Molecular Composition and Isotope Mapping of Natural Gas in the British Columbia Natural Gas Atlas

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Evans, C. (2019): Molecular composition and isotope mapping of natural gas in the British Columbia Natural Gas Atlas; *in* Geoscience BC Summary of Activities 2018, Geoscience BC, Report 2019-1, p. 77–84.

Introduction

Natural gas is a combustible fossil fuel of marketable value composed mainly of methane (CH_4). It is also a source for chemical derivatives such as feedstock to the plastics industry (Hunt, 1996). Natural gas emissions are a large component of the natural and artificial greenhouse gas budget (Whiticar, 1990, 1993; Khalil, 2000; Archer, 2009, 2010). The production of natural gas is a focus for economic development in the province of British Columbia (BC), including the development of liquefied natural gas exports (BC Ministry of Energy, Mines and Petroleum Resources, 2012a–c; BC Government, 2018; BC Ministry of Environment and Climate Change Strategy, 2018). In the last ten years, there has been a shift of commercial natural gas production in northeastern British Columbia (NEBC) to unconventional natural gas reservoirs (Hayes, 2018). These unconventional reservoirs can be hosted by a variety of stratigraphic formations and often require advanced completion technologies to yield economic volumes.

The British Columbia Natural Gas Atlas (BC-NGA) was initiated as a three-year project to collect samples and data on molecular composition (MC) and stable isotope ratio (ISO) geochemistry of natural gas (Evans and Whiticar, 2017) from wells in NEBC (Evans and Hayes, 2018, Figure 1). New analyses of the samples was undertaken by the Biogeochemistry Facility at the School of Earth and Ocean Sciences (BF-SEOS), University of Victoria, under contract with Geoscience BC.

The primary objective of the project is the collection, interpretation and dissemination of data through a publicly accessible website. The resulting information would be synthesized into a series of maps and well profiles of MC and ISO data collected from gas tests, including mud gas collected during drilling. Many of the samples were collected as part of the regulatory requirements of the BC Oil and Gas Commission (2015, 2016).

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Background

A geological framework for NEBC, published as the Conventional Natural Gas Play Atlas (BC Ministry of Energy, Mines and Petroleum Resources, 2006a–c), formed the foundation upon which the geochemistry data from this project were correlated (Evans and Hayes, 2018), but it did not include any geochemistry data. The BC Oil and Gas Commission requires geochemistry data from natural gas wells in BC to be publicly available; there are hundreds of reports available via download from the BC Oil and Gas Commission's website. A consolidated Geoscience BC database is planned to facilitate the dissemination of data from this project.

The study area is in NEBC and is part of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994). The sedimentary rocks form a thick stratigraphic package spanning thousands of metres of thickness and hundreds of millions of years. Within this stratigraphic column are hydrocarbon reservoirs that have been developed as a source for oil and gas production (BC Ministry of Energy, Mines and Petroleum Resources, 2006a–c). New unconventional hydrocarbon targets have been identified: the Horn River subbasin (BC Ministry of Energy, Mines and Petroleum Resources, 2011), the Montney play (BC Oil and Gas Commission, 2012; BC Ministry of Energy, Mines and Petroleum Resources, 2013a), the Cordova Embayment (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2015) and the Liard sub-basin (Ferri et al., 2017).

Natural gas is predominantly methane (CH_4, labelled C1) with smaller amounts of ethane (C_2H_6, labelled C2), propane (C_3H_8, labelled C3), butane (C_4H_{10}, labelled nC4), isobutane (C_4H_{10}, branching and labelled *i*C4) and often sour gas (hydrogen sulphide or H_2S). All sedimentary strata in NEBC contains organic material of some form and concentration, which has been the source for much of the natural gas. These gases are, by definition, biogenic, because they are sourced from organic material irrespective of microbial activity or thermogenic processes. Biogenic natural gas can be divided into two subcategories: microbial natural gas, which is gas sourced from organic activities, and thermogenic natural gas, which is gas produced by buried organic material altered by both pressure and temperature.

Interpreting isotopic data of hydrocarbon compounds as the ratio of the stable isotopes of $^{13}C/^{12}C$ and $^{2}H/^{1}H$ provides an indication of petroleum source and migration (Tissot and Welte, 1984; Rashid, 1985; Hunt, 1996). These data are visually presented in the form of Bernard and CD diagrams (e.g., Evans and Whiticar, 2016), crossplots (δ^{13}C1 versus δ^{13}C2; δ^{13}C2 versus δ^{13}C3; after Whiticar, 1999), plus Lorant and Prinzhofer diagrams (Prinzhofer and Battani, 2003).

The use of basic software is intentional. Using off-the-shelf software on a laptop was intended to demonstrate that not only the data are accessible for everyday users, the interpretation also does not require sophisticated hardware or software.

Data Sources

Gas samples from the petroleum industry gas wells were collected by an operating company and sent to the BF-SEOS for MC plus ISO analysis. The results were reported to the operating company with the understanding that a report would be submitted by them to the BC Oil and Gas Commission. Parallel analyses were completed by other labs with results sent to the BC Oil and Gas Commission and held under the confidentiality period for the wells. During 31 months, just less than 200 gas samples from mud-gas on three wells and production gas from 20 wells were submitted to BF-SEOS. Table 1 lists the samples submitted and the sample count.

Data Analysis and Results

The first step in the analysis was to confirm that the samples were representative of the reservoir fluids and not affected by more recent microbial or thermal exposure. Anomalous trends were determined and flagged as possible problem locations, but none of these map points or well profiles had isotopic data associated with them. Mud-gas samples were assumed to be a representative indication of the reservoir isotopes (Tilley and Muehlenbachs, 2006, 2013), despite inherently being contaminated by the atmosphere while drilling. Data previous to this study (Tilley and Muehlenbachs, 2013; Norville, 2014) have not been submitted to the BC Oil and Gas Commission.

Data collected and analyzed are geographically widely variable due to the specific focus of exploration and development activities undertaken by oil and gas companies. As such, widespread contouring of data presents specific problems due to data clustering and gaps. As a result, it was decided to avoid data contouring and instead use only representative 'coloured pins' to post raw data on the maps. These maps are available on the Geoscience BC website (http://www.geosciencebc.com/s/2015-013.asp). Detailed gas composition profiles will be presented in the author's thesis (Evans, 2018). Figure 1 shows a detailed gas composition profile for well with well authorization (WA) number 32990 (YOHO HZ INGA 11-24-087-24, unique well identifier [UWI] 00/11-24-087-24W6/0).

Figure 2 is a crossplot (after Whiticar, 1994; after Tilley and Muehlenbachs, 2013) for the example well profile (WA#32990) by the BF-SEOS. Many of the deeper samples shift 'downward' on the graph to isotopically ^{13}C depleted methane.

The isotopic shift of δ^{13}C1 (methane) in hydrocarbon-bearing horizons has been observed in other samples as well. Figure 3a and b are crossplots of all horizontal wells in the Montney play. There is a distinct shift in the apparent δ^{13}C1 baseline away from the anticipated response of the kerogen in Figure 3a (δ^{13}C1 versus δ^{13}C2), whereas the δ^{13}C2 and δ^{13}C3 appear to be within normal distribution of the kerogen in Figure 3b (δ^{13}C2 versus δ^{13}C3; after Whiticar, 1994). The new data from BF-SEOS and the Montney play data plot off trend of the data from similar diagrams (Tilley and Muehlenbachs, 2013). If this is an indication of a consistent kerogen shift, the previously used Bernard and CD diagrams for NEBC (e.g., Norville, 2014) should be adjusted. Further analysis using nitrogen and helium data (e.g., Whiticar, 1994) should be undertaken.

Table 1. List of gas samples submitted to the Biogeochemistry Facility at the School of Earth and Ocean Sciences (BF-SEOS), University of Victoria, with new analyses completed for stable isotope ratio data. Abbreviation: SCVF, surface casing vent flow.

Operator	Number of production gas wells	Number of mud-gas wells	Number of samples	Well authorization number listed	Date received at the lab
Yoho Resources Inc.		1	32	32990 single	October 4, 2017
Suncor Energy Inc.	2		2	Two wells (samples from SCVF)	November 8, 2016
Crew Energy Inc.	2		3	30876 and 31960	October 28, 2016
Shell Canada	2		4	29926, 29921	July 19, 2016
Crew Energy Inc.	14		29	Multiple wells	June 7, 2016
Saguaro Energy Ltd.		1	61	30308 single	April 29, 2016
Chevron Corporation		1	55	29747 single	April 22, 2016

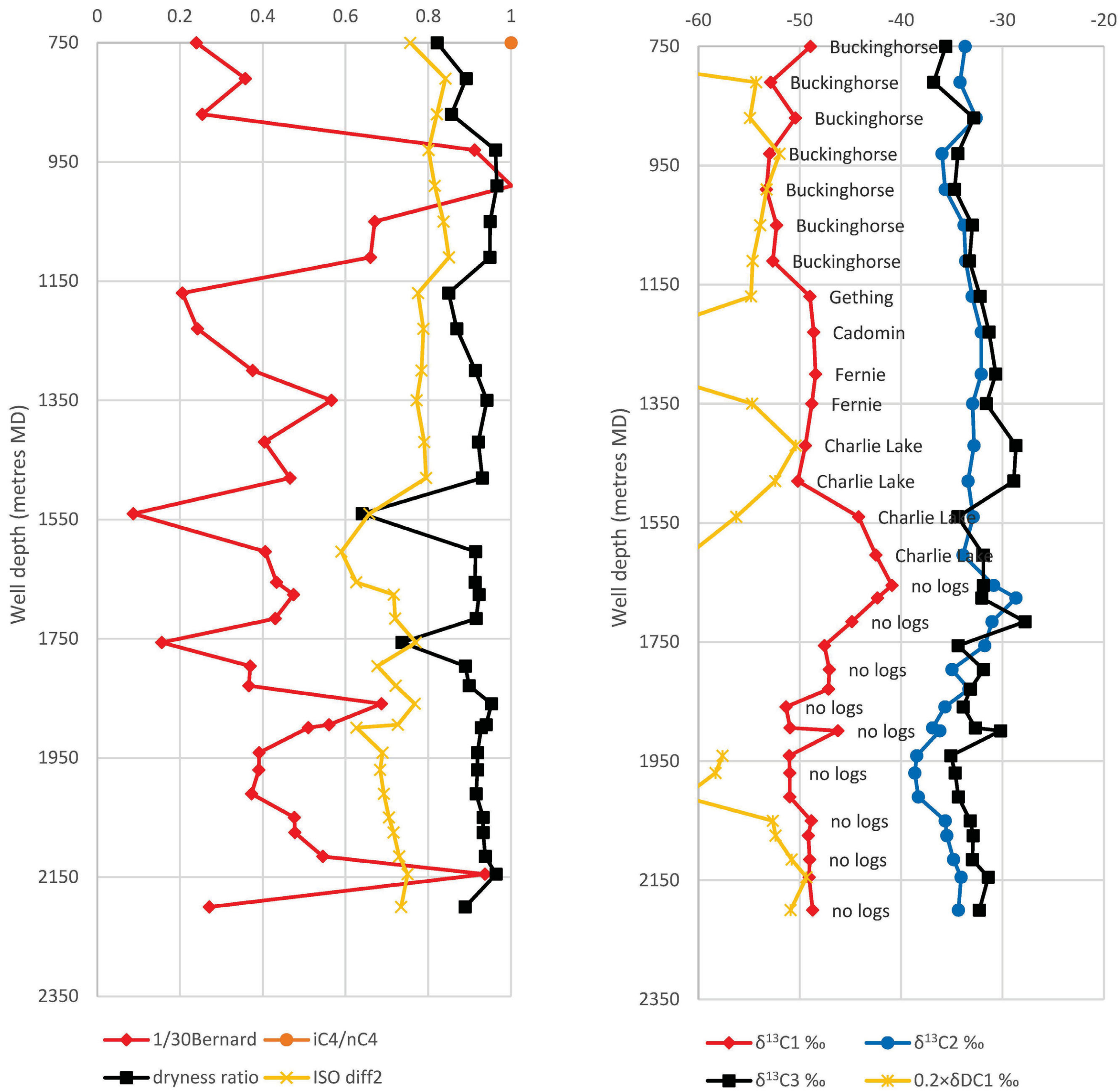

Figure 1. Well profile of molecular composition (MC) ratios and stable isotope (ISO) ratios in Upper Cretaceous to Triassic strata from vertical well WA#32990 (YOHO HZ INGA 11-24-087-24, unique well identifier [UWI] 00/11-24-087-24W6/0). There are no geophysical well logs taken for deeper horizons, but total depth was just below the Montney play. Abbreviations: Buckinghorse, Buckinghorse Formation; C1, methane; C2, ethane; C3, propane; *i*C4, isobutane; nC4, butane; Cadomin, Cadomin Formation; Charlie Lake, Charlie Lake Formation; D, deuterium; diff2, isotope difference ratio; Fernie, Fernie Formation; Gething, Gething Formation; MD, measured distance along well bore; WA, well authorization.

If analysis of postmigration methane generation by Wood and Sanei (2016, cited in Evans and Hayes [2017]) is consistent with results from this study, another interpretation technique using the Lorant and Prinzhofer diagrams (Prinzhofer and Battani, 2003) is required to explain this variation. The Prinzhofer diagram (Figure 4a) is only based on molecular composition as a crossplot of ratios (C2/C3 versus C2/*i*C4), but it illustrates a trend toward thermogenic processes. The Lorant diagram (Figure 4b) is an expression of an isotopic difference (δ^{13}C2–δ^{13}C3) compared to a molecular composition ratio (C2/C3) and infers that 'secondary cracking of oil and gas' is the dominant process. The trend to having migrated oil undergoing secondary cracking to methane may explain the shift downward to lighter kerogens that was originally seen in the BF-SEOS results for well WA#32990 (Figure 5a, b). A further extrapolation to secondary cracking of gas may be assumed from the last data point (Figure 5b).

Further evaluation is required for data on the stable isotopes of carbon, and possibly hydrogen if available, from the kerogens and pyrobitumens of NEBC.

Future Work

Geoscience BC has extended the BC-NGA project as a result of anticipated increased industry activity planned for new wells and sampling of production gas. Additional samples are expected in the next few months and recent analysis is already requiring integration. Further work is planned for increased analysis of individual segments of the well profiles, analysis for kerogen isotopes and new reporting on enhanced findings.

Conclusions

Much of the details of the three-year study are contained in the author's thesis, which was a requirement of BC-NGA. Maps of each play will be one of the primary products, but

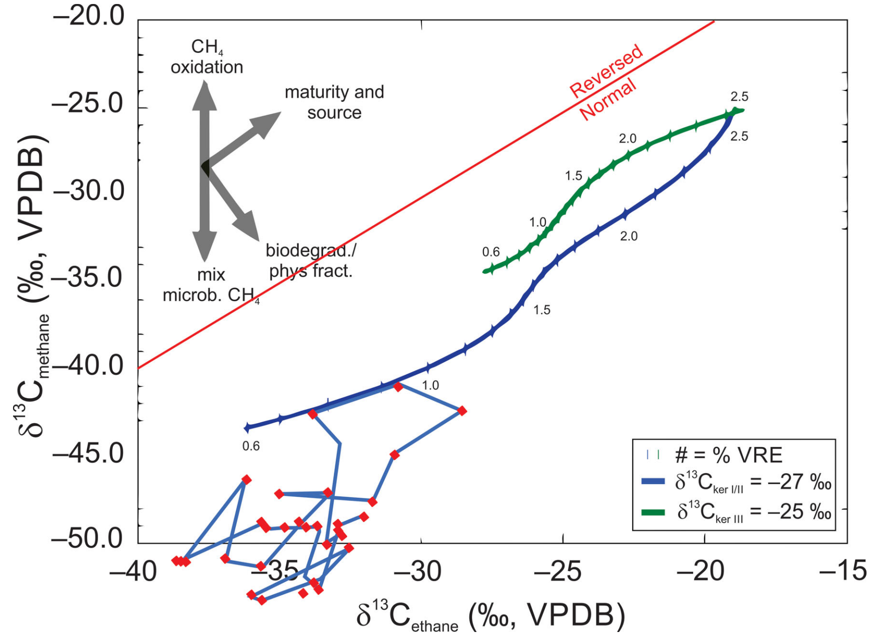

Figure 2. Crossplot of δ^{13}C1 versus δ^{13}C2 for well WA#32990 (YOHO HZ INGA 11-24-087-24, unique well identifier [UWI] 00/11-24-087-24W6/0), after Berner and Faber (1996). Abbreviations: biodegrad., biodegradable; ker, kerogen; microb., microbial; phys. fract., physical fraction; VPDB, Vienna Pee Dee Belemnite; VRE, vitrinite reflectance equivalent; WA, well authorization.

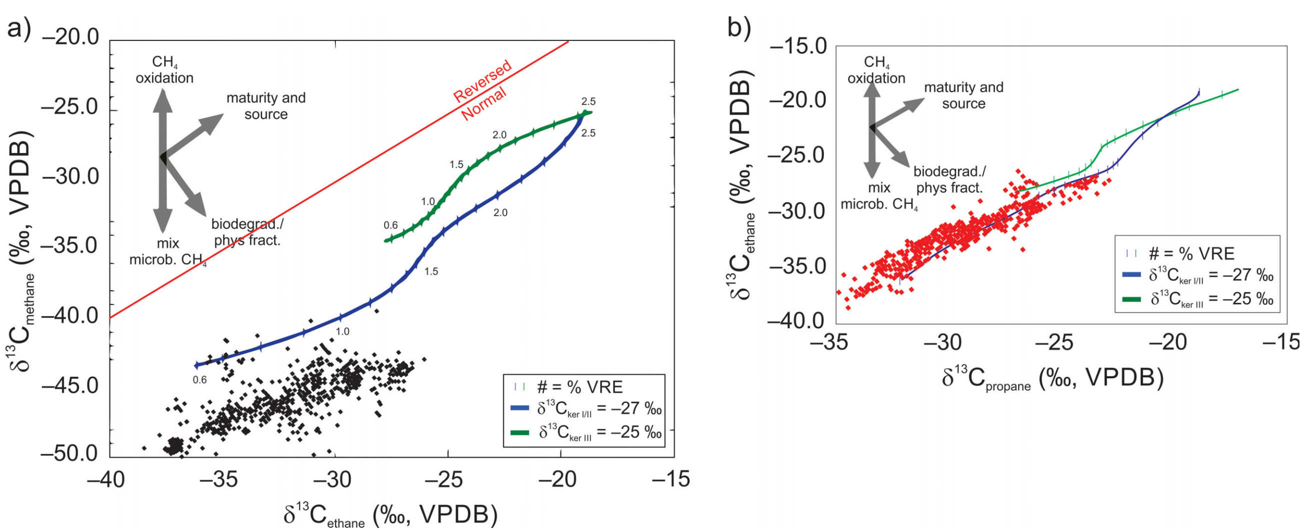

Figure 3. Crossplots of **a)** ^{13}C1 versus δ^{13}C2 and **b)** ^{13}C2 versus δ^{13}C3 for all horizontal wells in the Montney play, after Berner and Faber (1996). Abbreviations: biodegrad., biodegradable; C1, methane; C2, ethane; C3, propane; ker, kerogen; microb., microbial; phys. fract., physical fraction; VPDB, Vienna Pee Dee Belemnite; VRE, vitrinite reflectance equivalent.

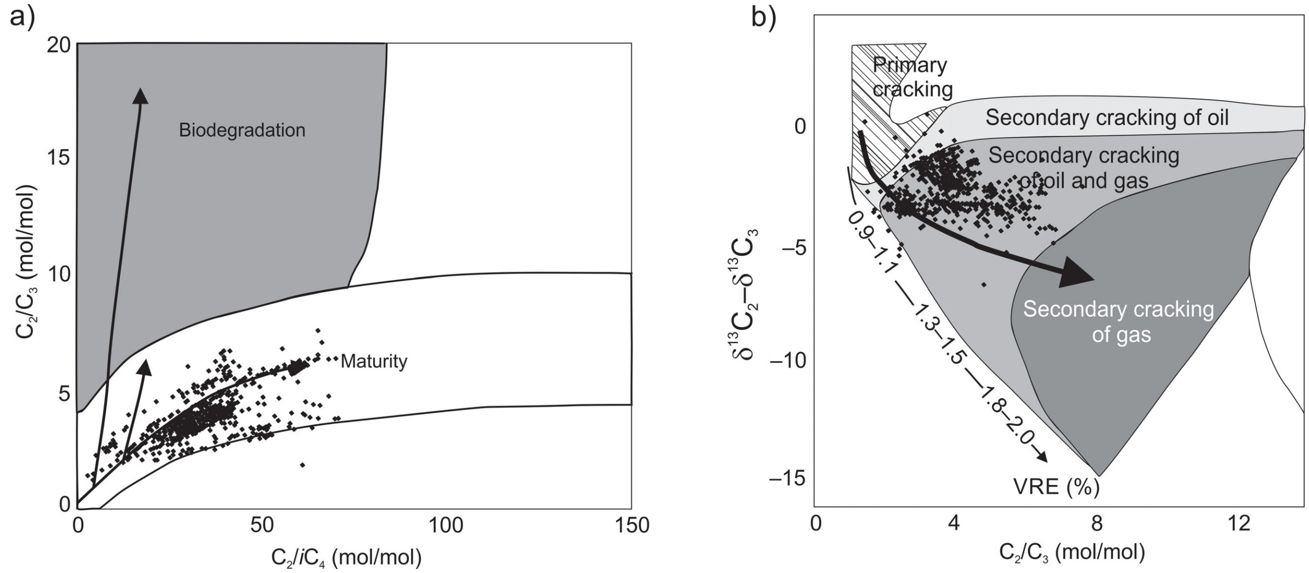

Figure 4. a) Prinzhofer C2/C3 versus C2/*i*C4 and **b)** Lorant δ^{13}C2–δ^{13}C3 versus C2/C3 diagrams for the Montney play horizontal profiles. Almost all Montney play gas is secondary cracking of oil and gas, but there are three separate paths of cracking that occur along some of the profiles. This requires further study as most data is from horizontal wells. Abbreviations: C2, ethane; C3, propane; *i*C4, isobutane; VRE, vitrinite reflectance equivalent.

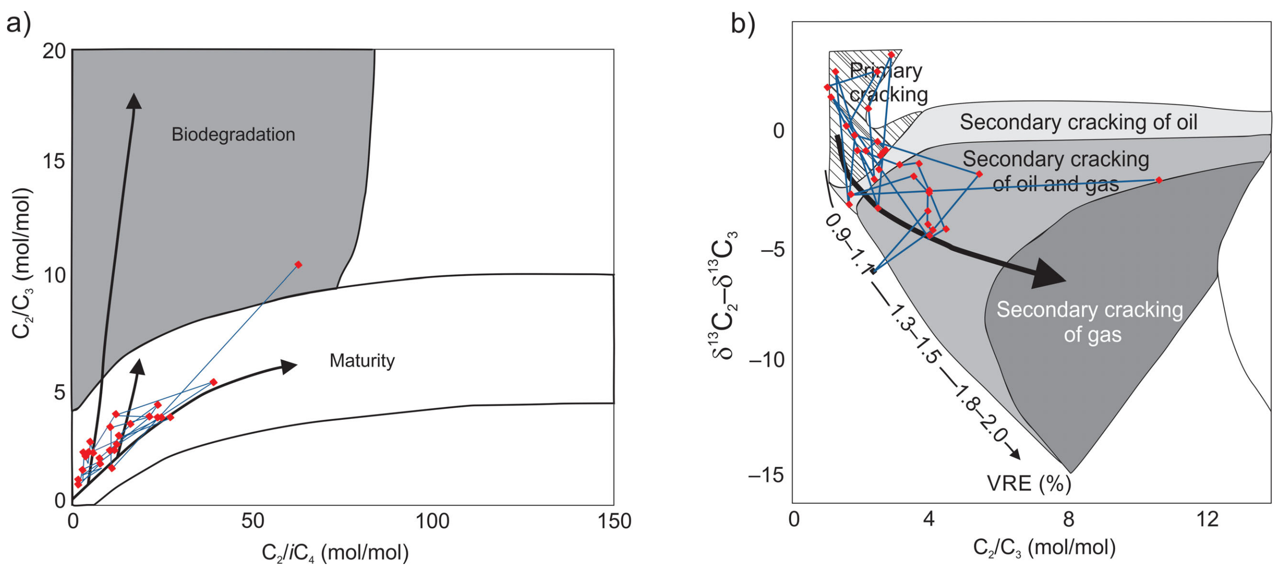

Figure 5. a) Prinzhofer C2/C3 versus C2/*i*C4 and **b)** Lorant δ^{13}C2–δ^{13}C3 versus C2/C3 diagrams for the unique vertical profile for well WA#32990 (YOHO HZ INGA 11-24-087-24, unique well identifier [UWI] 00/11-24-087-24W6/0). Abbreviations: C2, ethane; C3, propane; *i*C4, isobutane; VRE, vitrinite reflectance equivalent; WA, well authorization.

there are also combinations of ISO profiles that are possible from the well data. The BC Oil and Gas Commission instituted a regulatory requirement (BC Oil and Gas Commission, 2015) for mud-gas profiles and these are usually anticipated to be a vertical profile through the stratigraphy. Another profile orientation based on horizontal (HZ) profiles along multilateral HZ legs of unconventional gas wells may provide further insights into the geochemistry of the unconventional reservoirs.

Interpretation is required to identify the source and migration of many gases present in NEBC. Interpretative tools used in this study consisted of crossplots of molecular composition and isotopic data with some isotopic crossplots, such as δ^{13}C1 versus δ^{13}C2 crossplots, are more informative than others. The isotopic data trends presented here are not comparable to other published interpretations such as Bernard or CD plots, which should not be used in NEBC.

Acknowledgments

The author thanks Geoscience BC and the BC Oil and Gas Research and Innovation Society (OGRIS) for the opportunity to undertake this project. Support for the BC-NGA project has been sustained by the BC Oil and Gas Commission; the staff has been very helpful in supplying data, explaining data analysis and providing updates to the source database. Discussions with staff at Geoscience BC have influenced the direction of studies and Geoscience BC is releasing map products. Further support has been provided by the members of the Geoscience BC Project Advisory Committee. Also, the active operators have been very open with discussions and have provided support for the interim results. Acknowledgments are also due to G. Niebergall at Yoho Resources Inc. for the release of the data from well WA#32990. The author thanks M. Dawson for his review of this paper.

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