Regional Evaluation of the Doig Formation Thickness, Organic Richness and Maturity

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Summary

The Doig Formation, which has been historically viewed as a source-rock for conventional reservoirs in the Western Canada Sedimentary Basin, has become the focus of industry attention due to its potential as unconventional gas and natural-gas-liquids reservoir. In this study, nearly 1500 pyrolysis data points from 200 wells, were generated, compiled and reviewed. Continuous TOC logs were calculated from well logs, using published methods with locally adjusted coefficients. Structural maps were created from almost 900 wells, and a gross isochore map was calculated. The TOC from well logs was used to generate average TOC maps for the entire Doig interval and thermal maturity maps were created from thoroughly reviewed T_{max} values. The 80% confidence interval for TOC lies between 0.8 and 4.8 wt.%. Kerogen type ranges from II, through II-III, to III. Thickness increases from the northeast to southwest, with an average gross thickness of 84 m. Areas of anomalous thickness in excess of 240 m are located in the central western portion of the basin and immediately southwest of a structural trough coincident with the Fort St. John Graben complex. Immediately adjacent to this trough, there exists a structural low where TOC values higher than the background values occur. Thermal maturity ranges from early oil window in the eastern and southwestern portions of the basin, through condensate/wet gas, and peak dry gas in the western edge against the deformation front. Approximately one third of the total gross rock volume of the Doig is within the condensate/wet gas window. With this preliminary assessment of the hydrocarbon potential of the Doig Formation, we hope to provide insights for evaluating the additional potential of currently developed areas and new prospects, as well as lay the groundwork for an ongoing petroleum system analysis which will incorporate a study of lithological and reservoir properties, production data and a reconstruction of thermal history through basin modeling.

Introduction

The Triassic Doig and Montney formations have been historically viewed as source-rocks for other conventional reservoirs in the Western Canada Sedimentary Basin (WCSB), mainly in other Triassic, and Cretaceous strata (Du Rochet, 1985; Creaney and Allan, 1990; Riediger et al.,1990; Edwards et al.,1994). With the increasing focus on hydrocarbons in mudrocks, the industry has become interested in the potential of the Doig as an unconventional gas and natural-gas-liquids reservoir. The Doig Formation of the WCSB is continuous across northeast British Columbia and central western Alberta, and has an estimated total gas in-place ranging from 1.1 to 5.6 trillion m3 (Walsh et al., 2006). Compared to the underlying Montney, the Doig is not as well studied and understood; and basin-scale studies that focus on the entire Doig succession and the regional variation in its properties, are scarce.

Method

For this study, a total of 252 cuttings samples from 24 wells distributed across the entire extent of the Doig Formation were analyzed by whole-rock pyrolysis for total organic carbon (TOC), temperature of maximum rate of hydrocarbon generation (T_{max}), and other standard pyrolysis parameters. Another 1200 pyrolysis analyses from 170 wells from the public domain were compiled and T_{max} values were thoroughly reviewed for consistency. Continuous TOC logs were calculated from compressional sonic slowness and resistivity logs for all the wells, according to the methods described by Passey et al. (1990) and Carpentier et al., (1991), or Δ log R and CARBOLOG® methods, respectively. Coefficients were adjusted iteratively to match the laboratory data. For Δ log R, baseline resistivity (R_b) and baseline slowness (Δ_{tb}) values chosen for non-source clay-rich rocks were 23 ohm.m and 52 µsec/ft, respectively; the level of maturity (LOM) was calculated as a linear function of depth of burial, and is between 2 and 8 in the region. For the CARBOLOG® method, the organic matter (ρ_{om}) and mineral matrix (ρ_m) densities were set as constants at 1.2 and 2.71 g/cm3, respectively; the organic carbon conversion factor (k) was determined empirically to be 1.25. Structural maps for top and base of the Doig were created from formation picks in scouting database of approximately 900 wells. A gross isochore map was calculated from the top and base. Maps of TOC from both methods used, as well as T_{max}, were created using simple regression kriging with experimentally derived variograms of search radii of 25 km and 100 km, respectively.

Results

The median TOC of the Doig is 2 wt.%, with P10 and P90 between 0.8 and 4.8 wt.%, respectively. Thermal maturity ranges from immature along the subcrop edge to overmature near the deformation belt, with hydrogen index (HI) of nearly 0 to almost 500. A broad range of HI was observed for similar Tmax values through the oil window, suggesting the existence of kerogen types II, through II-III to III. However, in the analyses conducted for this study, no type II kerogen was observed, which differs substantially from other studies that found mostly type II kerogen in the Doig (Riediger et al., 1990; Ibrahimbas and Riediger, 2004; Walsh et al., 2006). The quality of the match between the laboratory and log-derived TOC values was assessed by subtracting the latter from the former. A reasonably good match to laboratory TOC was obtained with both CARBOLOG® and Δ log R methods. However, CARBOLOG® yielded a better estimation, as evidenced by a smaller lab-log average difference and a smaller standard deviation (Figures 1A and 1B). The relative higher weight that resistivity carries in Δ log R caused it to overestimate TOC in beds where the vertical resolution was insufficient to resolve small-scale variations in TOC, and possibly in cleaner siltstones where migrated hydrocarbons increased the resistivity above the baseline (Figure 1C).

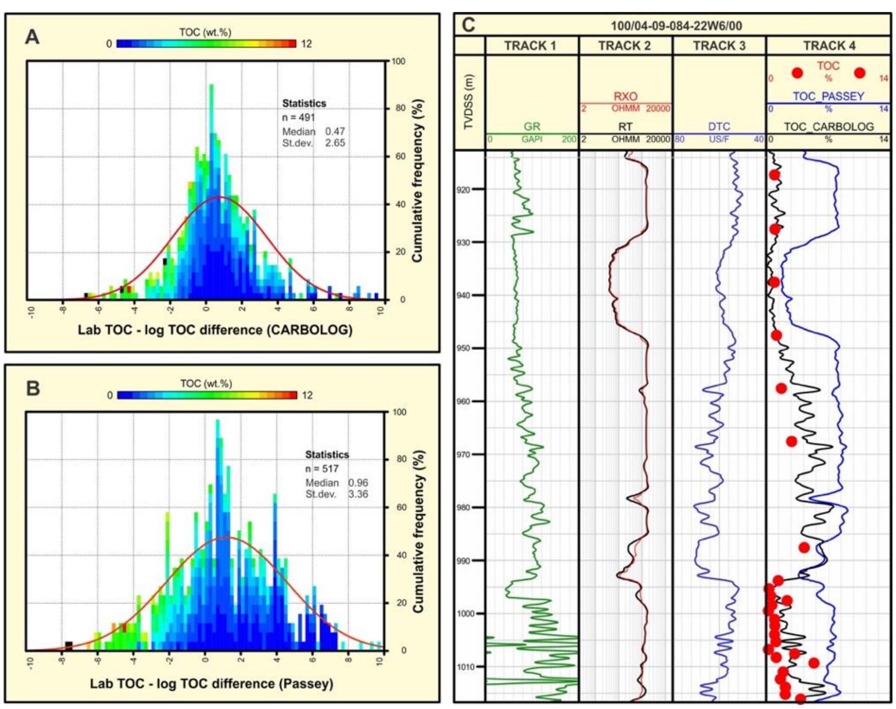

Figure 1 - Histograms of the difference between laboratory and log derived TOC values from both the CARBOLOG® (A) and Δ log R (B) methods; and example of the difference between both methods in a well log plot (C).

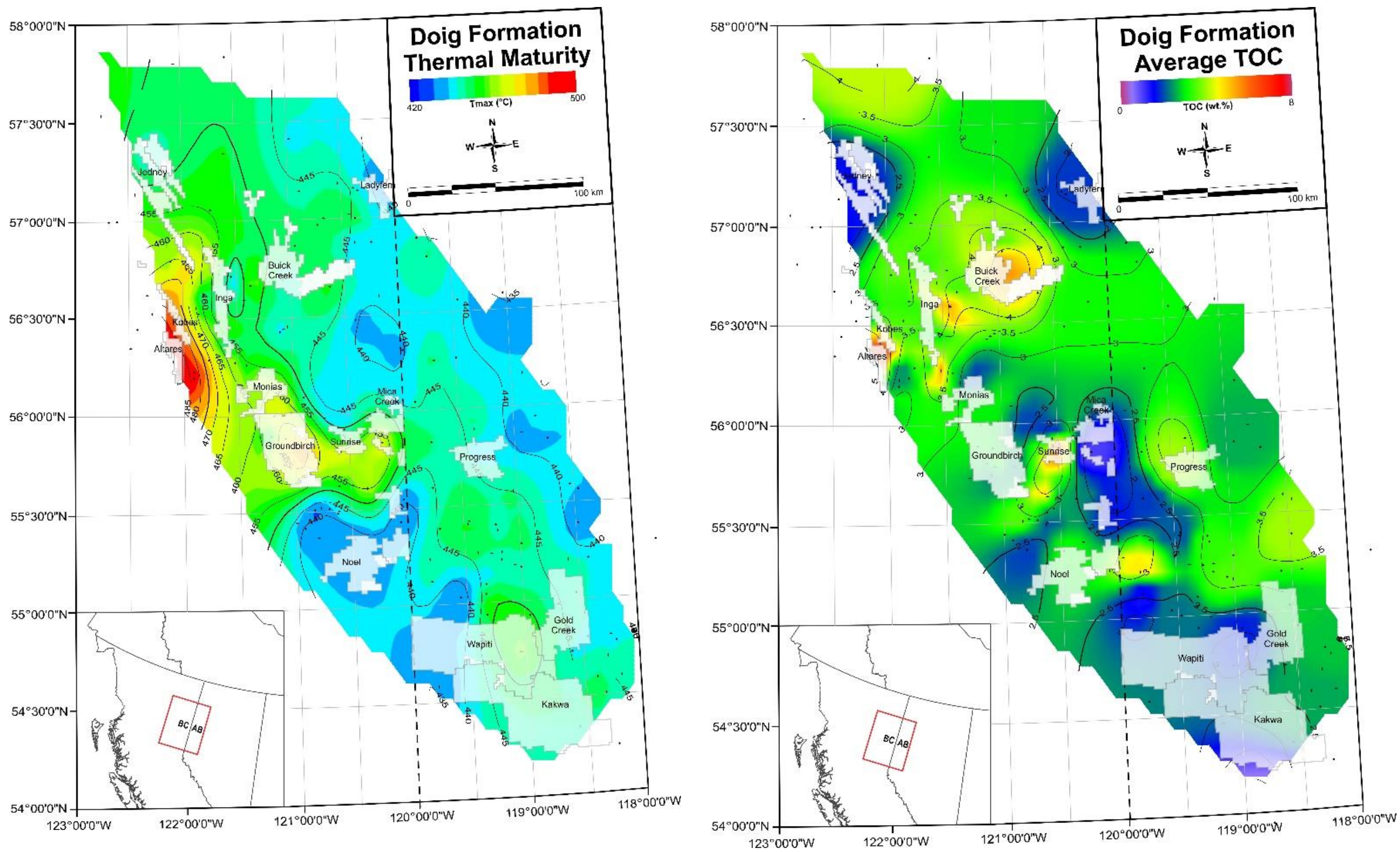

Figure 2 – Maps of thermal maturity (T_{max}) and average TOC (in weight percentage) of the entire Doig interval.

The average gross thickness of the Doig is 84 m, with P10 and P90 of 25 and 175 m, respectively. Thickness increases from the northeast to southwest, overall. Areas of anomalous thickness in excess of 240 m are located in the central western portion of the basin, around the Monias and Groundbirch fields. Thicknesses exceeding 160 m are found immediately southwest of a structural trough coincident with the Fort St. John Graben complex, aligned between the Progress and Noel fields. The average interval TOC map from CARBOLOG® has a background of 3% in weight, ranging from 1.2% to 7.5% in weight (Figure 2, left). Higher than background average TOC values coincide with the thicker areas on and immediately adjacent to the depression associated with the Fort St. John Graben. Another area of high TOC associated with a thick gross interval occurs on and around the Sunrise field, immediately east of the Groundbirch field. Elevated average TOC values are also observed near the Altares, Kobes, Inga and Buick Creek fields, without any association to anomalous thickness. The distribution of maturity ranges from early oil window in the eastern and southwestern portions of the basin, through condensate/wet gas, and peak dry gas in the western edge against the deformation front (Figure 2, right), according to the type II kerogen petroleum generation zones from Dow (1977). Although most of the area lies within the oil window, due to increasing thickness towards the west, approximately 34% and 5% of the total gross rock volume are within the condensate/wet gas and dry gas windows, respectively.

Conclusions

This preliminary assessment of the hydrocarbon potential of the Doig Formation provides insights for evaluating the additional potential of currently developed areas and new prospects, and will serve as the foundation for an ongoing petroleum system analysis incorporating an assessment of reservoir properties and a reconstruction of its thermal history through basin modeling. Maps of TOC, maturity and thickness used in conjunction highlight prospective areas for liquid-rich hydrocarbons. Ongoing work will improve on the quality of what has been presented here. Further subdivision of the Doig into Phosphate Zone and upper siltstone will highlight differences in thickness and TOC distribution of the more organic-rich basal interval. Log-derived TOC will be calculated for additional wells, creating a denser grid and improving the TOC map resolution and accuracy. Further assessment of hydrocarbon prospectivity will be made through total carbon thickness maps and integrating historic production data cross-correlated with maturity maps. The integration of production data is expected to provide insights on the influence of different kerogen types on the type of hydrocarbons generated. If there are multiple types of kerogen present in the Doig, as the data suggest, kerogen type will have to be taken into account when delineating liquid-rich areas. The mapping of lithofacies and reservoir properties will highlight relationships between rock types, kerogen type, TOC, paleo-topography and thickness.

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