Investigating the Mineral Potential of Brines in Saskatchewan: New Results from the Brine Sampling Project for 2018

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Abstract

The aim of the Saskatchewan Geological Survey's brine sampling project is to determine the distribution and concentration of the major and minor elements present in the subsurface of Saskatchewan, with a particular emphasis on lithium and other trace elements that could potentially be derived from basinal brines. Since 2011, wells producing from Paleozoic-aged strata in southeastern and west-central Saskatchewan have been sampled, and a database of major and minor elements present in the formation waters in Saskatchewan has been developed. Standard brine analysis completed by the oil and gas industry only typically measures for major elements, making these results the first publicly available data for trace elements in the province.

One of the objectives for the 2018 sampling season was to sample any wells newly producing from the Duperow Formation, due to the previously observed high lithium concentrations in this formation. A second objective was to sample a formation that had not been previously sampled in this program. The Torquay Formation was chosen for this, due to the large number of wells recently drilled into the formation, its stratigraphic depth, and because it is one of the older formations that have not yet been sampled in this program.

Resampling of wells was also done in 2018: two wells producing from the Winnipegosis Formation that were initially sampled in 2012 were resampled this year, to determine if there has been a change in brine chemistry over the production life of the wells. Resampling was done to verify that consistent trace element concentrations exist over time, to ensure that any future lithium-producing project will be economically viable.

The results presented in this paper will be added to the database of samples already publicly available on the Government of Saskatchewan website.

Keywords: *industrial minerals, brine, geochemistry, Williston Basin, lithium, bromine*

1. Introduction

The rising demand and subsequent increase in the cost of lithium has resulted in the possibility of producing this element from non-traditional sources, such as highly saline brines, which have lithium concentrations of 500 milligrams per litre (the concentration of lithium produced from brines in South America) or lower. The vast volume of brines present in the subsurface of Saskatchewan, which may contain economically significant amounts of trace elements, have the potential to create a new industry for the province. Previous research by the Saskatchewan Geological Survey has shown that lithium concentrations vary spatially and hydrostratigraphically (*i.e.*, by formation) across the province (Jensen, 2011, 2015, 2016; Jensen and Rostron, 2017).

In 2011, the Saskatchewan Geological Survey commenced a wellhead sampling program to determine the hydrostratigraphic and spatial distribution of the major and minor elements present in the brines throughout the

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province, and provide a publicly available database. A sampling campaign has been conducted since 2011, with the exception of 2014. The southeastern region of the province was sampled in 2011, 2012, 2013 and 2016 (Jensen, 2011, 2015, 2016), targeting wells producing from Paleozoic-aged strata. The sampling continued in the summers of 2016, 2017 and 2018, from wells in the southeast and southwest parts of the province. Additionally, some wells in the southeast that had been sampled in 2011 and 2012 were resampled in 2017 and 2018, to assess if there had been any changes in brine chemistry over the production history of the well.

There are thousands of analyses of formation waters from drill-stem tests and producing oil wells throughout the province, but there is little to no data for lithium and other trace elements. This is because petroleum and potash companies typically only analyze water samples for major ions such as chlorine, sodium, calcium, potassium and magnesium. In the past, other researchers have investigated the economic potential for brines (Kreis and Gent, 1992; Rostron *et al.*, 2002). Both these previous studies predominantly used drill-stem test (DST) samples, with a limited number of wellhead samples. Samples taken from wellheads have a lower possibility of being contaminated from drilling fluids compared to DST samples taken during the drilling process. All samples obtained for this study were taken from producing oil wells (with the exception of the Duperow sample, which was a water source well), at the wellheads, and all samples were collected from strata lying within the Williston Basin.

2. Current Work

Eleven samples from Ordovician- to Mississippian-aged formations were collected during 2018. Two samples were from wells producing from Ordovician-aged formations: the Red River and Winnipeg formations. Samples from eight wells producing from Devonian-aged formations were obtained: two in the Winnipegosis Formation, one in the Duperow Formation, and five in the Torquay Formation. An additional sample was collected from producing Mississippian-aged strata from the Midale Beds of the Madison Group (Figure 1). Sampling procedures are detailed in Jensen (2011).

Wells with high concentrations of lithium in previous years' sampling were resampled, to investigate the possibility of the brine chemistry changing over the production history of the well. Two wells that were first sampled in 2012 were resampled in 2018; both wells are in Township 2, Range 9 west of the Second Meridian (9W2) and were producing from the Winnipegosis Formation (wells 10 and 11 on Figure 1).

3. Results

a) New Sampling

Two of the objectives of the 2018 sampling season were to sample the brines from a formation that had not been previously sampled during the program, and to sample any wells newly producing from the Duperow Formation. The Torquay Formation met the criteria for brines not previously sampled, so five wells producing from the Torquay were chosen and sampled to meet the first objective, and one Duperow water-source well that had recently gone on production was chosen and sampled to meet the second objective.

Results of the formation water analyses are displayed in Table 1. Elements that are above detection limit are listed in the table; elements for which analyses were carried out but whose concentrations were below detection limit are listed in the table caption.

Values for total dissolved solids (TDS) range from 154 000 to 314 000 milligrams per litre (mg/L) and a variation in TDS values is apparent in the formations that have multiple samples. Chloride and sodium are the elements with the highest concentrations in all samples. Because of its potential economic significance, trace element data for lithium are highlighted in the following discussion.

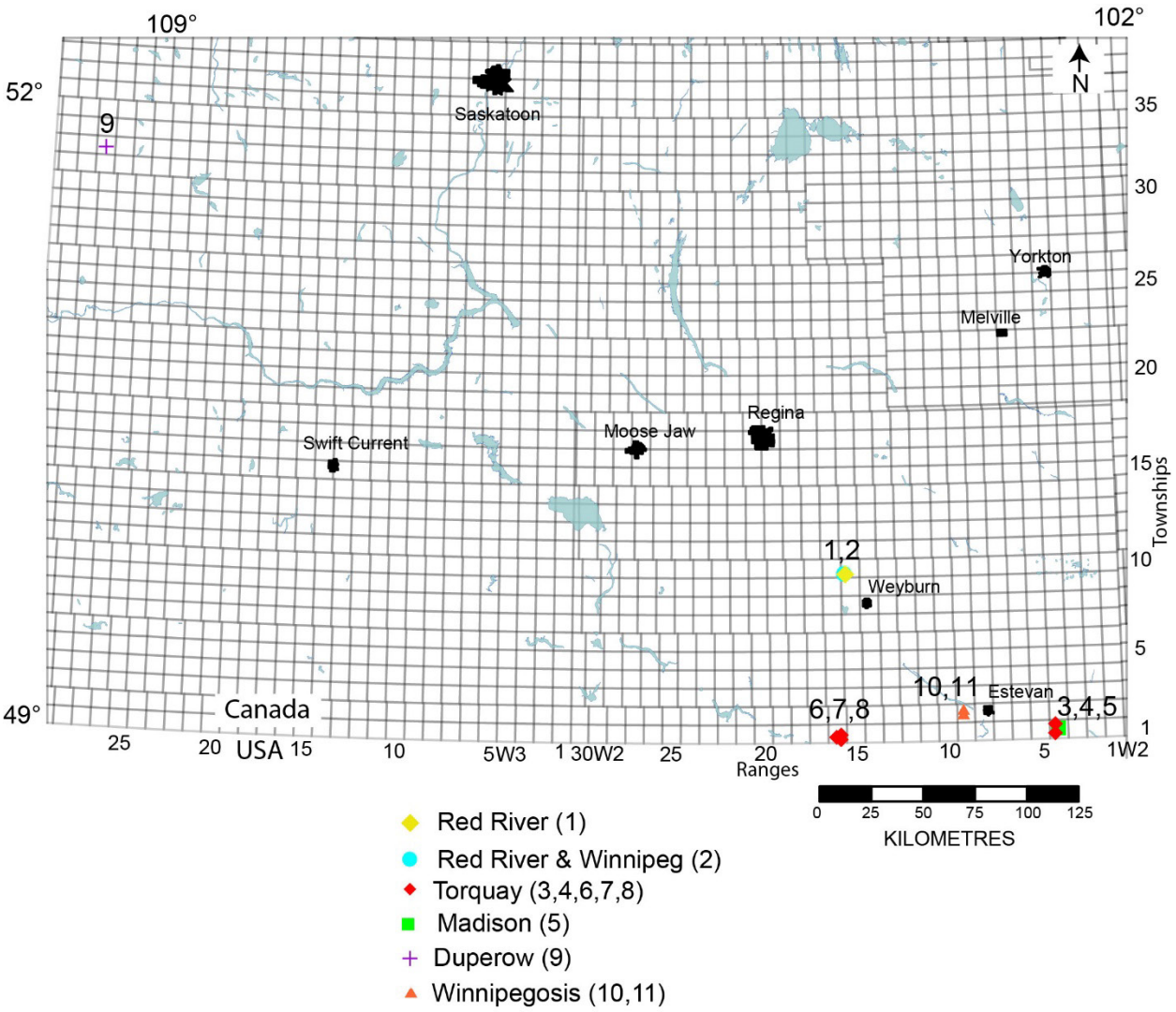

Figure 1 – *Location of wells sampled during the summer of 2018. All samples were obtained from currently producing wellheads within the Williston Basin. Numbers in brackets after the formation names correspond to the sample numbers shown in Table 1.*

Samples collected from the **Red River Formation** are from the southeastern part of the province. Lithium concentrations from the two samples taken in 2018 are 14 mg/L and 27 mg/L. The lower value—14 mg/L Li—is the lowest recorded in the samples collected in 2018. TDS values in the Red River Formation samples from 2018 are 262 000 mg/L and 269 000 mg/L.

Lithium concentration from the one **Midale Beds sample of the Charles Formation, Madison Group,** has a value of 23 mg/L. The TDS value of the Midale Beds sample is 294 000 mg/L.

Samples from the **Torquay Formation** have a narrow range in lithium concentrations (28 to 32 mg/L) and similar range in TDS values (275 000 to 279 000 mg/L).

The one sample from the **Duperow Formation** from the western region of the province has a lithium concentration of 41 mg/L and a TDS value of 154 000 mg/L. High TDS values do not seem to correlate directly with high trace element concentrations, as indicated by the high lithium concentration in this lower TDS value sample. This lithium concentration is one of the highest in the samples collected in 2018. It is lower, however, than the highest value previously recorded in samples from the Duperow Formation in southeastern Saskatchewan. That sample—from the well located at 14-12-7-11W2—with a concentration of 190 mg/L Li (Jensen, 2015), represents the highest lithium

concentration observed in this sampling project to date. This well has since been suspended, however, and we were unable to resample it.

Lithium concentrations in the two samples taken in 2018 from the **Winnipegosis Formation** are 45 mg/L and 48 mg/L. The Winnipegosis strata possess the highest concentrations of lithium found in the samples collected in 2018 (48 mg/L). The TDS values for the samples from 2018 are 313 000 mg/L and 314 000 mg/L; these samples represent the highest TDS from the 2018 sampling season.

b) Resampling

As for the past two years, wells that were previously sampled were resampled to determine if any changes in brine chemistry had occurred. Results of the resampling are displayed in Table 2.

In 2018, only two wells were resampled; both wells produced from the Winnipegosis. Lithium concentrations displayed little variation for both resampled wells, over the sampling duration of six years. TDS values are similar over the sampling duration, with differences ranging from 4800 to 19 500 mg/L. As previously noted by Jensen and Rostron (2017), these variations are within the analytical margin of error for highly saline brines. Most TDS variations are less than 5%, and all are below 10%. TDS values have slightly decreased in one of the Winnipegosis wells since the first sampling, whereas in the other Winnipegosis well the TDS has slightly increased since the beginning of sampling in 2012.

4. Discussion of Newly Sampled Wells

Lithium concentrations in the 2018 samples cover a small range compared to previous years' sampling. Values range from 14 to 63 mg/L Li, whereas lithium concentrations were as high as the triple digits in previous years (5 mg/L to 190 mg/L Li).

Note that sample 2 (Table 1) has its production interval in both the Red River Formation (for 7 metres) and the Winnipeg Formation (for 3 metres) whereas sample 1 has its entire production interval completed in the Red River Formation. The TDS values are similar for the two samples: sample 1 has a TDS of 262 000 mg/L and sample 2 has a TDS of 269 000 mg/L. However, on comparing the trace elements such as lithium and strontium, sample 2 has almost double the concentration of each element compared to sample 1. The lithium concentration in sample 1 is 14 mg/L *versus* 27 mg/L in sample 2, and the strontium concentration in sample 1 is 146 mg/L *versus* 296 mg/L in sample 2. As these wells are within close proximity to one another, a spatial variation would not result in the observed variation in the chemistry. It is interpreted that the variation in the trace element concentrations are a result of sample 2 being completed partially in the Winnipeg Formation, and deducing that the Winnipeg Formation has elevated concentrations of lithium and strontium compared to the Red River Formation, as the perforation intervals for the two formations are separated by 96 metres.

There are no other wells currently producing from the Winnipeg Formation in southeastern Saskatchewan, so the one well tested in 2018 that is partially producing from the Winnipeg allows for the first trace element analysis from this formation in this project. The results of the 2018 sampling have identified that there is a variation between the Red River and Winnipeg formations in terms of lithium concentrations. This knowledge will aid in future exploration for lithium in the province.

The sample from the well producing from the Duperow Formation in the western region of the province (well number 9 on Figure 1, just east of the town of Kindersley (not shown on Figure 1)) displays a relatively high concentration of lithium (41 mg/L) and a low TDS value (154 000 mg/L). However, higher lithium concentrations have been recorded in previous samples from Duperow wells in that region of the province (Jensen and Rostron, 2017). Additional sampling is needed to determine the reason for the variation in lithium concentrations in the Duperow Formation in the area near Kindersley, as there is a sparse number of data points (four) in the project for the Duperow Formation.

Table 1 – *Results for formation water analyses for samples collected during the summer of 2018. Concentrations for all elements are in milligrams per litre (mg/L). Values that are reported as 'bdl' indicate that the elemental concentration was below the detection limit. UWI = unique well identifier. Analyses were also carried out on the following elements, but all concentrations were below their respective detection limit: aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, copper, molybdenum, nickel, selenium, silicon, silver, tin, titanium, uranium, vanadium. Note: sample 2 has its production interval in both the Red River Formation (a total of 7 metres (m)) and the Winnipeg Formation (a total of 3 m).*

				Sample Location Lat./Long.		Sample Location UTM			Detection Limit ->	0.2	0.002	0.01	0	0.01	2	0.02	0.001	0.2	0.9
Well No.on Fig. 1	Collection Date	UWI	Licence #	Longitude	Latitude	Easting	Northing	Formation	Sample Interval (m)	Barium	Boron	Bromide	Calcium	Chloride	Iron	Lead	Lithium	Magnesium	Manganese
1	Summer 2018	92/08-06-010-15W2	00G229	-104.01979	49.79264	570549.9	5516036.8	Red River	2348 to 2370	0.90	31	106	2790	157 000	24.00	0.04	14.0	440	bdl
2	Summer 2018	23/09-06-010-15W2	12J275	-104.01919	49.79264	570593.1	5516037.4	Red River (7) +Winnipeg (3)	2357 to 2467*	1.90	57	187	5440	158 000	20.00	bdl	27.0	740	1.00
3	Summer 2018	02/01-06-001-04W2	68761	-102.52451	49.0145	681003.2	5432020.2	Torquay	2108	2.50	150	345	8810	171 000	bdl	bdl	29.0	1200	2.20
4	Summer 2018	02/13-29-001-04W2	68758	-102.51841	49.05746	681292.9	5436809.9	Torquay	1989	2.00	112	403	9300	173 000	bdl	bdl	28.0	1300	2.00
5	Summer 2018	91/16-09-001-04W2	11J398	-102.4816	49.0129	684146.5	5431940.1	Midale	1683	bdl	180	291	4460	185 000	bdl	bdl	23.0	910	bdl
6	Summer 2018	02/02-10-001-16W2	53886	-104.0609	49.0297	568211	5429586.9	Torquay	2369	1.60	172	292	4360	163 000	bdl	bdl	32.4	600	1.00
7	Summer 2018	91/01-02-001-16W2	14I082	-104.03642	49.02718	570439.9	5430924.5	Torquay	2381	2.70	172	299	5780	171 000	3.00	0.09	31.0	710	3.00
8	Summer 2018	91/15-15-001-16W2	15E124	-104.06188	49.02853	568576.8	5431051.2	Torquay	2355	2.00	179	281	4890	164 000	bdl	bdl	32.0	630	3.90
9	Summer 2018	02/16-15-032-26W3	56149	-109.59637	51.74959	182729.3	5743196	Duperow	965 to 1227	bdl	40	358	8230	90 600	bdl	bdl	41.0	1900	bdl
10	Summer 2018	21/09-22-002-09W2	87A031	-103.12313	49.13889	636861.1	5444596.2	Winnipegosis	2605 to 2610	14.40	106	533	12 900	191 000	bdl	bdl	48.0	1300	2.00
11	Summer 2018	11/08-22-002-09W2	86A105	-103.12096	49.13559	637028.5	5444233.3	Winnipegosis	2575 to 2584	13.70	105	518	12 400	191 000	bdl	0.48	45.0	1200	bdl

When sample interval is only one number the well is horizontal and the total vertical depth (TVD) is reported as the sample interval.

All location coordinates are in North American Datum 1983 (NAD83), Zone 13.

*Denotes the range of the sample interval. The actual perforated intervals are 2357 to 2361 m, 2365 to 2368 m (both of which are in the Red River Formation), and 2464 to 2467 m (which is in the Winnipeg Formation).

Table 1 – Continued

				Sample Location Lat./Long.		Sample Location UTM			Detection Limit ->	0.4	0.01	0.001	0.01	0.2	5	0.9		
Well No. on Fig. 1	Collection Date	UWI	Licence #	Longitude	Latitude	Easting	Northing	Formation	Sample Interval (m)	Potassium	Sodium	Strontium	Thallium	Zinc	HCO_3	SO_4*	TDS	pH
1	Summer 2018	92/08-06-010-15W2	00G229	-104.01979	49.79264	570549.9	5516036.8	Red River	2348 to 2370	2010	96 800	146	0.024	bdl	184	2083	262 000	5.90
2	Summer 2018	23/09-06-010-15W2	12J275	-104.01919	49.79264	570593.1	5516037.4	Red River (7) +Winnipeg (3)	2357 to 2467*	4480	98 500	296	0.074	0.44	196	770	269 000	6.03
3	Summer 2018	02/01-06-001-04W2	68761	-102.52451	49.0145	681003.2	5432020.2	Torquay	2108	3480	96 000	426	bdl	bdl	98	485	277 000	5.80
4	Summer 2018	02/13-29-001-04W2	68758	-102.51841	49.05746	681292.9	5436809.9	Torquay	1989	3520	94 500	442	bdl	0.39	118	424	277 000	6.09
5	Summer 2018	91/16-09-001-04W2	11J398	-102.4816	49.0129	684146.5	5431940.1	Midale	1683	2800	104 000	209	bdl	bdl	618	721	294 000	7.40
6	Summer 2018	02/02-10-001-16W2	53886	-104.0609	49.0297	568211	5429586.9	Torquay	2369	3210	98 100	266	bdl	bdl	186	749	278 000	6.49
7	Summer 2018	91/01-02-001-16W2	14I082	-104.03642	49.02718	570439.9	5430924.5	Torquay	2381	3250	97 100	346	0.020	0.60	62	552	279 000	5.32
8	Summer 2018	91/15-15-001-16W2	15E124	-104.06188	49.02853	568576.8	5431051.2	Torquay	2355	3190	95 800	297	bdl	0.43	103	651	275 000	5.86
9	Summer 2018	02/16-15-032-26W3	56149	-109.59637	51.74959	182729.3	5743196	Duperow	965 to 1227	3330	48 000	166	bdl	bdl	1020	1254	154 000	6.37
10	Summer 2018	21/09-22-002-09W2	87A031	-103.12313	49.13889	636861.1	5444596.2	Winnipegosis	2605 to 2610	6080	101 000	524	0.040	2.20	44	251	314 000	6.09
11	Summer 2018	11/08-22-002-09W2	86A105	-103.12096	49.13559	637028.5	5444233.3	Winnipegosis	2575 to 2584	6060	101 000	536	0.040	1.10	69	251	313 000	6.12

*[SO_4] is calculated from [total S] by factor 96.06/32.06. This assumes all S exists as SO_4, and may slightly overestimate SO_4 concentrations.

When sample interval is only one number the well is horizontal and the total vertical depth (TVD) is reported as the sample interval.

All location coordinates are in North American Datum 1983 (NAD83), Zone 13.

*Denotes the range of the sample interval. The actual perforated intervals are 2357 to 2361 m, 2365 to 2368 m (both of which are in the Red River Formation), and 2464 to 2467 m (which is in the Winnipeg Formation).

Table 2 – *Results of analyses for formation water samples taken over a span of six years, from wells 10 and 11 on Figure 1. Blue-shaded rows correspond to matching well locations. Concentrations for all elements are in milligrams per litre (mg/L). Values that are reported as 'bdl' indicate that the elemental concentration was below the detection limit. UWI = unique well identifier.*

			Detection Limit ->	0.4	0.04	0.04	0.2	0.02	0.1	0.002	0.01	0.002	0.2	0.01	0.1	0.02	0.2	2	0.02	0.001	0.2	0.9	0.2
UWI	**Formation**	**Sample Interval (m)**	**Collection Date**	**Aluminum**	**Antimony**	**Arsenic**	**Barium**	**Beryllium**	**Bismuth**	**Boron**	**Bromide**	**Cadmium**	**Calcium**	**Chloride**	**Chromium**	**Cobalt**	**Copper**	**Iron**	**Lead**	**Lithium**	**Magnesium**	**Manganese**	**Molybdenum**
21/09-22-002-09W2	Winnipegosis	2605-2610	Summer 2012	bdl	bdl	0.72	14.0	bdl	bdl	117	453	0.002	12 000	200 000	bdl	bdl	bdl	bdl	2.33	57.4	1200	bdl	bdl
21/09-22-002-09W2	Winnipegosis	2605-2610	Summer 2018	bdl	bdl	bdl	14.4	bdl	bdl	106	533	bdl	12 900	191 000	bdl	bdl	bdl	bdl	bdl	48.0	1300	2.00	bdl
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2012	bdl	bdl	0.61	13.0	bdl	bdl	111	398	bdl	10 700	182 000	bdl	bdl	bdl	bdl	bdl	53.5	1000	bdl	bdl
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2016	bdl	bdl	bdl	14.8	bdl	bdl	147	438	bdl	12 100	189 400	bdl	bdl	bdl	bdl	0.03	63.0	1180	bdl	bdl
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2017	bdl	bdl	bdl	13.4	bdl	bdl	108	380	bdl	11 200	186 000	bdl	bdl	bdl	bdl	bdl	47.0	1100	bdl	bdl
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2018	bdl	bdl	bdl	13.7	bdl	bdl	105	518	bdl	12 400	191 000	bdl	bdl	bdl	bdl	0.48	45.0	1200	bdl	bdl

When sample interval is only one number the well is horizontal and the total vertical depth (TVD) is reported as the sample interval.

Table 2 – Continued

			Detection Limit ->	0.1	0.4	0.04	9	0.002	0.01	0.001	0.01	0.2	0.09	0.1	0.02	0.2	5	0.9		
UWI	**Formation**	**Sample Interval (m)**	**Collection Date**	**Nickel**	**Potassium**	**Selenium**	**Silicon**	**Silver**	**Sodium**	**Strontium**	**Thallium**	**Tin**	**Titanium**	**Uranium**	**Vanadium**	**Zinc**	**HCO_3**	**SO_4***	**TDS**	**pH**
21/09-22-002-09W2	Winnipegosis	2605-2610	Summer 2012	bdl	5480	bdl	bdl	bdl	98 900	515	0.0400	bdl	0.2	bdl	bdl	2.00	76	357	319 200	6.38
21/09-22-002-09W2	Winnipegosis	2605-2610	Summer 2018	bdl	6080	bdl	bdl	bdl	101 000	524	0.0400	bdl	bdl	bdl	bdl	2.20	44	251	314 000	6.09
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2012	bdl	4990	bdl	bdl	bdl	92 900	448	0.0350	bdl	0.2	bdl	bdl	0.40	230	616	293 500	6.87
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2016	bdl	5680	bdl	10	bdl	101 000	519	0.0404	bdl	bdl	bdl	bdl	1.20	98	360	311 000	6.28
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2017	bdl	5230	bdl	bdl	bdl	99 900	468	0.0400	bdl	bdl	bdl	bdl	1.20	99	158	308 900	5.86
11/08-22-002-09W2	Winnipegosis	2575-2584	Summer 2018	bdl	6060	bdl	bdl	bdl	101 000	536	0.0400	bdl	bdl	bdl	bdl	1.10	69	251	313 000	6.12

*[SO_4] is calculated from [total S] by factor 96.06/32.06. This assumes all S exists as SO_4, and may slightly overestimate SO_4 concentrations.

When sample interval is only one number the well is horizontal and the total vertical depth (TVD) is reported as the sample interval.

5. Discussion of Resampled Wells

The two wells resampled in 2018 were both wells that produced from the Winnipegosis Formation. The 2018 results shown that there is only a small variation in major and minor element concentrations as well as TDS between the two Winnipegosis samples. These variations are within the acceptable analytical margin of error for measurements in saline brines. These results are interpreted by the authors to indicate that there has been a consistent concentration of lithium in the brines from this formation over the six-year sampling interval. This interpreted consistent concentration of lithium would represent a steady potential revenue stream for a lithium-producing project.

6. Future Work

- The Duperow Formation appears to have high lithium concentrations compared to TDS, thus any new wells producing from the Duperow are a primary target of this project, and if any are put on production in Saskatchewan, the wells will be sampled.
- Any other wells that are deemed to be in a region of the province that has exploration potential for lithium will also be sampled, as will wells drilled into a formation that isn't already in the database for this project.
- Because the source of the lithium in the brines of the Williston Basin is not known, analysis of core from formations already sampled is planned. The well producing from the Duperow Formation in southeastern Saskatchewan that yielded the highest lithium concentration in this study (190 mg/L) will be the first core analyzed.
- Core analysis will include determination of the lithium concentration in the various rock types in the core, to investigate if there is a variation in lithium concentration between the different rock types.
- Once the core from the Duperow Formation is tested for its lithium concentration, core from other formations will be tested, to determine if there is variation in lithium concentration between the different formations.
- The authors will continue monitoring drilling activity in the province, as any new wells penetrating the Winnipeg Formation would be of great interest and sampling them would add to the scant brines information that currently exists for this interval.

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