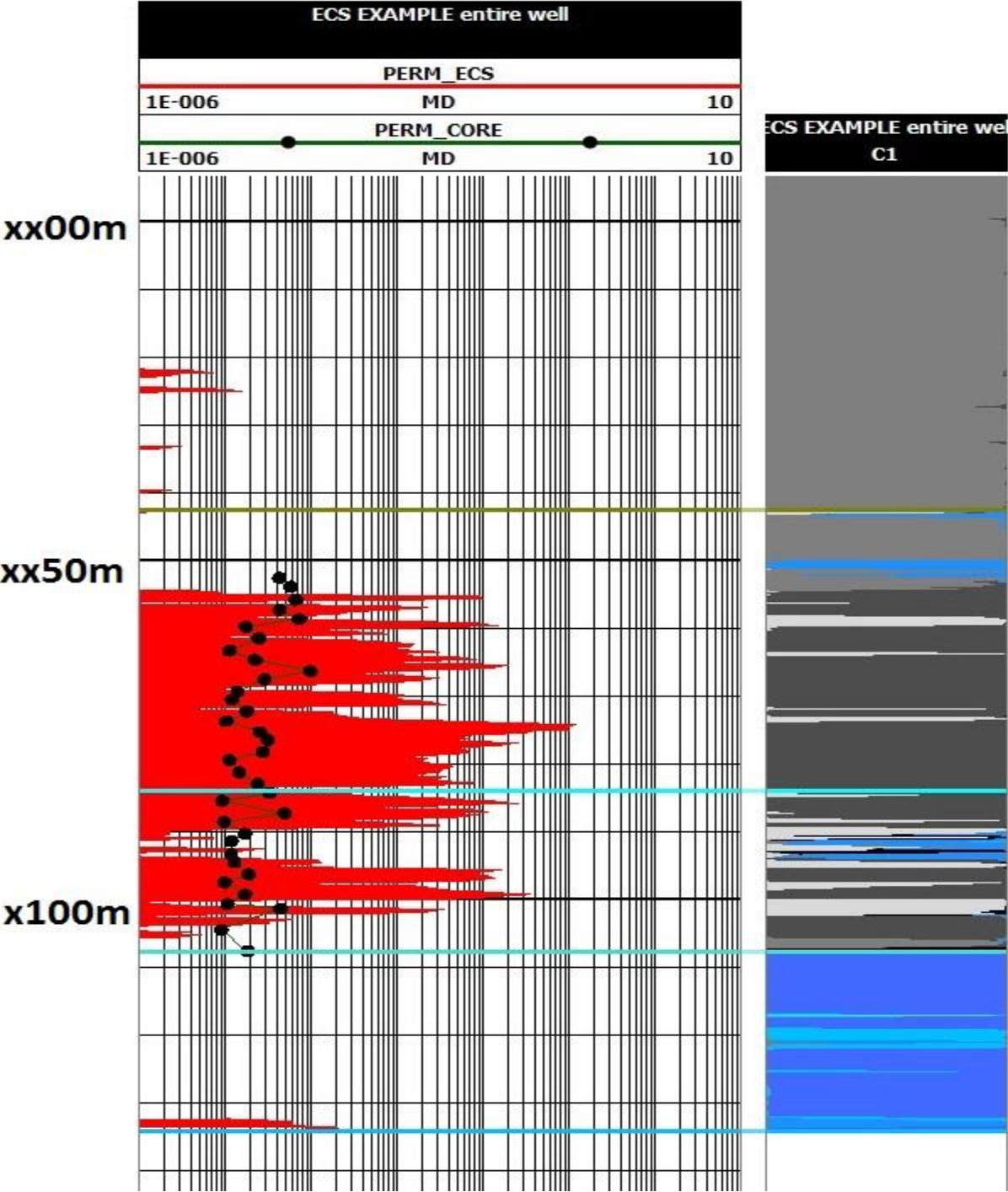


Fig. 5 Duvernay: Add core to perm. Some diagenesis has taken place!

Example 2c. Comparison of core and log permeability, Duvernay, Alberta

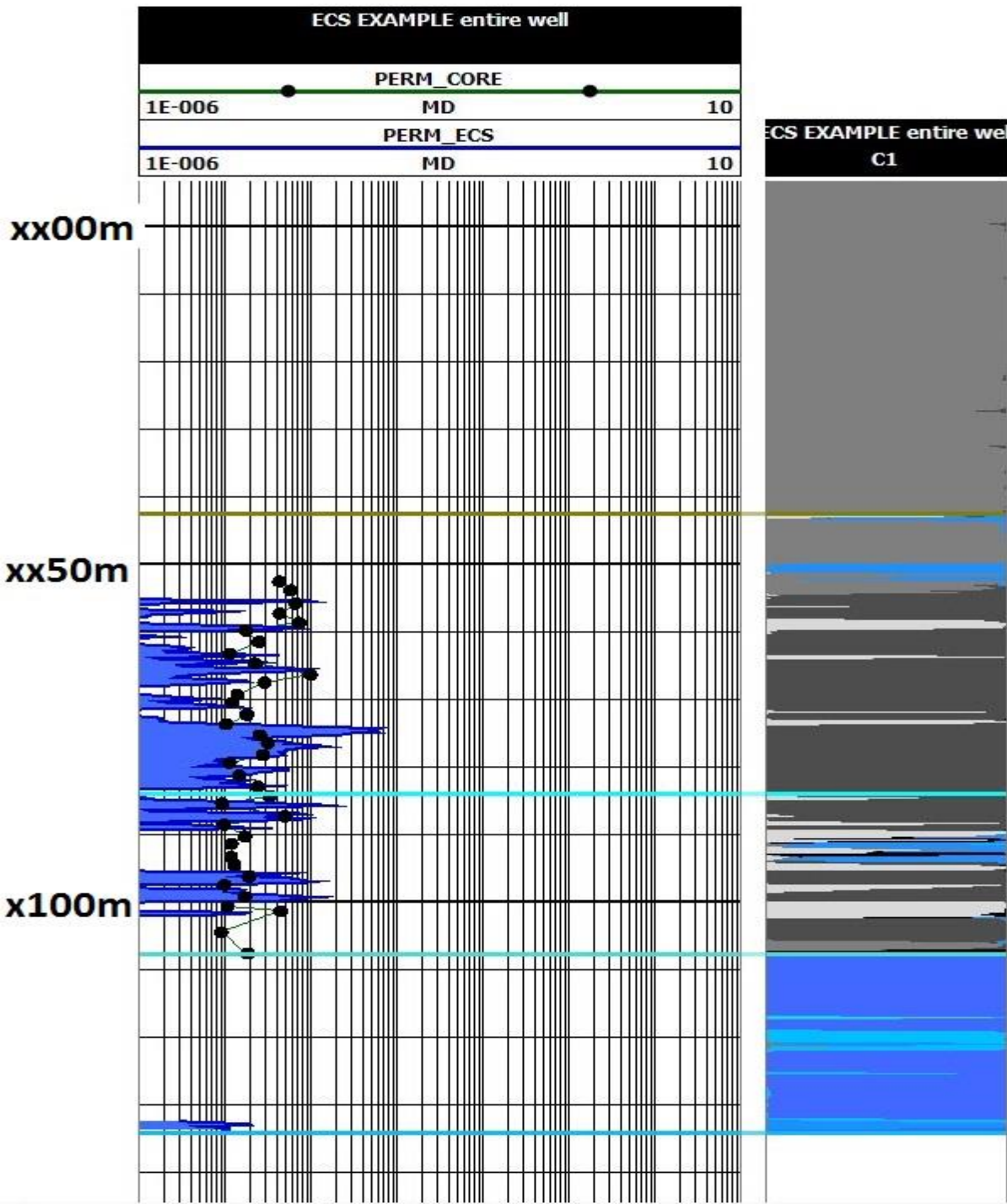


Fig. 6. Duvernay: Correction for diagenesis on perm.

Example 3a. Comparison of core and log water saturation, Duvernay, Alberta

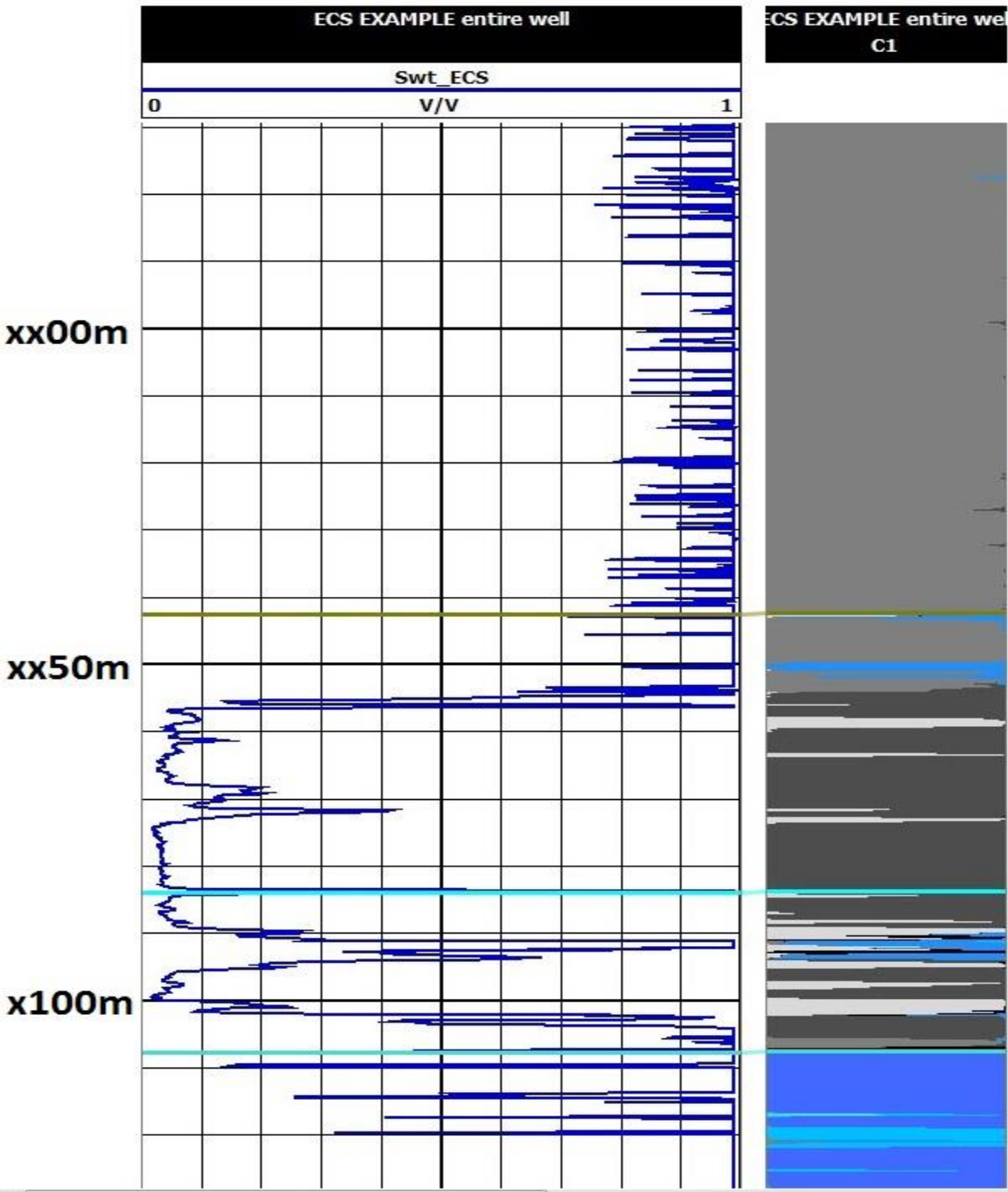


Fig. 7. Duvernay: Calculated Sw. Looks really Low...whoopie! Let's check against core before we celebrate.

Example 3b. Comparison of core and log water saturation, Duvernay, Alberta

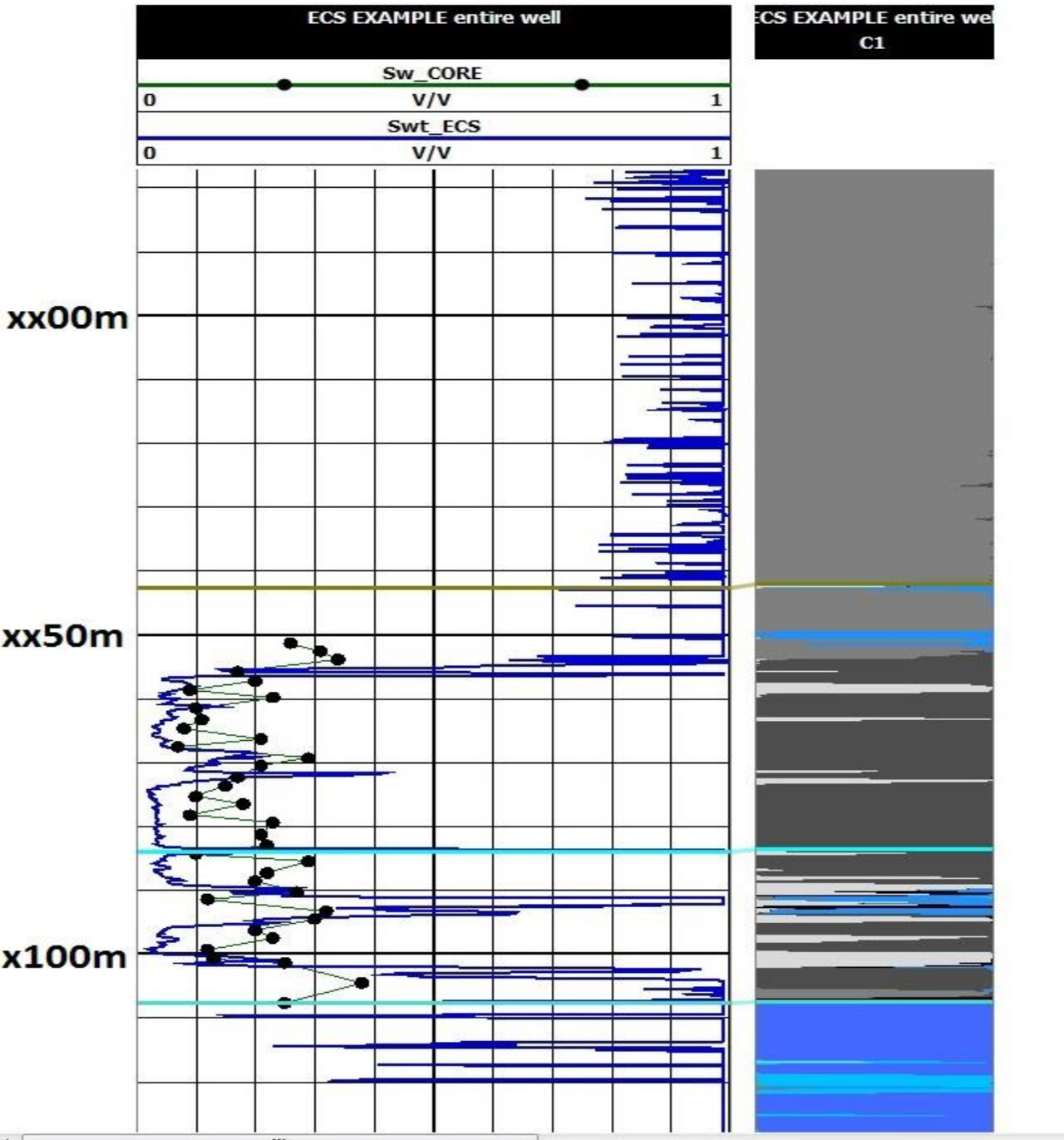


Fig. 8. Duvernay: Add Core to calculated Sw. Core Sw is higher due to diagenesis.

Example 3c. Comparison of core and log water saturation, Duvernay, Alberta

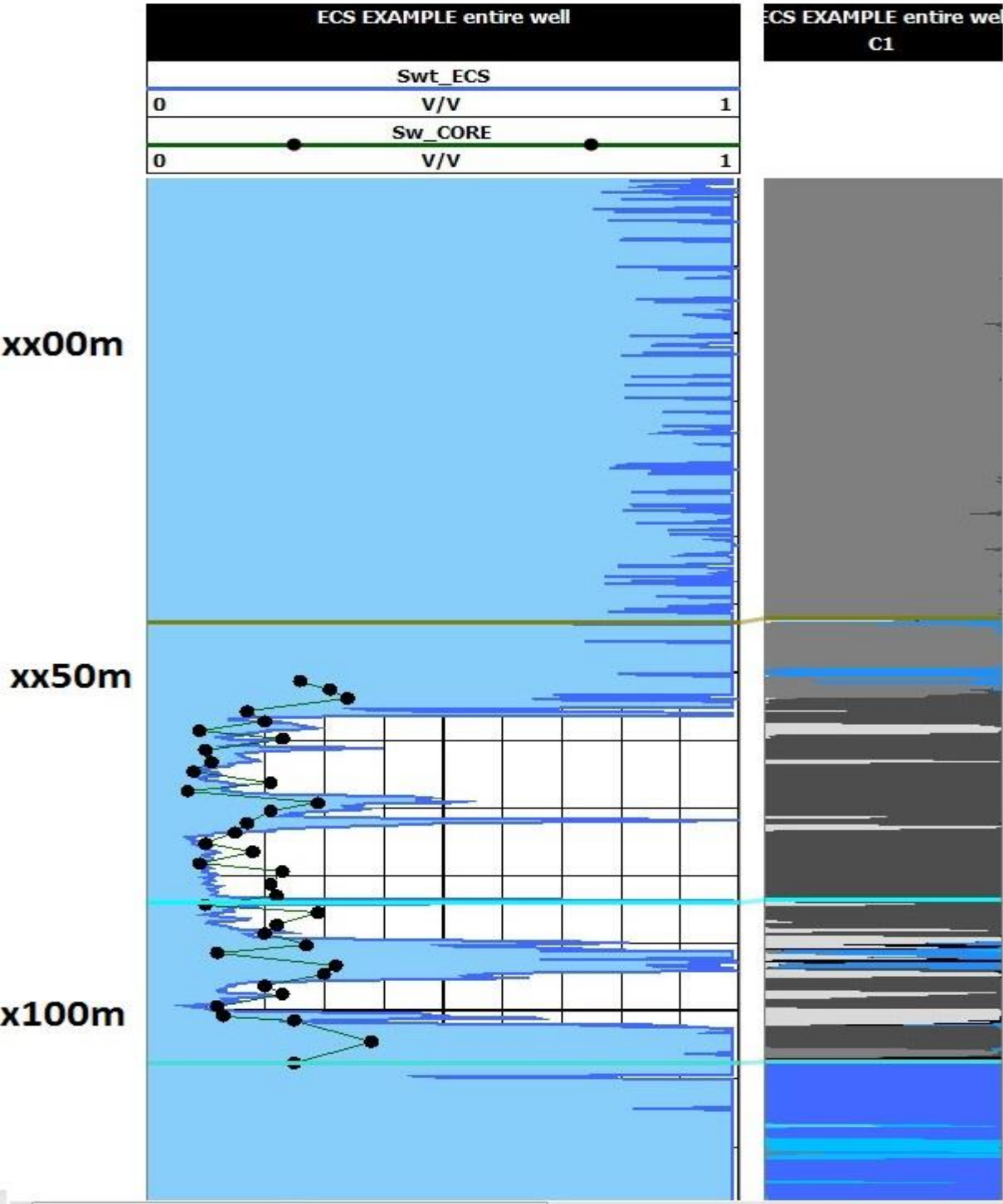


Fig. 9. Duvernay after Correction for Diagenesis by increasing Cementation and Tortuosity factors on Sw.



Example 4. Comparison of core and log porosity, Duvernay, Alberta

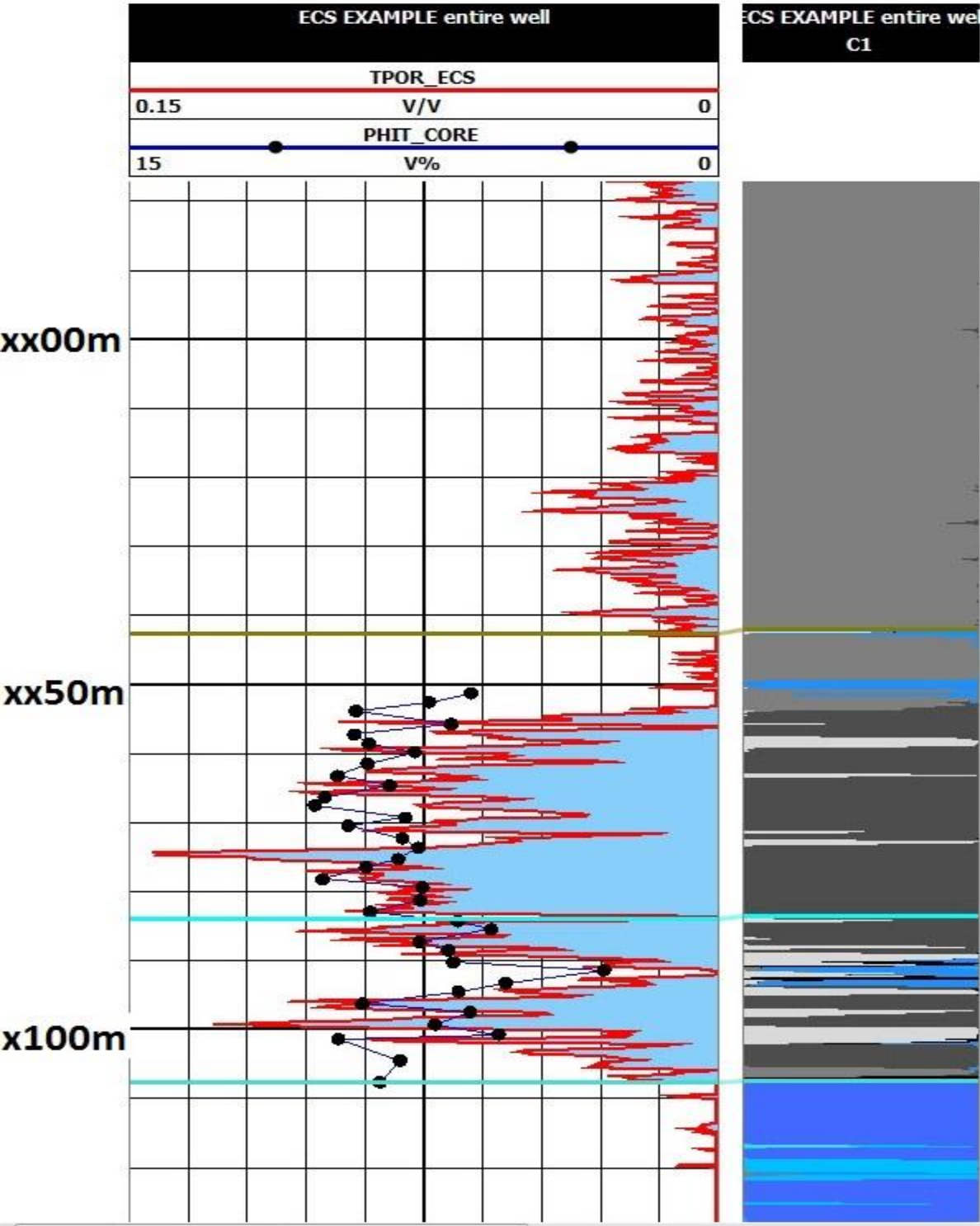


Fig. 10. Duvernay, Calculated Total Porosity and Core. Core porosity and log porosity require no correction. Kerogen was included in the log-calculated grain density.

Example 5. Comparison of core and log TOC, Duvernay, Alberta

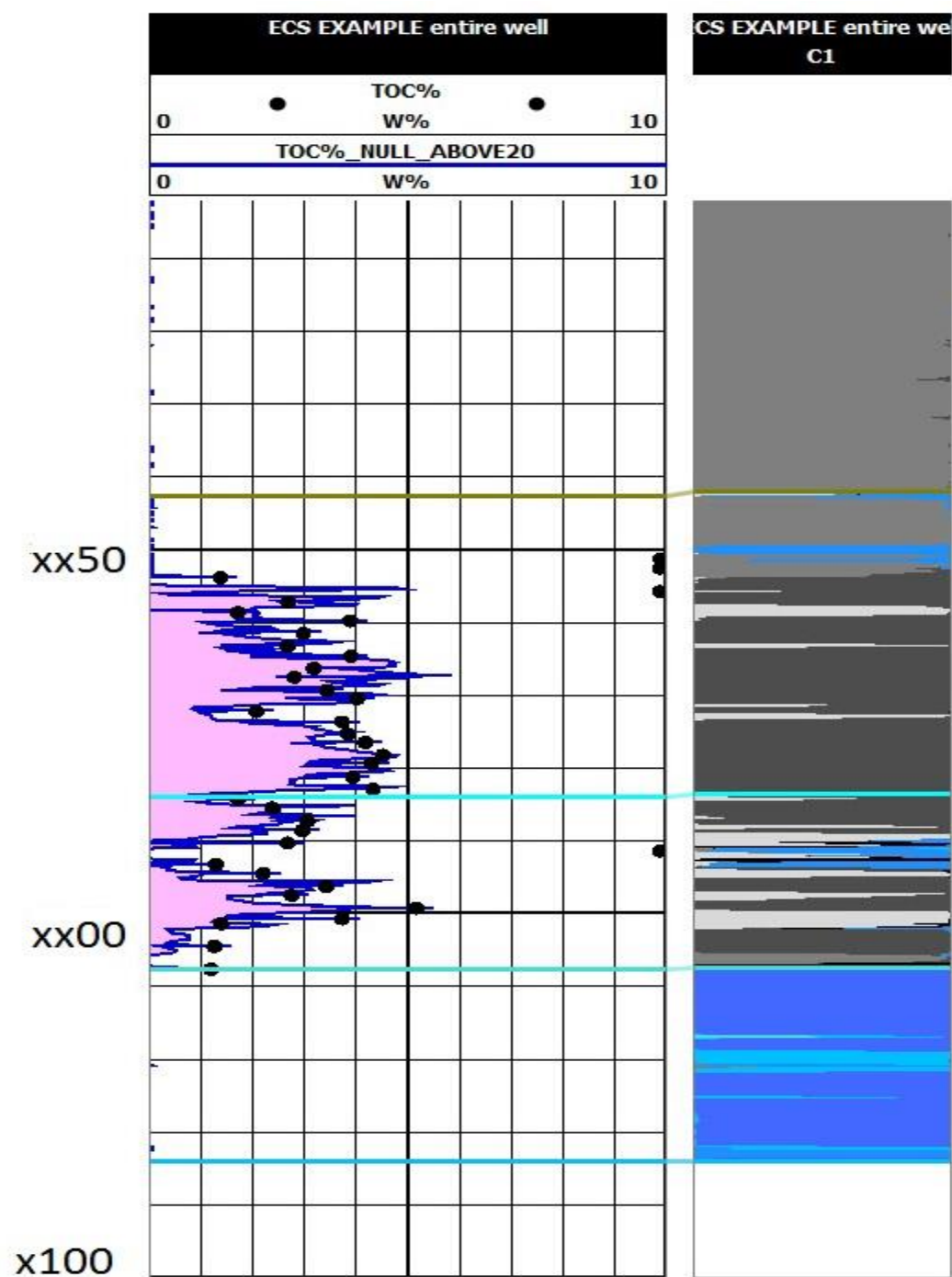


Fig. 11. Duvernay Total Organic Carbon & Core  
Total organic carbon core was clustered with uranium.

Example 6. Comparison of quartz from programs two and three, Duvernay, Alberta

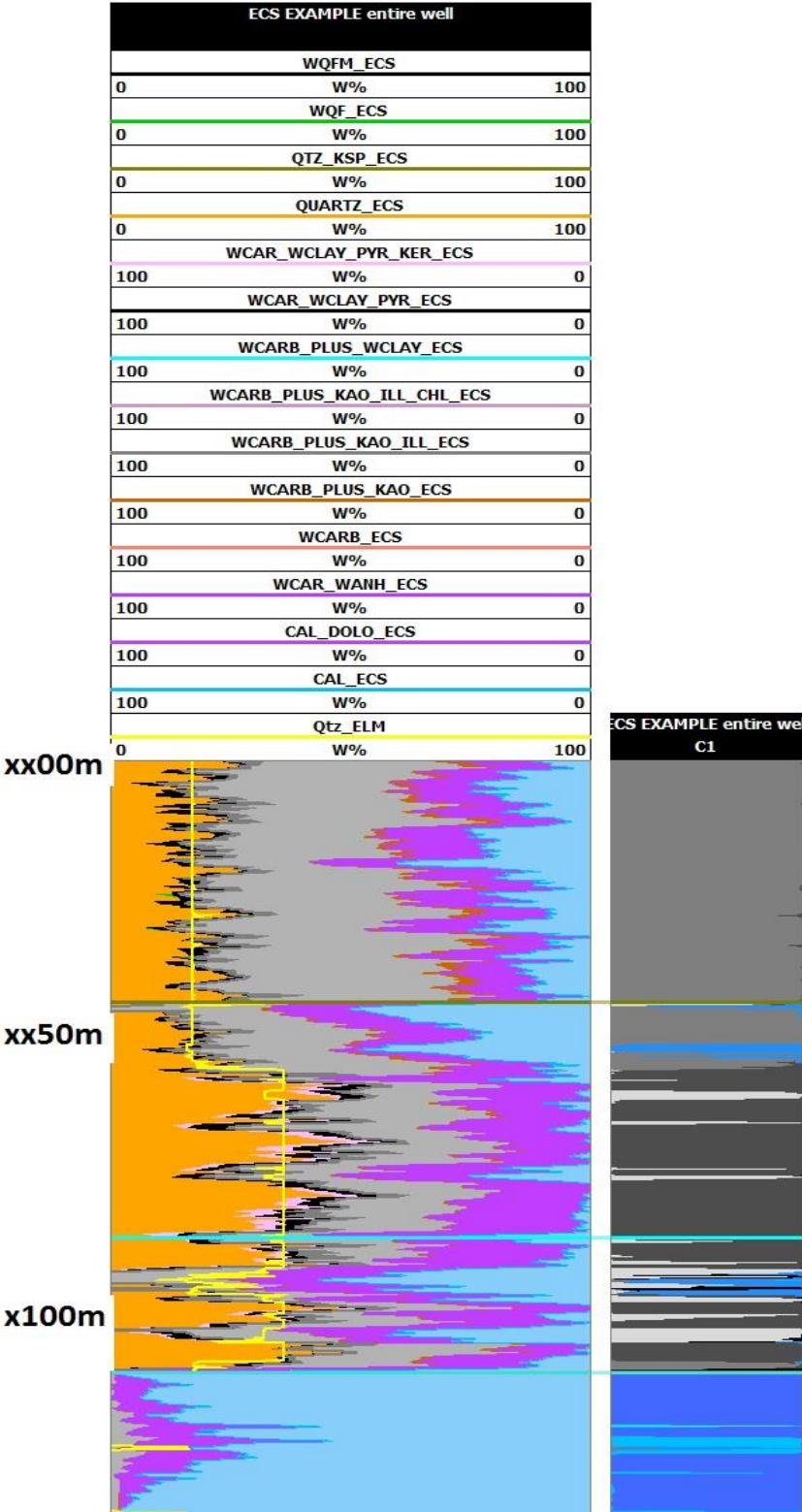


Fig. 12. Duvernay Mineralogy from Program 2, where orange is quartz vs. Program 3, where the yellow line is quartz. The yellow quartz line follows the lithology clustered in the right track. Core mineralogy is not released.

Example 7a. Comparison of Triassic cuttings mineralogy, Alberta

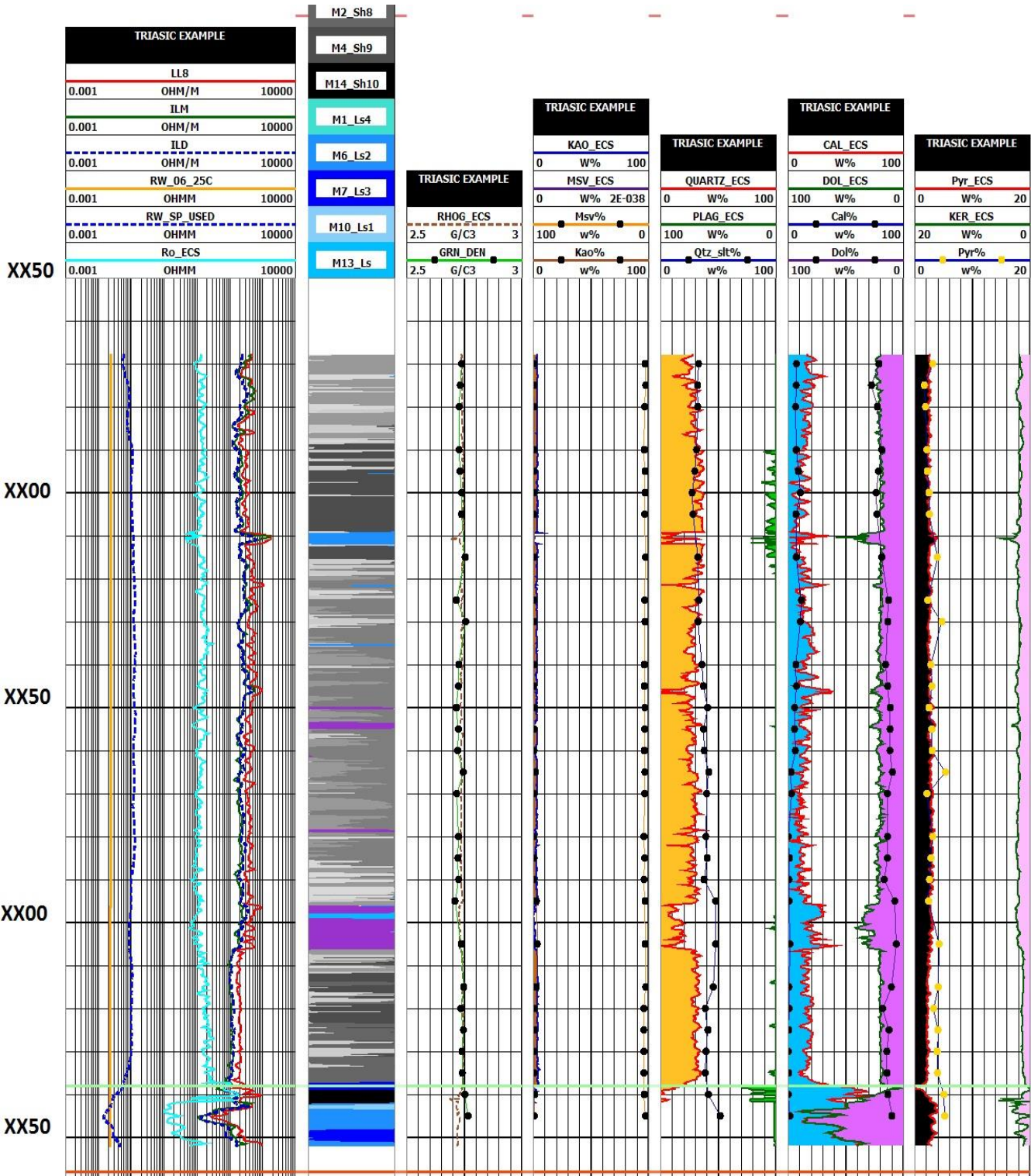


Fig. 13. Triassic Montney. Log Minerals are derived from **Predicted** Spectral logs; Cuttings are not included in **Program 2**. Note extensive analysis on cuttings.



Example 7b. Comparison of Triassic cuttings mineralogy, Alberta

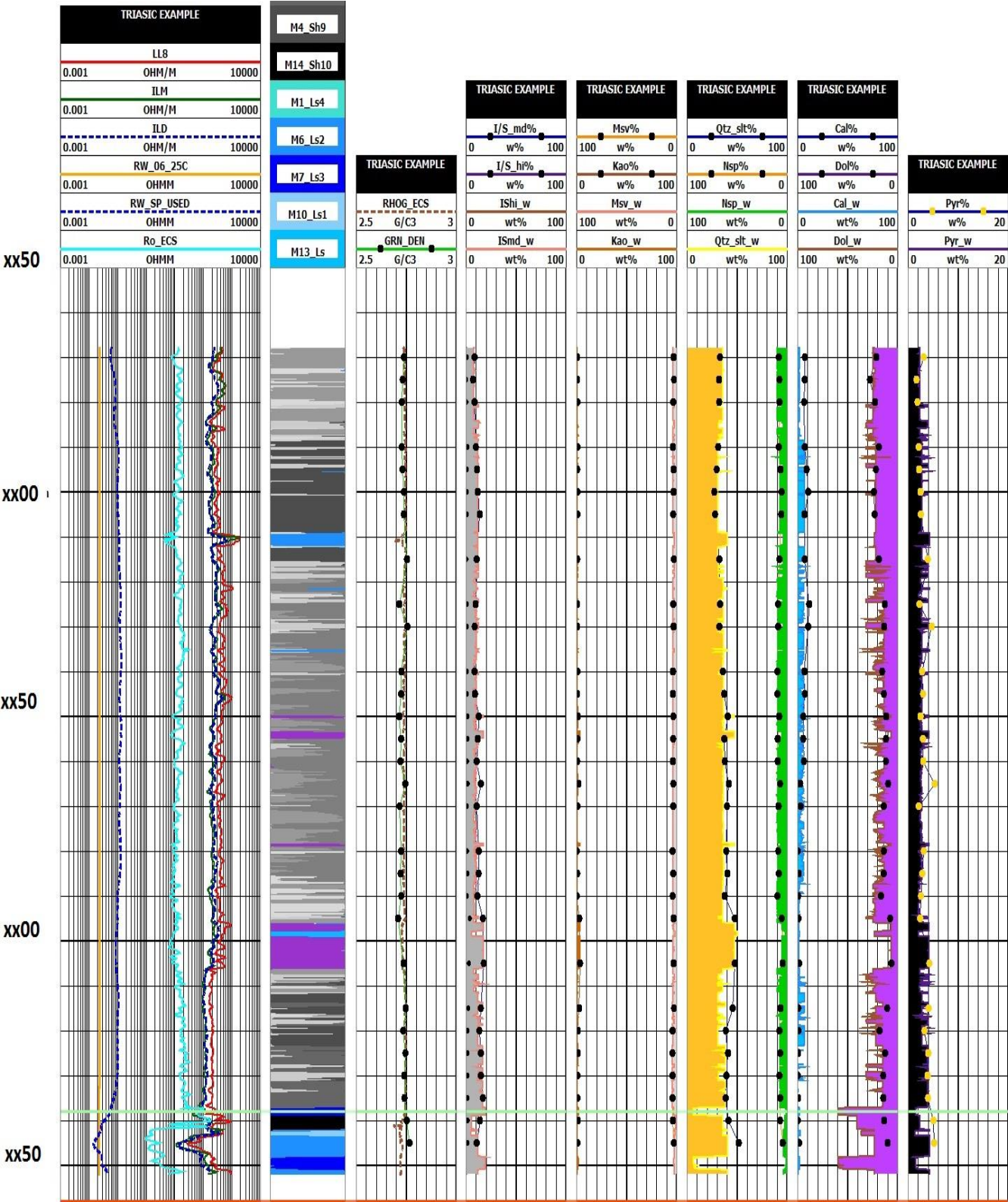


Fig. 14. Triassic Montney. Log Minerals are derived from **Program 3** which includes extensive analysis on cuttings. Note the improved fit to cuttings mineralogy when the cuttings minerals are included in the log computation.



**Providing a quote from the geologist, “I am impressed and glad that you were able match the cutting data so quickly! Cuttings are very useful because they give you lithological information over extended intervals unlike cores, which are generally very localized. And with a technology like [trade name omitted] you can really get more out of cuttings than [you] used to [get]”.**

## **Conclusions**

**We walked through the steps for calculations of the mineral groups and their normalization process to convert the mineral groups to individual minerals. Due to diagenesis there are many log-calculation parameters available to adjust, if the resulting minerals do not match quantitative mineral measurements.**

**We calculated grain density, total porosity, permeability and total organic carbon. We made adjustments when diagenesis resulted in core measurements that did not fit our log models.**

**When wells are analyzed and no core exists, a combination of cuttings mineralogy and Program 3 to include the cuttings measurements in the log analysis provides excellent results.**

**A log-core interpretation method that is designed to be flexible to match valid core, results in a core-calibrated data set, improving the hydrocarbon pore volume needed for reserve estimates.**

## **Acknowledgements**

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## **References**

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