Potential for Natural-Gas Liquid from Western Canadian Shales: Regional Variation in Thermal Maturity and Gas Composition, Northeastern British Columbia

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Introduction

Over the last thirty years a large volume of data has been collected on petroleum source rocks in Western Canada by government laboratories, university researchers and industry. The retained (nonmigrated) hydrocarbons in petroleum source rocks are now being exploited by horizontal drilling and fracturing as unconventional petroleum reservoirs. Much of the data collected for petroleum source-rock evaluation has new relevance for predicting the distribution and producibility of retained hydrocarbons referred to as shale gas and shale oil. As part of this study on predicting the distribution and producibility of liquid-bearing, fine-grained unconventional rocks (shales) in northeastern British Columbia (BC), new, publicly available data on maturity, source-rock properties and production are being compiled, and integrated with EXbase[1] data to map and predict the liquids-production potential of source rocks. The gaps in the datasets are being filled by data from additional sampling and analyses. The maps and related data in turn will be used to achieve the overall research goal of constraining petroleum-system models.

The present study builds on many excellent, previous studies and data compilations on source rocks in the Western Canadian Sedimentary Basin (WCSB) that have been produced to date. It is beyond the scope of this progress report to review all previous work and this task is reserved for a lengthier future contribution; this report only references papers of particular relevance to northeastern BC.

The variation in organic maturation and other source-rock properties in the WCSB occurs at multiple levels of hierarchy. The degree of organic maturation that governs hydrocarbon generation has been shown to occur at three such levels at least, referred to as 1st, 2nd and 3rd order variations by Bustin (1991). First-order variations that encompass the northeastern (Interior Plains) to southwestern (disturbed belt) region show an increase in organic maturity for all strata. This is a reflection of the overall westward thickening of the sedimentary prism, and hence depth of current and paleoburial. Third-order variations are local highs and lows (bull's eyes on maturity maps) thought to be due to faulting (in the disturbed belt), thermal anomalies and, in some areas, likely a lack of control. The most important and well-established 2nd order variations in maturity occur in the Peace River Arch of northeastern BC and adjacent parts of Alberta. In this area, it was documented early on (Karst and White, 1980) that there is a reversal in thermal maturity (coal rank) from the southwesterly trends of increasing maturity (1st order variation in maturity) to one of southwesterly decreasing maturity in northeastern BC and adjacent parts of Alberta. The importance of the reversal to oil exploration is that part of the WCSB succession in the deformed belt of northeastern BC is within the oil window rather than being overmature with respect to the oil window, and thus is prospective for liquid-hydrocarbon exploration.

This progress report presents updated mapping of the regional variation in organic maturity in northeastern BC and adjacent parts of Alberta. The maps are used to establish the spatial distribution of the oil window for specific horizons and to provide some initial results on the distribution of produced gas in the Montney Formation.

Methods

Publicly available data together with new information from analyses of cuttings and core samples taken from 125 wells in northeastern BC and adjacent parts of Alberta are used in this study. These samples were tested for maturation and typical source analysis by a combination of organic petrology and Rock-Eval–type pyrolyses. Handpicked mud-rock

[1] *EXbase is a proprietary historical database of mainly geochemical data.*

Keywords: *shale gas, shale oil, unconventional reservoir rocks, thermal maturity*

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chips were microscopically selected from cuttings samples for Rock-Eval and total organic carbon analyses. To date, about 3000 samples have been analyzed by Rock-Eval–type instruments (Espitalié, 1986), of which about 30% were either too mature and/or had S2 analyzer results that were too low to reliably determine maturity data. Vitrinite reflectance of handpicked coal fragments from cuttings samples was performed using well-established techniques.

To assess the potential effects of drying on vitrinite reflectance and Rock-Eval–type analyses of the cuttings samples (which is done routinely at the government storage facility and wellsite), outcrop samples of low maturation were previously run through the sample dryer used at the BC Ministry of Natural Gas Development sample-storage facility at Charlie Lake. No measurable change in T_{max} or vitrinite reflectance was detected that could be attributed to having dried the samples.

High-quality vitrinite reflectance data is limited to the major coal-bearing intervals of the Albian (Gates and Spirit River formations), as well as the Portlandian and Neocomian (Minnes Group and Nikanassin Formation). Vitrinite reflectance was measured on carbonaceous Mesozoic strata throughout the study area, and although these data are used to support the maturity data derived from T_{max}, neither their quality nor their quantity are sufficient for them to be considered separately. The T_{max} data used for preparation of the maps and cross-sections are based on trends from a series of sample analyses from specific wells (rather than single samples), since there can be considerable variation from sample to sample. Such variability is considered to reflect the compounded problems caused by cavings (since mainly cuttings were used), possible organic contamination from drilling fluids, variable kerogen types and instrumental variance.

Regional Trends in Maturity

The maturation data of surface exposures (Figure 1) for all analyzed horizons is generally consistent with northeastward-dipping isomaturity surfaces from the Interior Plains to the edge of the deformed belt, which mimics the current regional structure. Within the southwestern part of the study area, in the deformed belt, the isomaturity surfaces reverse and dip to the southwest and, where adequate data are available to allow validation, reverse once again to dip to the northeast. Superimposed on these regional trends are local highs and lows in maturity that define more complex patterns. Example isomaturity maps are presented here for select horizons only: Portlandian and Neocomian strata and the Upper Jurassic Gordondale Member (formerly the informal Nordegg member) of the Fernie Formation.

The maturation trends of Albian (not shown) as well as Portlandian and Neocomian strata (Figure 2) are similar, with the exception that the older strata have somewhat higher reflectance values (thermal maturity). Overall, on a regional scale, isoreflectance lines for both sequences parallel structural contours, which in turn parallel the northwest trend of the deformed belt. From northeast to southwest, maturation increases to maximum values at the eastern edge of the deformed belt, then decreases and, where adequate data exist to allow validation (for example in NTS 093P and 093O), increases once again. To the north-

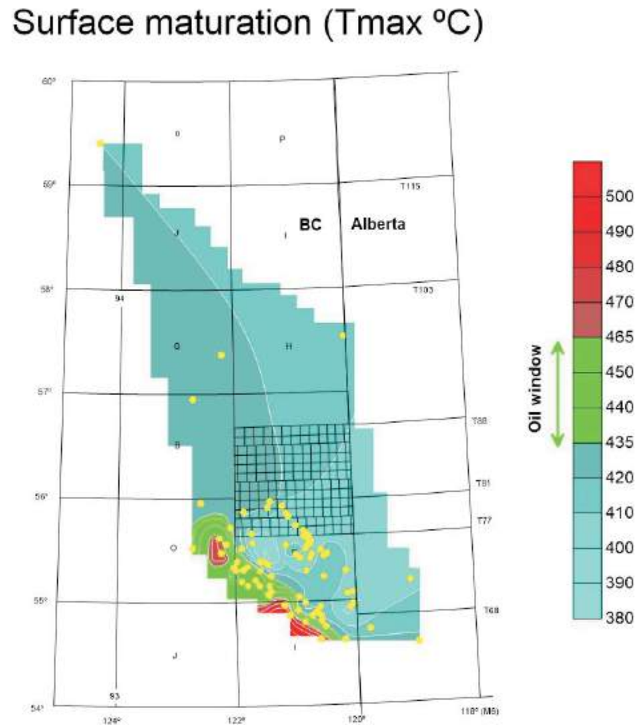

Figure 1. Isomaturity map of surface exposures, mainly in the northeastern British Columbia portion of the Western Canada Sedimentary Basin. Only the area up to the edge of the deformed belt is shown.

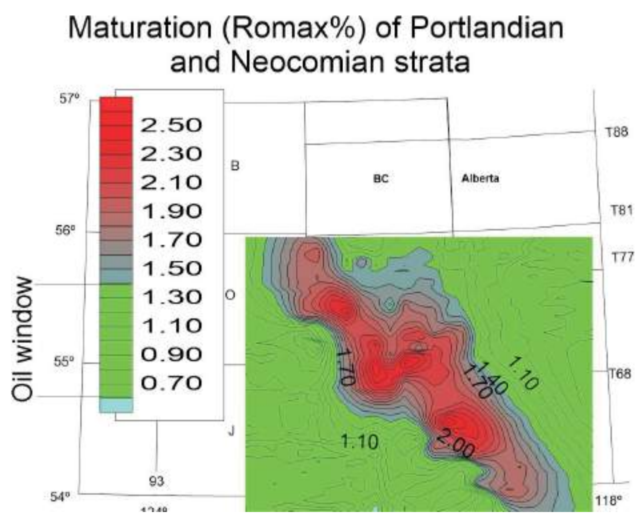

Figure 2. Isomaturity map for Portlandian and Neocomian strata in northeastern British Columbia. Contours are in % Ro_{max} from vitrinite reflectance.

west, maturation also decreases but not as markedly as the trends noted in the southwest. Superimposed on these regional trends are low-maturation lows and highs that form 'bull's eyes' on the isomaturation maps.

Regional trends in maturation for the Lower Jurassic Gordondale Member of the Fernie Formation (Figure 3) and other intervals (not shown) were based on T_{max} values from Rock-Eval–type analyses and corroborated by reflectance data collected from adjacent carbonaceous strata. In general, the maturation trends for both the Gordondale Member and Shaftesbury Formation (not shown) mimic those of the Albian as well as the Portlandian and Neocomian strata: isomaturation lines parallel structural contours, as well as the edge of the deformed belt, and the maturity initially increases toward the southwest, then declines. The trend is similar for the Gordondale Member. However, where data are available to allow validation, a second increase in maturity is evident.

Spatial Distribution of the Oil Window

Based on the combination of vitrinite reflectance and T_{max} data, the depth to the top (Ro = 1.35%; T_{max} 465ºC) and base (Ro = 0.65%; T_{max} 435ºC) of the oil window, as well as the thickness of strata within the oil window, have been mapped throughout the study area (Figure 4a, b, c). The depth to both the top and base of the oil window decreases to the southwest from the Interior Plains, toward the eastern edge of the deformed belt, and then increases in the deformed belt. This trend mimics the patterns shown on isomaturation maps of selected horizons outlined above. In the southeastern and northwestern parts of the study area, the top of the oil window occurs at depths ranging up to 1400 m (subsea), whereas to the southwest, the top of the oil window is missing (projected to be greater than 2600 m above sea level). The base of the oil window occurs at depths ranging up to 3500 m (subsea) in the southeastern part of the study area, is eroded in the southwestern part of the study area (projected to depth, thus about 1500 m above

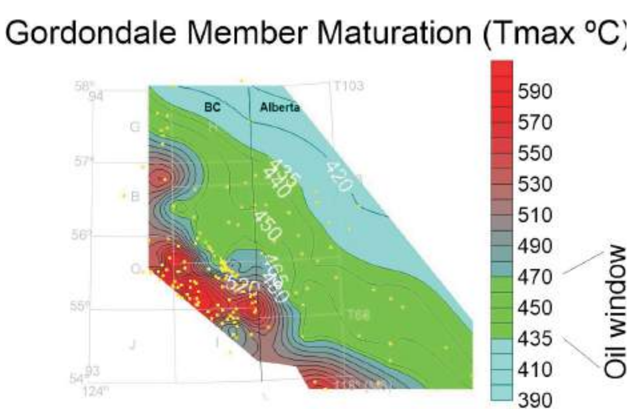

Figure 3. Isomaturity map for the Gordondale Member, in northeastern British Columbia, based on T_{max}°C data and corroborated by some vitrinite-reflectance data.

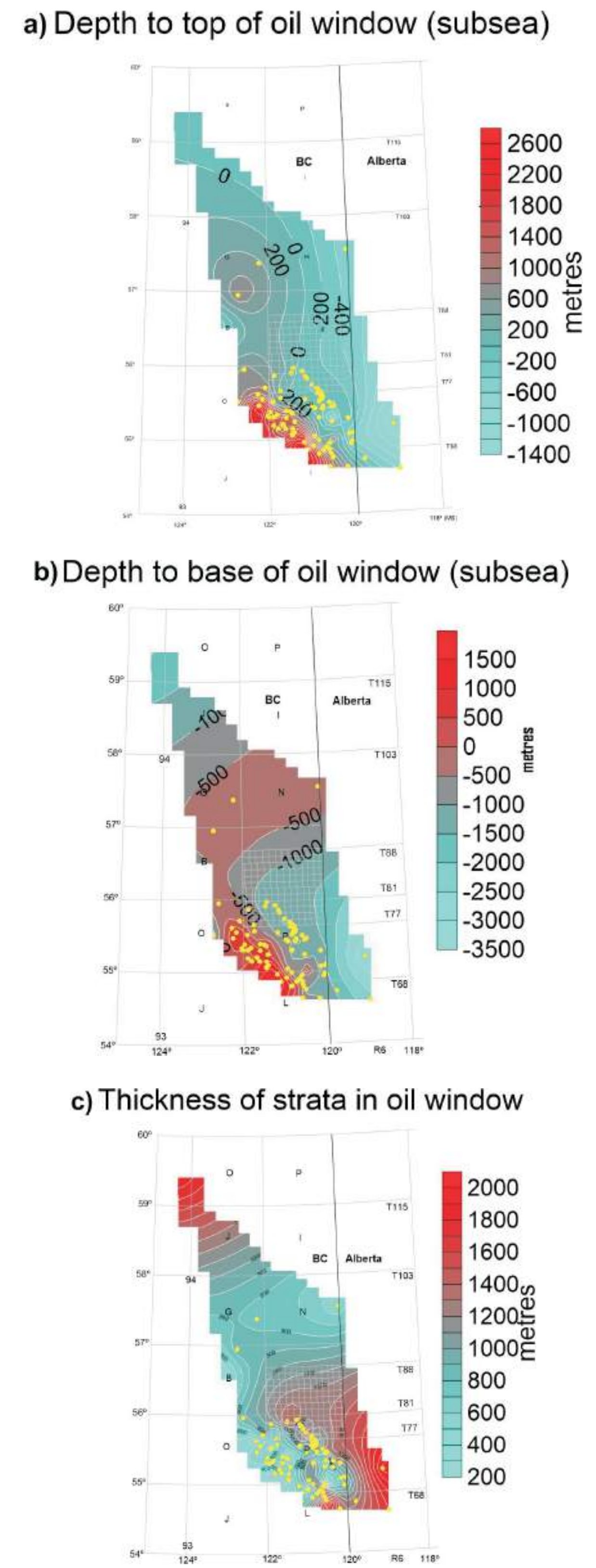

Figure 4. Regional maps, showing **a)** depth (subsea) to the top of the oil window; **b)** depth to the base of the oil window; **c)** thickness for strata within the oil window in northeastern British Columbia. These maps are based on the assumption that the oil window is invariant with kerogen type. Horizon-specific data needs to include consideration of kerogen type.

sea level), and initially decreases and then increases in depth toward the northwest. The thickness of strata within the oil window varies from 200 to >2000 m (Figure 4), with the thickest strata occurring in the southeastern and northwestern parts of the study area.

Montney Formation

As a result of the economic importance of the Montney Formation, a large number of wells cored in the formation have been tested over the last decade. Based on the integration of new data from this work, the thermal maturity of the Montney Formation is shown in Figure 5. Overall, maturity increases with depth of burial, but there is substantial variation that is at least partly attributable to varying paleogeothermal gradients, as determined from maturation gradients of individual wells (Bustin, 1991, 1999). The wetness of produced gas, as calculated from production tests (publicly available data), is mapped in Figure 6. On a regional scale, the degree of correlation between the variation in wetness and thermal maturity is as anticipated, with wetness initially increasing from northeast to southwest into the oil window and then decreasing at higher levels of maturity. The variation in hydrogen-sulphide content in produced Montney gas does not correlate with thermal maturity, depth of burial, or gas wetness and therefore requires further investigation.

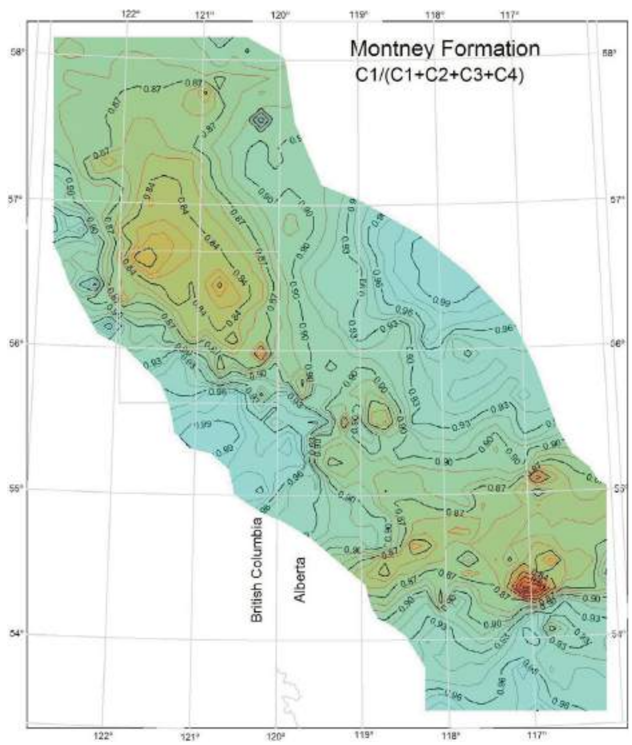

Figure 6. Gas wetness calculated using C1/(C1+C2+C3+C4), applied to gas hydrocarbons C1 through C4 (C1, methane; C2, ethane; C3, propane; C4, butane). The values are from analyses of samples collected in producing or tested wells in northeastern British Columbia.

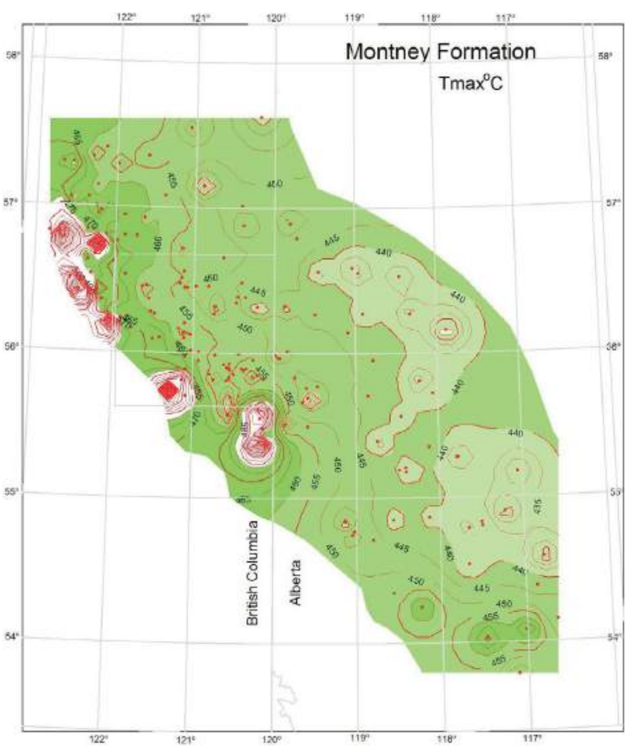

Figure 5. Regional thermal maturity of the Montney Formation, northeastern British Columbia, based on selective T_{max} values from Rock-Eval–type analyses. The lighter green corresponds to the early stage of the oil window and the darker green, to the last stage.

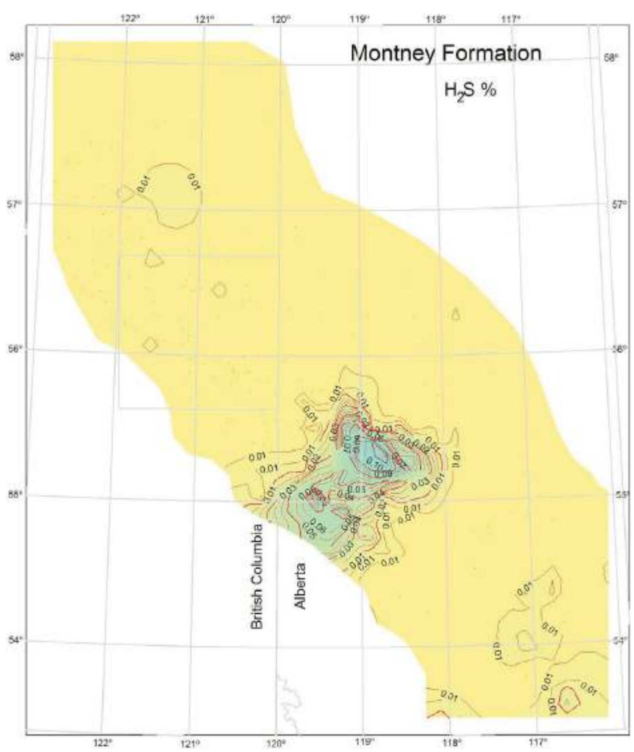

Figure 7. Distribution of hydrogen sulphide in Montney gas from produced or tested wells in northeastern British Columbia.

Summary and Conclusions

As part of this study on the resource potential for natural-gas liquid in northeastern BC, updated regional maps of thermal maturation, source-rock parameters and other relevant data are being produced. This mapping is based on the integration of a vast database of previous work by government, industry and researchers, and is augmented by new publicly available data and laboratory test results. The preliminary maps demonstrate at least three levels of hierarchy in thermal maturity and other parameters.

Acknowledgments

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