ORGANIC SHALE POTENTIAL OF THE MUSKWA–OTTER PARK INTERVAL WITHIN THE CORDOVA EMBAYMENT AREA OF NORTHEASTERN BRITISH COLUMBIA USING SONIC AND RESISTIVITY LOGS

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ABSTRACT

The Δ log R technique is used to identify and estimate the total organic carbon (TOC) content for 16 wells within the Muskwa–Otter Park interval around the Cordova Embayment in northeastern British Columbia. The Δ log R technique for calculating TOC is based on overlaying a correctly scaled porosity log on a resistivity log and interpreting the separation between the log curves. This separation can be transformed directly to TOC if the level of organic metamorphism (LOM), which is an index of organic maturity, is known.

For the wells analyzed, estimated maximum TOC content of the Muskwa–Otter Park shale ranges from 0.0 to 5.1 wt.%. For the individual wells, the average estimated TOC observed within the interval ranges from 0.7 to 1.6 wt.%. The observed range in TOC content is a reflection of interbeds of less abundant organic-lean nonsource-rock intervals (with relatively low TOCs) within the organic-rich source rocks of the Devonian shale formation. A general thickening trend of the interval is observed toward the centre, away from the boundary of the Cordova Embayment in the direction of the British Columbia–Northwest Territories border.

Considering the TOC content, the thickening trend of the Muskwa–Otter Park shale and current gas production from the interval (barring significant changes in the other reservoir properties of the shale unit within the Cordova Embayment), this basinal shale unit is likely prospective in the undeveloped parts of the basin trending northward toward the Northwest Territories. The results of this study are expected to provide a framework for a broader hydrocarbon resource assessment of shale formations within the Cordova Embayment.

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INTRODUCTION

The objective of this study was to use well logs to appraise the amount and distribution of total organic carbon (TOC) within the Muskwa–Otter Park interval of the Cordova Embayment. Data obtained from this study will supplement available TOC data to estimate the volume of hydrocarbon in-place within the Cordova Embayment. This basin has a relatively low level of unconventional shale exploitation activity when compared to the Horn River Basin in northeastern British Columbia, in spite of the fact that the Cordova Embayment hosts the same shale formations that are known to be prolific hydrocarbon reservoirs within the Horn River Basin. These include the Middle to Upper Devonian Muskwa–Otter Park formations and the Middle Devonian Evie-Klua formations.

TOC measurement is a priority in unconventional resource assessment and it is usually the first screen for quantifying organic richness or source-rock quality (Jarvie, 1991). Apart from being the source of hydrocarbons in reservoirs, organic matter in unconventional reservoirs is important because a significant fraction of the total porosity observed in such reservoirs is directly related to the amount of organic matter present within the rock matrix (adsorbed gas), which further necessitates the quantification of TOC.

STUDY AREA

This study will focus specifically on the Cordova Embayment area, British Columbia, Canada (Fig. 1). The Cordova Embayment covers an area of approximately 11 000 km^2 in the extreme northeastern corner of British Columbia, extending into the Northwest Territories (Kuuskraa et al., 2013), and is separated from the Horn River Basin on the west by the Presqu'ile Barrier Reef Complex (i.e., the Slave Point and Keg River reefal carbonates), which, in the Middle Devonian, extended from Alberta through British Columbia and into the Yukon and Northwest Territories.

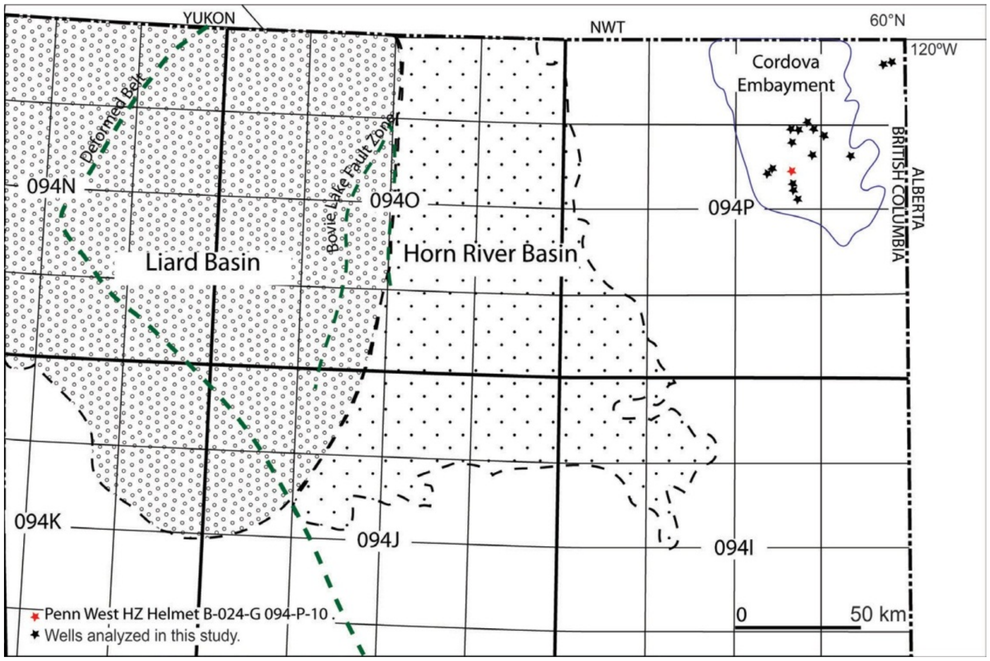

Figure 1. Location of the Cordova Embayment with respect to the Horn River and Liard basins of northeastern British Columbia. Locations of the 16 wells analyzed in this study are shown as stars (outline of the Bovie fault modified from MacLean and Morrow [2004]; outlines of the Liard Basin, Horn River Basin and the Cordova Embayment modified from British Columbia Oil and Gas Commission [2010]).

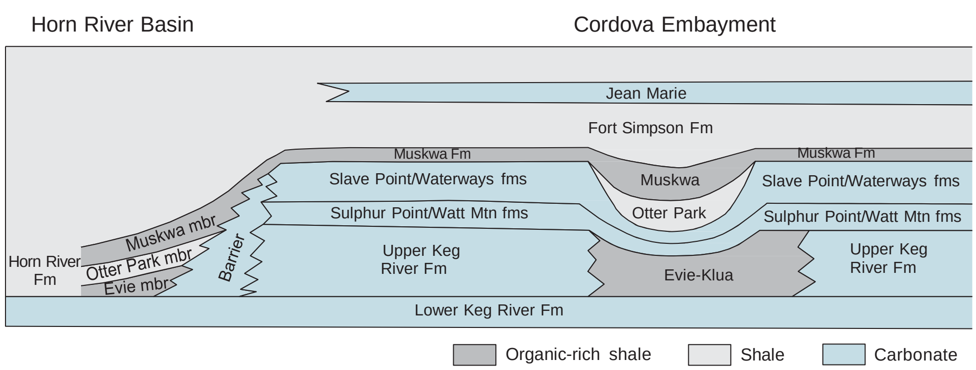

Figure 2. Middle to Late Devonian stratigraphic units within the Cordova Embayment and the adjacent Horn River and Liard basins (from Ferri & Griffiths, 2014).

During the Middle Devonian lowstand periods, shales were preferentially deposited in paleogeographic depressions of the Horn River Basin and the Cordova Embayment; hence, their boundaries are defined by a somewhat abrupt thinning and pinching out of these shale deposits (Fig. 2).

According to production data submitted to the British Columbia Oil and Gas Commission, between November 2007 and December 2013, 21 wells in the Cordova Embayment produced approximately 580.5 × 10^6 m^3 (20.6 BCF; billion cubic feet) cumulative gas from the Muskwa–Otter Park shales, with most of the production on record obtained from block G in NTS map area 094P/10. In May 2010, the Canadian Society of Unconventional Resources estimated the total gas in place for the Cordova Embayment at approximately 5665.6 × 10^{12} m^3 (200 TCF; trillion cubic feet; Dawson, 2010). From the viewpoint of exploiting these shale formations within the Cordova Embayment, the area contains a large number of wells and infrastructure that were used to develop the overlying Jean Marie Formation within the Helmet oil and gas field, which can enhance the cost-effective development of prospective shale formations within the Cordova Embayment.

THE Δ LOG R TECHNIQUE

In this study, the Δ log R technique established by Passey et al. (1990) is used to identify and estimate the amount of TOC contained in the Muskwa–Otter Park interval of the Cordova Embayment. This technique for calculating TOC is based on overlaying a correctly scaled porosity log on a resistivity log and interpreting the separation between the log curves. Passey et al. (1990) found that when correctly scaled transit-time (sonic) and resistivity log curves are overlain, they track (i.e., coincide) in fine-grained, water-wet, non-source rocks (Fig. 3). In organic-rich, fine-grained rocks, however, the curves will show a separation (termed Δ log R). The Δ log R curve separation in immature rocks is primarily a result of the deflection of the sonic log, when the inorganic rock matrix is replaced with low-density and low-velocity solid organic carbon. Upon maturation, the observed Δ log R curve separation is mainly attributed to the generation of hydrocarbons that replace water in the pore space of the rock, resulting in increased resistivity. The Δ log R log separation is used to predict TOC when the level of organic metamorphism (LOM), which is a linear index of organic maturity (Hood et al., 1975; Passey et al., 1990), is known.

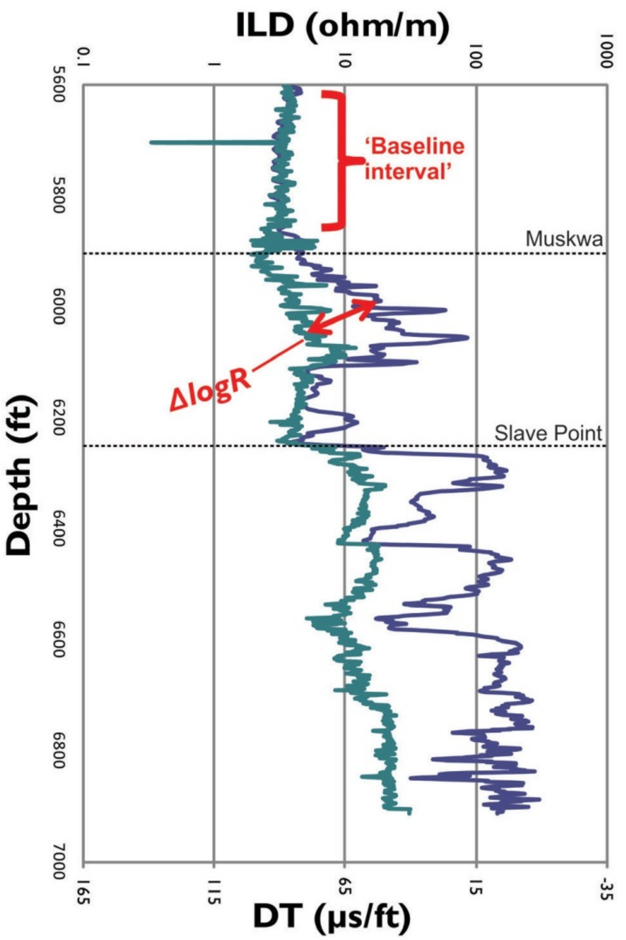

Figure 3. Sonic-resistivity overlay showing Δ log R separation in the Muskwa–Otter Park interval of the Chevron N Helmet C-074-B/094-P-10 well analyzed in this study. The scaling of the sonic (DT) to the resistivity (ILD) curve is 50 µsec/ft, corresponding to one decade of resistivity. The baseline interval is shown in nonsource-rock section of the log.

The following equations by Passey et al. (1990) were used in calculating Δ log R and estimating TOC:

$$\Delta \log R = \log_{10}(R/R_{baseline}) + 0.02 \times (\Delta t - \Delta t_{baseline}) \quad (1)$$

$$TOC = (\Delta \log R) \times 10^{(2.297 - 0.1688 \times LOM)} \quad (2)$$

where Δ log R is the separation of sonic and resistivity curves separation measured in log scale (resistivity cycles), R is the measured resistivity value obtained from the resistivity tool, Δt is the measured transit time values from the sonic log, $R_{baseline}$ is the resistivity corresponding to the measured $\Delta t_{baseline}$ and LOM is the level of organic metamorphism (after Hood et al., 1975).

In addition, structural and isochore maps of the Muskwa–Otter Park interval were made to reveal potential spatial relationships to TOC distribution within the Cordova Embayment and to constrain the spatio-temporal boundary of the reservoir.

RESULTS AND DISCUSSION

The Δ log R technique was used to estimate the amount of TOC for 16 wells with resistivity and sonic log curves, penetrating the Muskwa–Otter Park interval. Locations of analyzed wells are shown in Figure 1. For this analysis, the TOC for the Muskwa–Otter Park interval was estimated by using a LOM value of 11 for all the wells. This LOM value was chosen based on the consideration of available vitrinite reflectance data from Stasiuk and Fowler (2002; see Hood et al. [1975] for a vitrinite reflectance–LOM conversion table) and known hydrocarbon production from the interval. TOC data derived from Rock Eval™ were available for one of the wells analyzed in this study (Penn West HZ Helmet B-024-G 094-P-10) and were correlated with TOC values estimated from the Δ log R technique (calculated using LOM values of 11, 12 and 13) to illustrate how varying the LOM affects the value of the calculated TOC (Fig. 4).

For the Penn West HZ Helmet B-024-G 094-P-10 well, the log-derived TOC values calculated based on an LOM value of 11 are seen to provide the best fit with the TOC values derived from Rock Eval. In reality, the LOM can exhibit significant vertical variation (with depth/time); therefore, using a single LOM value for the Δ log R technique could result in inaccurate TOC values. The TOC derived from the Δ log R technique is very sensitive to the maturity of the shale (LOM) and, if incorrectly estimated, the absolute TOC value will be somewhat in error; however, the vertical variability in TOC will be correctly represented (Passey et al., 1990). Estimates of TOC calculated in this study are somewhat pessimistic because no background TOC value was added to the original TOC val-

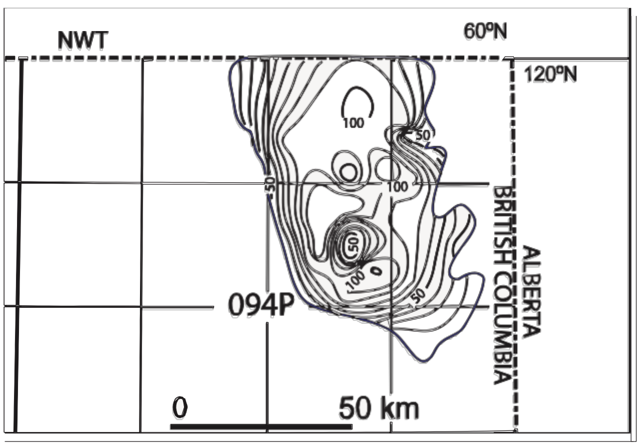

Figure 4. Isochore map of the Muskwa–Otter Park interval within the Cordova Embayment (contour interval = 10 m). A maximum thickness of 130 m for the Muskwa–Otter Park interval is observed around the centre of the Cordova Embayment.

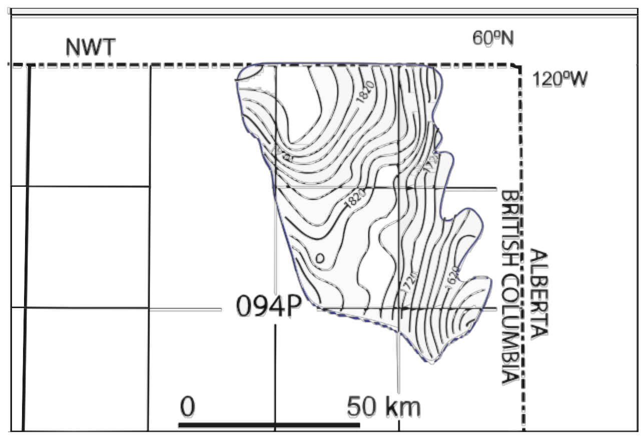

Figure 5. Structural map for the top of Muskwa Formation within the Cordova Embayment (contour interval = 20 m).

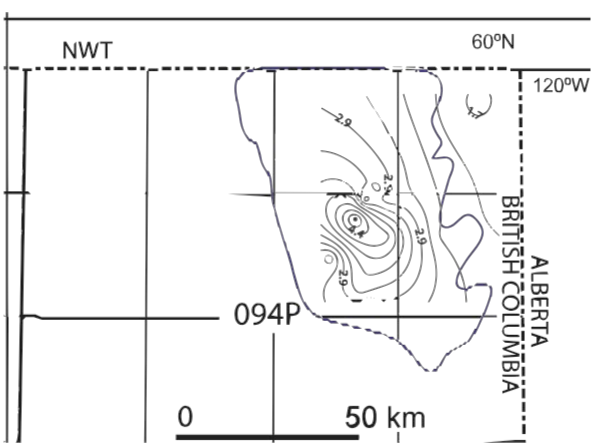

Figure 6. Maximum estimated total organic carbon (TOC) from the analyzed wells, calculated using the Δ log R technique (Passey et al., 1990) for the Muskwa–Otter Park interval (contour interval = 0.3 wt.%). Maximum calculated TOC within the Cordova Embayment is 5.1 wt.%.

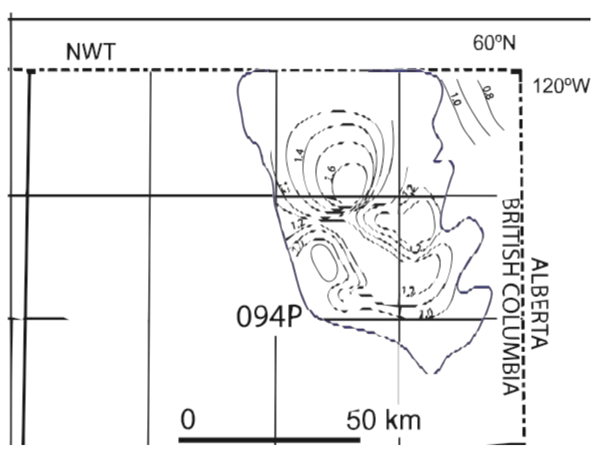

Figure 7. Average estimated total organic carbon (TOC) from the analyzed wells, calculated using the Δ log R technique (Passey et al., 1990) for the Muskwa–Otter Park interval (contour interval = 0.1 wt.%).

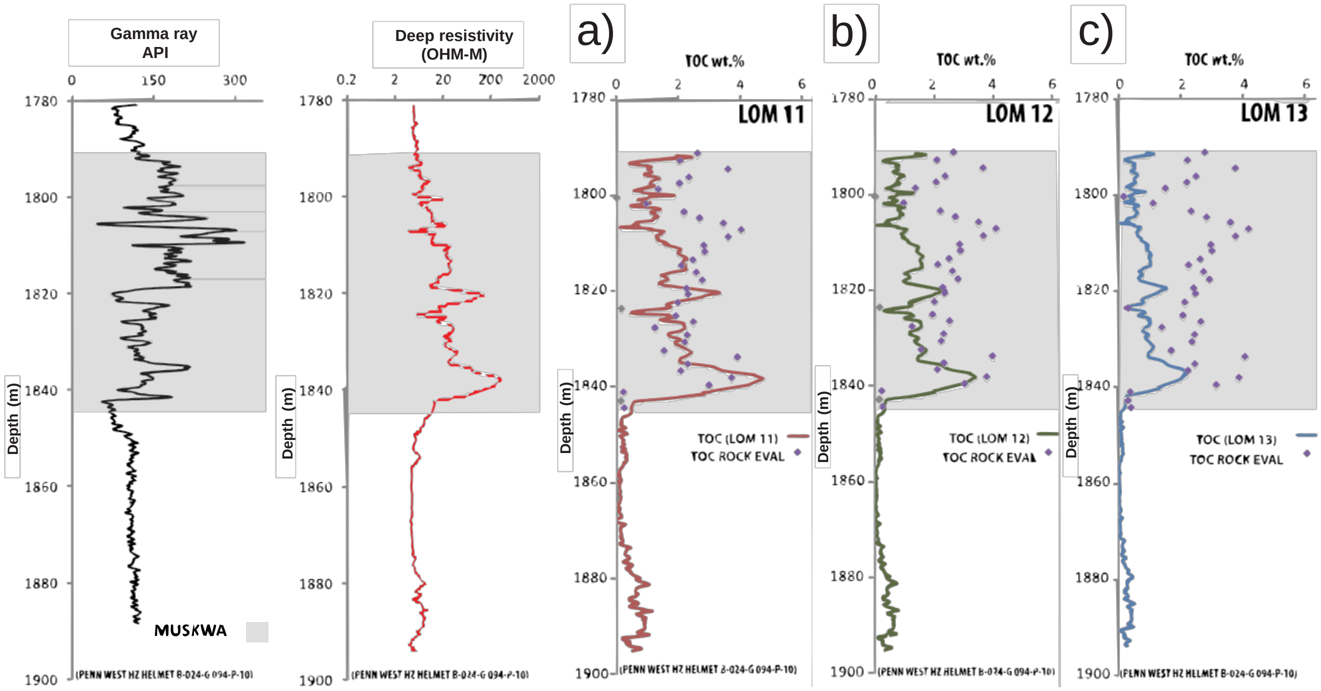

Figure 8. Log-derived total organic carbon (TOC) against TOC derived from Rock Eval™ for varying levels of organic metamorphism (LOM) for the Muskwa Formation: a) TOC calculated with LOM = 11 against TOC from Rock Eval; b) TOC calculated with LOM = 12 against TOC from Rock Eval; c) TOC calculated with LOM = 13 against TOC from Rock Eval TOC calculated based on an LOM value of 11 provides the best fit to the data obtained from Rock Eval. It should be noted that the Δ log R method (Passey et al., 1990) is very sensitive to the LOM value selected. In reality, LOM variation with depth (time) can lead to a poor correlation between the calculated TOC and the TOC measured from core samples. Gamma-ray and resistivity curves for the interval are displayed for comparison.

TABLE 1: SOURCE-ROCK EVALUATION CRITERIA BASED ON TOC VALUES (MODIFIED FROM MCCARTHY ET AL., 2011).

Source-rock quality	TOC (wt.%)
None	< 0.50
Poor	0.50–1.00
Fair	1.00–2.00
Good	2.00–5.00
Very good	> 5.00

ues computed using equations 1 and 2 above, which is common practice when using the Passey et al. (1990) method for estimating TOC.

For the wells analyzed, estimated maximum TOC content of the Muskwa–Otter Park interval ranges between 0.0 and 5.1 wt.% (for the individual wells, average estimated TOC within the interval ranges between 0.7 and 1.6 wt.%). It should be noted that the observed range in TOC content is a reflection of interbeds of less abundant organic-lean non-source rocks with the more prominent organic-rich source rocks of this Middle to Upper Devonian basinal shale unit.

Only estimated TOC values greater than 0.1 wt.% were used in computing the average TOC for the individual wells. In general, the estimated TOC profile through the Muskwa–Otter Park interval is observed to be higher toward the centre of the Cordova Embayment, in the area where the Muskwa–Otter Park interval is thickest, as observed in Figures 5 and 6. No clear relationship is observed between the isochore and structural maps for the Muskwa–Otter Park interval (Figs. 7, 8). A general thickening trend of the interval is observed toward the centre and away from the boundary of the Cordova Embayment in the direction of the British Columbia–Northwest Territories border, as observed in Figure 7.

CONCLUSION

Based on standard oil and gas industry criteria for rating source rocks (Table 1), the Muskwa–Otter Park shales in the Cordova Embayment mainly rank as fair to good source rocks, with few of the analyzed wells containing intervals with very good source-rock potential (> 5.0 wt.%). Considering the TOC content, the thickening trend of the Muskwa–Otter Park shales and current gas production from the interval (barring significant changes in the other reservoir properties of the shale unit within the Cordova Embayment), this basinal shale unit is likely prospective in the undeveloped parts of the basin trending northward toward the Northwest Territories. Data obtained from this study will form part of a larger resources assessment of shale formations (including the Evie/Klua shale) within the Cordova Embayment, scheduled to be completed by the summer of 2014.

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