British Columbia Natural Gas Atlas

Final Report – January 2019

Prepared for: BC-OGRIS

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1. Executive Summary.

The British Columbia Natural Gas Atlas (BC-NGA) project was conceived to produce a comprehensive geochemical database on the molecular and stable isotope composition of natural gases from wells in Northeast BC (NEBC). In addition to working with existing data, the project also analyzed new gas samples collected in NEBC. A primary goal was to provide this gas geochemical information in a publicly accessible format. The project built on the Conventional Natural Gas Play Atlas (BC Ministry of Energy, Mines and Petroleum Resources, 2006) with the goal of generating an updated atlas that reviewed the existing data and added new natural gas data. The data collected in this study will be accessible from Geoscience BC's Earth Science Viewer platform.

The gas geochemistry, in particular the addition of the gas carbon isotope ratios, was used to provide a better understanding of gas characters and petroleum systems in the region. This work has numerous potential uses and impacts, including economic and environmental. Firstly, the compiled database offers a regional perspective on the range and distribution of natural gas types and sources in NEBC. It is important that BC has a current window into the geochemical nature of gas occurrences in the region, e.g., for inventory and planning purposes. The mapping of gas geochemical signatures from NEBC can be useful to elucidate trends and predict outcomes, e.g., discern regional or stratigraphic differences in gas types. Other applications include assisting operators in locating the source of the gas from leaky wellbores for remediation efforts. This work may also potentially help identify the source of fugitive emissions assessments, both in groundwater and airborne.

Initial outcomes of the BC-NGA indicate that there are important, yet sometimes subtle variations in the geochemical characters of NEBC natural gases. Clearly, the gases are dominated by thermogenic sources, with little indications of microbial gas. The exception are the mudgas samples, that are more challenging to characterize due to evidence of atmospheric contamination. A further finding is that some production gas samples may be affected by operations and well stimulation activities. The results of the study indicate that many of the standard interpretive approaches and diagrams support the overall thermogenic nature and restricted variation of natural gas signatures in NEBC. However, there are more fine-scale, sub-play geochemical structures, such as stratigraphic interpretation of gas sources and migration pathways in the WCSB, that can only be resolved with more detailed approaches. This project employed a suite of molecular ratio and multi-isotope cross plots (e.g., $\delta^{13}C_1$, $\delta^{13}C_2$, $\delta^{13}C_3$) advanced and developed during this project. Much of the interpretative aspects are contained in Evans (2019). The completed public database has now been used to create a suite of publically-accessible maps on www.bcnga.com.

2. Introduction.

Natural gas is a valuable commodity as a combustible fossil fuel (EnergyBC 2012). Natural gas is composed primarily of methane (CH_4 labelled C_1) with smaller amounts of ethane (C_2H_6 labelled C_2), propane (C_3H_8 labelled C_3), butane (C_4H_{10} labeled nC4), iso-butane (C_4H_{10} branching and labelled iC_4), and occasionally sour gas (hydrogen sulphide or H_2S) (e.g., Tissot and Welte 1984, Hunt 1996, Berkowitz 1997). Natural gas is one of the largest energy sources in BC (EnergyBC 2012), and primary unconventional gas production in British Columbia is from the Montney Formation (Hayes 2018, OGC 2018), and a large part of production growth (MEM 2013) includes the extension of the Montney Formation into Alberta (AER 2018, Davies et al. 2018). Currently, the drilling and production activity in the Montney has resulted in increased available data from this area; other large natural gas plays are currently distant from gas infrastructure (Hayes 2018, Adams et al. 2016), including the Horn River sub-basin (MEM 2011), Cordova Embayment (MEM 2015), and Liard sub-basins (Ferri et al. 2017).

The BC Ministry of Energy, Mines and Petroleum Resources natural gas atlas of NEBC *("Conventional Natural Gas Play Atlas",* MEM 2006a, b and c), required updating and had no uniform database of geochemical data. This project assessed geochemistry using the geologic framework of the MEM (2006) for stratigraphic classification.

3. Background.

Natural gas development has a history of over 60 years in northeast British Columbia. With the advent of new drilling and completion techniques, British Columbia is experiencing a natural gas development renaissance. Extensive production will be needed to support a nascent LNG industry on the west coast of British Columbia.

Although new wells are being drilled utilizing state-of-the-art completion methods and production equipment, there is still a concern that compromised surface casing cements, from pressure cycling during hydraulic fracturing, could be funneling fugitive gases into the atmosphere. There are also additional concerns of fugitive gas emissions from live and abandoned well bores.

The ability to identify a leaking gas source, through the use of carbon isotope geochemistry, has many benefits. In the case of a leaking wellbore, an operator can lower remediation costs, by having a high level of certainty as to the gas source, thereby allowing the operator to quickly and efficiently plan remediation of leaking wellbore. This same methodology could be used to remediate old abandoned wellbores – the methodology would allow the service company to pinpoint the horizon(s) which is (are) leaking, thereby reducing fugitive gas emissions. Being able to detect natural gas emitted from natural gas development is critical to responsible development of the resource, and the health of communities including First Nations. Additionally, being able to document naturally-occurring thermogenic sources of natural gas will be a critical first stage in the development of a monitoring network.

The detailed characterization of natural gases has valuable benefits to the industry operators. It potentially allows them to optimize the gas revenue stream by understanding where certain gas-types might be found.

The geochemical character of natural gas is dependent on many factors, including the composition of the source rock, reservoir rock types, burial histories, maturation, primary and secondary migration, and the trapping mechanism in a reservoir. The organic matter type and amount in the source sediments are the most critical factors. Burial history, including the selective removal of overburden, depressurization, and recent gas generation can also influence the natural gas composition.

4. Data.

Work on the BCNGA project started in late 2015. Unedited gas molecular composition data were downloaded from the BCOGC database and QA/QC'd into a representative dataset for regional mapping. Filtering data was based on factors such as geographical distribution, well type, de-clustering well-pads, making a representative point for horizontal wells, and grouping strata (Evans and Whiticar 2017, Evans, 2019). Some stratigraphic intervals retained almost all data points, while other intervals underwent strong filtering, particularly recent production intervals dominated by horizontal wells. Gas isotopic data is more recent, and sparsely distributed across a few geological formations. New correlation coding was completed where necessary. Almost all isotopic data that can be reasonably traced to original lab reports have been used. The study included the evaluation of more than 14,000 publicly available OGC records for previous molecular composition analysis on production gas. Wells and test intervals with molecular composition or isotopic data were compared against the geophysical logs publicly available from the BCOGC and new stratigraphic intervals were assigned where warranted. The original BCOGC formation codes have been retained for reference.

Part of the project including analysing new gas samples from the NEBC. In the first year of the project, over 100 mudgas samples and 30 production gas samples were submitted by four operators; approximately 30 mudgas samples were submitted by one operator in the second year of the project; the third year of the project had one operator submit one well with 25 isotubes of mudgas and 15 isojars of chips, both collected while drilling. A number of samples were sent to other labs for analysis and reported directly to BCOGC. This project used data both from samples sent to the University of Victoria for analysis, and results from samples sent directly to the BCOGC from other sources.

Public Data

The BC Oil and Gas Commission (OGC) was the primary source of the natural gas data summarized by the BC-NGA project. All the data submissions are archived on the OGC website (https://files.bcogc.ca/thinclient/Login.aspx). All data generated by the BC-NGA project are public data available through the OGC. In order to access the data, users must know the well application number (WA#). A map view of the data elements is available online from the OGC at: https://data-bcogc.opendata.arcgis.com/datasets/9149cb556e694617970a5774621af8be_0/data and details of further data access are posted on the main OGC website.

Over 14,000 records (i.e., sample entries) of gas composition (MC) data were downloaded from the OGC gas analysis database (Evans, 2019). The dataset was edited to 9,275 records of mappable location and stratigraphic combinations for the plays in NEBC. Each well location can have multiple test depths and thus a 3D picture of the geochemistry is preserved by data indexed to WA# in combination with the test depth and its associated stratigraphic formation. The database has each data record as a WA# and depth (but possibly multiple dates) and is represented by one record in the database. The 9,275 records were validated for correlation with the stratigraphy by a third-party contract (Evans and Hayes 2018). There are over 600 records of natural gas stable isotope ratio data (ISO) held by the OGC, which were merged with the BC-NGA data tables.

Gas Sample Analysis

New gas samples were submitted to the Biogeochemistry Facility at the School of Earth and Ocean Sciences, University of Victoria (BF-SEOS). Only sweet gas intervals were sampled by the operating companies. As the category of exploration wells requiring sampling by the regulations for isotope analysis was limited in number over the past three years, the project scope was expanded to include natural gas from commercial production activities (i.e., 'production gas'). A few of these samples had a very minor H_2S component. The usual HAZMAT shipping procedures were adhered to and the samples were stored in a secure safety facility for hazardous gases.

The analytical procedure for the stable isotope ratio measurements used was Continuous Flow-Isotope Ratio-Mass Spectrometry (CF-IRMS, Merritt et al. 1995, Whiticar and Eek 2001), also termed Compound Specific Isotope Analyses (CSIA, Hayes et al. 1989, Brand et al. 1994, Jochmann et al. 2006). The on-line CF-IRMS method starts with the gas mixture in the sample. It is introduced to a gas chromatograph and swept by helium carrier gas through a column to partition them into individual compounds. This was followed by combustion in an oxidation oven with combination of copper oxide / platinum wires at 870 °C. This combustion quantitatively oxidized the hydrocarbon gases to carbon dioxide and combustion water for each gas species eluting sequentially from the gas chromatograph column. The combustion water was removed by a Nafion™ trap and the combustion carbon dioxide was inlet on-line to the

IRMS where the isotopologues (masses of 44, 45, and 46) from each C_1 to C_3 hydrocarbon species were separated and individually quantified (e.g., Whiticar and Eek, 2001).

For light hydrocarbon molecular composition analysis, samples were injected into a Gas Chromatograph with Flame Ionization Detection to obtain C_1, C_2, C_3, nC_4, and iC_4 abundances (relative mole fractions as ppm C_1-C_4 hydrocarbons).

After completion of sample analysis, the results were compiled (e.g., Figure 14) and reported to the operating company who submitted it to the OGC. Additional samples were analyzed by other labs (e.g., AGAT, Maxxam, Weatherford, Isotech, GChem) with similar reports sent to OGC and held under the usual confidentiality period for the wells. All the reports were downloaded by BC-NGA and merged into the data compilation.

Data Validation

Data included in the BC-NGA project has some constraints, as reducing multiple data to one location was required for mapping; data was reduced by selection of the most representative data for each location. This process will be re-evaluated as the BC-NGA project continues, but it has the possibility of skewing the BC-NGA dataset.

For spatial assignment of data, the regional database is constructed around a well location that is the surface hole X/Y coordinates plus the Z as the measured depth (MD) along the wellbore path. This is not the true geospatial location as that needs to be calculated from the well elevation and deviation survey. In addition, the thickness of the test interval and/or bottom depth/location needs to be factored in to determine the location centroid. More detailed queries to locate specific data at sub-kilometer specific locations, should be referred to the well survey reports held by the OGC.

This spatial assignment reduced the deviated well bottom hole locations to a single pad location and thus the statistical weighting of hundreds of horizontal well bores having multiple test results from a single pad and/or motherbore, was reduced in the database to a few for each map location. Additional data filtering focussed on age and style of data collection (e.g., recent drillstem testing and metering station production gas was preferred to older 'casing gas' or 'unknown'). Obvious errors in the data (e.g., $\delta^{13}C_1$ for any type of reservoir gas having a positive isotope value) were communicated back to OGC for an update from the lab.

Data then underwent a validation assessment using a plot of C_1 (methane) in ppm vs C_2 (ethane) in ppm. This was used to assess for samples where the mudgas samples were strongly affected by contamination from the circulation of air and drilling fluids down the wellbore. As shown in the figure below, WA#26660 had a non-linear scatter pattern, indicating contamination of the sample. This well had no isotope data and was excluded from the study.

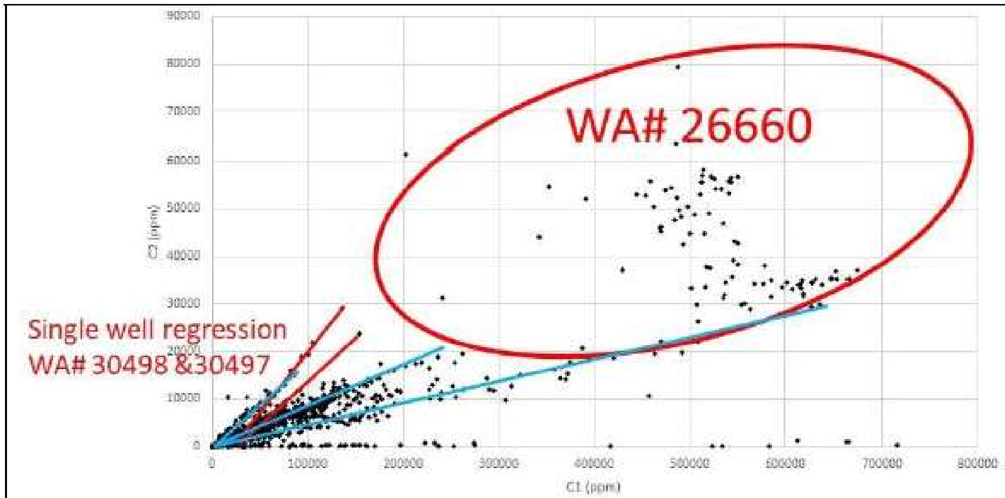

Figure 11. Plot of C_2 (ppm) vs C_1 (ppm) for all profile data (OGC+BF-SEOS) with highlighting for anomalies.

After it was determined that the sample was representative by having consistent internal trends in gas contents using typical plots, other data plots were used to determine if the gas source was microbial or thermogenic. The most common diagnostic tool for this determination is the CD Diagram (Figure 6, modified after Whiticar, 1999). Changes from kerogen to gas with different conditions of microbial or thermogenic activity (e.g., Tissot and Welte 1984, Rashid 1985, Hunt 1996) are also often expressed by the Bernard Diagram (Figure 5, Evans and Whiticar 2016a). These diagrams focus on natural gas source typing with distinction between microbial and thermogenic gases.

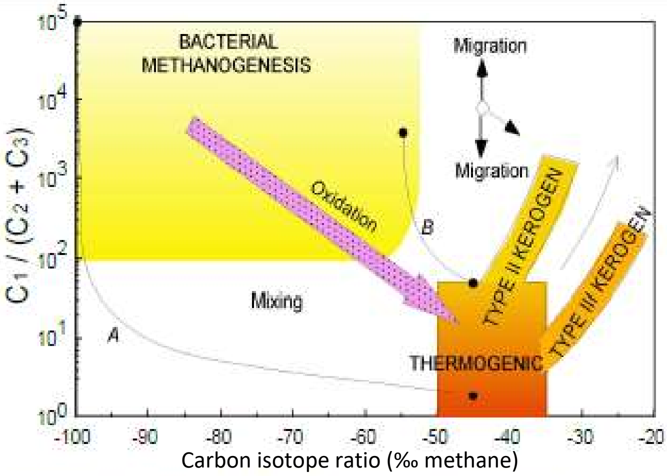

Figure 5. Template for Bernard Diagram (Whiticar, 2018 pers. comm., after Whiticar 1999).

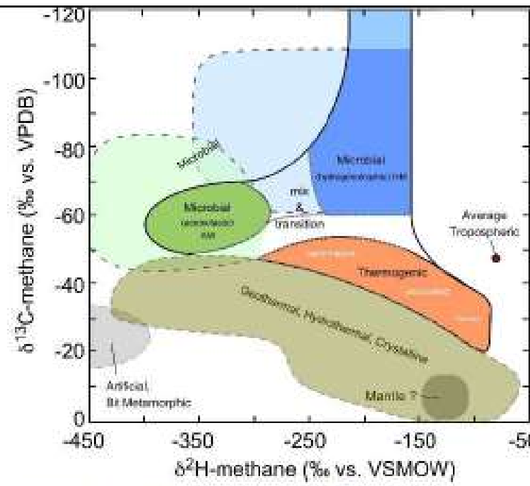

Figure 6. Template for CD Diagram (Whiticar, 2018 pers. comm., after Whiticar 1999).

Further geochemical analysis was completed using additional plots, such as the Berner-Faber diagrams of $\delta^{13}C_1$ vs $\delta^{13}C_2$ and $\delta^{13}C_2$ vs $\delta^{13}C_3$, templated for which are shown in Figures 7 and 8 (Whiticar 1990, 1994, 1999), respectively; these plots include Type II and III kerogen lines (after Berner and Faber 1988, 1996) plus the thermal maturation of the kerogen. Details of these interpretations are contained in Evans (2019).

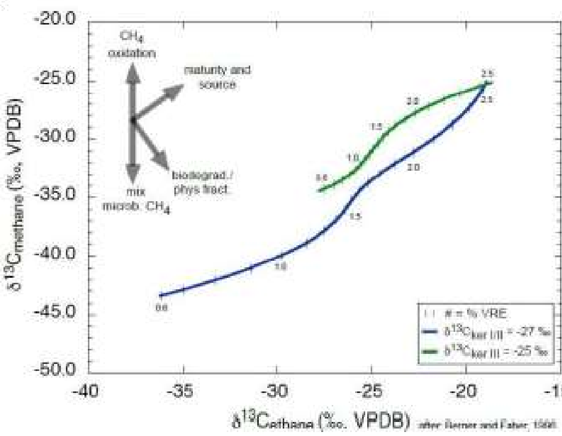

Figure 7. Template for $\delta^{13}C_1$ vs $\delta^{13}C_2$ diagram (Whiticar, 2018 pers. comm., after Berner and Faber 1996).

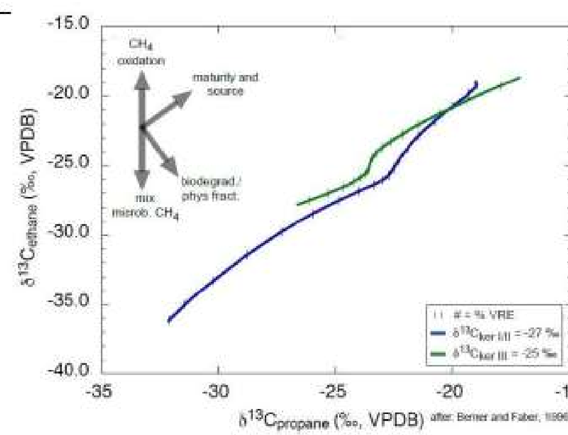

Figure 8. Template for $\delta^{13}C_2$ vs $\delta^{13}C_3$ diagram (Whiticar, 2018 pers. comm., after Berner and Faber 1996).

The inclusion of the plot $\delta^{13}C_2$-$\delta^{13}C_3$ versus molecular ratio of C_2/C_3 (Lorant Diagram, Figure 10, Prinzhofer and Battani 2003) enhanced the interpretation of petroleum system processes along with a plot of molecular ratios C_2/C_3 versus C_2/iC_4 (Prinzhofer Diagram, Figure 9, Prinzhofer and Battani 2003) as an approach to further distinguish between microbial and thermogenic gases (Evans, 2019).

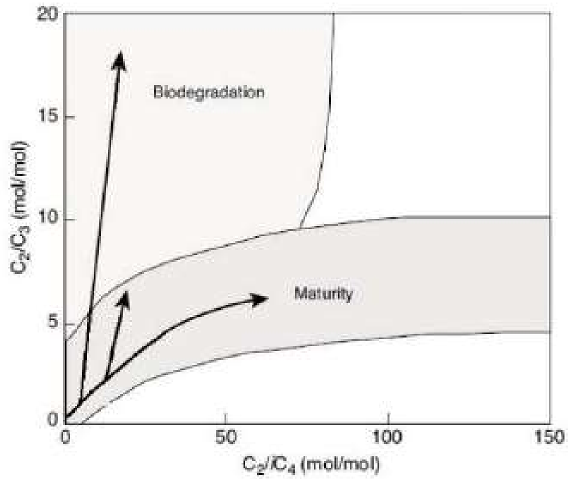

Figure 9. Template for Prinzhofer Diagram (Prinzhofer and Battani 2003).

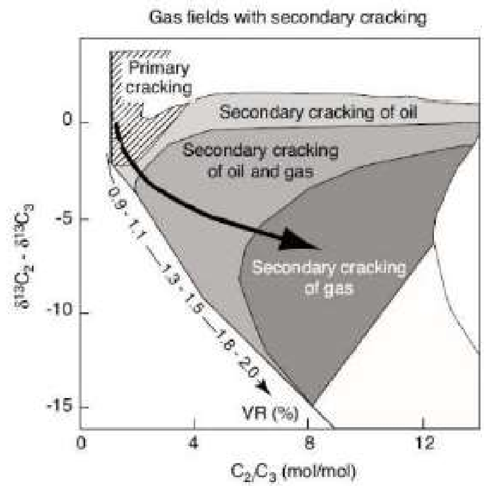

Figure 10. Template for Lorant Diagram (Prinzhofer and Battani 2003).

Although the use of carbon isotope data on carbon dioxide can be useful in some instances to characterize natural gases (Whiticar 1999), data exists for only one well profile (WA#32990).

5. Results and Discussion.

Data collected both from the OGC data, and the sample analysis conducted by the University of Victoria along with the maps will be posted on the www.bcnga.com site. The data has also been provided to Geoscience BC in tabular format and will be available through the Geoscience BC Earth Sciences Viewer (http://www.geosciencebc.com/s/WebMaps.asp) and on the project page hosted by Geoscience BC (http://www.geosciencebc.com/s/2015-013.asp) once the data is fully transferred and validated. This data is available for public usage, and the long-term hosting of the data will be secured over the next year.

Data analysis performed using the geochemical plots described in the previous section allowed the following conclusions:

1) mudgas sampling shows contaminant mixing of the gases with atmospheric circulation from the drilling process. Although undesirable, it is the standard for testing intermediate strata at this time. Correlating the mudgas results to reservoir gas testing from production gas samples is also problematic as production gas has similar data constraints with possible contamination from well stimulations, commingling, service injections, and swabbing.

2) Relying mainly on the isotope data for C_1 (methane) was inadequate to unambiguously characterize the natural gases; there was too much data variability for unique identification.

3) Isotopic data from ethane and propane provides better resolution of the thermogenic gas, as used in the plots of $\delta^{13}C_1$ vs $\delta^{13}C_2$ and $\delta^{13}C_2$-$\delta^{13}C_1$ vs iC_4/nC_4. The latter plot was particularly useful for gas specific characterization at the level of sidetracks on a horizontal well and may be useful for sub-play level characterization of natural gas in the future. The plots of $\delta^{13}C_1$ versus $\delta^{13}C_2$ and $\delta^{13}C_2$ versus $\delta^{13}C_3$ ('Berner-Faber Diagrams') have been useful for differentiating some plays.

4) Surface emission gases (primarily from Surface Casing Vent Flow) can often be identified as non-formation gases (sourced from a shallower unknown gas source) despite appearing as thermogenic on other characterization plots.

6. Project personnel.

Project personnel: Dr. Michael Whiticar (principal investigator), Dr. Sergei Verentich (laboratory technician), and Curtis Evans (M.Sc. student).

The project was supported by a Project Advisory Committee (PAC) designated by Geoscience BC and chaired by Carlos Salas (Geoscience BC) with members including Jeff Johnson (BCOGC), Matt Adams (Progress Energy), Randy Hughes (Painted Pony Petroleum), and Tony Cadrin (GCHEM).

7. Future work.

The project has been extended for a year in order to sample conventional wells and improve the regional coverage of the geochemical atlas.

8. Acknowledgements

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