

Isotopic Fingerprinting of Sulphur Sources for the Hydrogen Sulphide Gas in the Montney Formation, Northeastern British Columbia (NTS 093O, P, 094A, B, G–J, N–P)

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Introduction

The Triassic Montney Formation in northern British Columbia (BC) and Alberta is a significant unconventional gas producer and is calculated to have contributed 34% to the total 2017 natural gas production of Canada (National Energy Board, 2018). The distribution and concentration of hydrogen sulphide in the Montney Formation in BC is complex, with no clear trends across the regional hydrocarbon play or even within the local scale of multiwell pads (Chalmers et al., 2019). This uncertainty can be problematic for operators when planning and designing operations and production, as unexpected souring increases production costs due to special infrastructure required for handling sour gas. Understanding the sour gas risk informs operators and increases lead times for acquiring bulk sour gas service infrastructure, thereby reducing costs.

Hydrogen sulphide in petroleum systems can generate from a variety of processes, which include 1) thermal sulphate reduction; 2) bacterial sulphate reduction; 3) kerogen cracking; and 4) sulphide oxidation and/or decomposition of surfactants used for well completions. The authors are investigating the sources of sulphur that contribute to the formation of hydrogen sulphide in the Montney Formation, in order to decrease the uncertainty of encountering hydrogen sulphide during operations and production. The isotopic ratio of sulphur within the hydrogen sulphide gas can be used to identify the sources of the sulphur, as the isotopic ratio of sulphur sources varies according to formation processes and the geological period of sulphur source development (i.e., Triassic versus Devonian sulphates). The authors are using this variation in sulphur isotopic ratios to determine the sources of the hydrogen sulphide in the Montney Formation in BC. These data are used to develop a model for hydrogen sulphide formation, which can provide

recommendations to future well planning in the Montney Formation.

Methods

To determine the source(s) of sulphur that contributes to the formation of hydrogen sulphide in the Montney Formation, the authors have sampled drill cuttings from the 100/01-29-082-19W6/02 well (geoLOGIC systems Ltd., 2019; Figure 1). Samples were collected from the Charlie Lake, Halfway, Doig, Montney and Belloy formations. Mineralogy of the samples were identified by X-ray diffraction (XRD). Crushed samples (to particle size <250 µm) were mixed with ethanol, hand-ground in a mortar and pestle and then smear mounted on glass slides for XRD analysis (Munson et al., 2016). A normal-focus cobalt X-ray tube was used on a Siemens Diffraktometer D5000 at 40 kilivolts (kV) and 40 milliamperes (mA). The mineral composition was quantified by Rietveld analysis (Rietveld, 1967) using Bruker AXS TOPAS v.3.0 software.

The hydrogen sulphide sampling was performed by Stratum Reservoir, LLC (Calgary, Alberta). The separation technique by Seal et al. (2000) was used to isolate sulphur (sulphate) from the anhydrite mineral fraction in bulk samples. Between 20 and 30 g of sample were then cleaned by refluxing the organic solvent, toluene, within a soxhlet apparatus for a minimum of three days. Samples were dried at 110°C for 24 hours and then ground to <250 µm. Samples were then placed in a 100 mL solution of Na₂CO₃ (5% by mass) and magnetically stirred for two hours. This procedure converts the sulphate from a solid to aqueous phase. The mixture is filtered through a Büchner funnel and the solution is acidified to a pH of <4 using 20% HCl. To precipitate sulphate as a solid, 100 mL of BaCl₂·H₂O (20% by mass) is added to the filtered solution and the sulphate precipitates as pure barium sulphate (baryte). The baryte is filtered and dried in the oven at 110°C overnight. All baryte samples were sent to the Ján Veizer Stable Isotope Laboratory (Ottawa, Ontario) to measure both the sulphur and oxygen isotopic ratios.

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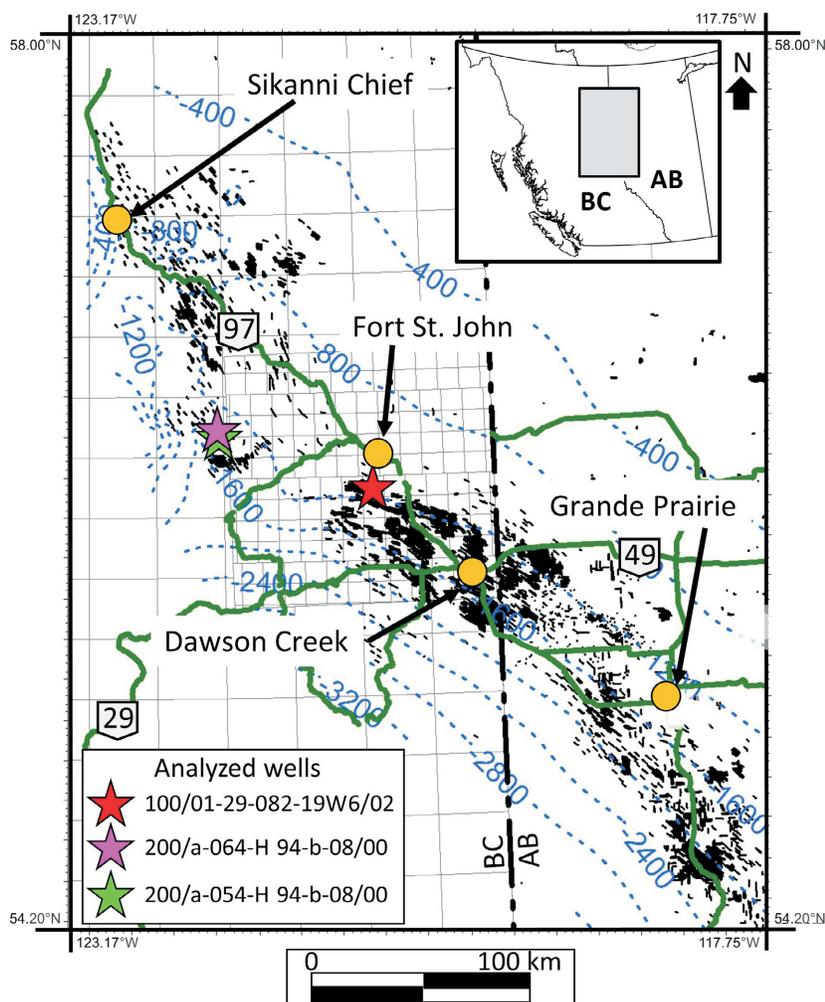


Figure 1. Location of the three wells analyzed in this study, northeastern British Columbia and northwestern Alberta. The depth contours (blue dashed lines) are to the top of the Montney Formation and are measured in subsea true vertical depth (SSTVD; metres). Orange circles represent major population centres in the region and the green lines are the primary roads. Well data (black dots) from geoLOGIC systems Ltd. (2019).

Results

The mineralogy of the Charlie Lake, Halfway, Doig, Montney and Belloy formations in well 100/01-29-082-19W6/02 is shown in Table 1. The Charlie Lake Formation has the highest anhydrite content (18.6–42.6%) and the Montney Formation contains between 0.6 and 1.0%. The Halfway, Doig and Belloy formations contain between 0.3 and 0.7%.

The sulphur and oxygen isotopic ratios for anhydrite and hydrogen sulphide gas are shown for wells 200/a-054-H 094-b-08/00, 200/a-064-H 094-b-08/00 and 100/01-29-082-19W6/02 (geoLOGIC systems Ltd., 2019) in Table 2 and Figure 2. The $\delta^{34}\text{S}$ sulphur isotopic ratios for the anhydrite in the Charlie Lake Formation range between 14.2 and 15.0‰. The $\delta^{18}\text{O}$ oxygen isotopic ratios for the anhydrite in the Charlie Lake Formation range between

7.69 and 8.86‰. The $\delta^{34}\text{S}$ sulphur isotopic ratios for the anhydrite in the Montney Formation range between 13.3 and 14.5‰. The $\delta^{18}\text{O}$ oxygen isotopic ratios for the anhydrite in the Montney Formation range between -1.0 and 0.2‰. The $\delta^{34}\text{S}$ sulphur isotopic ratios for hydrogen sulphide range between 12.4 and 20.9‰. Claypool et al. (1980) and Machel (1985) collected Devonian anhydrite samples across the Western Canada Sedimentary Basin. Their analyses showed that the $\delta^{34}\text{S}$ sulphur isotopic ratios range between 19.4 and 31.6‰, whereas the $\delta^{18}\text{O}$ oxygen isotopic ratios range between 12.9 and 28.3‰ (Figure 2).

Discussion

In well 100/01-29-082-19W6/02, the Charlie Lake Formation contains the highest anhydrite content (18.6–42.6%) whereas the Halfway, Doig, Montney and Belloy formations show minor anhydrite contents ranging between 0.3

Table 1. Mineralogy of the Charlie Lake, Halfway, Doig, Montney and Belloy formations in well 100/01-29-082-19W6/02 (geoLOGIC systems ltd., 2019).

Sample ID	Formation	Depth (TVD; m)	Anhydrite	Gypsum	Pyrite	Quartz	Feldspars	Clays	Carbonates	Fluorapatite
PBN-1	Charlie Lake	1392.5	42.6	0.3	0	9.1	7.5	4.1	38.1	0
PBN-2	Charlie Lake	1430	19.9	0.1	0	11.5	10.9	6.8	54.7	0
PBN-3	Charlie Lake	1467.5	21.7	0	0	14.6	12.4	9.3	43.4	0
PBN-4	Charlie Lake	1542.5	18.6	0	0	13.1	10.3	16.2	49.2	0
PBN-5	Halfway	1592.5	0.4	0.1	0.8	65.5	9.2	5.4	22.3	0
PBN-6	Doig	1642.5	0.4	0	1.2	31.5	8.5	31.2	50.1	7
PBN-7	Doig	1722.5	0.7	0	1.5	21.5	20.7	27.2	40.4	5.9
PBN-8	Doig	1757.5	0.3	0	2.4	19.7	14.3	36.8	52.4	7.3
PBN-9	Montney	1770	0.9	0	1.7	33.9	25.7	18	32.2	2.5
PBN-10	Montney	1790	1.0	0	2.2	26.7	38.4	11.2	26.8	0.3
PBN-11	Montney	1820	0.9	0	1.8	27.8	40.5	9.2	22	0
PBN-12	Montney	1857.5	0.6	0	2.4	30.9	33.4	12.8	24.7	0
PBN-13	Montney	1972.5	0.6	0	2.6	25.8	38.7	13.6	22.6	0
PBN-14	Belloy	2073.5	0.6	1.7	0.5	9.4	1.7	3.3	85.7	0

Abbreviation: TVD, total vertical depth

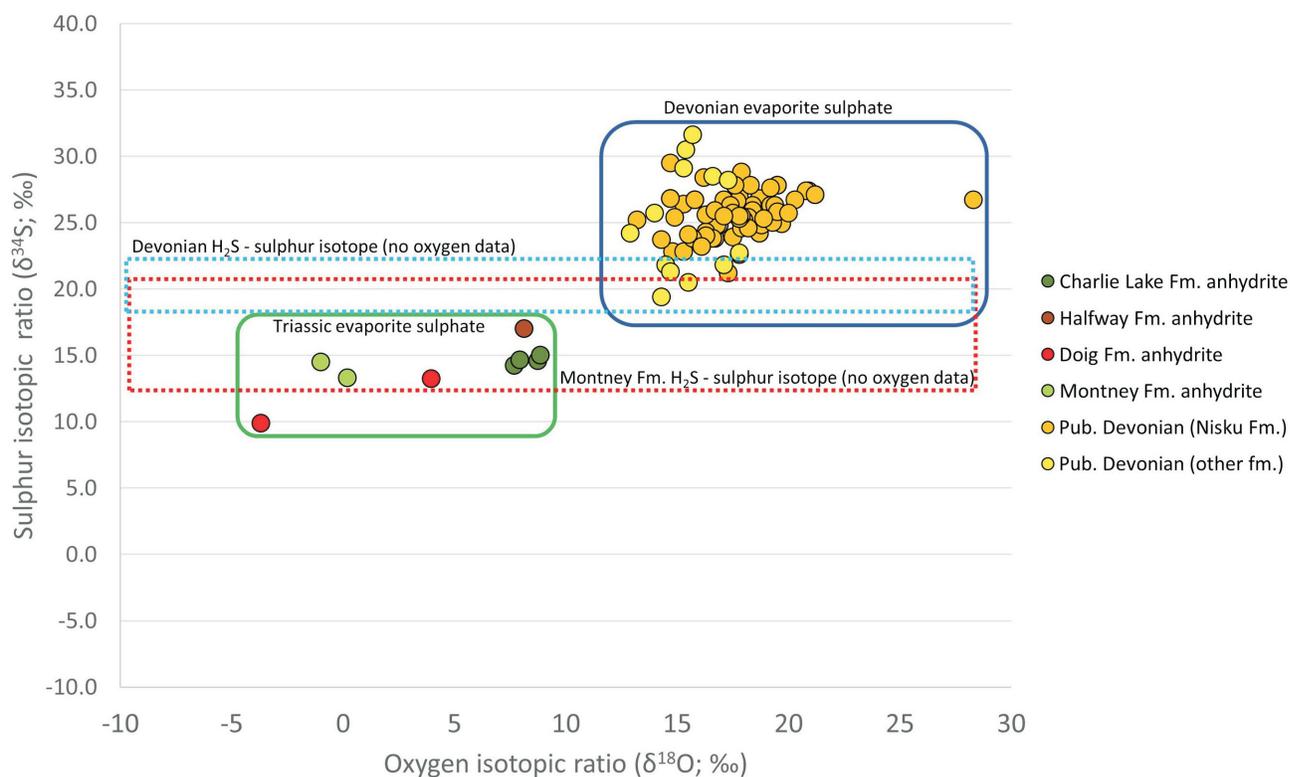


Figure 2. The sulphur and oxygen isotopic data from mineral separation of sulphate (anhydrite) from the Triassic Charlie Lake, Halfway, Doig and Montney formations in well 100/07-30-082-19W6M/00 (geoLOGIC systems ltd., 2019) and from the Devonian strata in the Western Canada Sedimentary Basin. Sulphur isotopic ratios for hydrogen sulphide are shown as dashed boxes for Montney Formation (red dashed box) and for Devonian reservoirs (blue dashed box; Krouse et al., 1988). Published (Pub.) sulphur and oxygen isotopic data for anhydrite from the Devonian strata are from Machel (1985) and Claypool et al. (1980). Sulphur isotopic ratios for hydrogen sulphide in the Montney Formation were obtained from wells 100/01-29-082-19W6/02, 200/a-064-H 094-b-08/00 and 200/a-054-H 094-b-08/00 (geoLOGIC systems ltd., 2019).

Table 2. The sulphur and oxygen isotopic ratios for anhydrite in the Charlie Lake, Halfway, Doig and Montney formations. Sulphur isotopic ratios for hydrogen sulphide gas are shown for three Montney Formation producing wells (200/a-054-H 094-b-08/00, 200/a-064-H 094-b-08/00, 100/01-29-082-19W6/02; geoLOGIC systems Ltd., 2019). Anhydrite was collected from well 100/01-29-082-19W6/02. Note, isotopic analyses were not conducted on sulphate minerals from wells 200/a-054-H 094-b-08/00 and 200/a-064-H 094-b-08/00.

Sample ID	Formation	Depth (TVD; m)	$\delta^{34}\text{S}$ of anhydrite (‰ VCDT)	$\delta^{18}\text{O}$ of anhydrite (‰ VSMOW)	$\delta^{34}\text{S}$ of H_2S gas (‰ VCDT)
PBN - 1	Charlie Lake	1392.5	14.2	7.69	-
PBN - 2	Charlie Lake	1430.0	14.6	8.75	-
PBN - 3	Charlie Lake	1467.5	14.7	7.94	-
PBN - 4	Charlie Lake	1542.5	15.0	8.86	-
PBN - 5	Halfway	1592.5	17.0	8.14	-
PBN - 6	Doig	1642.5	13.2	3.96	-
PBN - 7	Doig	1722.5	9.9	-3.69	-
PBN - 10	Montney	1790.0	14.5	-1.0	-
PBN - 13	Montney	1972.5	13.3	0.2	-
100/01-29-082-19W6/02	Montney	1794.5	-	-	16.9
200/a-064-H 094-b-08/00	Montney	2127.6	-	-	12.4
200/a-054-H 094-b-08/00	Montney	2336.0	-	-	20.9

Abbreviations: TVD, total vertical depth; VCDT, Vienna Canyon Diablo Troilite; VSMOW, Vienna Standard Mean Ocean Water

and 1.0%. In the same well, sulphur and oxygen isotopic analyses results for the anhydrite are similar in range for all samples with $\delta^{34}\text{S}$ sulphur isotopic ratios ranging between 9.9 and 17.0‰ and $\delta^{18}\text{O}$ oxygen isotopic ratios ranging between -3.69 and 8.86‰. These values differ markedly from the published sulphur and oxygen isotopic ratios for anhydrite in Devonian rocks. The $\delta^{34}\text{S}$ sulphur isotopic ratios for Devonian anhydrite range between 19.4 and 31.6‰ and the $\delta^{18}\text{O}$ oxygen isotopic ratios range between 12.9 and 28.3‰ (Claypool et al., 1980; Machel, 1985; Figure 2). The difference between the Triassic and Devonian anhydrite isotopic ratios is used by the authors to identify the sources of the hydrogen sulphide gas within the Montney Formation in BC. The $\delta^{34}\text{S}$ sulphur isotopic ratios for hydrogen sulphide gas in the three Montney Formation producing wells range between 12.4 and 20.9‰ (Table 2, Figure 2) and indicate the sulphur source for the hydrogen sulphide is either from Triassic anhydrite or a mixture of Triassic and Devonian anhydrite. Results show that the sulphur is not only from a Devonian source as is commonly believed by some Montney play operators. Previous studies show that anhydrite in the Montney Formation has been sourced from the Charlie Lake Formation within BC (Sharma, 1969) and in Alberta (Desrocher, 1997). The Montney Formation is at risk of souring, as many drilling locations are shown to have sour reservoirs both above and below the reservoir (Chalmers et al., 2019). The recommendation to operators who would like to assess the risk of souring, is that they map sour reservoirs above and below the Montney reservoir on their acreage, as well as map structures to determine location of potential conduits for anhydrite or hydrogen sulphide gas to enter the Montney Formation.

Future Work

Additional analyses on the formation of anhydrite within the Montney Formation will be carried out to determine textural relationships between the anhydrite minerals and the other mineral grains. Thick sections of a select sample set will be analyzed using a scanning electron microscope (SEM) to determine whether anhydrite was formed syndepositionally or postdepositionally.

Conclusions

Mineralogical and geochemical analyses of the Triassic Charlie Lake, Halfway, Doig, Montney and Belloy formations indicate that the hydrogen sulphide gas in the three wells 100/01-29-082-19W6/02, 200/a-064-H 094-b-08/00 and 200/a-054-H 094-b-08/00 are from the sulphate of the Triassic anhydrite or a mixture of Triassic and Devonian anhydrite and not purely from the anhydrite within the Devonian rocks. The scanning electron microscope textural analyses will determine if the anhydrite in the Montney Formation formed during deposition or postdeposition, which will further strengthen the geological model.

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