AER/AGS Open File Report 2021-04

Alberta Energy Regulator

Lithium and Helium in Alberta: Data Compilation and Preliminary Observations

AGS
ALBERTA GEOLOGICAL SURVEY

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S. Lyster, T.E. Hauck, G.P. Lopez, T.L. Playter, C. Reimert, D. Palombi and S.K. Schultz

Alberta Energy Regulator
Alberta Geological Survey

June 2022

ISBN 978-1-4601-5358-1

If you use information from this publication in other publications or presentations, please acknowledge the AER/AGS. We recommend the following reference format:

Lyster, S., Hauck, T.E., Lopez, G.P., Playter, T.L., Reimert, C., Palombi, D. and Schultz, S.K. (2022): Lithium and helium in Alberta: data compilation and preliminary observations; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2021-04, 36 p.

Publications in this series have undergone only limited review and are released essentially as submitted by the author.

Published June 2022 by:
Alberta Energy Regulator
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, AB T6B 2X3
Canada

Tel: 780.638.4491
Email: AGS-Info@aer.ca
Website: www.ags.aer.ca

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Acknowledgements

The authors acknowledge the support of oil well operators who allowed access to their sites for geochemical sampling. We would like to thank Matt Grobe, Tony Lemay, and Paulina Branscombe (Alberta Geological Survey) for their reviews of this report, which greatly contributed to the quality of the final product. Thank you also to the many Alberta Geological Survey staff members whose earlier work laid the groundwork for this report.

Abstract

The Western Canada Sedimentary Basin (WCSB) has a long history of oil and gas development, but a global shift towards other energy solutions has created a renewed interest in the WCSB for the exploration and development of critical minerals. Two of the minerals garnering interest are lithium, driven by an increasing demand for use in modern technologies such as rechargeable batteries, and helium, driven by an increasing demand for use in medical and technology industries as well as a depletion of the United States helium reserves in storage.

In 2020, the Alberta Geological Survey (AGS) began a project to investigate Alberta's prospectivity for lithium and helium resources. This project included gathering existing information and data about lithium and helium in Alberta; collecting and analyzing additional oil-field brine samples for lithium, and other constituents; reinterpreting publicly available geophysical data; and incorporating the helium information into the context of the AGS Geological Framework of Alberta.

The greatest prospectivity areas for lithium based on current data are in Devonian strata in the Peace River Arch area (northwestern Alberta) and in central Alberta near Red Deer. The areas of greatest helium prospectivity are in Devonian strata in the Peace River Arch area, Cretaceous strata in southern Alberta, and to a lesser extent in east-central Alberta and in Cambrian strata in southern Alberta, based on limited samples and correlations to similar units in Saskatchewan.

1 Introduction

The Western Canada Sedimentary Basin (WCSB) has a long history of oil and gas development, but a global shift towards other energy solutions has created a renewed interest in the WCSB for the exploration and development of critical minerals. The Alberta Geological Survey (AGS) undertook a study to develop knowledge of lithium (Li) and helium (He) resources in Alberta, which included compiling existing data, collecting and analyzing new samples, reinterpreting airborne geophysical data, and incorporating the information into AGS's Geological Framework of Alberta.

Lithium is a highly reactive metal with the ability to conduct electricity and heat while remaining malleable. Lithium is increasingly in demand for use in modern technologies such as rechargeable batteries. In Alberta, notable concentrations of Li have been found in formation waters of Devonian formations (Hitchon et al., 1993). For this study, steps were taken to create a comprehensive dataset. Data from existing AGS datasets, published literature, and mineral and resource assessment reports were compiled and cleaned to provide an overview of elevated Li concentrations in Alberta (Lyster et al., 2022). Six new brine samples were collected and analyzed, providing additional hydrochemical data (Reimert et al., 2022). A reinterpretation of publicly available airborne geophysical data (Natural Resources Canada, 2016) was conducted to investigate correlations between basement structures and fluid regimes for the potential sourcing of Li-enriched brines (McKenzie et al., 2022a, b).

Helium is a nonreactive gas that is lighter than air and has industrial uses for its inert nature. There is increasing demand for He production for use in medical and technology industries as well as a depletion of the United States He reserves in storage. Helium is commonly found in gas reservoirs in Alberta; however, the challenge is finding sufficient concentrations to make it economically viable for recovery. Most He is sourced from the natural decay of radiogenic minerals in Earth's mantle and crust and has been found trapped in strata overlying granitic and volcanic basement highs in Saskatchewan (Yurkowski, 2016). Helium concentrations compiled from gas test analyses, previously released by the AGS (Singh et al., 2021) and extracted from the Alberta Energy Regulator (AER) database, were accessed for this study to create a property model, which was used to identify continuous areas of interest.

2 Previous Work

2.1 Lithium

Lithium deposits of economic interest can occur within deposits such as granitic pegmatites (endogenously) or within evaporitic brines, salt flats, and clays (exogenously; Garrett, 2004). Within Alberta, recoverable Li resources are found within oil-field waters (Eccles and Berhane, 2011). The content of these waters has been the subject of investigation in Alberta since the 1970s. Reports detailing the Ca and Mg content of Alberta brines (Hitchon and Holter, 1971), the amount of Br, I, and B in Alberta formation waters (Hitchon et al., 1977), and the Li content of these waters (Hitchon, 1984) were produced using data from the Energy Resources Conservation Board in the 1970s and 1980s (Hitchon et al., 1993). A dataset review of 130 000 formation water analyses was conducted by Hitchon et al. (1993) and showed anomalously high Li values of up to 140 mg/L in the Devonian carbonate units (the Leduc and Swan Hills formations) in west-central Alberta. This dataset proved foundational for subsequent research and, not long after, modelling of Li resources was conducted by Underschultz et al. (1994), who identified two areas of 'significant resources' in west-central Alberta associated with the thickening of the Leduc Formation. Additional work by Bachu et al. (1995), using Li concentration and rock properties data, identified three areas for potential economic extraction of Li from formation fluids within west-central Alberta: two areas (north and south) in Leduc reef strata and one area in Beaverhill Lake Group strata. Eccles and Jean (2010) released a compilation of Li concentration values for formation waters and groundwaters in Alberta. This dataset was used by Eccles and Berhane (2011) to create an updated distribution map of Li-bearing formation waters, highlighting the area of Li-rich formation water near Fox Creek in west-central Alberta indicated in the previous studies. More recently, reports detailing the Li concentration of brines associated mainly with Devonian carbonate units were released by Huff (2016, 2019) and Lopez et al. (2019). Huff (2019) divided the brines in his study into three flow regimes based on geography, stratigraphic position, and hydrochemical characteristics. This division followed that of Bachu (1999) who, in his study of flow systems in the Alberta Basin, found that increased formation water salinity retarded the flow of formation water. Huff's (2019) trifold division—the central and western pre-Cretaceous flow regimes and the post-Jurassic flow regime—separated water sourced from Devonian carbonate units east of the Cooking Lake platform (central pre-Cretaceous) from that sourced from Devonian carbonate units west of the western platform margin (western pre-Cretaceous), as well as from younger strata (post-Jurassic). The post-Jurassic flow regime includes groundwater sourced from Cretaceous siliciclastic units (Huff, 2019). Only the brines in the two pre-Cretaceous flow regimes have Li concentrations of >50 mg/L, but likely have different evolutionary histories, suggesting that Devonian carbonate units house the richest Li-containing groundwater. Lithium data from the AGS and industry mineral assessment reports were compiled and released as a digital dataset by Lopez et al. (2019).

Authors have noted some overarching trends within these Li datasets. For instance, Li concentration has been noted to increase with the salinity of the brine (Hitchon et al., 1993; Underschultz et al., 1994; Bachu, 1995; Eccles and Berhane, 2011; Huff et al., 2019). Elevated Li concentration in brines sourced from the Swan Hills Formation was observed to correlate with the location of dolomitized carbonate units, and radiogenically enriched $^{87}Sr/^{86}Sr$ (Eccles and Berhane, 2011; Huff, 2019). It was also suggested that Li enrichment in the western portion of the province is associated with an influx of hydrothermal fluids based on the association of increases in radiogenic $^{87}Sr/^{86}Sr$ levels with increases in the mass ratios of K/Br and Li/Br (Eccles and Berhane, 2011; Huff, 2019). This is in contrast to brine samples from the central portion, which show the influence of evapoconcentration based on hydrogen and oxygen isotopes (Huff, 2019), but no correlation of elevated Li concentrations with $^{87}Sr/^{86}Sr$ values. Enrichment of Li in the central portion, through evapoconcentration and evaporite mineral dissolution, first involved the movement of mid-Devonian seawater toward the southeastern boundary of the Elk Point Basin from the open marine environment in the north (Huff, 2019). Following this migration, the brines near the southeastern margin of the Elk Point Basin were altered by the influx of dissolved potash constituents from the Prairie Evaporite Formation (Huff, 2019). These dense brines then permeated the underlying Winnipegosis / Keg River Formation and were driven westward by gravity (Huff, 2019). Laramide tectonism eventually pushed the central-regime brines up into the Leduc and Nisku formations (Huff, 2019).

The work of Hitchon (1984) and Hitchon et al. (1995) defined a 'detailed exploration threshold value' for Li of 75 ppm, as well as a 'regional exploration threshold value' of 50 ppm. These thresholds were established by evaluating the concentrations in economically producing fields of the time (Hitchon, 1984; Hitchon et al., 1995; Eccles, 2017). Early on, it was observed that the highest Li concentrations (up to 140 mg/L) occurred in formation waters from Devonian strata, including the Beaverhill Lake, Woodbend, Winterburn, and Wabamun groups (Hitchon et al., 1993, 1995; Eccles and Jean, 2010; Eccles, 2017).

This association of Li with Devonian strata is reflected in the three aquifers included by the E3 Metals Corp. in their Li resource model of the south-central Alberta area (in the Red Deer area): the Leduc reef margin, Leduc platform interior, and Cooking Lake interior aquifers (Spanjers et al., 2017a). The greatest Li-brine accumulations were found to occur in the dolomitized Leduc reefs deep in the subsurface (greater than 2200 m true vertical depth; Spanjers et al., 2017a).

This association of Li with Devonian strata is reflected in resource evaluations completed in south-central Alberta by E3 Metals Corp. (Spanjers et al., 2017a, b; MacMillan and Binks, 2018) and in west-central Alberta by Channel Resources Ltd. (Eccles et al., 2012b), Lithium Exploration Group, Inc. (Eccles et al., 2012a), and MGX Minerals Inc. (Eccles and Dufresne, 2016).

The origin of the brines containing Li in Alberta has been the topic of much research and is beyond the scope of this report. For a brief synopsis of the origin and characteristics of formation waters in the Alberta Basin, please see Huff (2019). However, it is worth highlighting some key pieces of work in order to give some context to the data presented here. Formation waters within the Devonian through Cretaceous strata in the Alberta Basin have been divided into three groups based on chemical composition and reservoir geology (Connolly et al., 1990a, b). Group I waters are associated with carbonate reservoirs and Group II waters come from clastic horizons. Group III waters are also associated with clastic deposits, however, in contrast to groups I and II waters, Group III waters are meteoric in nature and are distinct from the stratigraphically lower, saline waters of groups I and II. Devonian brines would fall largely under Group I. These brines, from Devonian reservoirs, have been hypothesized to have been the result of seawater evaporation (Spencer, 1987). Huff (2019), by using hydrogen, oxygen, and strontium isotopes, was able to demonstrate regional differences in Li source, indicating that Devonian brines from near the Peace River Arch area experienced hydrothermal input, possibly during the Laramide orogeny. The general idea of an evaporitic source was also modified to account for the influence of meteoric water (Huff, 2019). These brines are thought to have played a key role in the dolomitization of Devonian units within Alberta (Stacey et al., 2020).

2.2 Helium

Helium is a noble gas that is nonreactive and occurs in natural gas deposits in trace amounts (Hutcheon, 1999). Its nonreactive nature lends He to be a useful isotopic tracer for investigating fluid origin and migration (Hiyagon and Kennedy, 1992; Hutcheon, 1999). Primordial He sourced from the mantle, or from the atmosphere and associated with ancient meteoric water within sediments, is enriched in ^{3}He relative to radiogenic He, which is produced by the decay of radioactive elements in igneous rock (Hutcheon, 1999). Helium isotope data for the Alberta Basin are available from Hiyagon and Kennedy (1992). Hutcheon (1999) delineated two intervals of unusually high He partial pressures by analyzing data from the Alberta Energy and Utilities Board (EUB) and, by comparing the data to the isotope work of Hiyagon and Kennedy (1992), was able to infer possible sources for these anomalous He reservoirs. The first interval of high He partial pressures identified was in Devonian reservoirs within 500 m above the Precambrian crystalline basement in central and northern Alberta. The second interval of high He partial pressures was found to be within Lower Cretaceous Mannville Group reservoirs approximately 1000 m above the basement, predominantly in southern Alberta. Upon comparison with the work of Hiyagon and Kennedy (1992), Hutcheon (1999) found that the shallower Cretaceous Mannville Group reservoirs were dominated by ^{3}He, whereas the deeper Devonian reservoirs were rich in ^{4}He. Hutcheon (1999) postulated that the He in the shallower reservoirs was sourced from atmospheric He during the Laramide orogeny, accumulating underneath the Joli Fou Formation shale, whereas the He in the deeper Devonian reservoirs in west-central Alberta near the Peace River Arch is sourced from the Precambrian basement. Because the low permeability of sedimentary layers beneath the Devonian deposits makes He diffusion unlikely, McLellan and Hutcheon (1993) concluded that the He must have travelled along reactivated basement faults, a view that Hutcheon (1999) reiterates. Even though some He was noted to occur within Triassic deposits as well as in the Cretaceous Colorado Group, the Devonian strata and Mannville Group were the largest reservoirs.

Regionally speaking, the occurrence of high concentrations of He within Devonian strata in the Peace River Arch area (near the border with British Columbia), agrees with data from British Columbia, which suggests that much of its He is also associated with Devonian deposits (Johnson, 2012). On the eastern side of Alberta, it is also likely that other strata in close proximity to the basement (such as the Cambrian strata) house He, considering that much of Saskatchewan's He-rich natural gas occurs in Cambrian strata (Sawatzky et al., 1960; Burwash and Cumming, 1974; Yurkowski, 2016) and Manitoba's He resources span the Mississippian, Devonian, and Lower Ordovician to Precambrian strata (Nicolas, 2018). The He produced near Swift Current, Saskatchewan, from upper Cambrian deposits (Deadwood Formation), is sourced from the radioactive decay of elements in Precambrian basement rocks (Burwash and Cumming, 1974).

3 Geological Setting

The data compiled for this report pertain to subsurface fluids within the Phanerozoic sedimentary succession of the Alberta Basin. The sedimentary succession rests unconformably on the Precambrian basement and comprises a wedge-shaped package of rocks that thins progressively eastwards towards the Canadian Shield in northeastern Alberta. There are two broad bedrock sedimentary packages: (1) a lower Paleozoic to Middle Jurassic interval dominated by carbonate rocks, evaporites, and terrigenous shales recording deposition in shallow seas along the western margin of Laurentia, and (2) an Upper Jurassic to Paleogene succession of siliciclastic rocks, which were deposited in front of the evolving Canadian Cordillera. Strata from nearly all Phanerozoic geological ages are represented in the data; however, deposits of the Silurian System are largely absent from the Alberta Basin (Figure 1).

Deposits of the Cambrian System comprise mixed carbonate-siliciclastic rocks with carbonate rocks dominating the deep, western part of the basin, becoming increasingly shaly to the east. Cambrian strata are limited to the southern half of the province (Figure 2a). In southeastern Alberta, Ordovician rocks rest on shaly Cambrian strata and represent the western fringe of preserved Ordovician carbonate units, which were eroded significantly prior to Devonian deposition in Alberta (Figure 2a). The top of the Cambrian and Ordovician strata forms the sub-Devonian unconformity in central and southern Alberta. To the north, the Devonian is underlain by Precambrian basement rocks.

Devonian strata in the basin make up two broad intervals: (1) a Middle Devonian succession of carbonate rocks and abundant evaporites with lesser shale, red beds, and sandstone; and (2) a Middle to Upper Devonian succession of conspicuous carbonate buildups with off-reef shaly strata; evaporites make up a significant proportion of the Devonian succession in southern Alberta, coinciding with the Southern Leduc shelf (Figure 2). Some carbonate buildups in the basin comprise biostromal strata with basin-wide extent (e.g., Wabamun Group), whereas other Devonian buildups form isolated bioherms (e.g., Leduc and Swan Hills formations; Figure 2a).

Devonian strata are overlain by Mississippian to Permian deposits, which are mostly restricted to parts of western and southern Alberta. These strata comprise carbonate and siliciclastic rocks, the latter of which make up a larger portion of the succession within the Permian. The bulk of the Permian succession is centred on the Peace River Embayment, an area of the Peace River Arch that through tectonic events collapsed into a series of extensive grabens (Barclay et al., 1990; O’Connell, 1990; Richards et al., 1994; Figure 2b).

Like the Carboniferous and Permian succession, much of the Triassic and Jurassic deposits are restricted to the western part of the province (Figure 2b). The Triassic succession comprises mixed carbonate-siliciclastic rocks with some evaporites. The overlying Jurassic strata include a thick succession of shale that contains a number of sandstone beds. The Middle to Upper Jurassic marks the transition into active convergence along western Laurentia (Pană and van der Pluijm, 2015; Pană et al., 2018).

Lower Cretaceous deposits contain thick sandstone units that reflect denudation of an active cordillera to the west, which is also evidenced by the lack of carbonate and evaporite strata throughout the remainder of the sedimentary succession. Cretaceous deposits are widespread across the basin and record ongoing erosion of the cordillera and associated foreland basin deposition.

Paleogene sandstone deposits record the last preserved pulses of active tectonism in the cordillera (Pană and van der Pluijm, 2015), and are the youngest bedrock strata in the Alberta Basin (Figure 2b).

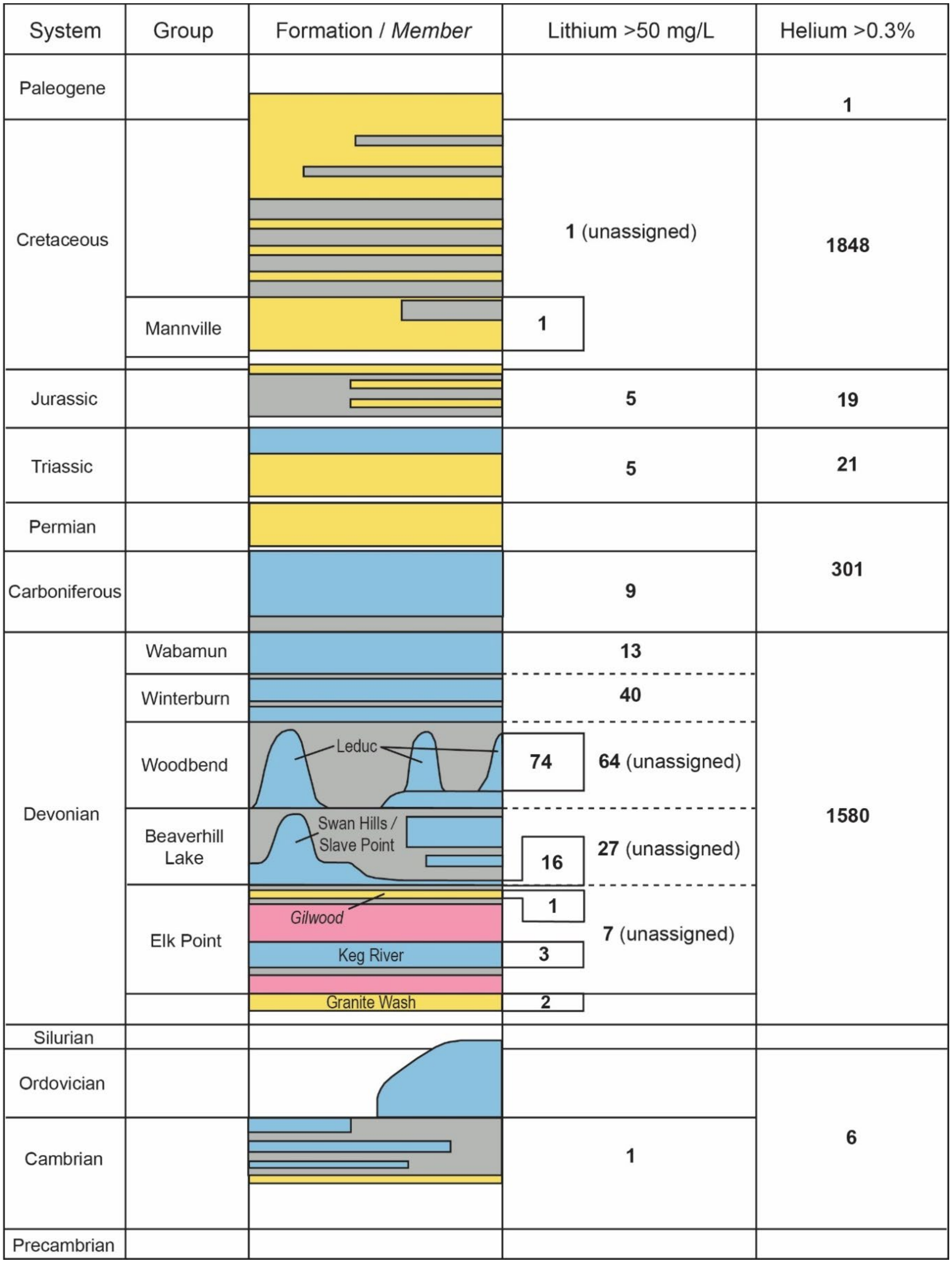

Figure 1. Simplified stratigraphic chart displaying the number of water samples in Alberta with elevated lithium and helium values by stratigraphic unit. Colours represent generalized lithology: grey, shale and mudstone; yellow, sandstone and siltstone; blue, limestone and dolostone; pink, halite and anhydrite.

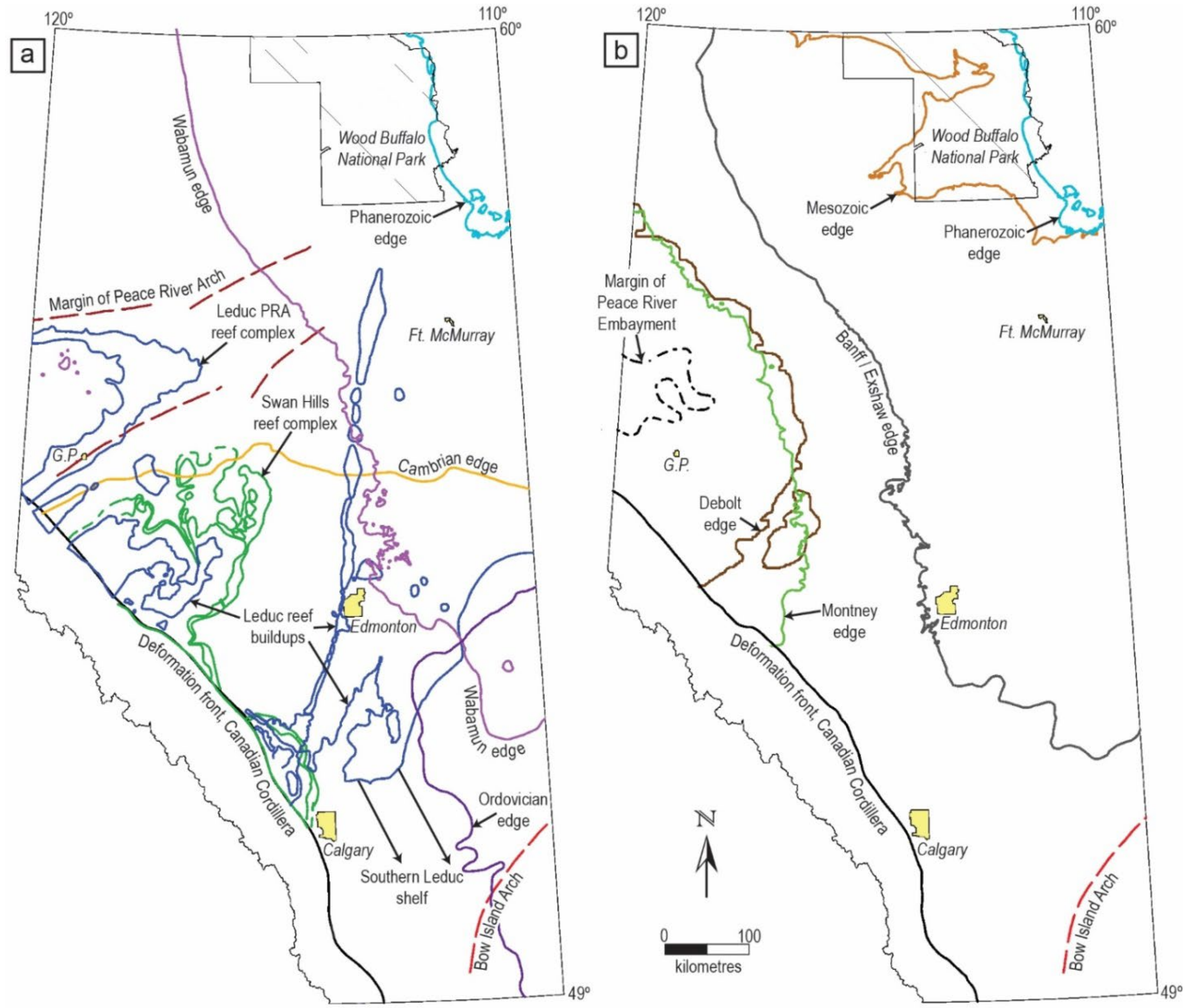

Figure 2. Depositional and structural elements within the Phanerozoic sedimentary succession of Alberta: (a) Cambrian to uppermost Devonian (Wabamun Group) strata, and (b) Carboniferous and younger strata. Margin of the Peace River Arch and Bow Island Arch modified from O'Connell (1994) and Kent and Christopher (1994), respectively. Leduc Formation edges (blue lines) modified from Switzer et al. (1994). Swan Hills reef complex edge modified from Wendte and Uyeno (2005). Peace River Embayment outline modified from Richards et al. (1994). Abbreviations: Banff, Banff Formation; Debolt, Debolt Formation; Exshaw, Exshaw Formation; Ft., Fort; G.P., Grande Prairie; Montney, Montney Formation; PRA, Peace River Arch; Wabamun, Wabamun Group.

Figure 2 shows some of the many paleotopographic elements that affected deposition of the Phanerozoic sedimentary succession in Alberta. In northwestern Alberta, the Peace River Arch (PRA) was a positive paleotopographic element during the Paleozoic up until the Carboniferous, when it partially collapsed into a series of grabens. The resulting positive accommodation feature is named the Peace River Embayment (Richards et al., 1994), where thick late Paleozoic through Permian strata accumulated. The area of the PRA is known to be structurally complex with abundant basement-rooted faults (O'Connell, 1994). In southeasternmost Alberta, the Bow Island Arch trends northeast from the United States–Canada border into Saskatchewan (Figure 2). This positive paleotopographic feature affected depositional patterns throughout the Phanerozoic (Kent and Christopher, 1994).

4 Lithium Data and Occurrences

The AGS has previously released datasets focused specifically on Li occurrences in groundwater and formation waters in Alberta (Eccles and Jean, 2010; Lopez et al., 2019). These datasets contain little information other than Li concentrations and, although they provide a useful look at where there are elevated Li concentrations, they do not allow for interpretation of context, such as fluid origins. There are other AGS datasets that contain more geochemical analytes and provide more robust information (Huff et al., 2011, 2012, 2019) and these data were included in this study. The AGS also collected and analyzed additional brine samples specifically for this study (Reimert et al., 2022). These datasets are useful but limited in coverage of geographic areas and geological units. The AGS oil and gas wells database (AGSWDB), which was used as a source for Eccles and Jean (2010), contains province-wide data and information on more analytes than just Li. The AGSWDB was accessed and the additional analyte data fields were extracted from it. Only minimal culling was done on the data from the AGSWDB.

There are other sources of Li data available in the public domain, but few that are in easily usable formats. The sources used in this study included published literature (Connolly et al., 1990a, b); mineral assessment reports submitted to Alberta Energy (Dufresne, 2011; Eccles and Dufresne, 2017; Eccles, 2018a–c; Lappin, 2018); and National Instrument 43-101 resource assessment submissions (Eccles et al., 2012a, b).

All of the data sources combined have a total of 1081 data records. For more details or to download the compiled dataset see Lyster et al. (2022). Table 1 shows a summary of the data sources used in this study of the geochemistry of Li-bearing water samples.

Figure 3 shows the distribution of Li-bearing formation waters based on the geological age of the host strata, as specified in the original data source. Of the 950 data points with geological units specified, 453 are from Devonian strata and 382 are from Cretaceous strata, which together comprise most of the data.

A value of 50 mg/L is generally considered the minimum Li concentration to be of interest for further exploration (Hitchon et al., 1993). Table 2 shows a summary of the samples with elevated Li concentrations grouped by geological interval as identified in the original source. The source information varied in the level of precision, ranging from member to formation to group to age. For example, there are 74 Leduc Formation samples and 64 Woodbend Group samples, those 64 Woodbend Group samples may or may not include additional Leduc Formation samples.

Figure 4 shows the Li concentrations in water samples from Devonian strata. Most of the elevated Li values in these brines are in the Peace River Arch area in northwestern Alberta and in central Alberta, near Red Deer. Most of the samples come from exploration programs looking for Li so there is a possibility of sampling bias.

Figure 5 shows the Li concentrations in water samples from Cretaceous strata. Although there are many water samples from Cretaceous strata, there are only two with Li concentrations above 50 mg/L.

Table 1. Sources of lithium occurrence geochemistry data for Alberta.

Data Source	Reference	Data Records	Notes
DIG 2021-0022	Reimert et al. (2022)	6	
DIG 2019-0002	Huff et al. (2019)	22	
DIG 2012-0001	Huff et al. (2012)	39	
DIG 2011-0007	Huff et al. (2011)	38	
OFR 2011-10	Eccles and Berhane (2011)	18	10 points are also in Eccles et al. (2012b), with different fields in each
AGSWDB	n/a	743	34 data points are also in Connolly et al. (1990a, b); duplicates removed from AGSWDB points
NI 43-101 Fox Creek	Eccles et al. (2012b)	10	Data points are also in Eccles and Berhane (2011), with different fields in each
NI 43-101 Valleyview	Eccles et al. (2012a)	62	
MAR 20180001	Eccles (2018a)	12	
MAR 20180008	Eccles (2018b)	10	
MAR 20180009	Eccles (2018c)	22	
MAR 20180012	Lappin (2018)	75	
MAR 20170006	Eccles and Dufresne (2017)	18	
MAR 20110005	Dufresne (2011)	7	
Published literature	Connolly et al. (1990a, b)	43	34 points are also in AGSWDB; duplicates removed from AGSWDB points

Abbreviations: AGSWDB, Alberta Geological Survey oil and gas wells database; DIG, digital dataset; MAR, mineral assessment report; NI, National Instrument; OFR, open file report.

Determining the source of the Li-enriched brines is of interest for improving predictions of where these brines might occur outside of previously sampled areas. Earlier AGS work by Huff (2019) explored this subject. The data in Lyster et al. (2022) contains information that may be used to further elucidate the source of the brine in various formations and geographic areas. It is suggested in Bachu et al. (1995) that there are different flow regimes within the Alberta Basin. Huff (2019) used the ratio of $^{87}Sr/^{86}Sr$ isotopes, among other indicators such as $\delta^{18}O$ and $\delta^{2}H$, to approximate water that has interacted with the basement, and this study followed that example.

An elevated $^{87}Sr/^{86}Sr$ ratio implies hydrothermal fluids derived from the basement, whereas a lower $^{87}Sr/^{86}Sr$ ratio is consistent with Phanerozoic seawater origin, approaching the isotopic composition of Devonian seawater. Figure 6 shows a crossplot of strontium concentration versus the ratio of $^{87}Sr/^{86}Sr$ isotopes with the clusters of elevated radiogenic strontium (basement fluid) and basinal fluid data points outlined. Machel and Cavell (1999) used a $^{87}Sr/^{86}Sr$ value of 0.712 as the MAximum Sr Isotope Ratio of BAsinal Shale (MASIRBAS). The data in Figure 6 show three values between 0.712 and 0.713, with the clearest breakpoint in the data between the cluster of basinal fluid points and elevated $^{87}Sr/^{86}Sr$ at 0.713. The 160 data points containing strontium isotope ratios in the dataset have been divided into elevated radiogenic strontium (ratio above 0.713) and nonelevated (ratio below 0.713). Of these 160 data points, 87 are from Devonian strata, 57 from Cretaceous strata, 8 from Carboniferous strata, and 8 from Jurassic strata.

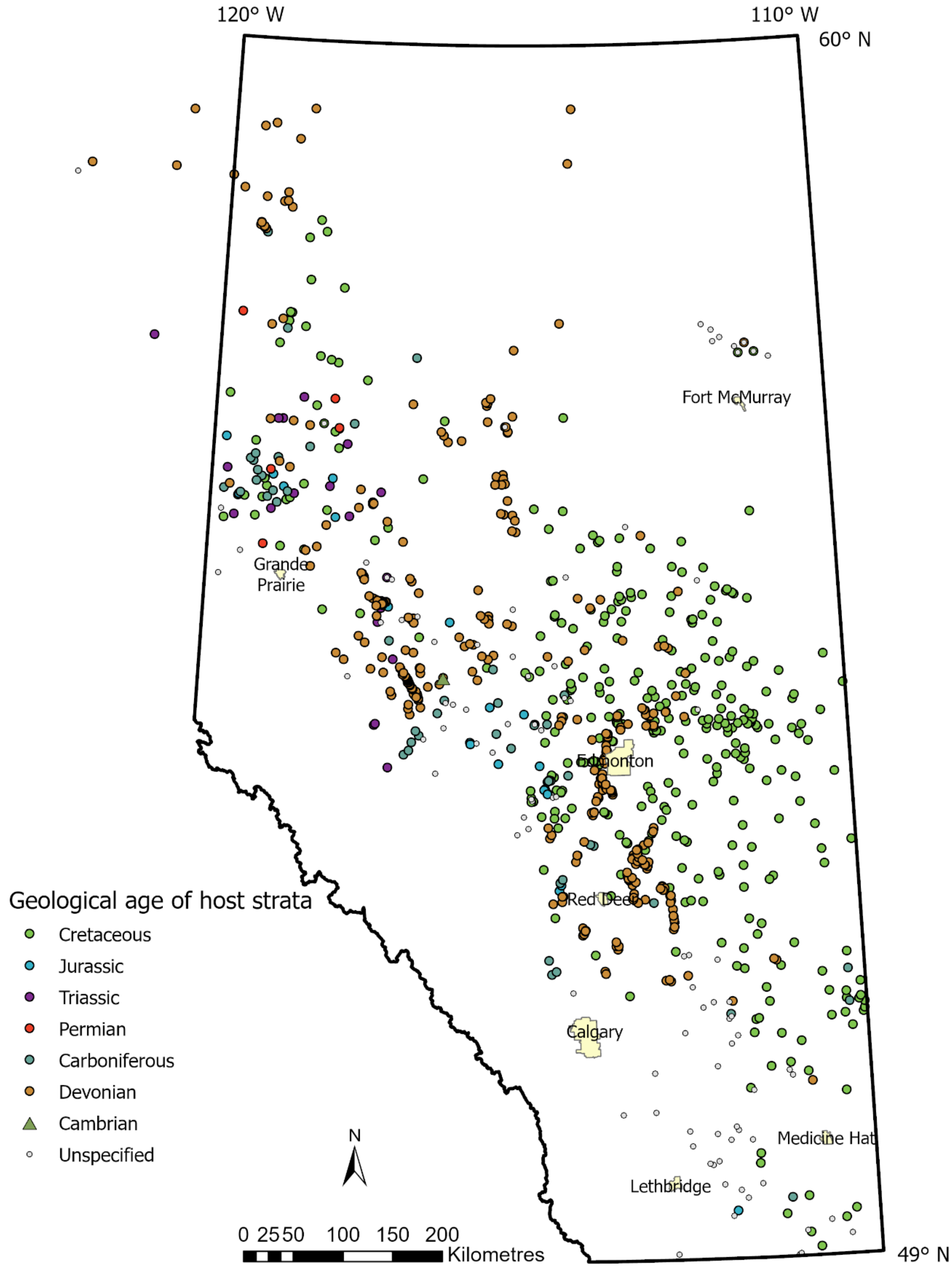

Figure 3. Locations of water geochemistry samples of lithium-bearing formation waters in Alberta, symbolized according to the geological age of the host strata. See Table 1 for sources of data.

Table 2. Summary of water samples with lithium concentrations above 50 mg/L in Alberta. See Table 1 for sources of data. Abbreviations: P25, 25th percentile; P50, 50th percentile; P75, 75th percentile.

Geological Interval (as specified in source data)	Sample Count	Mean (mg/L)	Minimum (mg/L)	P25 (mg/L)	P50 (mg/L)	P75 (mg/L)	Maximum (mg/L)
Cretaceous System[1]	1	130.0					
Mannville Group	1	53.0					
Jurassic System	5	61.8	53.0	60.0	62.0	66.0	68.0
Triassic System	5	57.8	55.0	57.0	58.0	59.0	60.0
Mississippian System	9	54.9	51.0	52.0	54.0	58.0	60.0
Wabamun Group	13	81.0	51.0	72.0	82.0	89.0	115.0
Winterburn Group	40	77.2	51.0	66.7	74.3	84.8	140.0
Woodbend Group[2]	64	74.7	50.0	64.8	67.9	74.0	140.0
Leduc Formation	74	72.0	50.0	65.3	72.4	76.2	103.5
Beaverhill Lake Group[2]	27	80.0	60.0	75.0	77.2	80.9	130.0
Swan Hills / Slave Point Formation	16	84.6	58.3	78.9	86.6	87.4	112.0
Elk Point Group[2]	7	62.0	51.0	51.5	53.7	74.5	77.0
Gilwood Member	1	98.0					
Keg River Formation	3	69.0	54.0	56.0	58.0	76.5	95.0
Granite Wash	2	83.0	71.0	77.0	83.0	89.0	95.0
Cambrian System	1	81.0					

[1] may or may not be from the Mannville Group
[2] may or may not include additional samples of the formation/member below

Figure 7 shows a bromine-chlorine crossplot with the elevated and nonelevated $^{87}Sr/^{86}Sr$ ratios highlighted. This relationship suggests that the more extensively available chlorine and bromine values (967 and 923 data points, respectively) could be used to identify flow regimes.

Figure 8 shows a map of the strontium isotope ratios of water samples from Devonian strata overlain on an interpretation of geophysical data (McKenzie et al., 2022a, b). The easternmost cluster of data points approximately corresponds to the central pre-Cretaceous hydrological regime mentioned in Huff (2019). The points to the west have a more complex mixture of origins, suggesting that the western pre-Cretaceous hydrological regime may actually have two distinct sources of some currently undefined origin. A closer study of the Peace River Arch area would be necessary to identify specific flow paths that may be related to structural features or basement lineaments. Appendix 1 contains geochemical crossplots using the data from Lyster et al. (2022), following the type of plots in Huff (2019).

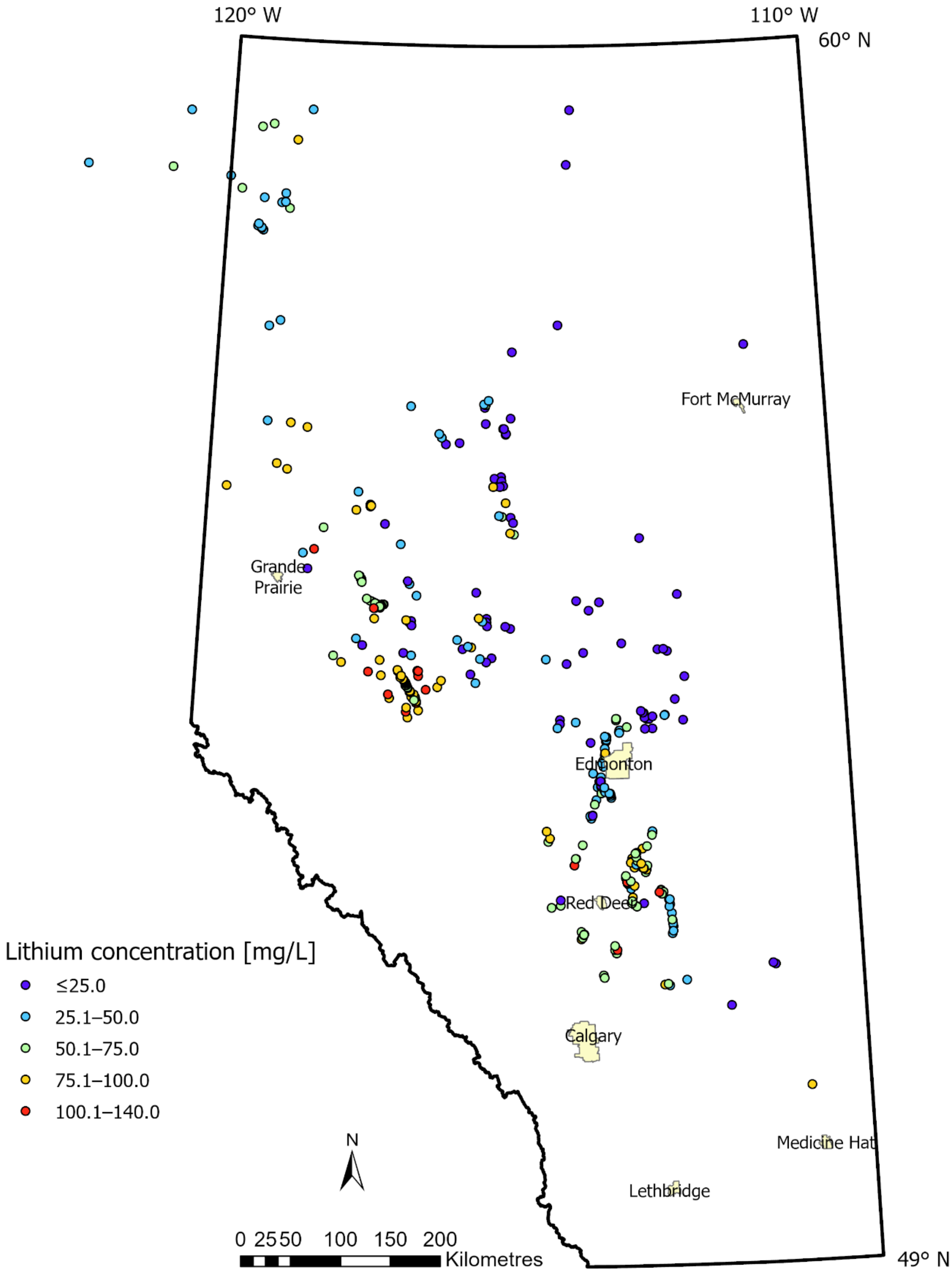

Figure 4. Lithium concentrations in water samples from Devonian strata in Alberta. See Table 1 for sources of data.

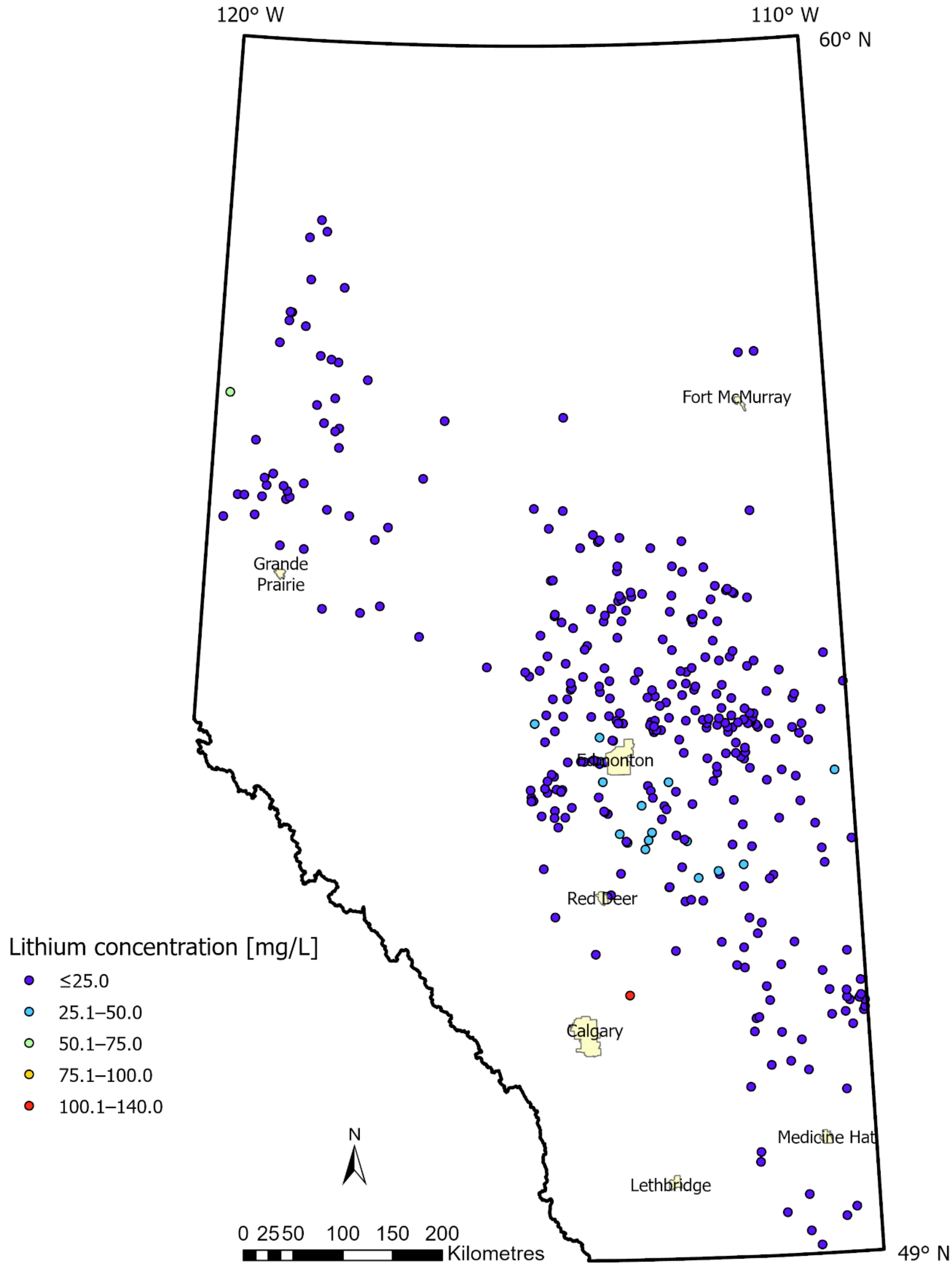

Figure 5. Lithium concentrations in water samples from Cretaceous strata in Alberta. See Table 1 for sources of data.

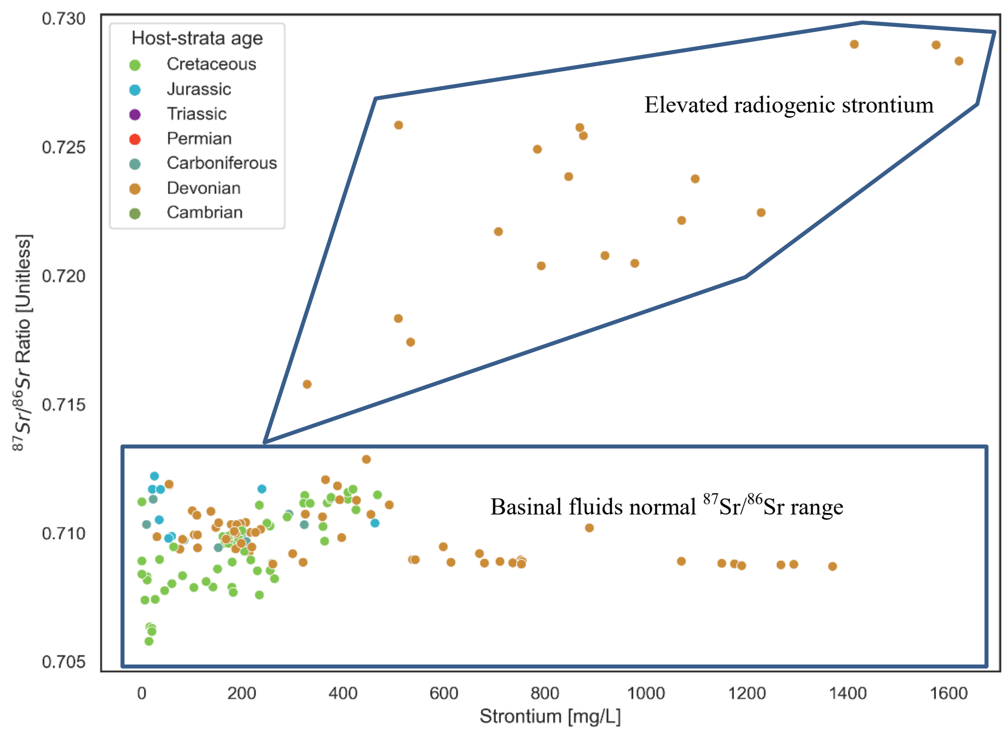

Figure 6. Strontium concentration versus $^{87}Sr/^{86}Sr$ ratio in lithium-bearing formation waters in Alberta. See Table 1 for sources of data.

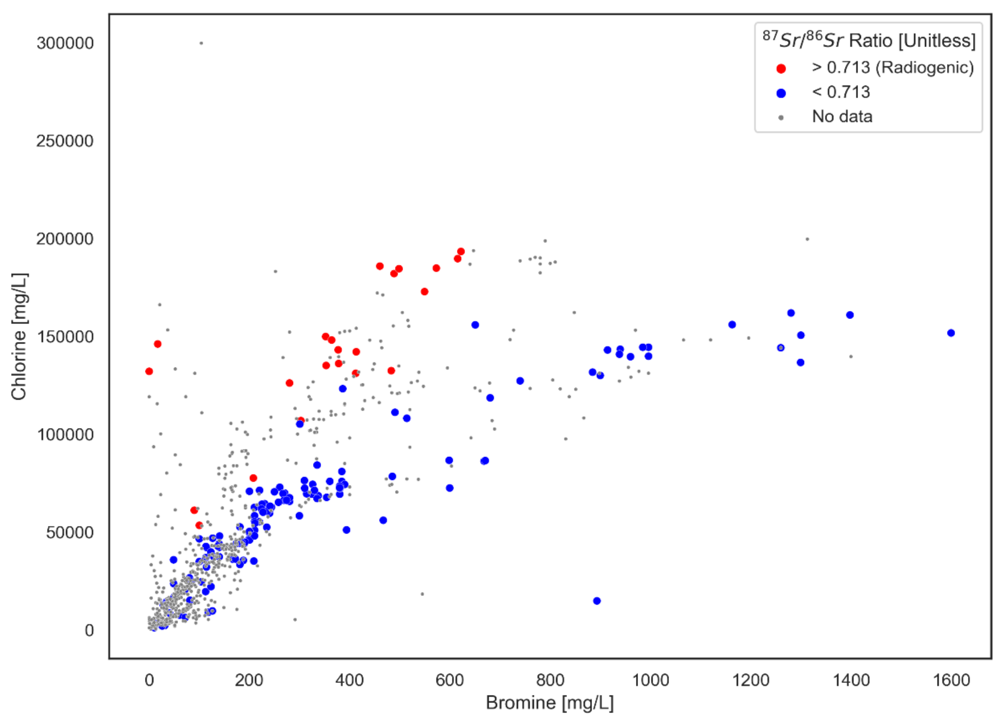

Figure 7. Bromine versus chlorine concentration in formation waters in Alberta; samples with an elevated radiogenic strontium isotope ratio (>0.713) in red and samples with a nonelevated strontium isotope ratio (<0.713) in blue. See Table 1 for sources of data.

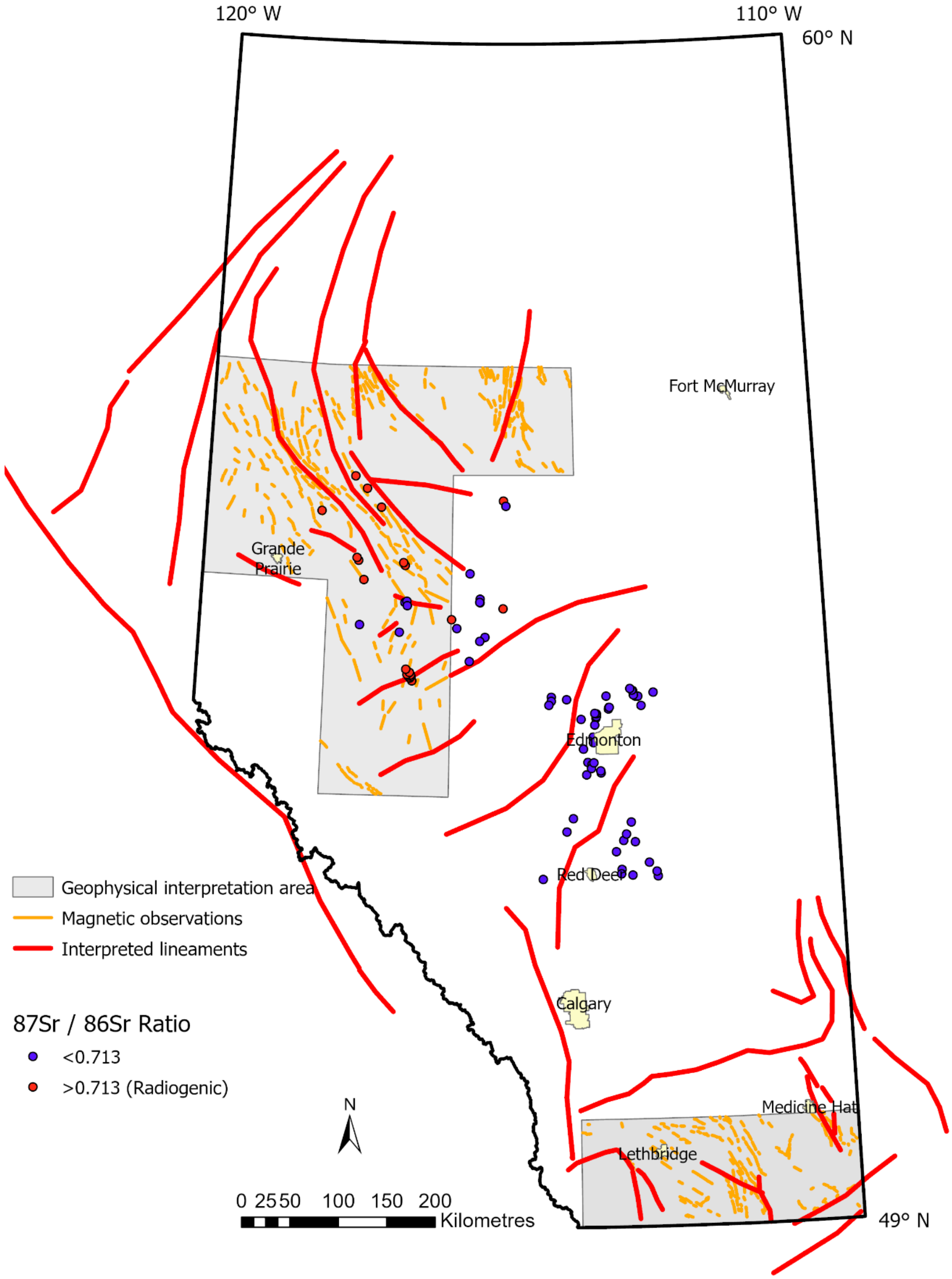

Figure 8. Locations of water samples from Devonian strata in Alberta overlain on an airborne geophysical survey reinterpretation (McKenzie et al., 2022a, b). Samples with an elevated radiogenic strontium isotope ratio (>0.713) in red and samples with a nonelevated strontium isotope ratio (<0.713) in blue. See Table 1 for sources of data.

5 Helium Data and Occurrences

Helium data from gas analysis tests were previously released by the AGS (Singh et al., 2021) and were used in this study. This dataset contains 22 168 points from 17 703 wells that have He concentrations greater than 0%, with minimum values of 0.01% or 0.1% depending on the detection limit of the specific tests. Of these data points, 3801 have a He concentration of at least 0.3%, generally considered to be the economic threshold (National Research Council, 2010) and used in similar work in British Columbia, Saskatchewan, and Manitoba (Johnson, 2012; Yurkowski, 2016; Nicolas, 2018). Table 3 shows a summary of samples with He concentrations over 0.3% (from Singh et al., 2021), summarized by geological interval as determined by placing the sample locations within the Geological Framework of Alberta (GFA; Alberta Geological Survey, 2021).

Figure 9 shows the locations of 1580 gas samples with a He concentration of at least 0.3% taken from Devonian strata. Most of the samples are from the Peace River Arch area and to the northeast of that area.

Figure 10 shows the locations of 1848 gas samples with a He concentration of at least 0.3% taken from Cretaceous strata. Most of the samples are from southern Alberta, in the Lethbridge to Medicine Hat area. The next densest cluster of points is in east-central Alberta, near the border with Saskatchewan.

To determine prospectivity, it is important to include the gas analysis samples with no detectable He so as not to bias the modelling towards the enriched He samples. The gas analyses with no detectable He were extracted from the AER database, by following the same process as outlined in Singh et al. (2021) but omitting the step where a minimum He concentration criterion was applied. This resulted in over 350 000 gas analyses that were used to model He concentration within the GFA.

The He data points were georeferenced and loaded into Petrel 2019. A simple 3D property model was created using the GFA as a stratigraphic framework with one layer per model zone. The property modelling method used was kriging with a single variogram model for all zones. This model is too simplistic for resource calculations or detailed examination of zones but at the scale of province-wide prospectivity it provides a first-pass look at where the He concentration values over 0.3% outweigh the zeros in the dataset. Large continuous areas where the modelled concentrations are at least 0.3% were combined by geological age to highlight the areas of potential prospectivity, areas where the samples with elevated He concentrations are more common than samples with lower He concentrations. Figure 11 shows the locations of the potential prospective areas produced by this method. There are three large prospective areas: near the Peace River Arch in Devonian strata; in southern Alberta in Cretaceous strata; and in east-central Alberta in Cretaceous strata.

In addition, there is probably a He prospective area in Cambrian strata in southeastern Alberta based on correlation with work in Saskatchewan (Sawatzky et al., 1960; Burwash and Cumming, 1974; Yurkowski, 2016). There are only six samples from the Ordovician-Cambrian geological interval in Alberta so determining a specific prospective area cannot be done with any degree of confidence yet.

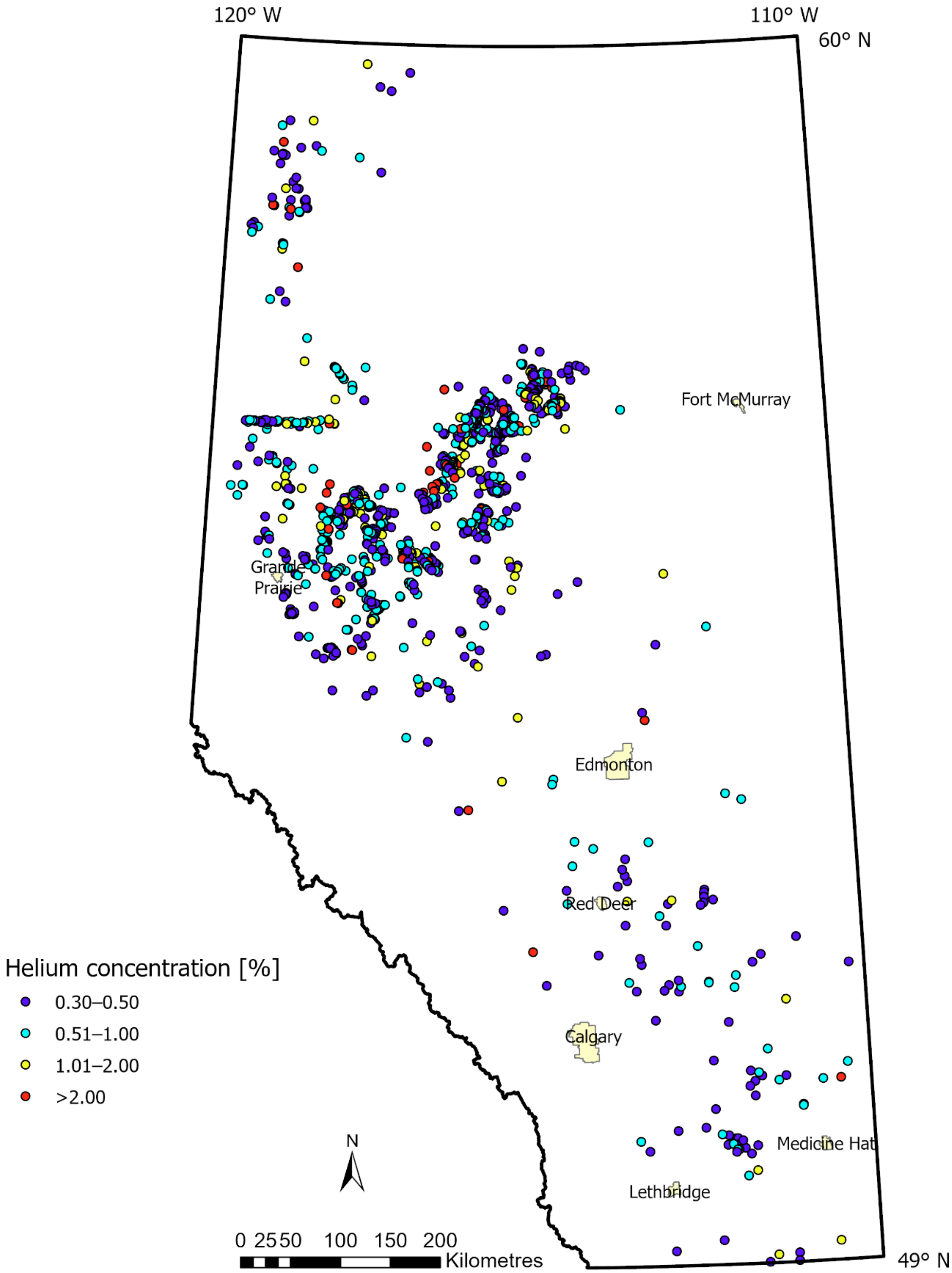

Figure 9. Gas samples with helium concentrations of at least 0.3% in Devonian strata in Alberta. Data from Singh et al. (2021).

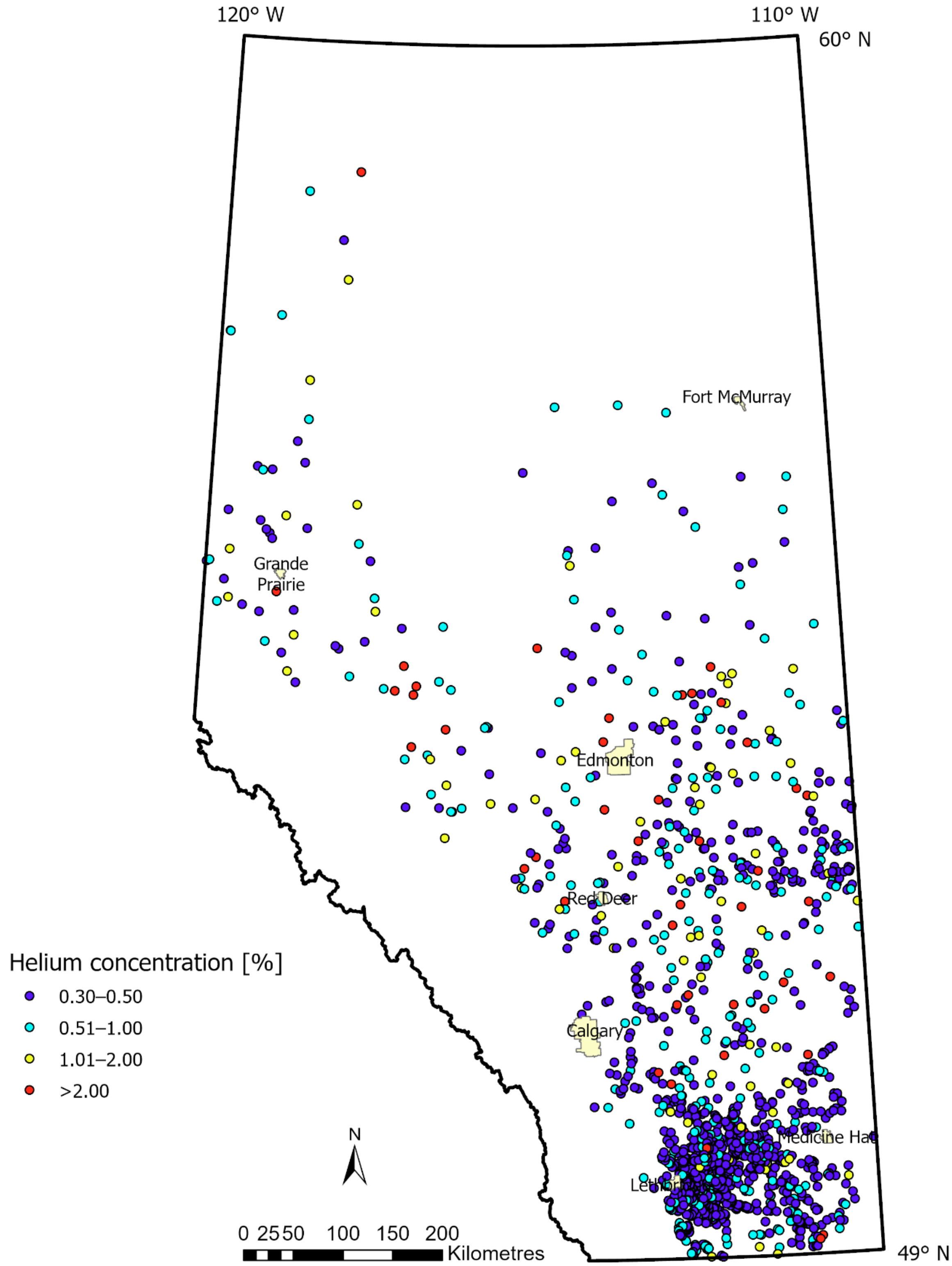

Figure 10. Gas samples with helium concentrations of at least 0.3% in Cretaceous strata in Alberta. Data from Singh et al. (2021).

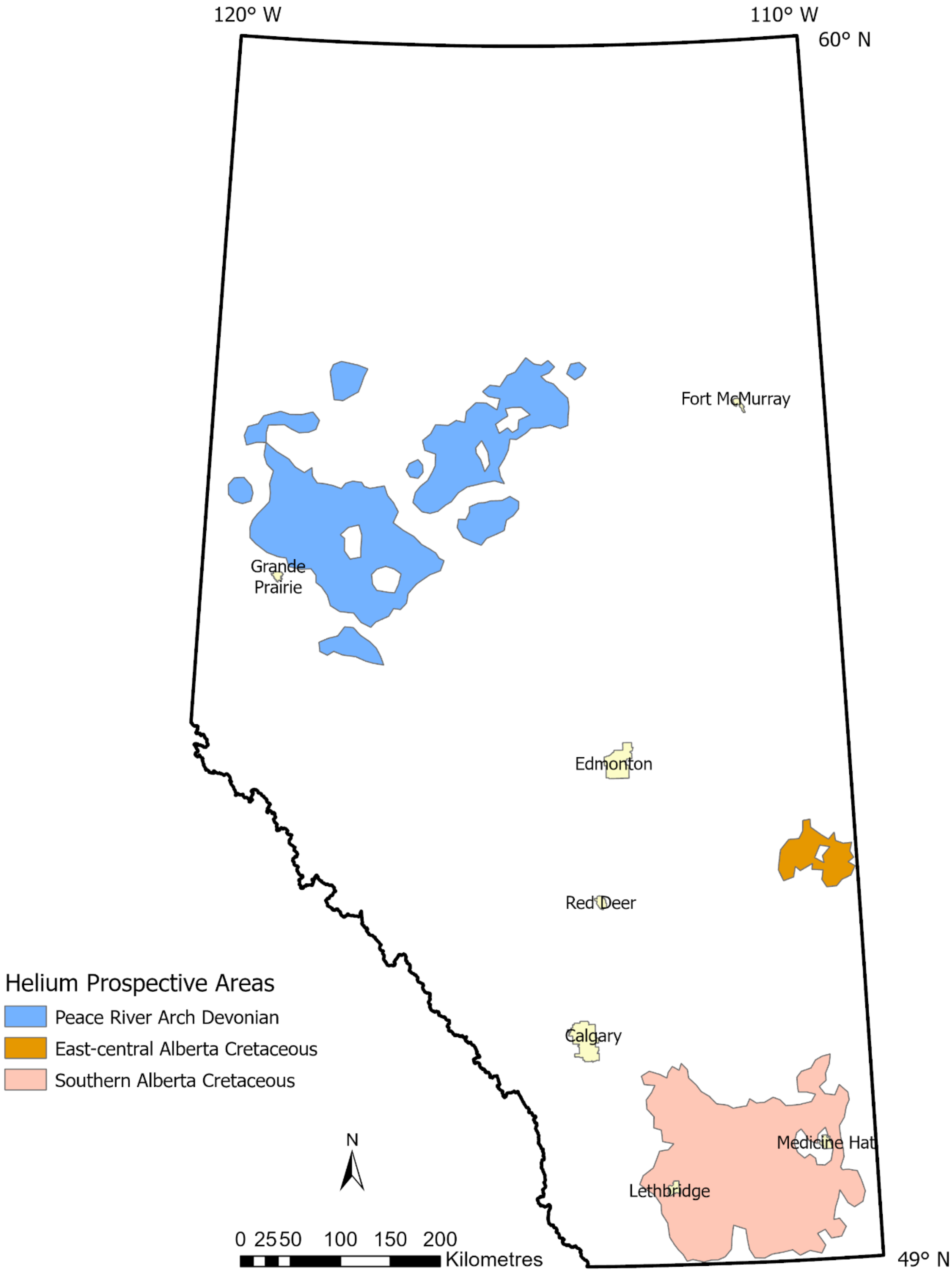

Figure 11. Helium prospective areas in Alberta estimated from gas analysis test data (data from Alberta Energy Regulator database and Singh et al., 2021).

Table 3. Summary of gas samples with helium concentrations above 0.3% in Alberta (data from Singh et al., 2021). Abbreviations: P25, 25th percentile; P50, 50th percentile; P75, 75th percentile.

Geological Interval	Sample Count	Mean (%)	Minimum (%)	P25 (%)	P50 (%)	P75 (%)	Maximum (%)
Paleogene	1	0.31					
Cretaceous	1848	0.58	0.30	0.34	0.40	0.52	9.44
Jurassic	19	0.72	0.30	0.40	0.56	0.93	2.32
Triassic	21	0.65	0.30	0.42	0.55	0.80	1.77
Permian–Carboniferous	301	0.52	0.30	0.34	0.42	0.52	3.27
Devonian	1580	0.74	0.30	0.39	0.53	0.83	10.00
Ordovician–Cambrian	6	1.83	1.16	1.43	1.49	2.01	3.22
Undifferentiated; directly above Precambrian	25	0.90	0.31	0.39	0.60	1.04	3.65

6 Conclusions and Future Work

For this work the Alberta Geological Survey compiled existing datasets to gather any values that could be useful in identifying areas in Alberta that are prospective for lithium or helium; carried out a small brine sampling program to fill in knowledge gaps and explore previously unsampled geological units; and had airborne geophysical data reinterpreted to identify structural features that may have enabled fluid flow from the basement to present-day reservoirs.

The areas of samples with the most elevated lithium concentrations, based on current data, are in Devonian strata in the Peace River Arch area in northwestern Alberta and in central Alberta near Red Deer. The areas of greatest helium prospectivity are in Devonian strata in the Peace River Arch area, Cretaceous strata in southern Alberta, and to a lesser extent in east-central Alberta. Cambrian strata in southern Alberta may also be of interest based on limited samples and correlations to similar units in Saskatchewan.

Future work to better delineate these emerging resources could include: geochemical analysis of potential lithium-bearing formations to determine whether the lithium-bearing brine is sourced from nearby to its host strata or transported from other sources (i.e., Precambrian basement); additional brine sampling to better delineate the lithium-bearing zones and expand knowledge of sparsely sampled areas; collecting and analyzing new rock and brine samples to allow the comparison of lithium isotopes in rock samples to brine samples to investigate a relationship between the two; conducting nonstandard analyses, such as for helium isotopes, to attempt to identify helium sources; and reinterpreting more airborne geophysical data and incorporating the structural interpretation into a basinal fluid flow model.

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Appendix 1 – Plots of Geochemical Data

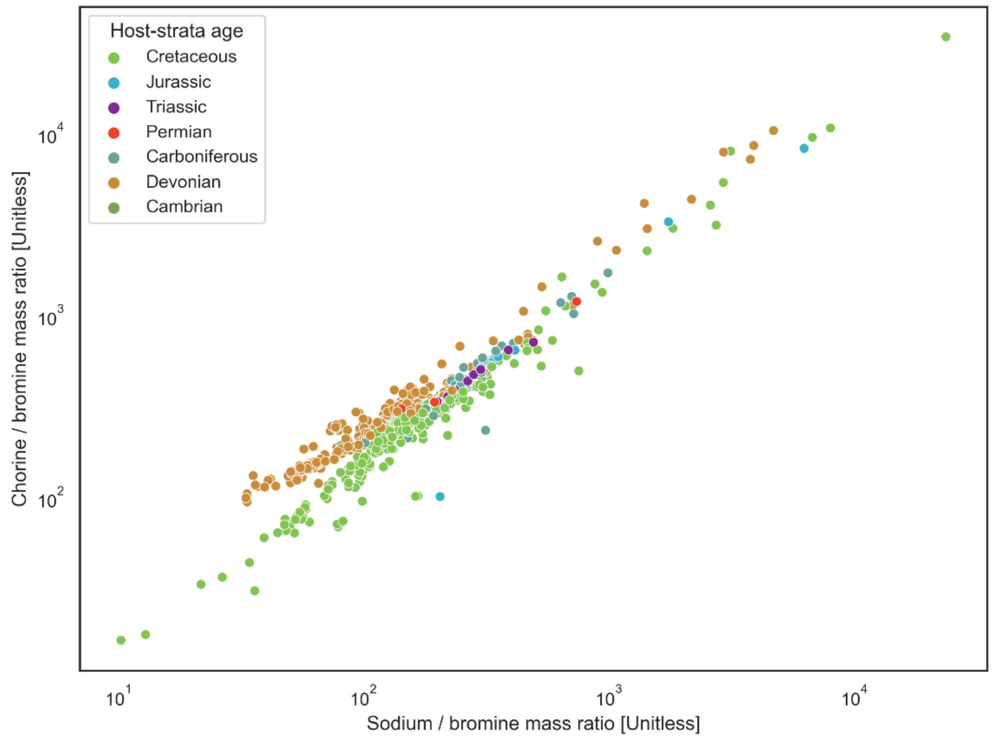

Figure 12. Sodium/bromine mass ratio versus chlorine/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022).

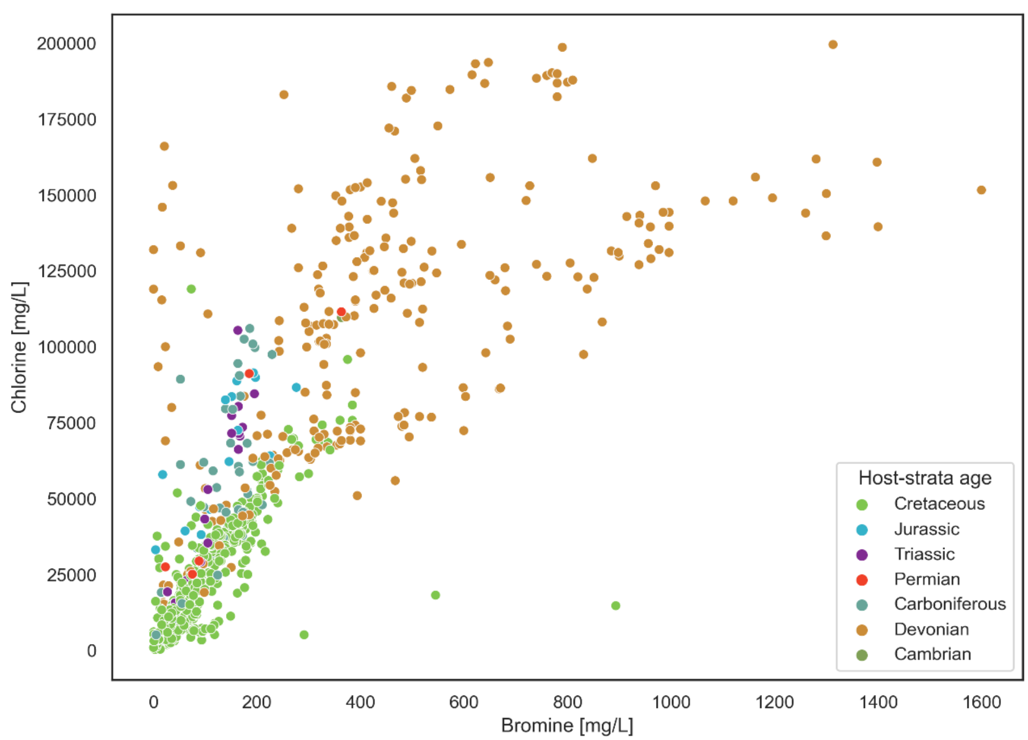

Figure 13. Bromine concentration versus chlorine concentration in formation waters in Alberta. Data from Lyster et al. (2022).

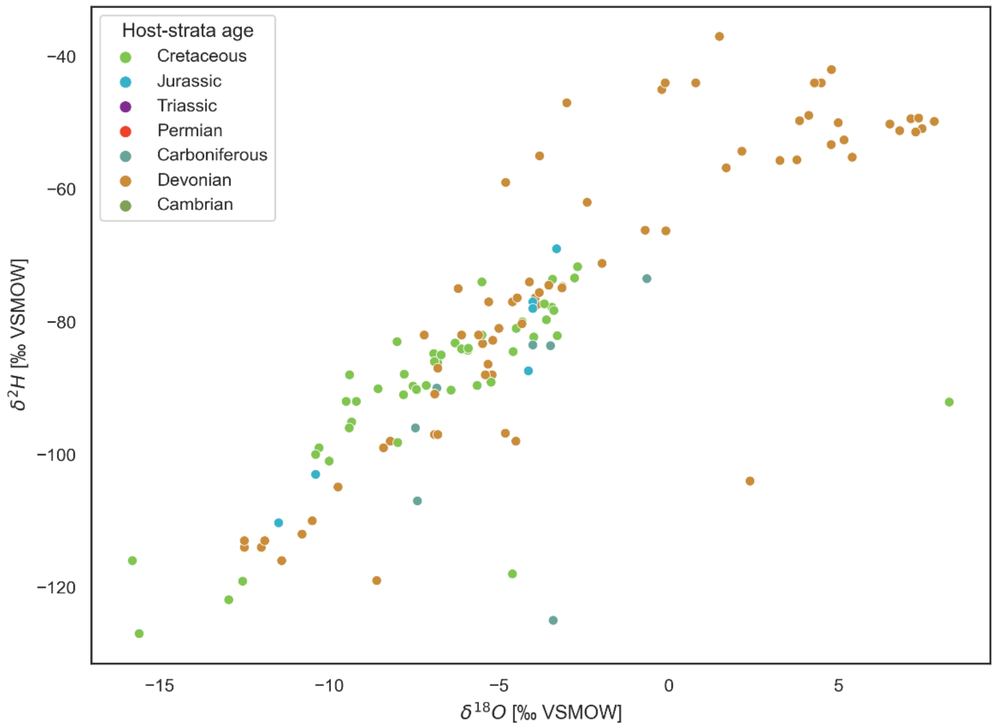

Figure 14. Delta oxygen-18 versus delta hydrogen-2 in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

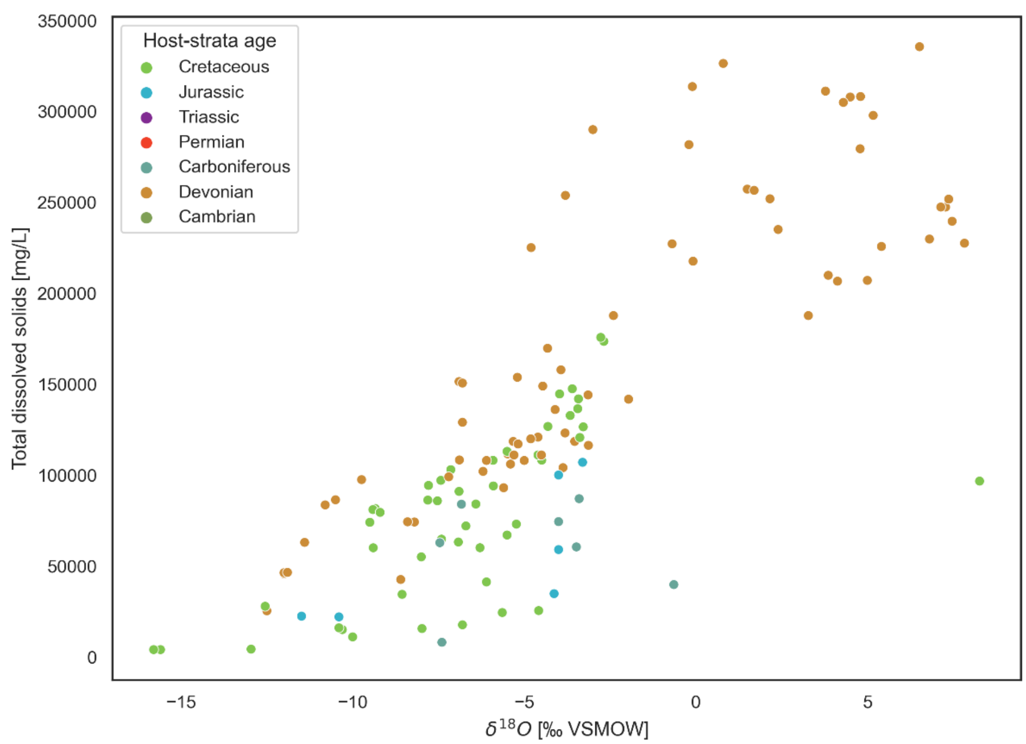

Figure 15. Delta oxygen-18 versus total dissolved solids concentration in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

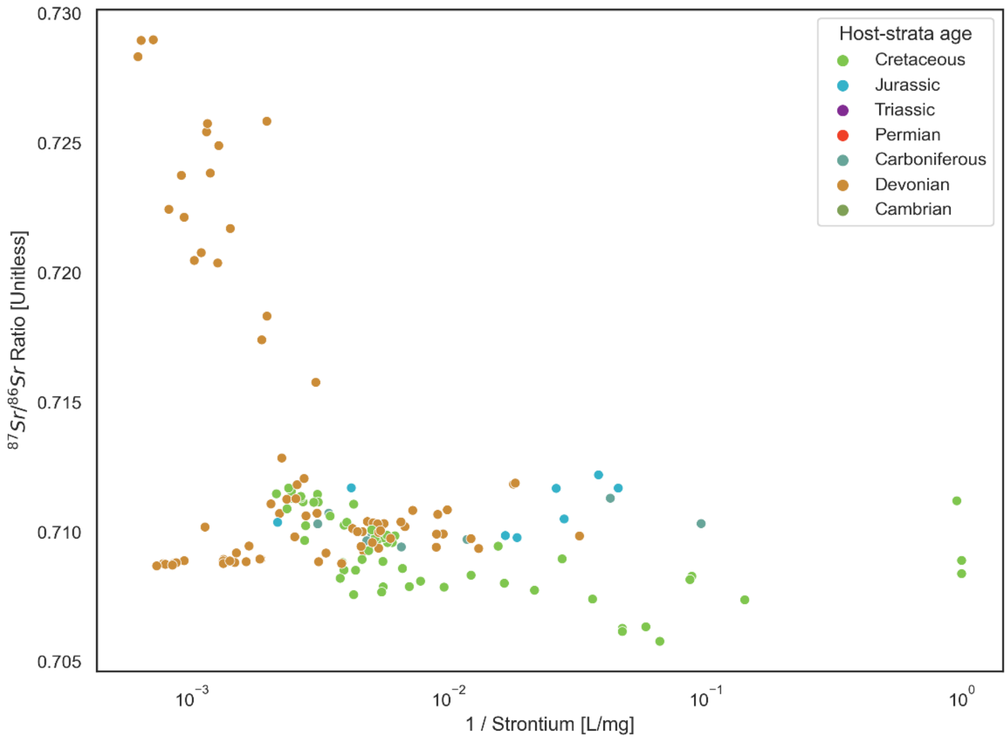

Figure 16. Inverse strontium concentration versus strontium-87/strontium-86 ratio in formation waters in Alberta. Data from Lyster et al. (2022).

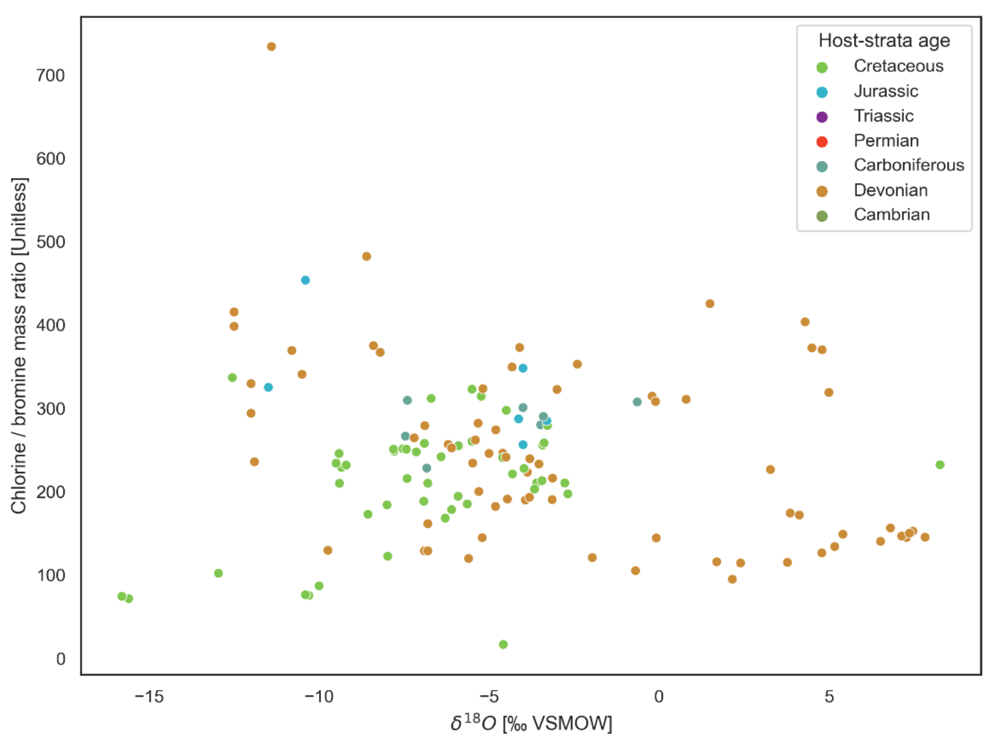

Figure 17. Delta oxygen-18 versus chlorine/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

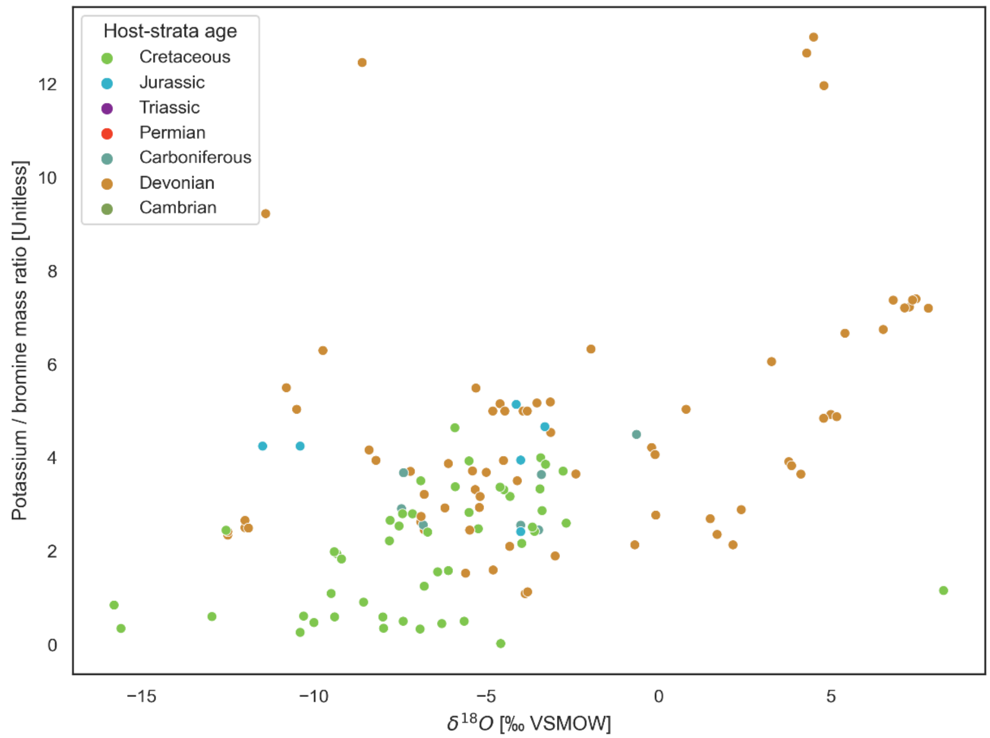

Figure 18. Delta oxygen-18 versus potassium/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

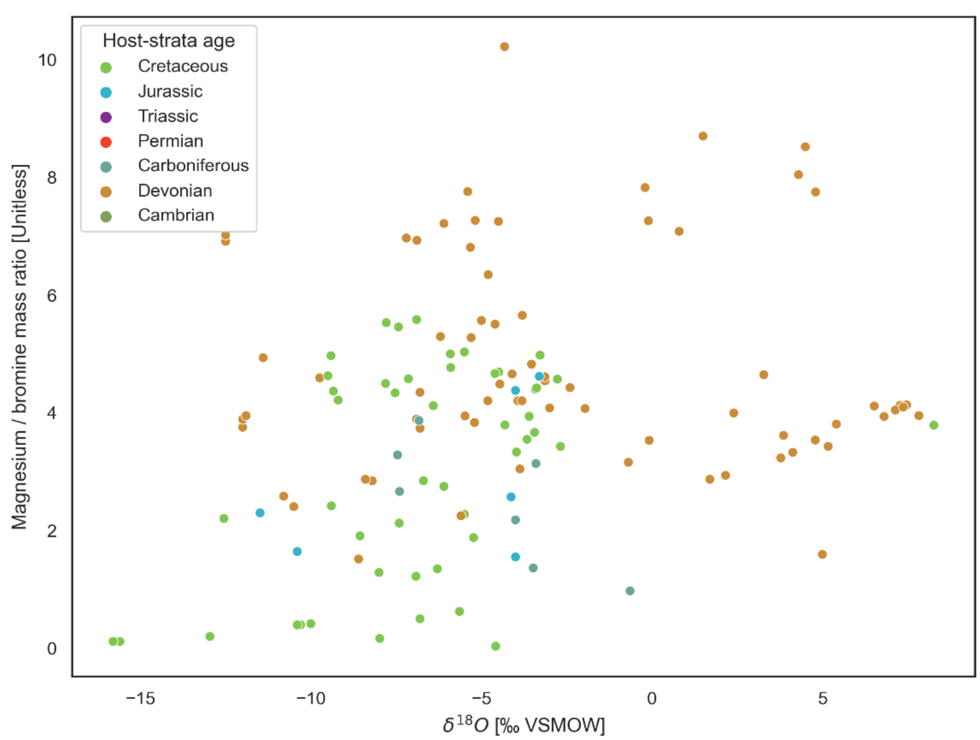

Figure 19. Delta oxygen-18 versus magnesium/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

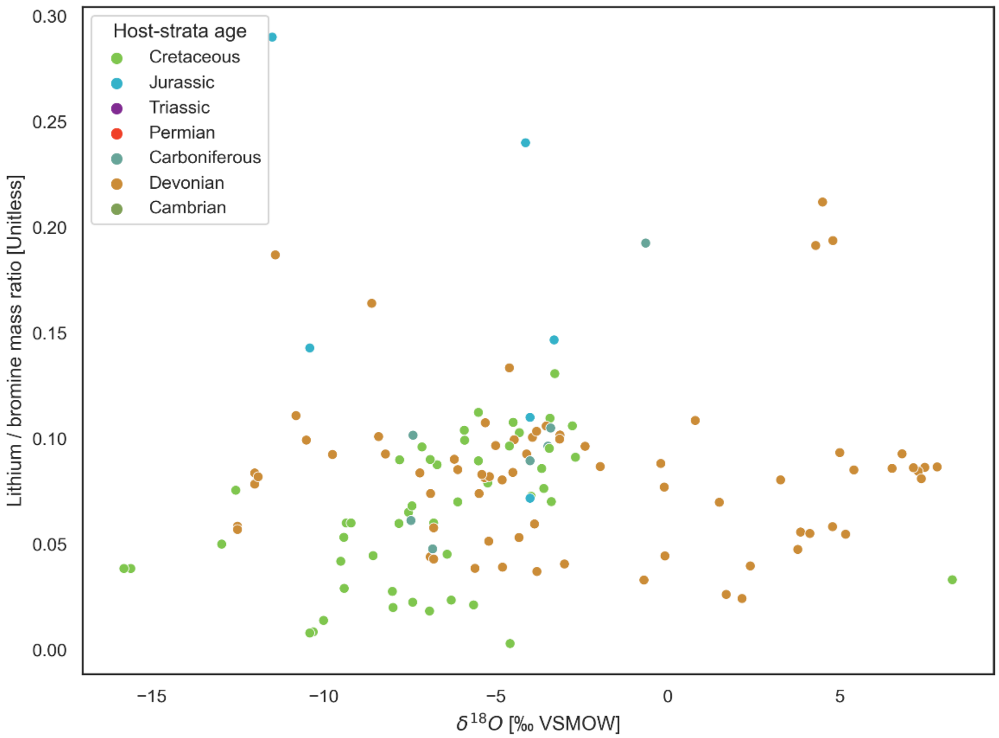

Figure 20. Delta oxygen-18 versus lithium/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

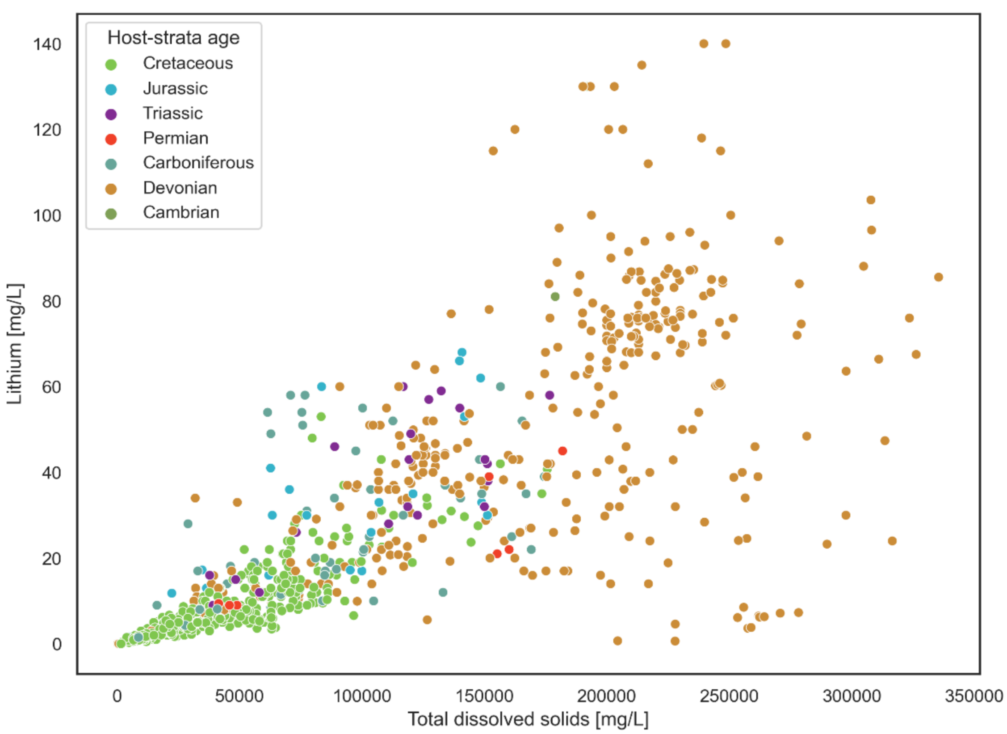

Figure 21. Total dissolved solids concentration versus lithium concentration in formation waters in Alberta. Data from Lyster et al. (2022).

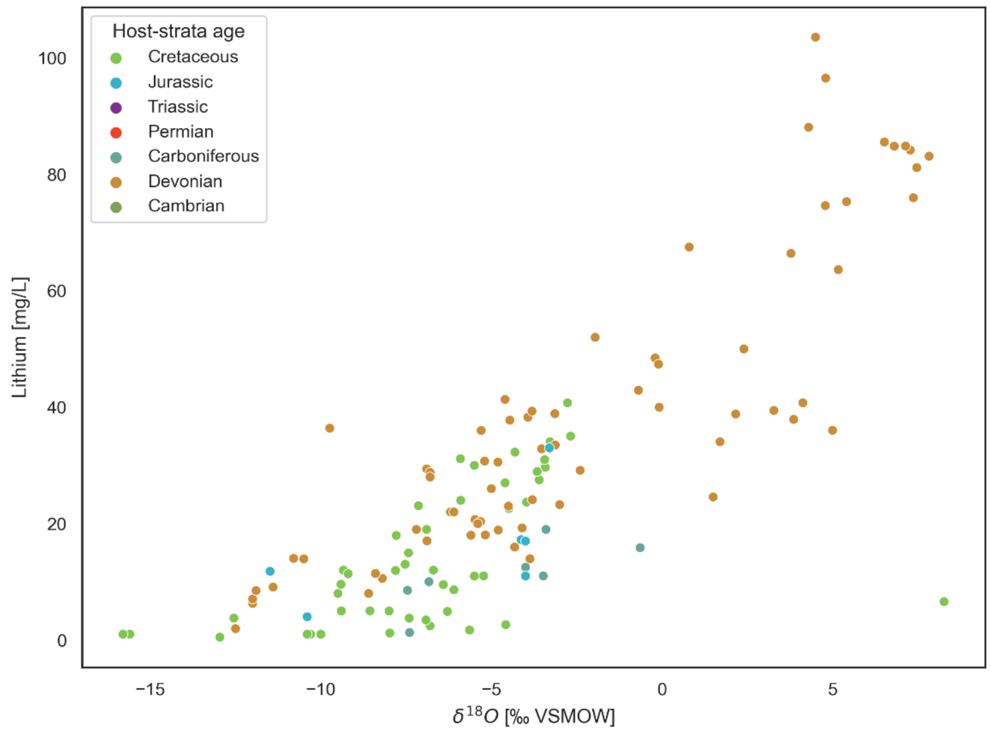

Figure 22. Delta oxygen-18 versus lithium concentration in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

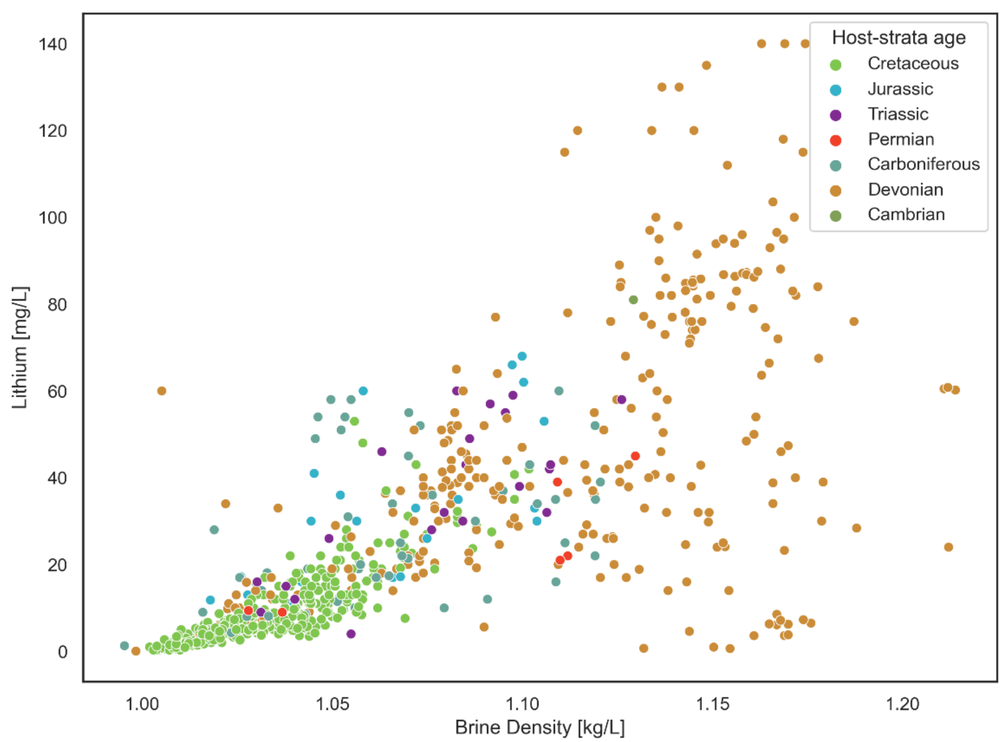

Figure 23. Brine density versus lithium concentration in formation waters in Alberta. Data from Lyster et al. (2022).

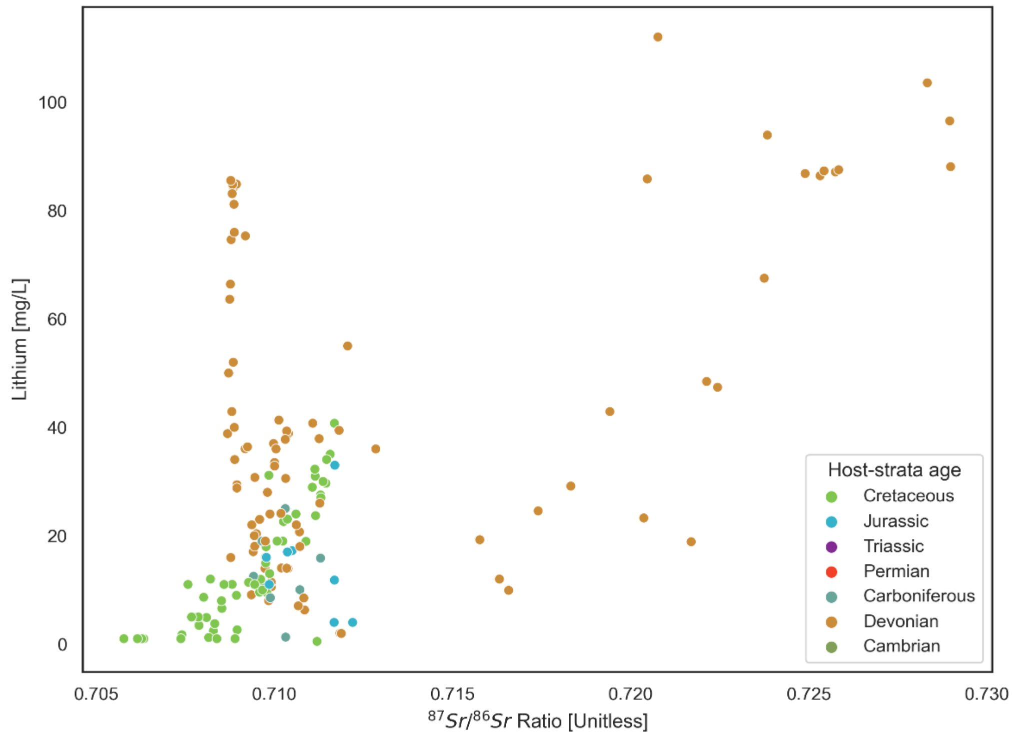

Figure 24. Strontium-87/strontium-86 ratio versus lithium concentration in formation waters in Alberta. Data from Lyster et al. (2022).

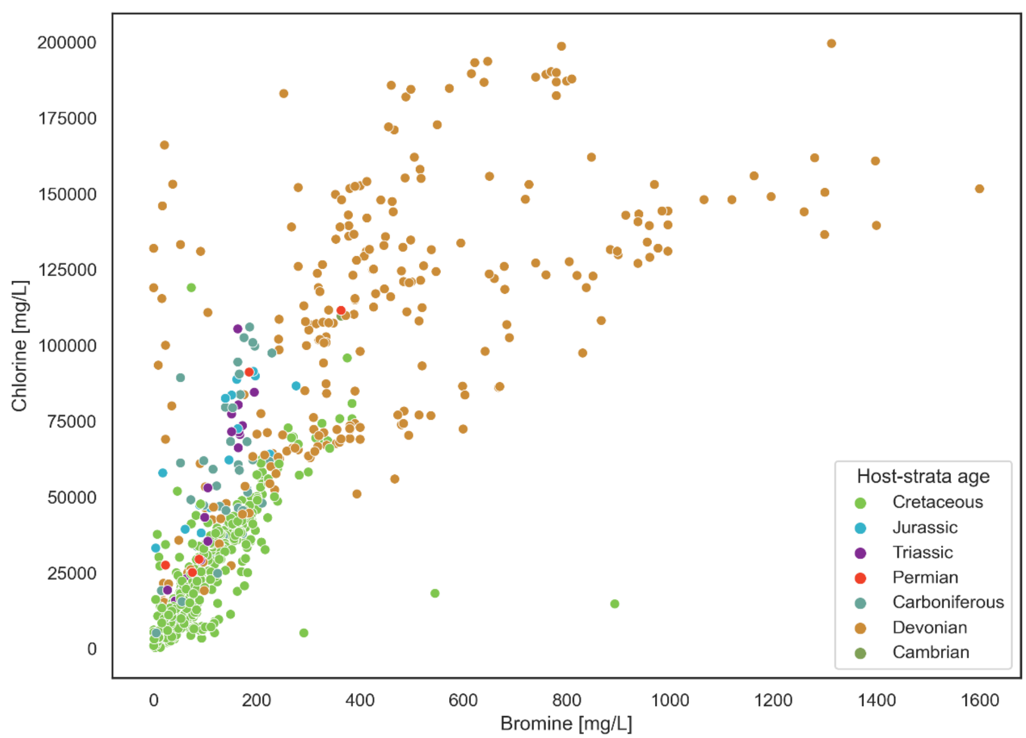

Figure 25. Bromine concentration versus chlorine concentration in formation waters in Alberta. Data from Lyster et al. (2022).

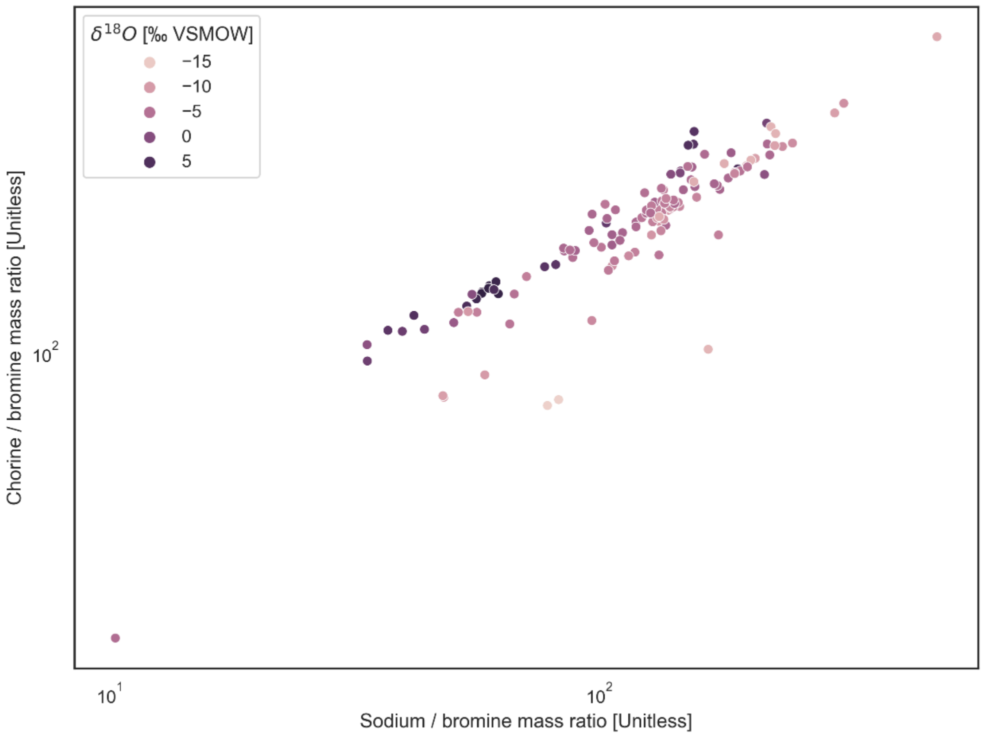

Figure 26. Sodium/bromine mass ratio versus chlorine/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

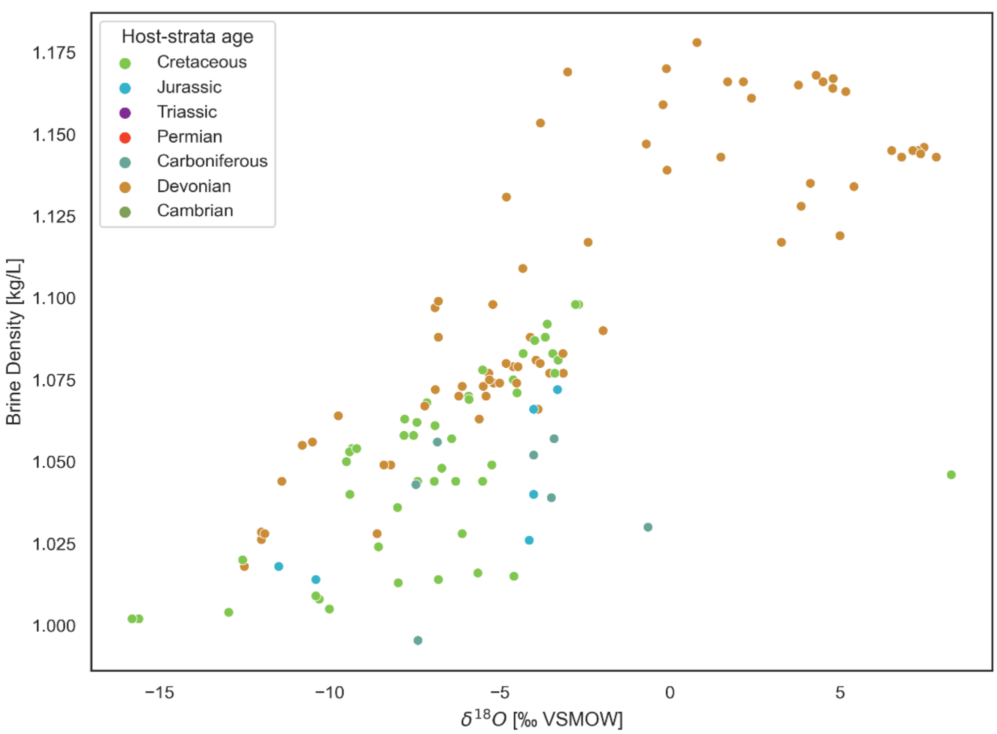

Figure 27. Delta oxygen-18 versus brine density in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

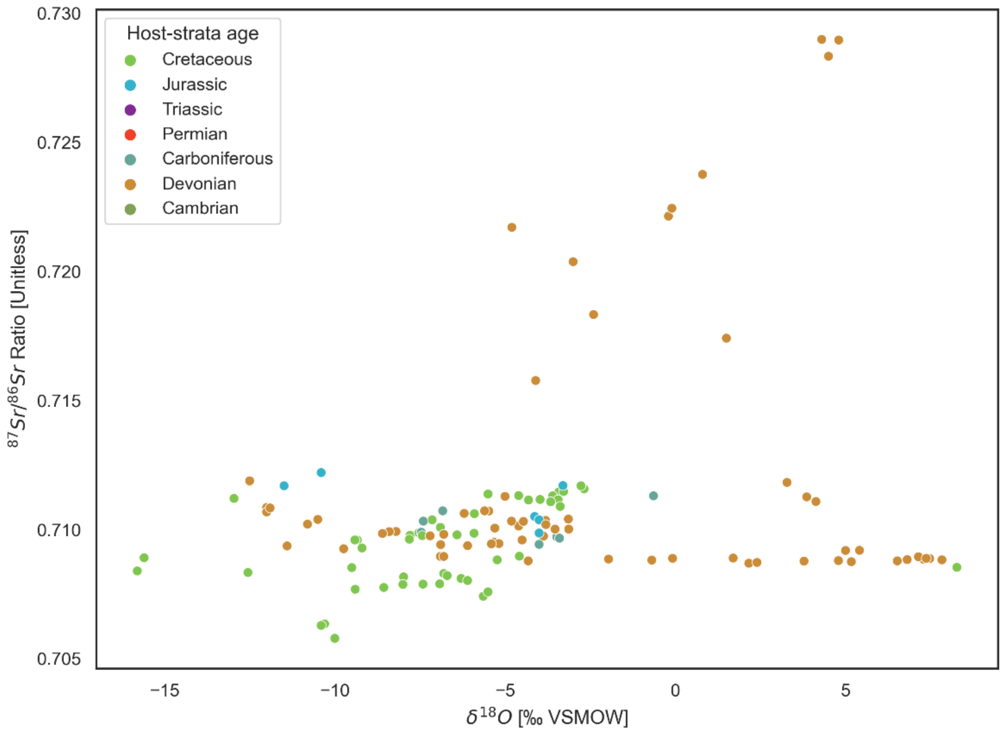

Figure 28. Delta oxygen-18 versus strontium-87/strontium-86 ratio in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

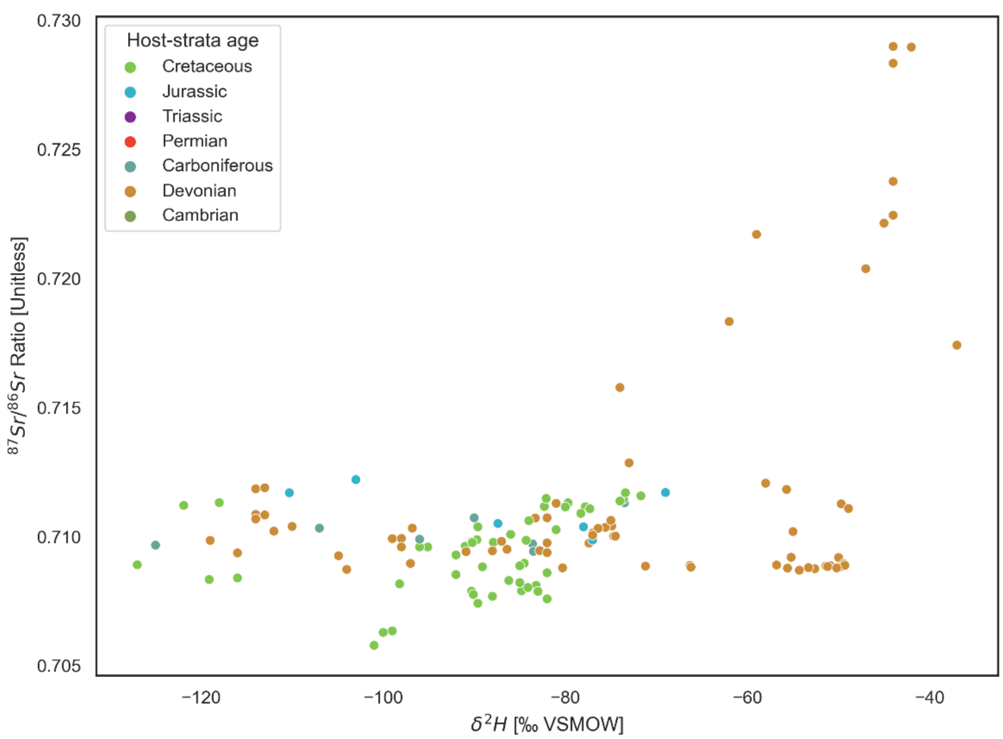

Figure 29. Delta hydrogen-2 versus strontium-87/strontium-86 ratio in formation waters in Alberta. Data from Lyster et al. (2022). Abbreviation: VSMOW, Vienna Standard Mean Ocean Water.

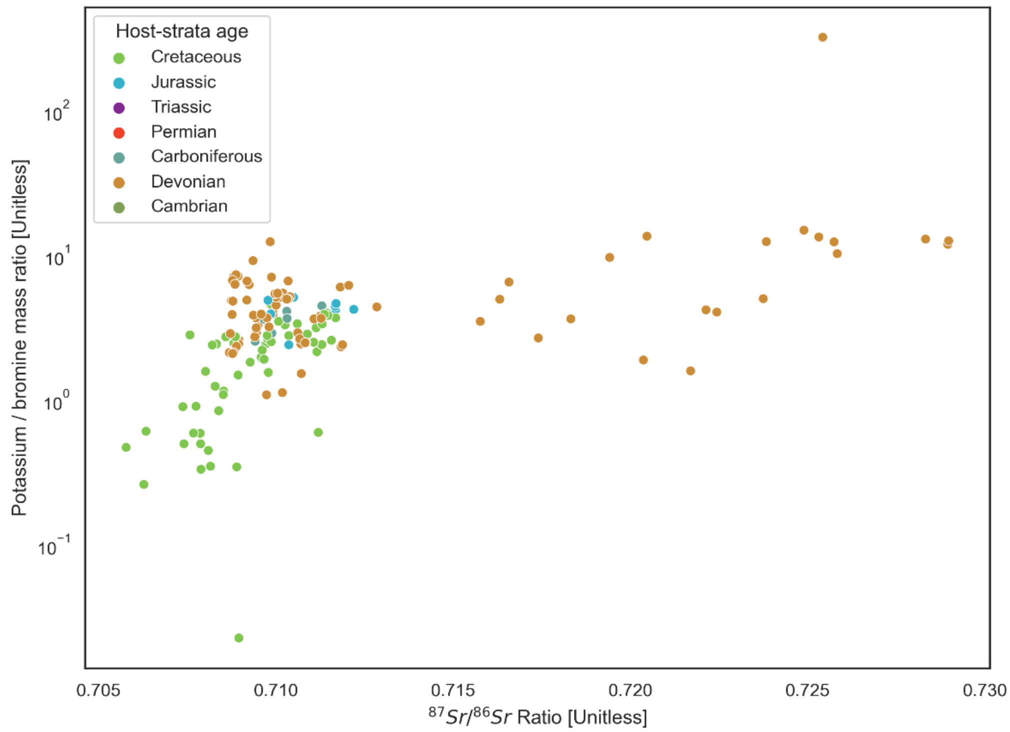

Figure 30. Strontium-87/strontium-86 ratio versus potassium/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022).

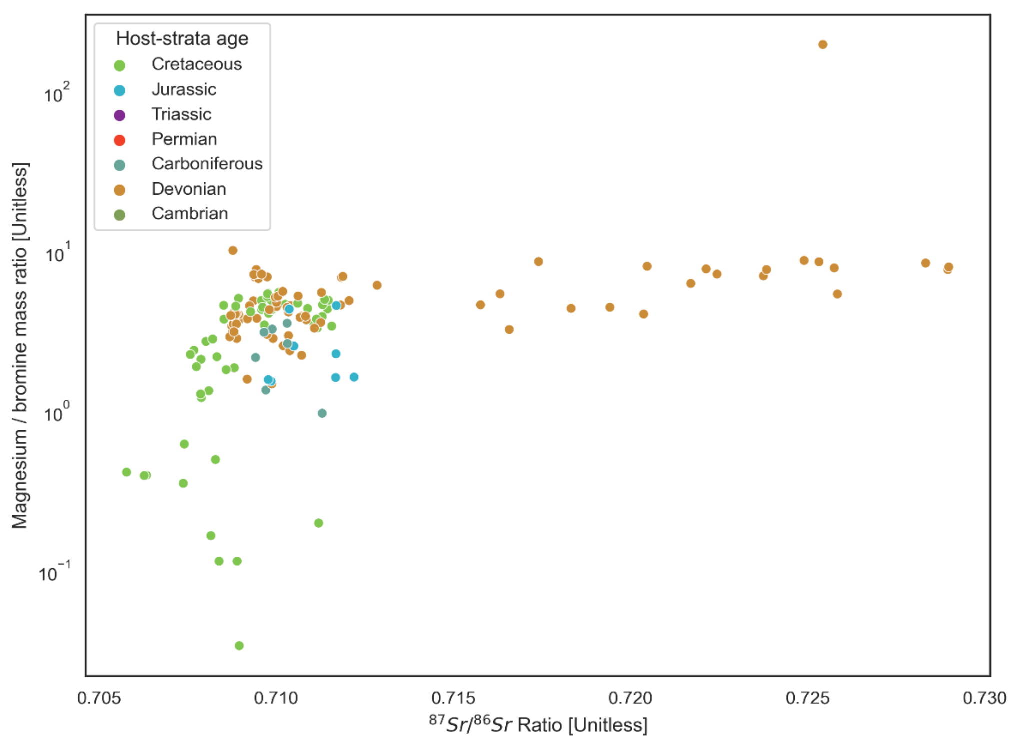

Figure 31. Strontium-87/strontium-86 ratio versus magnesium/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022).

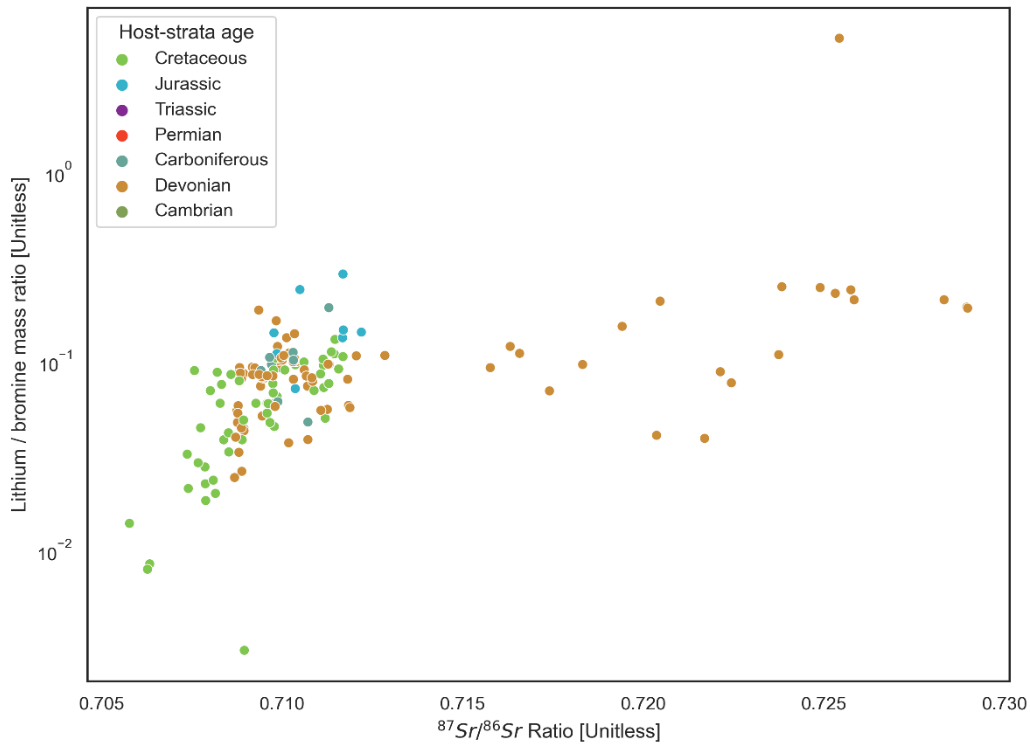

Figure 32. Strontium-87/strontium-86 ratio versus lithium/bromine mass ratio in formation waters in Alberta. Data from Lyster et al. (2022).