Northeastern British Columbia Lithium Formation-Water Database Project (NTS 093P, 094A, B, G–J, O, P, Part of 093I): 2022 Field Sampling Program Update

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Introduction and Background

In the fall of 2021, the northeastern British Columbia (BC) lithium formation-water database project was initiated to 1) collect, assess and characterize subsurface brines for dissolved metal concentrations, and 2) establish the potential for extracting critical minerals and metals from brine in northeastern BC (Wilson et al., 2022). This project was devised in response to the increasing demand for lithium and other critical minerals and metals, as identified by the Canadian government (Natural Resources Canada, 2021). These minerals and metals will help enable the country's transition to low carbon energy.

This project expands upon previous discoveries of elevated concentrations of dissolved metals (specifically lithium) in a number of geological formations in both Alberta and Saskatchewan and throughout the Western Canada Sedimentary Basin (Figure 1; Eccles and Jean, 2010; Eccles, 2011; Jensen, 2012, 2016; Jensen et al., 2017; Blondes, 2018; Lopez et al., 2020). Despite historical oil and gas industry sampling of formation water for routine water analyses, the publicly available datasets for the brine chemistries and associated lithium concentrations remain relatively limited. This is due to historical samples not being routinely analyzed for lithium and other metals. At present, Alberta has recorded over 1600 formation-water samples with lithium concentrations (Eccles, 2011; Lopez et al., 2020) and Saskatchewan over 200 (Jensen, 2012, 2016; Jensen et al., 2017) whereas northeastern BC, prior to this project, had only recorded five samples with lithium concentrations (Eccles, 2011). This data scarcity presents a significant challenge for operators looking to develop lithium resources in BC. Adding data is complicated by the fact that formation water can only be sampled from existing oil and gas infrastructure, that is, from wells that are in production and can bring associated water to surface. This joint study, conducted by Canadian Discovery Ltd. and Matrix Solutions Inc. (Matrix) for Geoscience BC, strives to deliver an initial lithium and other dissolved minerals and metals brine database through a large-scale sampling program undertaken in northeastern BC. Supporting partners include the Northern Development Initiative Trust, the Geological Survey of Canada (GSC) and LithiumBank Resources Corp. This study aims to collect and analyze formation-water samples to create a statistically robust stratigraphic database of up to 500 samples from 380 oil and gas wells within active oil and gas fields in northeastern BC. Background information pertaining to lithium deposit types, enrichment mechanisms and direct lithium extraction technologies was published in Wilson et al. (2022). All of the final deliverables from this project will assist operators in making exploration, development and investment decisions and help to inform important policy decisions on permitting prospective critical mineral and metal resources and regulating their exploration and extraction within the province.

This paper provides an interim update on the progress of sampling underway in northeastern BC, as well as a brief description of ongoing activities and key challenges encountered as part of this effort.

Project Design and Progress

This project represents a first of its kind in northeastern BC and was devised in a three-phase approach, which was slated to take place over approximately 24 months but the timeline has been extended to accommodate additional participation from key operators. The three project phases comprise:

1) co-ordination and scoping,
   a) project co-ordination, logistics and safety standards,
   b) prospective formation review and high-level scoping of wells to be sampled,

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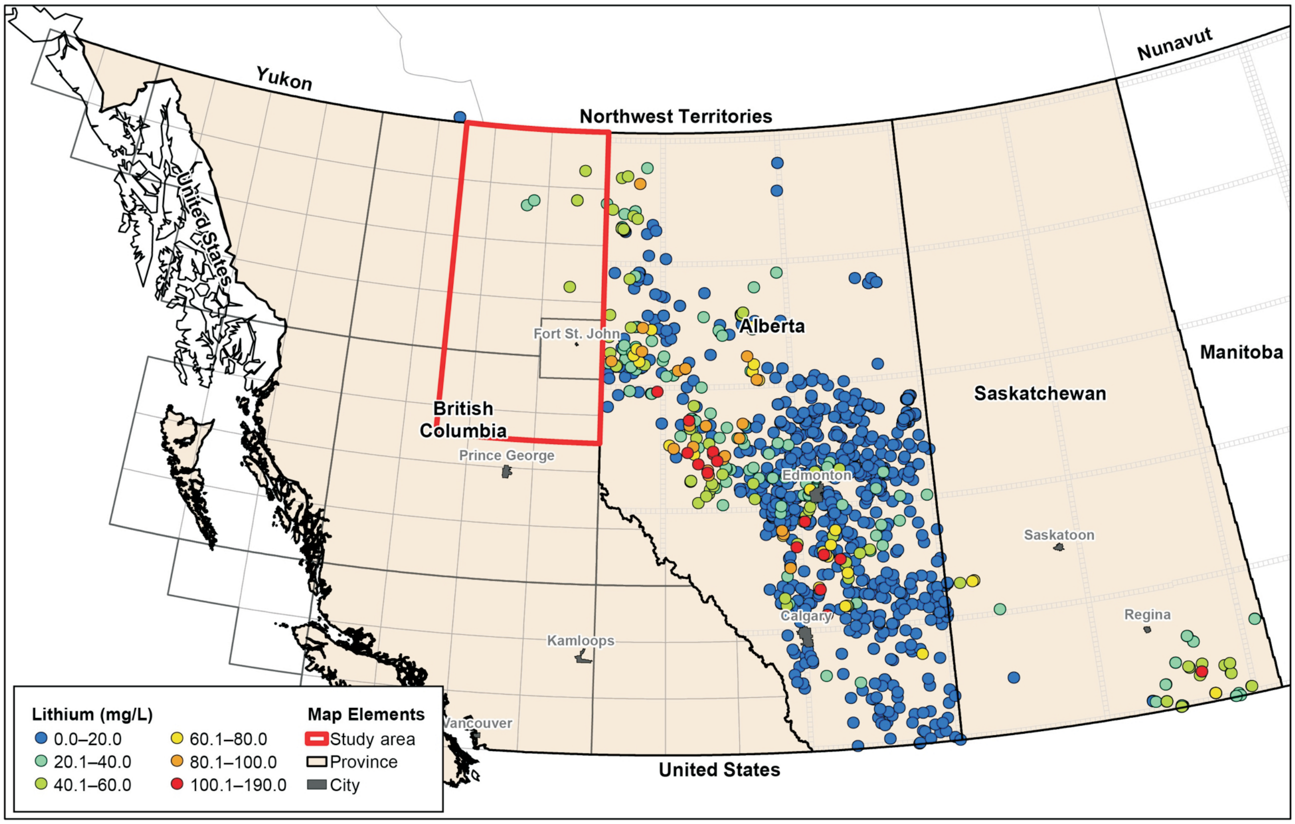

Figure 1. Concentration of lithium in formation waters throughout the Western Canada Sedimentary Basin (data from Eccles and Jean, 2010; Jensen, 2012, 2016; Jenson and Rostron, 2017).

  c) operator engagement, access negotiations and field logistics,
2) field sampling and data analysis,
  a) field sampling program,
  b) laboratory analysis,
  c) data processing, quality assurance–quality control (QA-QC) and analysis,
3) geological interpretation and lithium potential (final report),
  a) incorporate data into the broader geological and hydrogeological framework,
  b) advance the understanding of geological controls and natural variability of lithium in formation waters,
  c) preliminary assessment of aquifer volumes, deliverability and economic viability of lithium extraction.

Phase 1: Co-Ordination and Scoping

The co-ordination and scoping phase has been completed, with details provided in Wilson et al. (2022). The preliminary well scoping methodology, detailed in Wilson et al. (2022), took into consideration a number of geological and hydrogeological factors to focus sampling efforts on up to 20 geological formations with adequate aquifer potential. The selected intervals spanned Devonian to Cretaceous strata, with formations comprising both clastic- and carbonate-dominant lithologies.

In addition to the work undertaken to devise the preliminary program, the first phase of work also included the commencement of the engagement process with key operators of wells producing from the target formations (Wilson et al., 2022).

Phase 2: Field Sampling and Data Analysis

Logistical planning for individual sampling programs at key operator sites formed the first steps of the second phase of the project. To date, the program has partnered with key operators who have agreed to facilitate access to their production infrastructure for brine sampling. The project team is grateful for their participation. These operators are Crescent Point Energy Corp., Enercapita Energy Ltd., Erikson National Energy Inc., ISH Energy Ltd., Ovintiv Inc., Shell Canada Limited, Tourmaline Oil Corp. and Whitecap Resources Inc.

Sixty-two samples have been collected and sampling continues at the key operator sites. It is noted that there is an overall decrease in total attainable sample numbers compared to the original sampling targets for the program. This is due to challenges encountered while undertaking such a large-scale, operationally complex program, which are discussed in subsequent sections. These challenges included the variable suitability of the infrastructure type at the sampling sites and the complications encountered while sampling during a pandemic. The project team strives to collect additional samples, as the schedule allows, and continues to maintain ongoing discussions with additional operators in the area.

Phase 3: Geological Interpretation and Lithium Potential

The final deliverable for this project, which forms the third and last phase of work, is a preliminary, high fidelity and vetted database, which will serve as the foundation for additional formation-water chemistry studies in BC. Ideally, it will aid and inform regulatory policy considerations, as well as act as a catalyst to further brine resource exploration and development. This database will be accompanied by a final report, which will describe the data in the broader geological context of northeastern BC. The final report will include but not be limited to water chemistry mapping, graphical analysis and initial geochemical and enrichment interpretations of concentrated minerals and metals in formation-water brines.

Sampling Methods and Analytical Suite

To achieve the project goals, it is important to ensure that the sampling and data collection methods used in this program conform to necessary standards and follow rigorous QA-QC procedures. This objective is addressed through the following key operations:

1) assemble and quality check well data prepopulated for each infrastructure type and sample location, capturing key metadata of importance to the project and checking with operators for accuracy
2) use standardized sampling procedures
3) use a nationally accredited laboratory, which has significant expertise in analyzing oil and gas field brines with specific applications to lithium and other metal concentration assessment
4) adhere to standardized QA-QC methodologies
5) document chain of custody procedures

Metadata Collection

Metadata parameters are considered those parameters that are not explicitly analyzed but collected prior to and as part of the program activities. This includes sampling locations, sample collection dates, stratigraphic and depth intervals, infrastructure types used for sampling, as well as additional details on specific conditions of sampling. These parameters are organized into three main categories corresponding to their order of collection:

1) prefield metadata collection and confirmation
2) field metadata collection
3) postfield metadata quality checks

The full list of metadata parameters is shown in Table 1. All metadata parameters are collected as available. In cases where certain information is unavailable, a best effort approach is made to document the circumstances involved.

Sampling Methodology and Procedures

A standardized sampling procedure was devised and implemented for the program, which involved sampling at four key infrastructure types: 1) production wellhead, 2) oil separator, 3) treater, and 4) onsite production-stream storage tank, under certain circumstances. In general, the preference is to sample at isolated 'in-test' separators, however, in practice, this is not always feasible depending on the operation's infrastructure and production configuration. Variations in infrastructure configuration accounted for the majority of unforeseen sampling constraints and the inability to sample at some sites led to a reduction in the sample numbers originally proposed. The main problem encountered was that many operations in northeastern BC have 'wet-metered' configurations with little or no means of isolating production from individual wells or zones. Measures were taken to adapt the sampling procedures to include additional sampling options to attain a reasonable sample coverage.

Of utmost importance during sampling is safety. There is an inherent risk in oilfield sampling that necessitates rigorous safety requirements. All oilfield sampling programs must comply with WorkSafeBC requirements and limits (WorkSafeBC, 2022), as well as operator-specific safety standards and procedures. The following descriptions are illustrative of the procedural sampling methodologies for data integrity but do not include the full safety procedures.

Wellhead Sampling

Sampling at the wellhead involves collecting a fluid sample from a sampling port at the wellhead production assembly. For this project, an oilfield wellhead is defined as any mechanism fitted onto a well that has structural and pressure-containing interface capabilities, and includes at least one valve to isolate the well from the atmosphere. The surface pressure control is provided by a master valve, which is installed on the production tubing located above the casing bowl. Wellheads can have multiple isolation valves and chokes to control fluid flow. Wellheads are typically attached to a surface casing bowl that is welded/attached to the surface casing or surface conductor pipe, which has been cemented in place to ensure adequate well structural integrity.

Wellhead sampling is conducted after the necessary safety precautions are observed, such as testing and releasing wellhead pressure and properly opening infrastructure isolation valves.

Table 1. Metadata collection parameters for the field sampling program of the northeastern British Columbia lithium formation-water database project.

Phase	Data type	Metadata parameter
Prefield metadata collection and confirmation	Location	Unique well identifier (UWI) Global Positioning System co-ordinates, easting Global Positioning System co-ordinates, northing Ground elevation, metres above sea level (m asl) Operator company Producing field name
	Formation	Formation sampled (formation name) Formation member name (if available) Geological age (e.g., Devonian) geoSCOUT downhole temperatue (degrees Celsius) Production zone, if known
	Well and infrastructure	Well type: oil or gas Well safety: sweet or sour? Well type comment: fracked well, flowback or other condition of produced water
	Completion	Well completion depth top (elevation m asl) Well completion depth base (elevation m asl) Most recent well intervention type and date: workover, fracking, etc.
	Production and fluids	Certainty of singular production zone (ranked: 1-low to 10-high) Water cut (percentage if known, e.g., 75%) Additives: yes or no Additive information: concentration, location added, type (descaler, oxygen scavenger, biocide, unknown, proprietary, etc.) Pressure of producing well? Production hours of well (in test or other production condition or parameter)
Field metadata collection	Sampling and infrastructure	Sample ID(s) (prepopulated; coincides with chain of custody) Confirm if sample is sour (Y or N) Operator company Supporting operator: last name, first name Collection date, time Number of sample bottles Infrastructure type sampled (e.g., separator, wellhead, etc.) Infrastructure additional comment (single or multiwell, in test condition and running time) Sample temperature at collection (degrees Celsius) Degree of emulsification (approx. percentage, e.g., 10%) Description of sample: clear/cloudy, colour, emulsion, product, smell, gassy, turbid, etc. Field note / additional comments
Postfield metadata quality checks	Collection and transmittal details	Chain of custody (COC) number Date shipped Transit time Lab arrival date and time Date sample processed and analyzed Observations about sample when analyzed, if applicable

Separator Sampling

Test separators are used in oilfields to measure the flow rates of various wells and collect water and hydrocarbon samples from one or more wells at a satellite location. Test separators for this sampling program will either be two phase or three phase. Two phase means that oil and water are separated from gas, whereas three phase means that oil, water and gas are each separated. For both two phase and three phase, a sampling valve on the separator tank should be present, which can be opened to produce a fluid sample. Where feasible, the owner and operator will ensure that the wells flowing to the separator will be 'into test' at least 24 hours prior to sample collection to flush the lines and ensure no risk of contamination from other wells. For some infrastructure and production configurations, the only way to collect a sample is to collect a commingled fluid sample. Where this was the case, it was explicitly documented as such and was identified as representing only one formation production interval despite being sourced from a group of wells.

Treater Sampling

A heater treater uses heat, delivered by a burner and fire tube, to heat the liquid inside the tank, which accelerates the process of separation. Similar to a two-phase separator, the valves and piping will send the gas to either sales or flare and the oil will be sent downstream, in this case to storage tanks. Produced water is also separated at this tank and is sent downstream to a disposal well. A sampling valve is usually present on treaters to gain access to production fluids, which can be collected along the oil production stream.

Onsite Production-Stream Tankage

Where present, onsite storage tanks may provide an additional means of sampling although these tanks may contain commingled fluids, which will need to be assessed for their degree of representation of discrete formation zones of interest. In these cases, sampling ports at the base of the tanks may provide access to the brine fraction of production fluids inside; the suitability and accessibility must be assessed in co-ordination with the well owner/operator. This infrastructure is considered as a last resort option for sample collection given that the formation waters will have equilibrated to surface pressure and temperature conditions, and therefore some additional margin of error may be introduced as chemical constituents equilibrate in such tanks.

Sample Collection

Once infrastructure access to fluids is attained, sample collection is undertaken. The sampling procedure observed for this program conforms to the methods outlined in Lico et al. (1982), which is regarded as the foundational reference for oilfield formation-water and brine sampling. Water is collected in an intermediate 9 L carboy and if there is an oil-water mixture, approximately 8 L of water or emulsion is collected. Sample temperature is taken immediately after collection. The sample is then capped and contained in the sealed carboy and allowed to sit for a period of time to assess whether the emulsion breaks down on its own. Once the emulsion separates adequately, the spigot at the base of the carboy (where the denser formation water will separate out) is used to fill individual 1 L laboratory-provided standard oilfield sampling bottles. In total, three 1 L bottles are collected for the project, one primary unfiltered and unpreserved sample, one secondary or duplicate raw sample and one sample filtered through two filters, a prefilter and a 0.45 mm filter, and preserved with nitric acid. The secondary sample was collected to serve as a duplicate sample in accordance with the QA-QC procedures and will serve as a backup sample in the event of damage or integrity issues in transit. It may also be used for reruns if results from a primary sample are flagged for inconsistencies. The filtered and preserved samples were collected to check for possible sample quality degradation in the raw unfiltered samples.

Nationally Accredited Laboratory

The petroleum testing services at AGAT Laboratories Ltd., with laboratories in Fort St. John and Fort Nelson, BC, and an oilfield water laboratory in Calgary, Alberta, were selected for this project. A full suite of water chemistry analyses, including lithium-ion concentration, has been devised to capture routine brine chemistry for characterization, along with the full suite of dissolved metal parameters of interest to this study. The routine analysis includes pH, electrical conductivity, Ca, Mg, Na, K, Fe, SO_4, Cl, Mn, carbonate, bicarbonate, NO_3, NO_2, NO_3^+, NO_2^-, N, alkalinity, hardness and calculated total dissolved solids (TDS). The dissolved metals analysis includes analysis for Al, Sb, As, Ba, Be, Bi, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Mo, Ni, K, Se, Si, Ag, Na, S, Sr, Sn, Tl, Ti, U, V and Zn and has explicitly been selected to run on an inductively coupled plasma–optical emission spectrometry (ICP-OES) instrument (in contrast to standard ICP–mass spectrometry instruments) to mitigate requirements for analytical dilution and achieve better accuracy and precision for dissolved lithium and other sensitive parameters.

Support for this analytical program has been provided by the GSC, which has agreed to provide scientific input and share analytical costs in support of their parallel yet separate study, which will further analyze the collected samples for a suite of isotopic parameters.

QA-QC Procedures

In accordance with Matrix standard practices, QA-QC protocols were followed for the sampling program. These QA-QC measures included the collection and analysis of duplicate samples, as well as a review of the results from the laboratory QC samples. Field blanks and trip blanks were prepared for the conducted sampling events.

To determine the reproducibility of analyses, a duplicate of a primary sample was analyzed. Duplicates were taken for each sampled formation or at every seventh collected sample (depending on the number of samples collected). All duplicate samples analyzed were judged to be acceptable, with all relative difference values less than 30% and acceptable charge balances within a 10% error.

A field blank is a sample of organic-free, laboratory-supplied de-ionized water that is exposed to the sampling environment and then submitted blind to the laboratory along with the other samples in the set. Field blanks are used to measure incidental or accidental sample contamination (i.e., artifacts or analytes detected by analysis but not present in the samples). The field blank does not need to be analyzed for every sampling event, but can be analyzed should analytical data for the actual samples appear anomalous.

A trip blank is a sample of organic-free, laboratory-supplied de-ionized water that is used to determine whether or not cross-contamination of particular compounds has been introduced to the actual samples during sample transportation. The trip blank remains unopened and is not exposed to the sampling environment. The sample is submitted to the laboratory as a blind sample along with the other samples in the set. The trip blank does not need to be analyzed every time, but can be analyzed should analytical data for the actual samples appear anomalous.

Chain of Custody Procedures

A standard chain of custody documentation procedure was used to capture sampling details and the details of relinquishing each sample for transit to the laboratory. This included information such as sampling time, bottle numbers, analytical requirements and transit times as part of the sample submissions. Copies of the signed forms were documented for each step.

Preliminary Sampling Results and Challenges

Well Sampling

At the time of writing, 62 samples had been collected and plans are to collect more than 100 additional samples by early 2023. The project timeline was extended to accommodate for challenges encountered during the sampling program. Table 2 and Figure 2 show the progress of the sampling program by formation/member.

In total, 26 formations/members of interest were targeted for the sampling project. Of these identified units, 13 formations/members have been sampled to date, with an additional three currently unrepresented formations slated for upcoming sampling (Table 2). Six formations/members are approved for access but have not been sampled to date as details and confirmations are under consideration. Four formations/members did not have adequate infrastructure access to conduct sampling over the project timeframe. The details of the vetting of the original wells by formation/member can be found in Wilson et al. (2022).

Stratigraphic coverage to date has been successful as samples have been collected from a number of key formations in Devonian, Triassic and Cretaceous units. In general, the Triassic and Cretaceous units have a greater number of wells accessible for sampling in the project area. Unfortunately, sampling from some Paleozoic units that are the stratigraphic equivalents to lithium-enriched formations in Alberta and Saskatchewan has not been possible to date because of operational constraints. These units in BC include the Keg River and Shunda formations, and opportunities to obtain samples from these formations will continue to be pursued, however, sampling limitations are expected to persist for these wells.

The results of the sample analyses will be released following an exclusivity period (six months after the end of the sampling field program) granted to the participants of the program. However, it can be reported that the anonymized values of notable lithium concentrations range from low values of 0.1 mg/L to approximately 100 mg/L. The higher concentrations reported to date are within the range of technical limits for direct lithium extraction (DLE) technologies (Grant, 2022), and are interpreted to warrant additional investigations for lithium brine resource potential in northeastern BC.

Program Challenges and Adaptations

To date, the attained sample numbers are lower than initially anticipated. This highlights a number of important challenges encountered in a large-scale program of this scope. These include unforeseen circumstances encountered during the proposed project timeline. Three key challenges were identified during the course of the project:

1) infrastructure configuration and well access limitations, which together filtered a significant number of wells from the original proposed well list
2) changes and limitations to the BC Mineral Tenure Act regulatory environment during the operator engagement phase
3) external factors—the COVID-19 pandemic and the subsequent surge in energy prices led to a number of schedule postponements

The infrastructure and operational configurations had a considerable effect on the suitability of sampling sites, particularly with respect to obtaining representative isolated (i.e., not commingled) zone and well source samples. In general, such configuration information and operational knowledge is not readily available through public data sources and is only evident upon conversations with local field operators. A significant number of candidate wells were filtered out because grouped production from multiple wells within a producing field were commingled directly into a production stream without field or well level separation. Variations of this grouped production setup are often referred to as wet-metered and offer limited discrete sampling opportunities compared to traditional onsite separators. In northeastern BC, many operators choose a wet-metered configuration to minimize remote operation and equipment costs. As the original well lists were vetted by operators, exceptions were made to collect the most representative sample base, given some of the infrastructure limitations. This was done under the premise that well-documented commingled fluid samples from a target formation were better than the alternative of not being able to

Table 2. Progress of the northeastern British Columbia lithium formation-water sampling program by formation/member.

Geological age	Formation/ member	Samples collected to date (number of samples)	Sampling underway (number of samples)	Potential for additional sampling approved but details under consideration with operators (A-denotes unconfirmed numbers)	Confirmed sample totals	Sampling access restricted[1] - ongoing efforts to secure access (X-denotes restricted access)
Cretaceous	Dunvegan					X
Cretaceous	Cadotte			A		
Cretaceous	Spirit River/Notikewin			A		
Cretaceous	Bluesky		1	A	1	
Cretaceous	Gething	2	2	A	4	
Cretaceous	Cadomin/Chinkeh	2	15	A	17	
Cretaceous	Nikanassin			A		
Jurassic	Rock Creek					X
Jurassic	Nordegg			A		
Triassic	Baldonnel/Pardonet	3		A	3	
Triassic	Charlie Lake	9		A	9	
Triassic	Coplin	4	1	A	5	
Triassic	Boundary	5	1	A	6	
Triassic	Halfway	14		A	14	
Triassic	Doig		21	A	21	
Triassic	Montney (undifferentiated)	3		A	3	
Triassic	Upper Montney	8	8	A	16	
Triassic	Middle Montney	3	8	A	11	
Permian	Belloy			A		
Mississippian	Debolt	3		A	3	
Mississippian	Shunda					X
Mississippian	Pekisko		4	A	4	
Devonian	Jean Marie	3	4	A	7	
Devonian	Fort Simpson/Muskwa	3	3	A	6	
Devonian	Slave Point			A		
Devonian	Keg River/Pine Point					X
	Subtotals	**62**	**68**	**~20–50**	**130**	
				Potential total samples:	**170**	

[1]Restrictions exist due to numerous sampling challenges, such as operator well availability, operator capacity, infrastructure configurations and schedule limitations

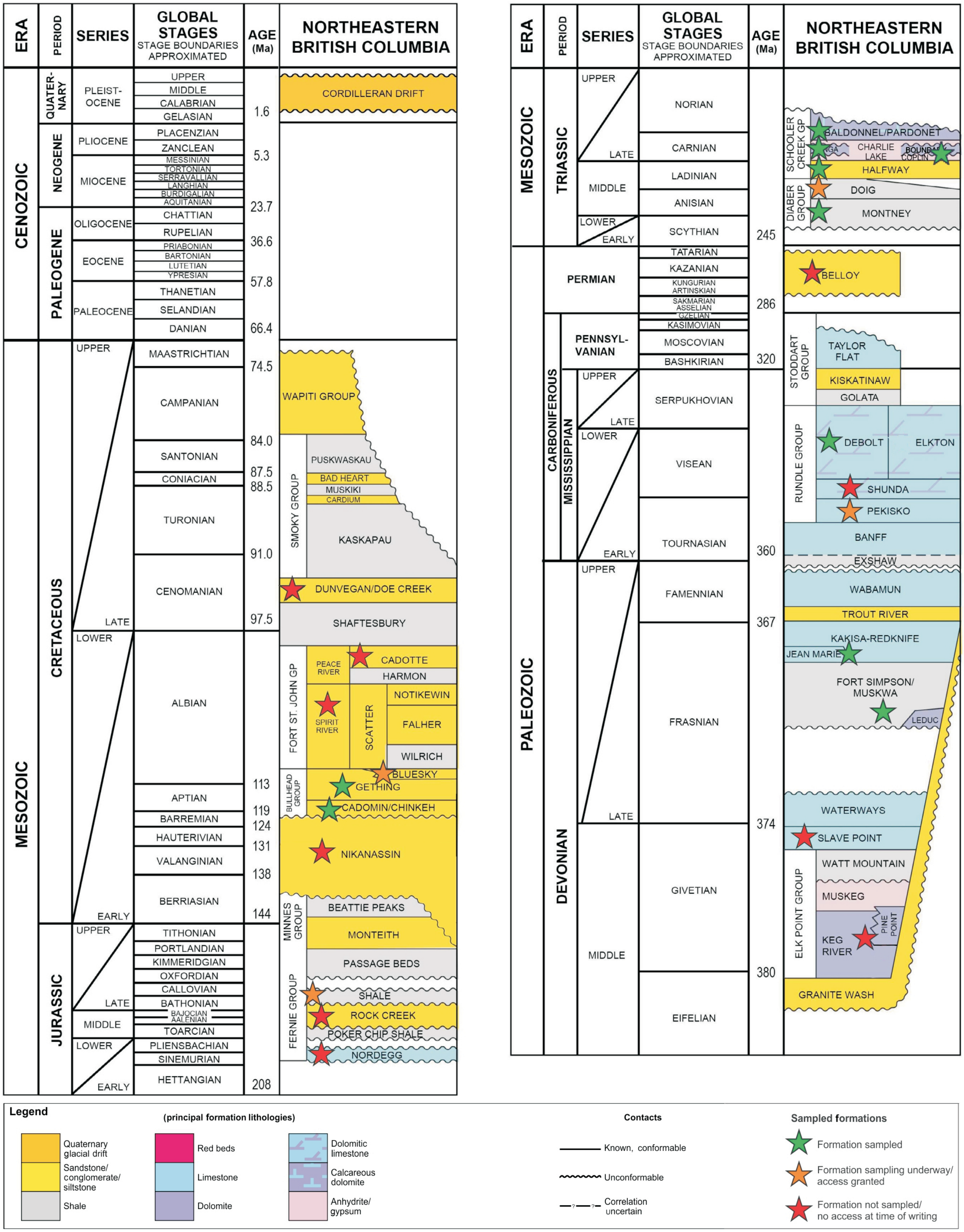

Figure 2. Stratigraphic column of northeastern British Columbia showing sample distribution (modified and reproduced with permission from Core Laboratories Petroleum Services, 2017).

collect samples at all. These exceptions, documented in the metadata collection, allowed for commingled fluid sampling where the commingled production stream was known to be producing from the same or equivalent formation interval. Special care was taken to ensure none of these exceptions had any commingled production from different stratigraphic zones. This measure helped to mitigate this filtering effect on the well lists available for each formation.

Another significant challenge, which arose part way through the project, was a change in the interpretation and application of provincial Mineral Tenure Act regulations pertaining to minerals dissolved in subsurface brines. This change significantly impacted whether operators and project proponents decided to participate in the program. Ultimately, a vast majority of the participating operators supported the need for data collected in projects of this nature, choosing to participate in the project despite these regulatory challenges.

Lastly, the project was conducted during the COVID-19 pandemic, which introduced a number of additional logistical challenges. It drove stricter health and safety policies and requirements of some of the larger operators participating in the program. In order to facilitate and minimize the burden to operators, they were given the option to have their local staff collect samples for the program. In these cases, all the metadata and chain of custody documentation was provided to the operator along with instructions for the standard sampling operating procedure. The project team documented this in the metadata collection and worked with operators to capture the necessary information and samples for the program. Also, during the pandemic, surges in energy prices led to increased production at oil facilities already impacted by a reduced work force. This affected the ability of some operators to be able to participate in the program.

Conclusions

Subsurface brine resource exploration is accelerating in North America as the demand outlook for critical minerals and metals points to shortfalls before the end of the decade. Currently a window of opportunity exists to evaluate and identify the potential to develop these new resources. Characterizing the chemistry of formation waters in northeastern British Columbia is an important first step to inform regulatory policy considerations, de-risk early exploration activities to incentivize investment and development, as well as support the academic advancement of knowledge on resource prospects such as geothermal and dissolved mineral production, particularly for critical minerals and metals. The database and final report from this project will assist in these activities and help support the development of a broader critical minerals and metals industry in British Columbia and Canada.

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