Horn River Shales …Boring and Black? ...or…Beautifully Complex?

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Summary & Introduction

The Horn River Basin (HRB) represents one of the largest unconventional gas accumulations in North America. It is located in north eastern British Columbia, north of Fort Nelson. The Basin is bounded by the Keg River and Slave Point carbonate platforms and the Bovie Lake Fault (Figure 1). Estimates indicate that the HRB could hold as much as 500 trillion cubic feet of natural gas (DOB, Sept. 10, 2009). Activity in the HRB has kept a measured pace, balancing the development of significant gas reserves with challenging logistics in a relatively low price environment. EOG Resources Canada Inc. has a significant land position in the basin, with an active drilling program. Future plans include a steady increase in activity over the next several years to develop the acreage.

The Horn River Shales are Devonian in age and are individually referred to as the Evie, Otter Park and Muskwa Formations. They represent the basinal equivalents of the Elk Point, Beaverhill Lake and Woodbend Groups. These formations are subdivided using lithofacies and mineralogical considerations in conjunction with detailed well log correlation. A number of distinct depositional packages have been recognized within these shales. Differentiation of these packages is critical as it can impact OGIP, completion strategies, and ultimately gas recovery.

These shales could initially be described as homogeneous, ubiquitous, black and boring… however, upon more detailed inspection… their underlying complexity begins to emerge. Advanced techniques in rock property analysis, in combination with core calibrated petrophysical examination permits a much more detailed characterization of these shales and a better understanding of the distinct contribution of each lithofacies to the overall production. This display will use the core taken at EOG Maxhamish D-12-L/94-O-15 (Figure 2) to illustrate the importance of these techniques. D-12-L was drilled in 2006 and was one of the first wells to target shale gas in the HRB; 122m of core were cut with 93m recovered, which spans most of the Horn River section.

Stratigraphy

Figure 3 presents a stratigraphic model to illustrate the relationship of the Horn River shales to their platform equivalents. It is based on a compilation of literature, including Mossop and Shetsen, 1994, Wendte and Muir, 1995, Morrow et.al, 2002, Gilhooly, pers. comm. and our interpretation of the stratigraphy from correlation with well logs and core data. It shows the depositional packages that EOG has recognized at D-12-L.

The Evie Formation is the most highly radioactive and organic rich zone at the base of the Horn River shales, directly overlying the deep water carbonates of the lower Keg River Platform succession. The Evie is the basinal equivalent of the Keg River and Sulphur Point reefal developments.

On the carbonate platform, above the Sulphur Point Formation, the middle Givetian sub-Watt Mountain unconformity has been recognized, but no equivalent strata in the Horn River Basin has been identified previously (Morrow et al., 2002 and Meier-Drees, 1994). At D-12-L, there is a thin, more clay rich zone immediately above the Evie, and below the Middle Devonian Carbonate (see Figure 2 and 3) that can be mapped regionally over the basin. It is possible that this unit may be equivalent to the Watt Mountain Formation.

The term Middle Devonian Carbonate (MDDC) has been applied to the thin regionally extensive basinal carbonate zone (Encana, 2008) that may be mapped across the HRB. It is correlated to the carbonates at the base of the Slave Point, immediately above the sub-Watt Mountain unconformity.

The Otter Park Formation has been subdivided into three main units based on relative organic and clay richness. Correlation back to the carbonate platform is difficult in the Otter Park, and the relationships indicated in Figure 3 have been inferred from regional stratigraphic correlation.

The lower Otter Park is a relatively thin, organic rich zone (Figure 2) that can be correlated across the entire basin. It is likely equivalent to the Slave Point and possibly the initial Swan Hills reef developments.

The middle and upper Otter Park have a different character compared to the lower Otter Park, with a different depositional style; being generally more clay rich and exhibiting clinoform geometries. Each contains a package of more clay rich, organic poor shales, overlain by shales that are slightly more organic rich and clay poor by comparison (Figure 2). The two units in the middle Otter Park have been equated to the intraformational unconformity in the Swan Hills Formation and the upper part of the Swan Hills respectively. It is possible that the clay-rich sediment at the base of the middle Otter Park may be related to this unconformity. The upper Otter Park is most likely equivalent to the basin-filling clinoforms of the Waterways Formation.

The overlying Muskwa Formation is the basinal equivalent of the Cooking Lake and Leduc reef developments and it is equivalent to the Duvernay Shales. The Muskwa is overlain by the clinoforms of the Fort Simpson Shales.

Sedimentology and Lithologic Observations from D-12-L/94-O-15 (core display well)

Generally, the Horn River Shales look very similar at the core scale, though there are a few key differences. Specialized analysis is vital to adequately characterize these shales. XRD is critical to accurately determine mineralogy. Porosity and permeability must be measured with some type of crushed sample protocol, as traditional methods are insufficient. Thin sections show some of the differences in texture as do SEM and backscatter, but more specialized techniques are required for analysis of pore geometry and pore structure. Argon-ion milled thin sections have an extremely flat surface and nano-scale pore geometry and grain architecture are much more easily observed; pores as small as 5 nm have been observed in the Barnett Shale (Loucks et al., 2009).

A comparison of these different scales is provided in Figure 4 on four samples from the Horn River Shales. Observe the variation in texture, mineralogy and grain architecture in between each of the samples. It is also apparent that like the Barnett (Loucks, et al., 2009), much of the porosity in the Horn River Shales is associated with the organic matter. As such, the TOC measurement is very important.

The Muskwa is a dark grey to black, siliceous mudstone. In the core, it is weakly laminated to massive with some quartz filled fractures. There are also some calcite filled fractures at the top. The mineralogy is largely dominated by quartz (70-85%), with minor clay (7-15%), feldspar, dolomite, and pyrite. The TOC ranges from 3 to 7%. Porosity and gas-filled porosity were measured using tight rock analysis, and found to be 4 to 8% and 3.7 to 6.5 % respectively. Pressure-decay permeabilities range from 175 to 335 nd.

The Otter Park (Upper & Middle) is much more argillaceous than the Muskwa, and is dominated by dark grey, argillaceous, siliceous mudstone. In the core, it is also weakly laminated; however, the core breaks much more frequently than the Muskwa except in calcareous intervals. There are numerous pyrite nodules and a few fine quartz filled fractures. The mineralogy is 30 to 60% quartz, 15 to 45% clay, with minor dolomite, pyrite, and calcite. The TOC ranges from 1 to 4%. The total porosity ranges from 3 to 7% and the gas-filled porosity ranges from 3 to 4%. Pressure decay permeabilities are generally less than 100 nd.

The Otter Park (Lower) is a grey to black siliceous mudstone, much more like the Muskwa in character. Unfortunately only small sections of this unit were recovered in the core. The mineralogy is 70% quartz, 12-15% clay, minor calcite, dolomite, feldspar, and pyrite. Total porosity ranges from 3.5 to 6% and the gas-filled porosity ranges from 3 to 5.8%. The pressure decay permeabilities range from 200 to 300nd. The TOC content is 2 to 5%

The Middle Devonian Carbonate is a light grey calcareous mudstone that is interbedded with dark grey, calcareous, siliceous mudstone. As with the lower Otter Park, recovery over this unit is poor. The mineralogy is 40 to 80% calcite, up to 30% dolomite, 5 to 20% quartz, and minor clay and pyrite. Total porosity is 3% and the gas-filled porosity is 2.5%. The pressure decay permeability is less than 100 nd. The TOC is 1.4%.

The Watt Mountain? zone is a dark grey to black zone that is interbedded with dark grey, argillaeous and siliceous, slightly calcareous mudstone. It is difficult to distinguish in core from the Evie, however the core does break more frequently here. The mineralogy is 46% quartz, 22% clay, 11% calcite, and minor pyrite, feldspars, and dolomite. The TOC is 3.8%. Total porosity is 5.6% and the gas-filled porosity is 3.6%, but the permeability is only 100 nd.

The Evie is a dark grey to black, siliceous and calcareous laminated mudstone that is punctuated with thin beds very fine grained skeletal material. Fractures are only observed in rare thick carbonate beds and are calcite filled. The TOC in the Evie is high and ranges from 4 to 6.5%. The mineralogy is 50 to 70% quartz, 10 to 16% calcite, 6 to 20% clay, and minor feldspar and pyrite. The total porosity ranges from 5 to 9%, the gas-filled porosity ranges from 3 to 7%, and the permeability ranges from 180 to 330 nd.

Lower Keg River platform succession observed at the base of D-12-L is a light grey laminated carbonate mudstone to wackestone with abundant brachiopods. It is commonly fractured. The total porosity is only 3% and the permeability is very low, less than 100 nd.

Petrophysics

It is critical in these shales to be able to calculate important reservoir parameters from wireline logs, such as lithology, gas-filled porosity, TOC, and saturation. At D-12-L, EOG has run a full suite of logs including spectral gamma, neutron/density-PE, induction, elemental capture spectroscopy (ECS), sonic scanner, and formation imaging (FMI). The standard log suites for D-12-L are presented in Figure 2, as well as the mineralogical analysis and summary calculations of gas-filled porosity, TOC, and gas saturation.

The total reservoir section in the Horn River shales is highlighted very well using a simple normalized sonic-resistivity separation – the Dlog R technique (Passey et a., 1990). However, it is necessary to characterize these rocks in more detail and identify those intervals that have the best porosity and permeability. To do this, other parameters must be compared. The mineralogy measured in core fits well to that from the ECS tool. As well, there is a strong correlation between gas-filled porosity and TOC and an inverse relationship to clay content. Also, it shows that there is also a relationship with the density-neutron separation, which could be used to highlight better reservoir if no other data is available.

Initially, simple cross plots between various wireline datasets and core were used to establish the core to log relationships. EOG uses a multiple linear regression to achieve a better correlation between log calculated parameters and core measurements from D-12-L. This approach utilizes a statistical routine that calculates correlation coefficients between each core measurement and all of the log curves. It allows the user to choose which curve or set of curves should be used to create the model. For example, TOC data was compared against bulk density, gamma ray, Dlog R, deep resistivity, sonic, and neutron porosity. The best correlation coefficients were observed for the bulk density (0.75) and the gamma ray (0.60), which were then both used to calculate TOC. The overall correlation between the TOC data from D-12-L and the calculated TOC model is 0.77. A multiple linear regression was also used to calculate total porosity (0.80), gas-filled porosity (0.73) and gas saturation (0.57).

Summary and Implications

Are they black and boring?… or in fact… beautifully complex? The core at D-12-L illustrates just how complex these shales are and the importance using a multidisciplinary approach; combining regional stratigraphy, specialized core analysis and petrophysical modeling. The first step is to understand the rocks - specialized core analysis techniques for shales are critical to adequately characterize the mineralogy, TOC, textural relationships, etc. and to observe nano-scale pore geometry. Petrophysical modeling is essential to calibrate the core data to wireline logs, but to also facilitate the identification of key stratigraphic zones. Each stratigraphic zone exhibits mineralogical and geochemical characteristics that can be correlated across the Horn River Basin and relate to regional changes in deposition.

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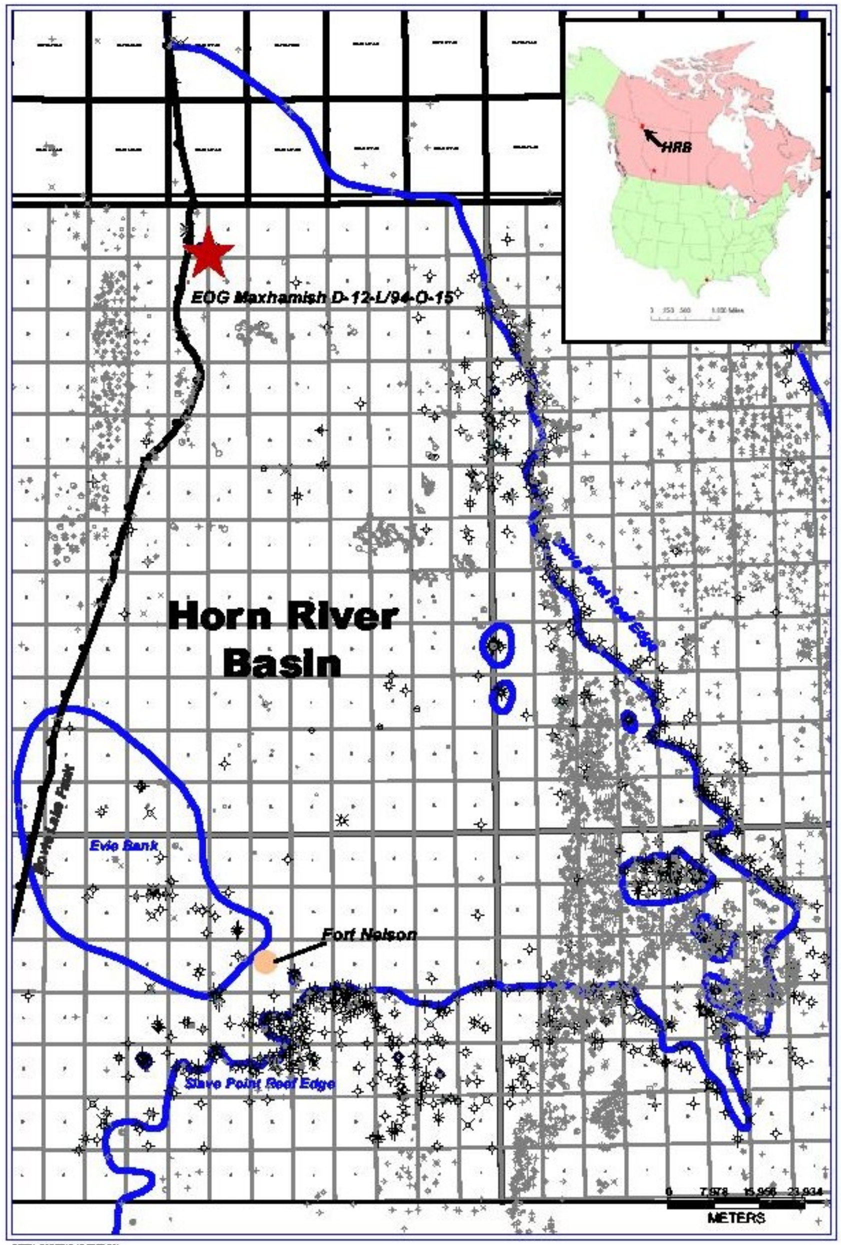

Figure 1. Map showing the location and limits of the Horn River Basin. The location of the core at D-12-L/94-O-15 is also highlighted.

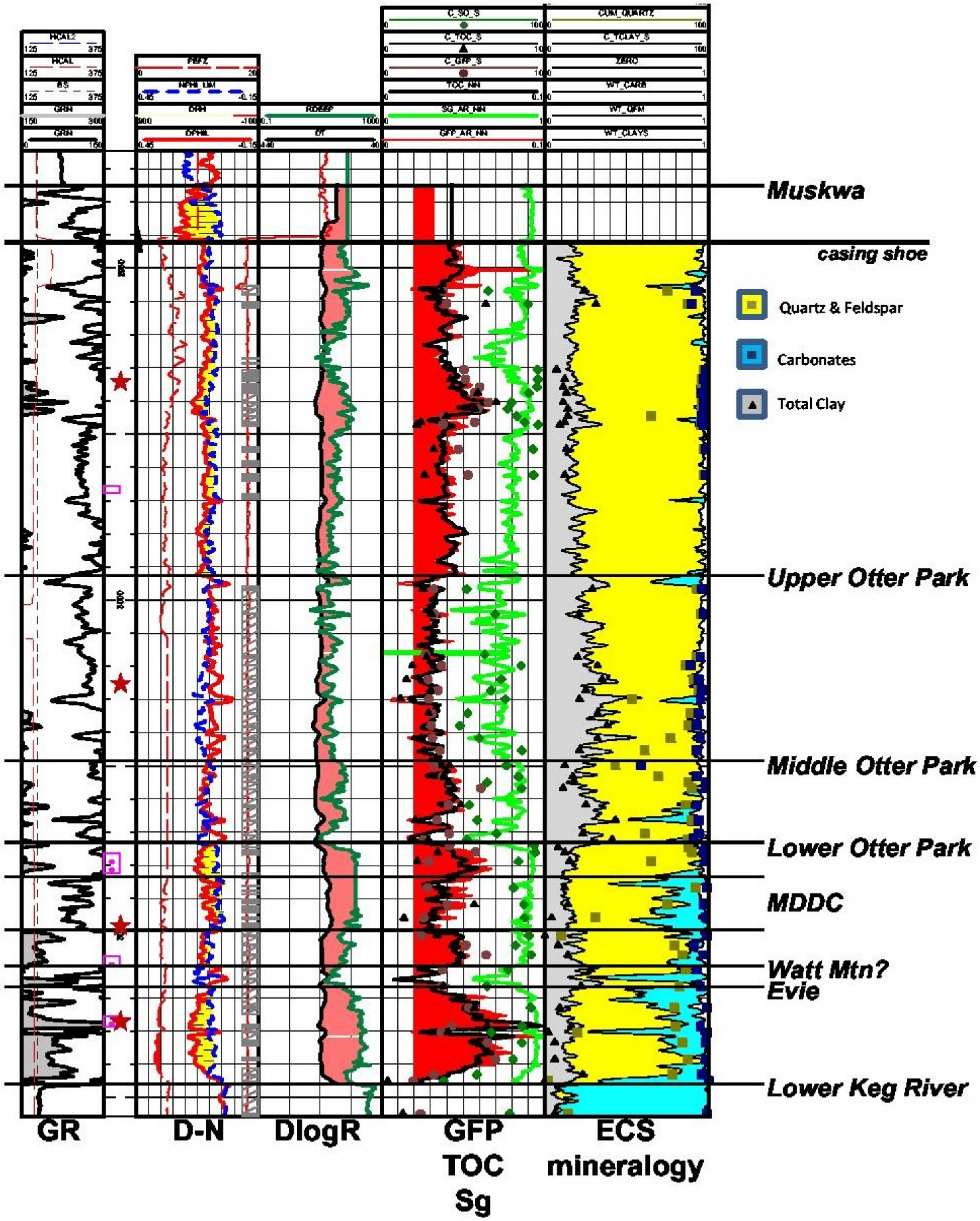

Figure 2. Type log for EOG Maxhamish D-12-L/94-O-15. The plot includes standard gamma ray, density-neutron and sonic-resistivity curves. It also includes calculated relationships (multiple linear regression analysis) for gas-filled porosity, TOC, and gas saturation that are calibrated to core. The XRD core data is compared with a simplified version of the ECS log. Core recovery is shown on the D-N track in grey. The red stars indicate the specific samples shown in Figure 4.

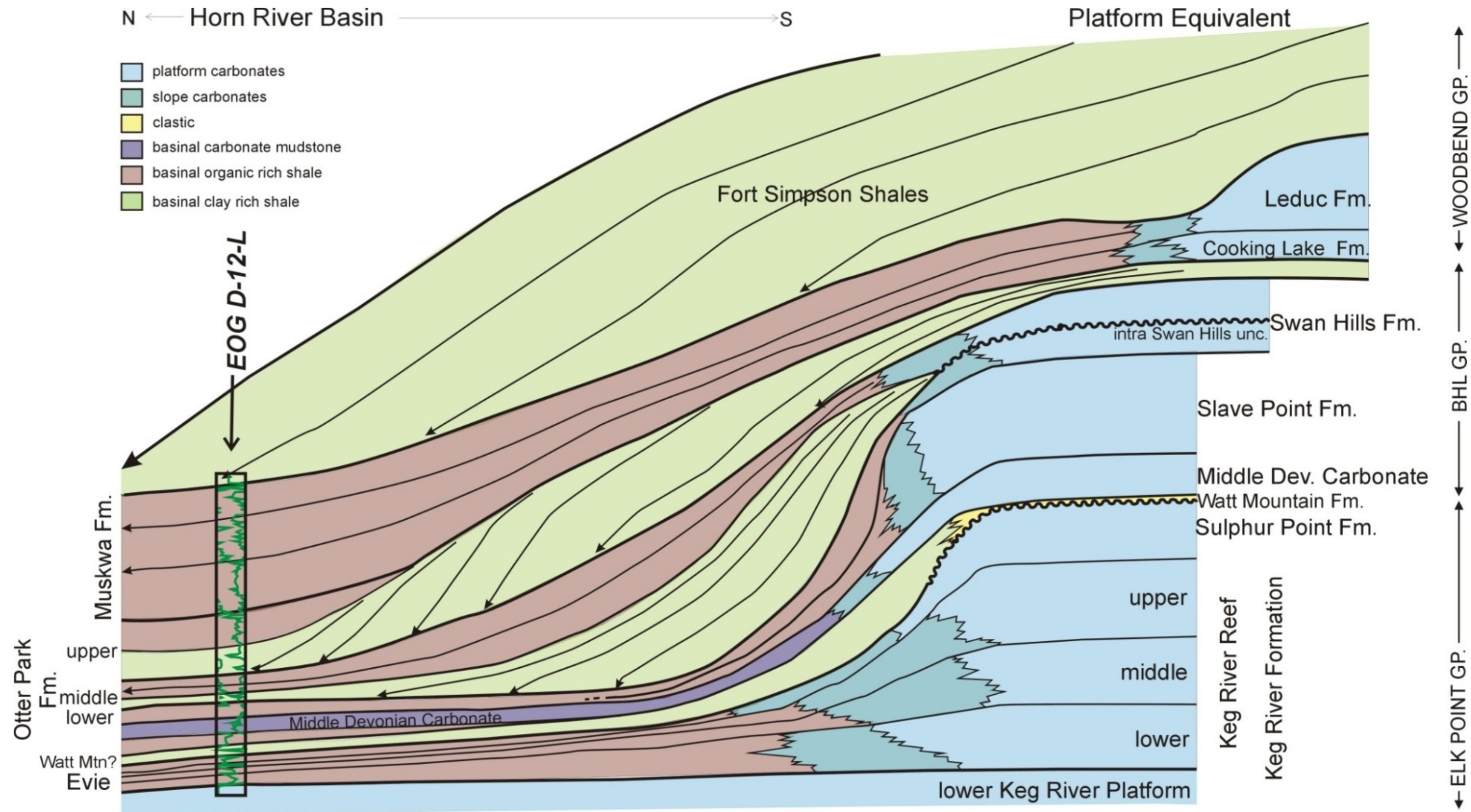

Figure 3. Stratigraphic model showing the stratigraphy of the Horn River Shales and their relationship to their platform equivalents(modified after Gilhooly and Lewis, pers. comm).

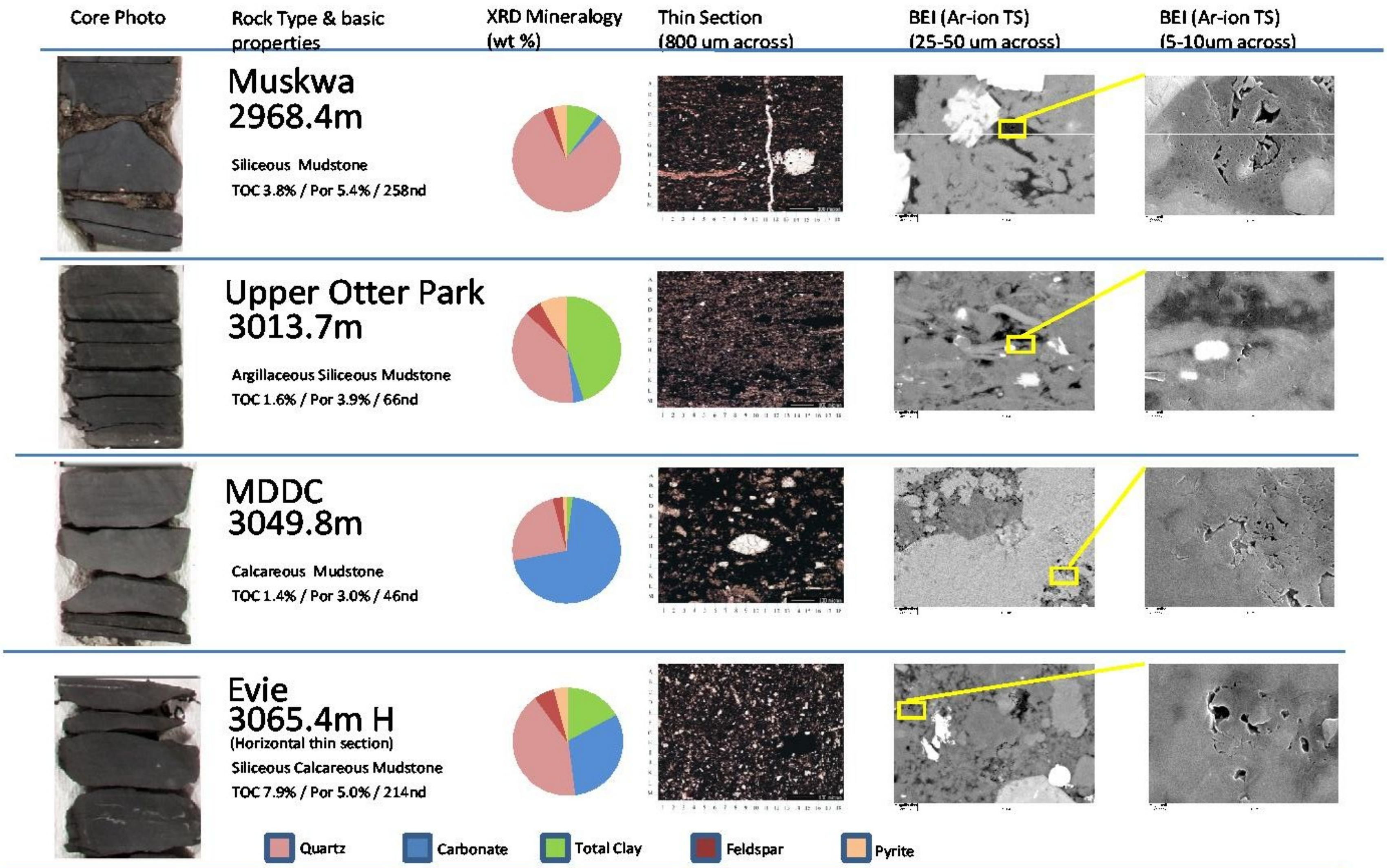

Figure 4. Comparison of select samples from D-12-L at different scales… from hand sample to the micro- and nano- scale. The thin sections and backscatter images shown here are argon ion milled. Observe the texture and complexity of each sample with each increase in magnification. The lithology, TOC, total porosity, permeability, and XRD mineralogy of each sample are shown for reference. In the thin sections photos, the organic matter is black. In the backscatter photographs, the organic matter is dark grey to black depending upon the scale. In the 5 to 10um photos, the porosity is black.