Implications of the Inorganic Geochemistry of Flowback Water from the Montney Formation, Northeastern British Columbia and Northwestern Alberta: Progress Report

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Owen, J.N. and Bustin, R.M. (2017): Implications of the inorganic geochemistry of flowback water from the Montney Formation, northeastern British Columbia and northwestern Alberta: progress report; *in* Geoscience BC Summary of Activities 2016, Geoscience BC, Report 2017-1, p. 49–54.

Introduction

The development of unconventional oil and gas resources requires injections of large volumes of fluid at high pressures and rates, in order to hydraulically fracture the reservoir and hence create a system permeability high enough that hydrocarbons can be produced economically. Fracturing fluid, used in completions of the Montney Formation in the Western Canada Sedimentary Basin as well as almost all shale completions elsewhere, previously consisted mainly of freshwater as the base fluid. There is currently a trend to blend freshwater with flowback water from previously fractured wells and/or produced water from other wells to reduce freshwater usage. Much of the motivation for reducing freshwater usage during hydraulic fracturing is based on economics and real, or perceived, environmental issues related to depletion of freshwater resources.

The flowback water volume from hydraulic fracturing is generally significantly less than the injected volumes due to imbibition of the completion fluid into the reservoir matrix (i.e., Engelder et al., 2014). The actual amount of flowback fluid varies greatly between wells with most flowback volumes measuring significantly less than 25% (i.e., Haluszczak et al., 2013) of the injected fluid volume, although the actual values vary significantly and some wells flow back more fluid than the volumes injected.

The chemistry of the flowback water is a complex product of the volumes and chemistry of the injected completion fluid, reservoir connate water, plus reactions that occur between the fluids and the reservoir rock and tubulars. The flowback fluids thus provide important data and insights relevant to optimizing reservoir completions, and recognizing, preventing and/or remediating damage to the reservoir, fluid system, proppant pack and tubulars. Additionally, knowledge of the chemistry and volumes of flowback water are critical to designing optimal blends for recycling, treatment and/or disposal of the fluids.

In support of the Geoscience BC–supported study on the controls on producible hydrocarbons in northeastern British Columbia (NEBC), a study of the flowback water chemistry from wells completed in the Montney Formation in NEBC and northwestern Alberta has been undertaken. To date, this study includes the collection of flowback samples, produced water samples (from selected wells) and ancillary information from 31 wells in six geographic areas (Figure 1). These studies have been made possible by close co-operation with industry. The sampled wells include

- 18 wells completed in the upper Montney Formation,
- 11 wells completed in the middle Montney Formation, and
- 2 wells completed in the lower Montney Formation.

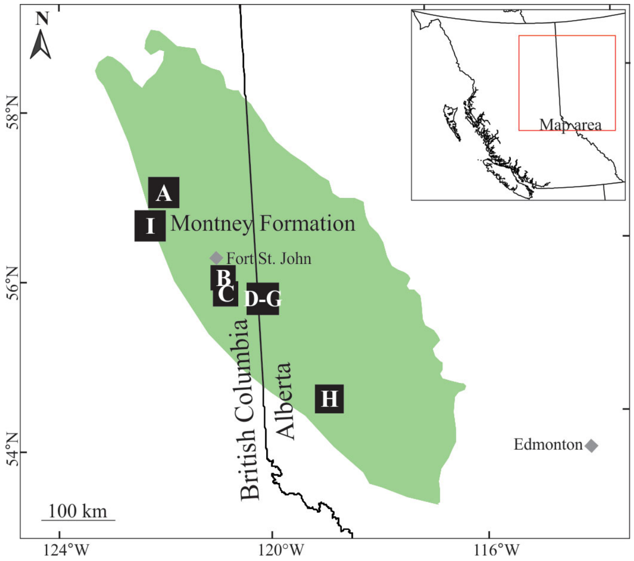

Figure 1. The location of the study sites in northeastern British Columbia and northwestern Alberta. The locations of the sites (A–I) are shown as black squares. The extent of the Montney Formation is shown in green (modified from Edwards et al., 1994).

Keywords: *British Columbia, inorganic geochemistry, stable isotopes, hydraulic fracturing, flowback water, Montney Formation*

In this paper, some preliminary results will be provided and the nature of the ongoing work will be described.

Experimental Methods

Flowback water samples were collected on site throughout the flowback period, with more frequent sampling (2–3 samples per day) earlier in the flowback period and decreasing to one sample per day after the first week of sampling. The higher frequency of sampling earlier in the program allows for the capture of the higher variability in the initial flowback water. In addition to the flowback water samples, produced water samples were collected at two of the sites following the flowback period (sites A and B). The samples were stored at 4°C prior to analysis. As samples were not preserved on site, the samples were heated in a hot water bath back to reservoir temperature (~75–80°C) for 24 hours prior to subsampling. After heating, the samples were subsampled for 1) pH, conductivity and alkalinity analysis; 2) anion analysis; and 3) dissolved metals analysis. Prior to heating, a subsample was collected for stable water isotope analysis. The pH, conductivity and alkalinity tests were conducted at The University of British Columbia (UBC; Vancouver, BC) on filtered, unpreserved samples. The anion analysis is currently in progress at a commercial laboratory. The dissolved metal samples were filtered and preserved with nitric acid to pH <1. These samples were processed further by acid digestion in order to remove any organics in the fluid. The acid digestion process involved an initial step of adding trace metal grade nitric acid and hydrochloric acid in a 2:1 ratio to the sample and heating it on a hot plate until evaporated. This heating and evaporating step was then repeated with only nitric acid added to the sample. The dried sample was then rediluted in a 1% HNO_3 solution. The dissolved metals were measured using inductively coupled plasma–optical emission spectrometry (ICP-OES) and inductively coupled plasma–mass spectrometry (ICP-MS). The isotope samples were mixed with activated charcoal to remove organics and then filtered. These samples were run on a liquid-water isotope analyzer and analyzed for $\delta^{18}O$ and $\delta^{2}H$. The ICP-MS, ICP-OES and isotope analyses were conducted at laboratory facilities in the Department of Earth, Ocean and Atmospheric Sciences at UBC (Vancouver, BC).

In support of this study, an analysis of the hydraulic fracturing fluids was also completed. This generally involved creating a composite sample by combining the fluids used in different fracturing stages based on similar conductivity readings. The composite samples were then submitted for the same suite of analyses as the flowback and produced waters.

In addition to the geochemical analyses, a mineralogical analysis is also being undertaken. Core samples from adjacent wells (as the studied wells were not cored) are being analyzed using X-ray diffraction. These results will be used to support the geochemical modelling.

Preliminary Results

General Parameters – pH, Alkalinity, Conductivity and Total Dissolved Solids

The pH of sampled flowback waters are typically near neutral (pH 6–8) and in general decrease over the flowback period. There is some variability in the flowback water from the site D wells completed in the upper Montney Formation, with values ranging from acidic (pH <4.5) to slightly basic (pH >9). In addition, produced waters from the two site B wells are slightly acidic (pH 4.6–5.7).

The alkalinity of the flowback fluids generally decreases over the flowback period. Overall, the flowback waters from the upper Montney Formation wells have low alkalinity with values remaining between 100 and 200 mg/L as $CaCO_3$. The early flowback water from the middle and lower Montney Formation can have alkalinity values up to 400 mg/L as $CaCO_3$.

Conductivity is high in the Montney Formation flowback water (Figure 2a–d). In flowback samples from the upper Montney Formation and the upper portion of the middle Montney Formation, the conductivity generally ranges from 50 to 200 millisiemens (mS) per cm (Figure 2a–c). The flowback water from the lower portion of the middle Montney Formation has lower conductivity with values below 100 mS/cm (Figure 2c). The conductivity in the flowback water from the lower Montney Formation ranges from approximately 15 mS/cm to approximately 130 mS/cm (Figure 2d).

The total dissolved solids (TDS) range, estimated from conductivity, for the upper Montney Formation flowback and the upper portion of the middle Montney Formation flowback is approximately 30 000–130 000 mg/L. Relative to these flowback waters, the TDS for flowback from the lower portion of the middle Montney Formation is lower with a range of 4500–65 000 mg/L. The flowback from one of the lower Montney Formation wells falls within this range with TDS values from 7000 to 55 000 mg/L, whereas the other lower Montney Formation well is higher (12 000–83 000 mg/L). These TDS values are approximate and once all of the anion results are available the TDS will be recalculated using all ion concentrations.

Major Cations

The major cations increase in abundance over the flowback period resulting in an increase in TDS. The dominant cation in all Montney Formation flowback water is Na. All Na concentrations in the flowback water samples are above 1000 mg/L and the maximum values in the different wells range from approximately 5000 to 50 000 mg/L (Figure 3a–d).

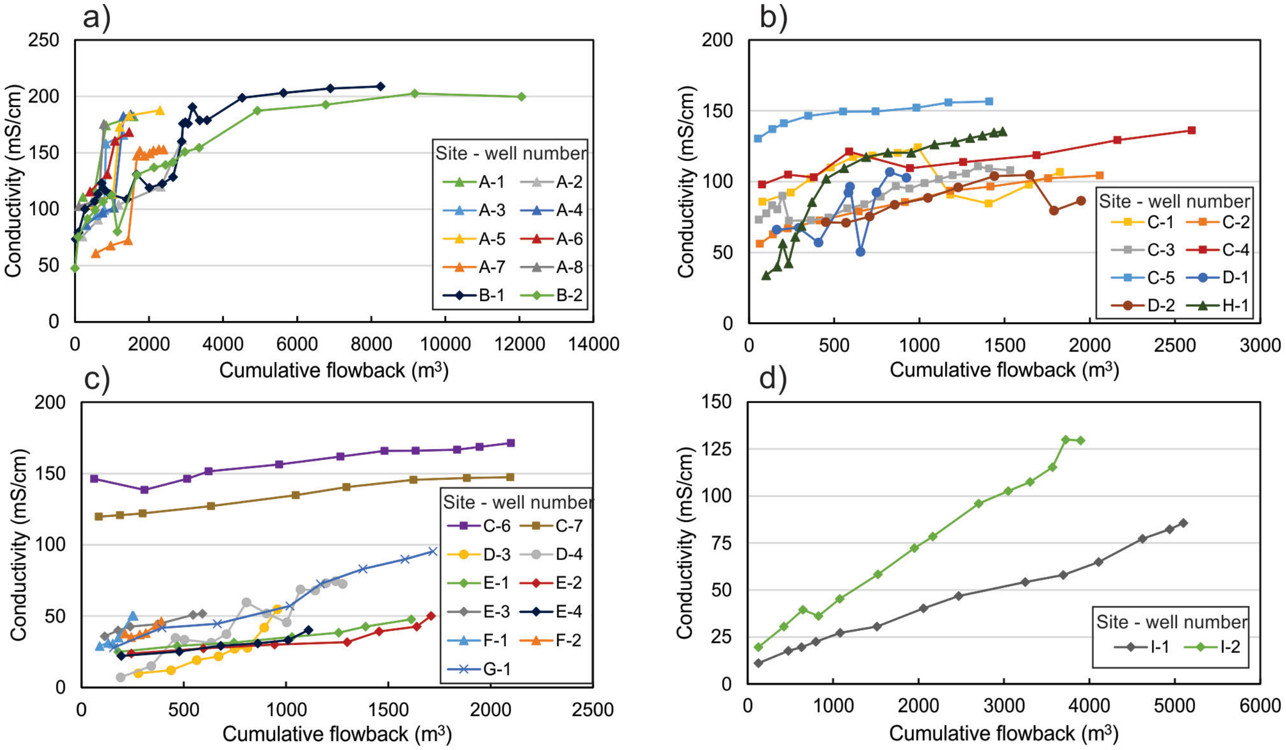

Figure 2. Conductivity in flowback water throughout the flowback period, from wells in northeastern British Columbia and northwestern Alberta: **a)** upper Montney Formation wells from sites A and B, includes both flowback and produced waters; **b)** upper Montney Formation wells from sites C, D, H; **c)** middle Montney Formation wells from sites C–G; and **d)** lower Montney Formation wells from site I. Note the variability in the scales. Abbreviation: mS, millisiemens.

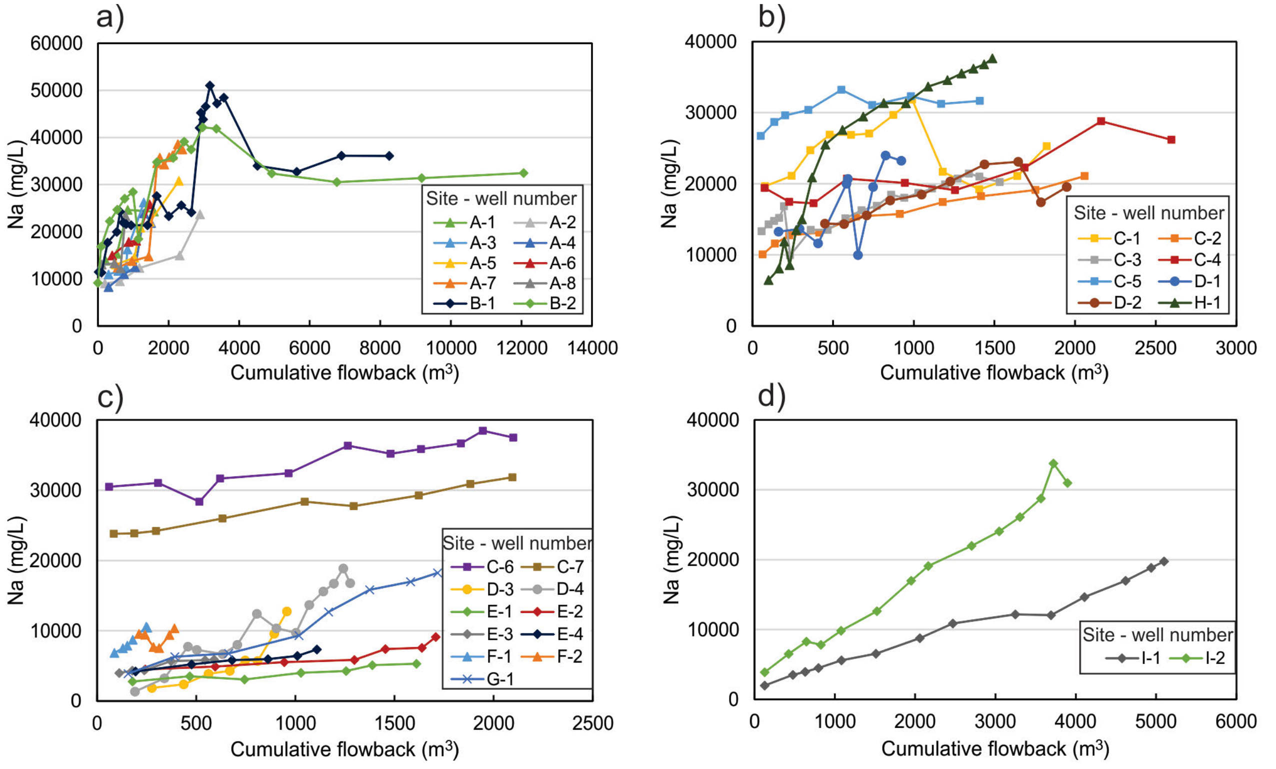

Figure 3. Concentrations of Na in flowback water throughout the flowback period, from wells in northeastern British Columbia and northwestern Alberta: **a)** upper Montney Formation wells from sites A and B, includes both flowback and produced waters; **b)** upper Montney Formation wells from sites C, D, H; **c)** middle Montney Formation wells from sites C–G; and **d)** lower Montney Formation wells from site I. Note the different scale for the y-axis in 3a.

Following Na, the order of elements from highest to lowest concentration is Ca, K, Mg and Sr. Concentrations of Sr are higher than Mg concentrations in flowback water from some wells. Concentrations of Ca range between 10 and 17 000 mg/L, with the majority of values below 10 000 mg/L. Concentrations of K, Mg and Sr remain below 2500 mg/L in all samples and are often much lower than this.

Variability in Major Cation Flowback Water Chemistry

In general, the major cation concentrations are higher in flowback water from wells in the upper Montney Formation and the upper portion of the middle Montney Formation. These wells have higher concentrations from the beginning of the flowback period onward relative to other wells completed in different stratigraphic intervals of the formation. The one area with wells completed in the lower portion of the middle Montney Formation has consistently lower major cation concentrations whereas the two lower Montney Formation wells, situated in the northwestern part of the study area, have intermediate concentrations. The flowback waters from the two lower Montney Formation wells initially have low TDS and low cation concentrations that are comparable to the early flowback water chemistry for the wells completed in the lower portion of the middle Montney Formation. However, the cation concentrations in the lower Montney Formation flowback show a greater increase over the flowback period, most notably for Na, K and Sr (e.g., Na concentrations in Figure 3d).

Barium

Barium (Ba) concentrations display the greatest amount of variability in Montney Formation flowback water (Figure 4a–d). The Ba concentrations are low (<25 mg/L) at sites A, B and D–H, which include wells from both the upper and middle Montney Formation (Figure 4a, c). At site C, which is located in the same area as sites B and D–G, the Ba concentrations are higher (Figure 4b). The maximum Ba concentrations for both middle and upper Montney Formation flowback waters at this site are in the range of 200–300 mg/L. Similar Ba values are measured in the flowback water from the two wells completed in the lower Montney Formation at site I (Figure 4d). The concentrations at these two wells increase from <5 mg/L in early flowback up to maximum values of approximately 200 and 450 mg/L at the end of the flowback period. Initial results indicate that there is a negative correlation between Ba and sulphate. The site I wells initially have higher sulphate concentrations and the Ba concentrations only begin to increase once the sulphate values begin to decrease. Other wells that have consistently high sulphate concentrations (e.g., one well at site G and the site H well) have low Ba concentrations (<1.5 mg/L).

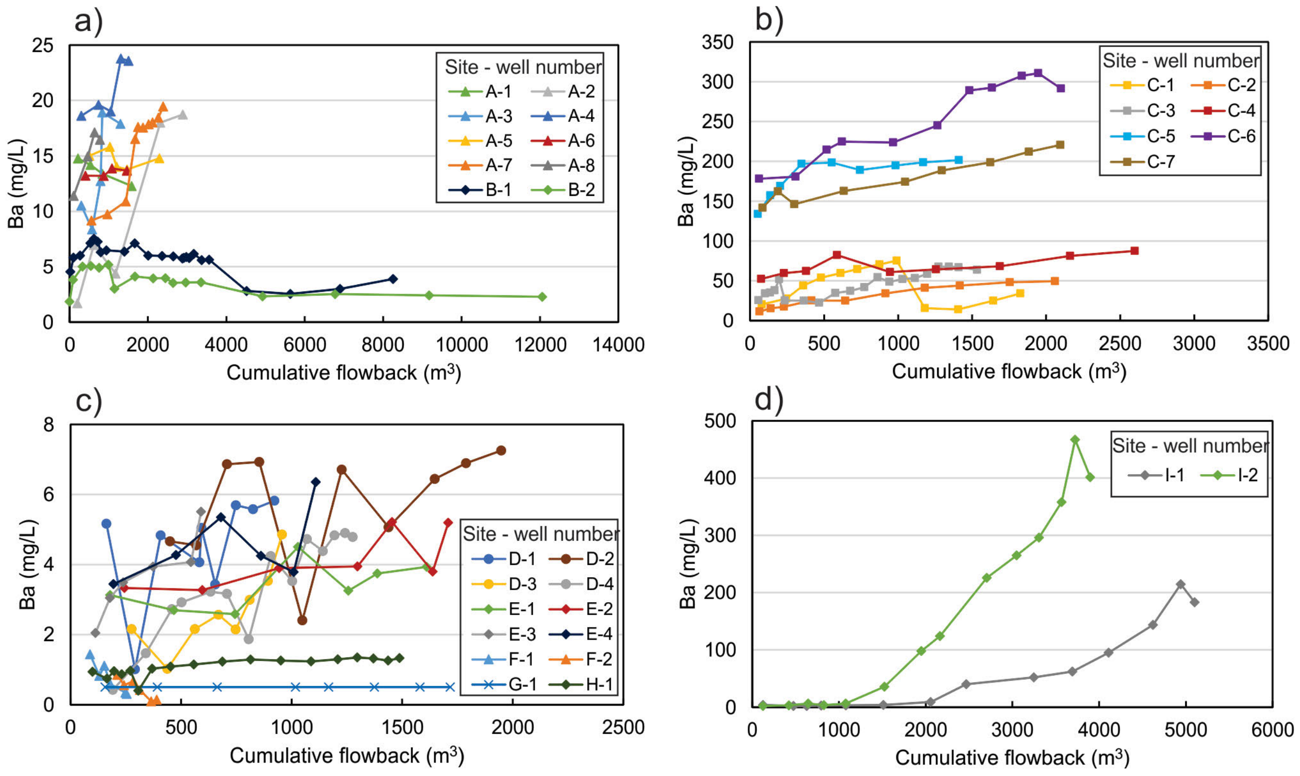

Figure 4. Concentrations of Ba in flowback water throughout the flowback period, from wells in northeastern British Columbia and northwestern Alberta: **a)** upper Montney Formation wells from sites A and B, includes both flowback and produced waters; **b)** upper and middle Montney Formation wells with high Ba concentrations from site C; **c)** upper and middle Montney Formation wells with low Ba concentrations from sites D–H; and **d)** lower Montney Formation wells from site I. Note the variability in the scales of the axes.

Currently, the sulphate results are only available for a limited number of wells as the anion analysis is still in progress. The relationship between Ba and sulphate will be investigated in more detail once the remaining sulphate data becomes available.

Isotopes of δ^{18}O and δ^{2}H

The isotope analysis included an analysis of both the flowback water and the hydraulic fracturing fluids. The isotope values will supplement the inorganic geochemical data by providing additional information that can be used to estimate the connate water contribution to flowback water. Overall, the hydraulic fracturing fluids have δ^{18}O and δ^{2}H isotope values that plot on or close to the global meteoric water line (GMWL, defined as $\delta^2H = 8\cdot\delta^{18}O + 10‰$; Figure 5). However, there are some samples that plot away from this line, which indicate the hydraulic fracturing fluids have a base of a blend of freshwater and recycled flowback water. Water produced from deep formations, including waters produced during hydraulic fracturing, typically have elevated δ^{18}O and δ^{2}H isotope values relative to meteoric water and results that plot to the right of the GMWL (i.e., Sharma et al., 2014; Rowan et al., 2015). The flowback waters analyzed as part of this study generally have values that plot away from the GMWL indicating mixing of the hydraulic fracturing fluid with another more saline end member (i.e., the connate water; Figure 5). The change in the isotope values of the flowback waters over time is interpreted to be due to mixing with connate water rather than water-rock interactions as the time for water-rock interactions (between the injected hydraulic fracturing fluid and the rock) is not sufficient to significantly change the isotopic signature of the water (Rowan et al., 2015).

Further Work

The work for this study is currently ongoing. Full anion results to complete the geochemical analysis are being run and compiled, after which detailed analysis of the chemistry of both the flowback waters and the hydraulic fracturing fluids will be completed. The full dataset will allow for further interpretation of the results, which will provide insight into the variability across the formation as well as assist with determining the sources of the ions in flowback water. The combined geochemical results of the flowback water and the hydraulic fracturing fluid from this study, along with the mineralogy from the X-ray diffraction analysis and existing produced water geochemical results, will be used for geochemical modelling to determine the dominant geochemical processes that are impacting the flowback water chemistry.

The results of this study will determine the variability in flowback water chemistry within the Montney Formation and contribute to the understanding of the geochemical processes that cause flowback water to change over time and to vary between different sites. Characterizing the flowback water chemistry in different areas of the Montney Formation will in turn assist in flowback water management for future oil and gas development in the region. Potential beneficial outcomes related to the geochemical analysis undertaken in this study include optimizing the selection of hydraulic fracturing fluid chemical additives when recycling flowback water and determining the ideal mixing ratios to use in the make-up water for future hydraulic fracturing jobs.

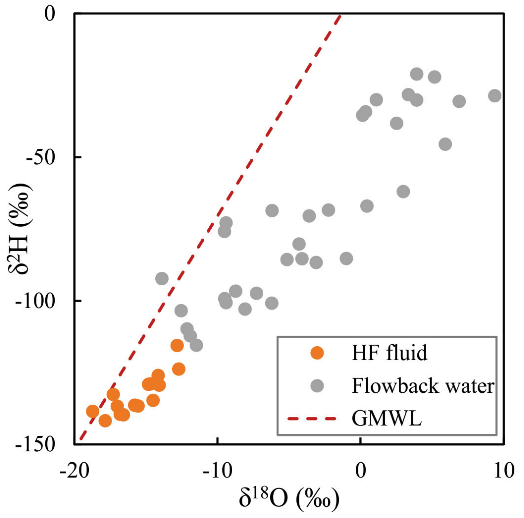

Figure 5. The δ^{18}O and δ^{2}H isotope values for hydraulic fracturing fluids and flowback waters from the eight wells at site A. Results for this site are provided as an example of the isotope results obtained as part of this study. The hydraulic fracturing (HF) fluid samples plot close to or slightly away from the global meteoric water line (GMWL). In general, the later flowback samples have higher values and plot farther to the right. The GMWL is plotted for reference.

Acknowledgments

The authors would like to thank ARC Resources Ltd., Black Swan Energy Ltd., Unconventional Gas Resources, and other companies, which wish to remain anonymous, for collecting the samples and providing other data in support of this study. Geoscience BC is also thanked for the funding provided in support of this study. This manuscript benefited from review by S. Hazell.

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